IT Investment under Competition: The Role of Implementation Uncertainty

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Abstract

How does competition impact firms' incentive to invest in information technology (IT)? Prior literature suggests opposing predictions on the direction in which competition drives IT investment. This paper analyzes a game theoretic model of duopoly competition and shows that an important feature of IT investment sheds new light on firms' IT investment decisions: the outcome of an IT implementation can be highly uncertain. In the absence of implementation uncertainty, the opportunity to invest in IT hurts firms' profits because the productivity gains are competed away. Implementation uncertainty creates a possibility of differentiation through IT investment which can lead to higher profits. Interestingly, increasing implementation uncertainty can lead to lower investment risk and higher expected profits. Moreover, firms in highly competitive markets may be better able to recoup the returns from their IT investments, and, therefore, more motivated to invest in risky IT, compared to firms in less competitive markets.

1 Introduction

It is well documented that competition influences the value of and, therefore, firms' incentive to invest in information technology (IT) (Melville et al. 2004, Forman 2005). However, how a firm's IT investment decision changes with the competitive environment is less clear. Prior research suggests two conflicting predictions. On the one hand, firms in highly competitive industries may be more motivated to invest in IT since successful use of IT often improves a firm's performance and competitive position (Bharadwaj 2000; Dehning and Stratopoulos 2003). The rise of Walmart against its competitors since the 1980s is largely attributed to its heavy investment in IT (Wells and Haglock 2008). Empirical work on IT adoption lends support to that firms facing high levels of competitive pressure are more likely to invest in information technologies, such as electronic data interchange (EDI) (Premkumar et al 1997; Iacovou et al 1995) or electronic commerce applications (Zhu et al 2003).

On the other hand, firms in highly competitive industries may be less motivated to invest in IT. Prior studies show that firms' incentive to invest in technological innovation depends on their ability to appropriate the return to their investment (Cohen and Levine 1986; Gilbert 2006), and the value of IT investment is more likely to be competed away in competitive industries and captured by trade partners or customers in the forms of lower prices and higher quality (Bresnahan 1986; Hitt and Brynjolfsson 1996). For instance, Davenport (1998), while describing an IT adoption decision in a competitive industry, documented that Air Products and Chemicals, a commodity manufacturer, decided not to follow its competitors' investment in state-of-the-art enterprise systems. Its management reasoned with the uncertain return from such an investment. Empirical work examining IT investment and firms' profitability has not explicitly considered the impact of industrial competition and thus far provided mixed findings with some suggesting none or negative association between IT investment and firms' profitability (e.g., Brynjolfsson and Hitt 1996, Aral and Weill 2007) while others suggesting positive association (Mithas et al 2012).

In this paper, we study firms' IT investment decisions in a competitive environment. We demonstrate that an important feature of IT investment sheds new light on firms' incentive to invest in IT and helps us understand the conflicting predictions of prior theories: the outcome of an IT implementation can be highly uncertain. This paper examines how industrial competition may impact a firm's incentive to invest in IT as well as the return from its IT investment when IT implementation may not succeed.

We focus on firms' investment in commercially available information technologies, and so adoption of such IT is not exclusive. In addition, we focus on IT investment with the objective of improving process efficiency and, therefore, reducing costs. Spending on commercially available IT represents the majority of firms' overall IT budget (Gartner 2014), and the top reason for acquiring IT applications is to improve organizational performance (Ulrich 2006). For instance, EDI and enterprise resource planning (ERP) systems are broadly adopted to enhance firms' operational efficiency and reduce their marginal costs.

IT implementation projects are plagued by intrinsically high failure rates. According to Standish Group, despite decades of advancement in software engineering, 24% of IT implementation projects failed (e.g., are cancelled before completion, or the system is never used), and another 44% are challenged (e.g., over budget or failed to deliver required functions) (Standish Group 2009). ERP systems reportedly have even higher failure rates (Hitt et al 2002). Dewan et al. (2007) find empirical evidence that IT capital investment is substantially riskier than non-IT capital investment. The failure of IT implementation can have a significant impact on firms' profits. Flyvbjerg and Budzier (2011) provide a number of compelling examples including that of Levi Straus which took a $192.5M charge in 2008 after trying to adopt a SAP system.

The causes for frequent IT project failure are quite complex and include social, behavioral and technical reasons. One major reason is that the assumptions, logics and capabilities embedded in an enterprise IT system do not match with the firm's existing organizational structure and processes. The technical and organizational know-how required for evaluating such a match is oftentimes difficult, if not impossible, for a client firm to obtain prior to adoption, and can only be learned through implementation and use (Attewell 1992). While some firms successfully transformed their business processes and organizational control to adapt to the enterprise IT system, many find such sweeping changes quite challenging. Firms could risk disrupting their existing culture, facing resistance to change, and creating extensive training requirements (Umble et al 2003). Moreover, implementation outcome depends on the dialectic interplay among the diverse interests of stakeholders, which cannot be determined prior to completion of implementation (Cooper and Zmud, 1990).

In this paper, we investigate client firms' incentive to invest in IT in a differentiated market when the outcome of their IT implementation is uncertain. We consider a standard Hotelling model in which two firms compete in a horizontally differentiated market. The duopolists are located at the ends of a unit line, and consumers are uniformly distributed along the line. Both firms face an opportunity to invest in IT to reduce marginal production costs and thus to improve their efficiency. Higher IT investment may lead to lower marginal costs. The outcome of the IT implementation is, nevertheless, uncertain: if the project succeeds, the adopter achieves the anticipated cost savings;

if the project fails, the adopter bears the project cost although its marginal production cost does not improve. Both firms simultaneously decide whether to and how much to invest in IT. The IT projects are then implemented if the firms decide to invest in IT. Both firms observe the outcome of each other's IT investment, and announce their prices simultaneously after knowing each other's new marginal costs. Consumers observe the prices and make a purchase decision. Transaction takes place.

First, we examine a benchmark model without implementation uncertainty and show that the quandary that firms face while making their IT investment decisions resembles that of a Prisoner's Dilemma game. Each firm benefits from investing in IT if his competitor does not. But if both firms invest in IT, in a symmetric equilibrium, they lower their marginal costs by the same amount. Competition forces them to pass the entire benefit from marginal cost reduction to consumers in the form of lower prices. Thus firms retain the same profit margin and market share with the added burden of IT investment, and this leads to lower profits. This finding holds irrespective of the level of competition in the market.

Next, we introduce implementation uncertainty, and demonstrate that when the outcome of IT implementation is uncertain, firms in different markets pursue different investment strategies for different types of IT. For moderate or high-risk IT, firms in highly competitive markets pursue an *Aggressive* investment strategy characterized by high levels of IT investment. They aim to leverage their IT investment as a possible source of differentation, and achieve a dominant position if their implementation succeeds but their opponents' does not. The strategic trade-off that they face is no longer described by a Prisoner's Dilemma game. Instead, their expected profit increases when they have the opportunity to invest in IT. In contrast, firms in less competitive markets pursue a more conservative *Responsive* investment strategy. Their investment is largely motivated by competitive necessity to avoid being left behind with a less efficient process and a higher cost structure. We also examine the impact of IT implementation uncertainty on firms' investment risk as measured by profit volatility using the Coefficient of Variation. We discuss the managerial implications and contributions of our findings in the Discussion section.

2 Literature Review

This paper is related to a stream of research on strategic IT investment and its impact on firms' performance. This literature, however, either does not consider the impact of competition or focuses on industries that are quality differentiated (i.e., vertical differentiation). More importantly, this literature does not consider the inherent uncertainty of IT project implementation.

For instance, Thatcher and Oliver (2001) and Thatcher and Pingry (2004a) develop models of monopolistic firms that can invest in IT at no cost. In these models, IT investments can be used to influence product quality, efficiency and demand. They identify conditions under which IT investments have a favorable impact on firms' revenues, profits and productivity.

Several scholars have studied IT investment decisions and their impact on firms' performance in models of duopoly competition. These models focus on competitors that are quality differentiated, and IT investments are typically used to influence quality related parameters in the model. Quan et al. (2003) and Thatcher and Pingry (2004b) develop models that extend the monopoly models of Thatcher and Oliver (2001) and Thatcher and Pingry (2004a) while retaining the assumption of costless IT investments. They compare the results from monopoly and duopoly models and highlight several interesting findings. In particular, Quan et al. (2003) use numerical simulation techniques to show that the impact of IT investment on firms' profits and productivity is different when consumers are more quality sensitive vs. when consumers are more price sensitive. Thatcher and Pingry (2004b) also compare the results from monopoly and duopoly models but their focus is on identifying whether the impact of IT investments on firms' quality and profits is unambiguous (i.e., monotone given all feasible values of the model parameters) or ambiguous. They find that IT investments that reduce the cost of quality lead to unambiguous increase in quality and firms' profits.

Barua et al. (1991) and Demirhan et al. (2007) also study quality-differentiated models of duopoly competition while relaxing the assumption of costless IT. In these models, the firms invest in IT to enhance product quality. Barua et al. (1991) examine the impact of IT investment on enhancing service offerings that are provided free of cost to consumers. They show that the duopolistic firms over-invest relative to the monopoly level of investment and that the benefit from the resulting service enhancement flows largely to consumers. The presence of switching costs reduces consumer welfare and can result in lower industry profits. Demirhan et al. (2007) study the effect of declining IT costs and consumer switching costs on the dupolists' investment strategies. They find that the falling cost of IT can lead to a reduction in the profits of both competitors and that an increase in switching cost can sometimes lead to an increase in consumer surplus. Finally, Demirhan et al. (2005) examine the impact of the falling cost of IT where IT is used to enhance product quality and find that this cost reduction can intensify or relax competition between the two firms depending on consumers' price and quality sensitivity.

Our paper differs from this literature in several respects. First, we analyze how the uncertain outcome of IT implementation impacts firms' incentive to invest in IT. This is an important feature of IT adoption, as we discuss in the Introduction, and is currently missing in this literature. Second, our research examines horizontally differentiated markets. This approach allows us to parameterize the degree of competition, and thus to directly examine the impact of competition on IT investment. There is a vast literature in Economics and Marketing that studies horizontally differentiated markets using the framework originally proposed by Hotelling (1929) and refined by d'Aspremont et al. (1979). The key difference is that in vertical models of quality, all consumers agree on which firm offers a superior quality. Whereas in horizontal models, there is an element of "fit" between firms and consumers so that some consumers prefer one firm while others prefer the competing firm. Consumers may prefer one seller to another because of the physical proximity of the business to consumers' location (i.e., convenience) or their specific taste. For example, demand in the grocery retail business is driven by location proximity. Retail grocers may also differ in terms of the kind of merchandise they choose to specialize in (for example, ethnic food from different parts of the world) and thus attract consumers with certain preferences. Other such examples include consumers who prefer Microsoft to Apple and vice-versa for desktop OS and Google's Android vs. Apple's iOS for mobile OS.

This paper is also related to the literature on firms' incentive to invest in a process innovation that lowers production cost but does not result in exclusive rights for the investor. Only a few papers in this literature, however, consider the uncertain outcome of firms' investment. Quirmbach (1993) considers a model in which firms have the opportunity to invest a fixed amount to participate in an innovation and face a fixed probability of success. The firms that succeed at research then enter the commodity market and engage in various forms of competition (e.g., Bertrand, Cournot or perfect collusion). The initial research investment does not change a firm's production cost if it succeeds, rather it acts as an entry cost. In Dasgupta and Stiglitz (1980b), a firm producing a commodity faces no effective competition initially possibly because it enjoys a patent on the technology for producing the commodity. Other firms can compete to share the market in the future by undertaking R&D activities, while the incumbent firm continues to engage in R&D activities lest its monopoly position be eroded. Firms' R&D investment determines the timing of the invention with uncertainty—firms that invest more are more likely to succeed early. The outcome of the invention is predetermined: the invention lowers the marginal production cost to a fixed amount independent of the level of R&D investment.

This paper differs from the above two papers in that we consider a differentiated market rather than a commodity market. Moreover, in our model, the amount of cost reduction depends on the level of IT investment, and the outcome of the IT investment is uncertain. Our approach is consistent with prior empirical findings showing that higher levels of IT investment generally lead to higher productivity gain, although IT projects are fairly risky, contributing to large variation in return to firms' IT investment (Brynjolfsson and Hitt 1996, 1998).

3 Model Setup

We analyze a model of duopoly competition in which each firm may invest in IT to reduce its marginal cost of production. We use the horizontal differentiation framework of Hotelling (1929) and d'Aspremont et al. (1979). The duopolists are located at the ends of a unit line–firm 1 is located at 0 and firm 2 is located at 1–and each offers a product for sale at prices P_1 and P_2 respectively. Consumers are uniformly distributed along the line, and each demands one unit of the product. We model consumer misfit costs or transportation costs as a quadratic function of the distance between the consumer and the seller. Thus, a consumer located at $x \in [0, 1]$ incurs a misfit cost of tx^2 if she buys from firm 1, or a misfit cost of $t(1-x)^2$ if she buys from firm 2. Parameter t serves as a proxy for the level of differentiation between the two firms. When t is small, the two products become close substitutes since consumers do not have a strong preference for one product over the other (or $t\left|x^2-(1-x)^2\right|$ is small). Thus lower t implies less differentiation and more intense competition[1]. Prior literature has also used the parameter t as a measure of the intensity of competition (see Villas-Boas and Schmidt-Mohr (1999) and Boone (2001)). The utility that a consumer gains from purchasing firm 1's product is $U - tx^2 - P_1$ and that from purchasing firm 2's product is $U - t(1-x)^2 - P_2$. We retain a common assumption for horizontal models that U is large enough so that the market is fully covered (otherwise the firms become local monopolists).

The current technology allows each firm to produce their products at a constant marginal cost c. Both firms face an opportunity to invest an amount f in IT to reduce their marginal cost, where $f \in [0, +\infty)$. The outcome of the IT implementation is uncertain. With probability α, the implementation succeeds, and firm i is able to reduce his marginal cost by Δc_i, where $f_i = k(\Delta c_i)^2$, $k > 0$ and $i = 1, 2$. Hence the marginal return to IT investment decreases the more a firm invests in IT. k is a scaling parameter, representing the inverse effectiveness of converting IT investment into marginal cost reduction. With probability $(1-\alpha)$, the implementation fails, and the firm retains his marginal cost at c despite his IT investment.

The timing of the two-stage game is as follows. First, in the investment stage, firms decide

[1] $t = 0$ corresponds to perfect (Bertrand) competition and when t is sufficiently large the firms behave like local monopolists.

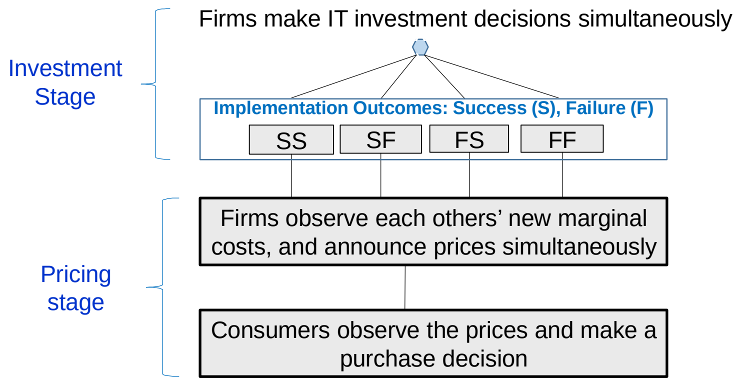

Figure 1: Two-stage game with uncertain IT implementation outcome

simultaneously whether to and how much to invest in IT. The IT projects are then implemented. If a firm's implementation is successful, his new marginal cost is equal to $c - \Delta c$, where $\Delta c \geqslant 0$; otherwise, he retains his original marginal cost at c. The outcome of the IT implementation becomes common knowledge. Next, in the pricing stage, the two firms announce their prices simultaneously after observing each other's new marginal costs. Consumers observe the prices and make a purchase decision. Transaction takes place.

The timing of the game is illustrated in Figure 1. There are four possible implementation outcomes: SS, SF, FS, FF. The first letter represents the implementation outcome of firm 1, S (Success) or F (Failure), and the second letter represents the implementation outcome of firm 2. Each implementation outcome assigns a set of new marginal costs $\left(c_1^j, c_2^j\right)$ to the firms, where $j = SS$, SF, FS, or FF. In the pricing stage, the firms set their prices simultaneously given the new marginal costs.

We solve this game through backward induction. We first focus on the pricing stage and solve for the equilibrium pricing strategy and firms' profits given each implementation outcome. Next, we will analyze firms' optimal investment strategy, given their pricing strategy in the second stage. We focus on the *Subgame Perfect Equilibrium* of the game.

4 Analysis

4.1 Pricing Stage

In this subsection, we begin with the second stage of the game. Both firms have completed the IT investment stage, and the outcome of the implementation has been realized. If firm i's IT implementation was successful, then his new marginal cost is $c_i = c - \triangle c_i$, where $f_i = k \triangle c_i^2$,

$0 \leqslant \triangle c_i \leqslant c$. If firm i's IT implementation failed, he retains his marginal cost at c despite the IT investment. Note that even if both firms succeed at their IT implementation, they may enter this stage of the game with different marginal costs if their investment levels are different. The firms observe each other's marginal costs, and simultaneously announce their profit maximizing prices.

The utility that a consumer gains from purchasing firm 1's product is $U - tx^2 - P_1$ and that from purchasing firm 2's product is $U - t(1-x)^2 - P_2$. Thus, a consumer located at x buys from firm 1 if $U - tx^2 - P_1 \geqslant U - t(1-x)^2 - P_2$. A consumer buys from firm 2 if $U - tx^2 - P_1 < U - t(1-x)^2 - P_2$.

The market share of each firm can be calculated by considering the indifferent consumer ($\overline{x}$) who obtains equal utility from buying from either seller:

$$U - t\overline{x}^2 - P_1 = U - t(1-\overline{x})^2 - P_2 \qquad \Leftrightarrow \overline{x} = \frac{P_2 - P_1 + t}{2t} \tag{1}$$

Therefore, firm 1's market share $m_1 = \overline{x}$, and firm 2's market share $m_2 = 1 - \overline{x}$. Given consumers' decision, both firms set their prices to maximize their profits given their marginal costs:

$$\max_{P_i} m_i \left(P_i - c_i\right),$$
$$s.t., 0 \leq m_i \leq 1.$$

Solving the two optimization problems simultaneously, one can show that each firm's equilibrium pricing strategy and market share depend on their own as well as their opponent's new marginal cost. If the two firms' marginal costs are not too far apart, then they both have positive market shares. If one firm is much more efficient than the other firm, then the more efficient firm would price his product so low that the opponent cannot make any profit selling his product, and, thus, has zero market share. This result is summarized in the following Lemma. All proofs not included in the body of the paper are in the Appendix.

Lemma 1. *If $|c_1 - c_2| \leqslant 3t$, then both firms have positive market shares in equilibrium. Their optimal pricing strategy is characterized by*

$$P_1\left(c_1, c_2\right) = t + \frac{2c_1 + c_2}{3},$$
$$P_2\left(c_1, c_2\right) = t + \frac{c_1 + 2c_2}{3},$$

and their market shares are $m_1\left(c_1, c_2\right) = 1/2 + \left(c_2 - c_1\right)/6t$, and $m_2\left(c_1, c_2\right) = 1/2 + \left(c_1 - c_2\right)/6t$.

If $|c_1 - c_2| > 3t$, then the more efficient firm (i.e., the firm with a lower marginal cost), say firm i, sets the price $P_i = c_{-i} - t$. All consumers buy from firm i; firm i's opponent, firm $-i$, has

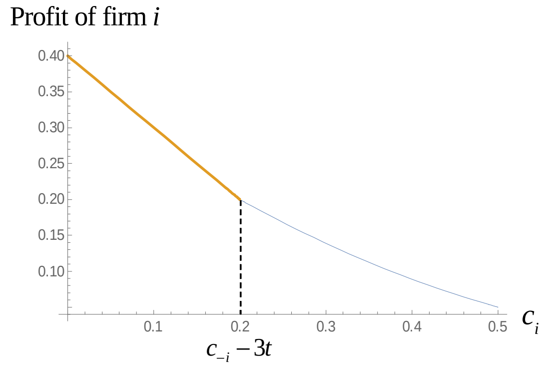

Figure 2: Firm 1's equilibrium profit given different marginal cost levels. Plot for $c_{-i} = 0.5$, $t = 0.1$.

a zero market share in equilibrium, i.e., $m_i = 1, m_{-i} = 0$.

Figure 2 shows how firm i's gross profit (ignoring the cost of IT investment) changes with his marginal cost holding his opponent's marginal cost constant, where $i = 1, 2$. Firm i's equilibrium profit increases as his marginal cost declines. Once his marginal cost is so low that $c_i < c_{-i} - 3t$, his profit improves significantly faster with further marginal cost reduction. This is because when $c_{-i} - 3t \leqslant c_i \leqslant c_{-i} + 3t$, both firms have positive market shares in equilibrium. If firm i has a cost advantage against his competitor, he finds it optimal to lower his price to gain a larger share of the market. His profit margin on each sale improves although less than his lead in marginal cost, since his opponent responds with a lower price as well. Whereas once $c_i < c_{-i} - 3t$, firm i's new marginal cost is so low that firm $-i$ can no longer match prices with firm i. Any further reduction in marginal cost translates directly into an increase in firm i's profit margin. The prospect of such lucrative return may motivate firms to invest heavily in IT in some markets as we will discuss below.

4.2 IT Investment Decision

In this subsection, we solve for firms' optimal investment decisions. The payoff of a firm's IT investment depends on the amount and outcome of his own IT investment as well as that of his opponent's. A firm's IT project succeeds with probability α, and it fails with probability $1 - \alpha$. There are four possible outcomes as shown in Figure 1. Denote firm i's marginal cost and profit given outcome j by c_i^j and π_i^j respectively, where $i = 1, 2$ and $j \in \{SS, SF, FS, FF\}$.

Note that if the implementation is unsuccessful, each firm retains their original marginal cost, or $c_1^{FS} = c_1^{FF} = c$, and $c_2^{SF} = c_2^{FF} = c$. If the implementation is successful, each firm achieves a new and lower marginal cost. Define $c_1^{SS} = c_1^{SF} = c_{1S}$, $c_2^{SS} = c_2^{FS} = c_{2S}$, where $f_i = k\,(c - c_{iS})^2$, $i = 1, 2$. Therefore, there is a one to one mapping between a firm's IT investment amount, f_i, and his new marginal cost in the event of a successful implementation, c_{iS}. The firms' problem of searching for the optimal IT investment level (f_i) is equivalent to search for a new marginal cost in the event of a successful IT implementation (c_{iS}), which maximizes the firm's expected profit. Therefore, firm i's investment decision can be described as:

$$\max_{c_{iS}} E(\pi_i) = \max_{c_{iS}} \left(\alpha^2 \pi_i^{SS} + \alpha(1-\alpha)\pi_i^{SF} + \alpha(1-\alpha)\pi_i^{FS} + (1-\alpha)^2 \pi_i^{FF} \right)$$

$$s.t., \; c_{iS} \in [0, c], \text{ and } E(\pi_i) \geq 0,$$

where $i = 1, 2$. The payoff of a firm's IT investment given each outcome (π_i^j, where $j \in \{SS, SF, FS, FF\}$) can be derived by applying Lemma 1. Below we derive firm 1's profit given each outcome. Firm 2's profit given each outcome can be derived similarly.

If the implementation outcome is SF, firm 1's new marginal cost is $c_{1S} \leq c$, and firm 2's marginal cost remains c. Firm 1's optimal pricing strategy and profit in the pricing subgame depend on his new marginal cost. If firm 1's new marginal cost is low such that $c_{1S} < c - 3t$, then in the pricing subgame, in equilibrium, firm 1's price $P_1(c_{1S}, c) = c - t$. Firm 2 cannot generate any profit from selling in the market because no consumer would buy from him even though firm 2 sells at marginal cost (c). Hence, firm 2's market share is 0, and firm 1's market share is 1.

If firm 1's new marginal cost is relatively close to firm 2's marginal cost, then the two firms share the market. In equilibrium, firm 1's price $P_1(c_{1S}, c) = t + (2c_{1S} + c)/3$, and firm 2's price $P_2(c_{1S}, c) = t + (c_{1S} + 2c)/3$. Firm 1 has a market share $m_1(c_{1S}, c) = (c - c_{1S})/6t + 1/2$. Thus, firm 1's payoff given this outcome is

$$\pi_1^{SF} = \begin{cases} \left(\frac{c-c_{1S}}{6t} + 1/2\right)\left(t + \frac{2c_{1S}+c}{3} - c_{1S}\right) - f_1 & \text{if } \max\{0, c-3t\} \leq c_{1S} \leq c \\ (c - t - c_{1S}) - f_1 & \text{if } 0 \leq c_{1S} < c - 3t \end{cases},$$

where $f_1 = k(c - c_{1S})^2$. If the implementation outcome is FS, firm 1's marginal cost remains c, and firm 2's new marginal cost is $c_{2S} \leq c$. Applying a similar argument as in the case of SF, one can show that firm 1's payoff given this outcome is

$$\pi_1^{FS} = \begin{cases} \left(\frac{c_{2S}-c}{6t} + 1/2\right)\left(t + \frac{2c+c_{2S}}{3} - c\right) - f_1 & \text{if } \max\{0, c-3t\} \leq c_{2S} \leq c \\ 0 - f_1 & \text{if } 0 \leq c_{2S} < c - 3t \end{cases},$$

where $f_1 = k(c - c_{1S})^2$. If the implementation outcome is FF, both firms' marginal costs remain c. Thus, the two firms share the market in the pricing subgame. In equilibrium, firm 1's price

$P_1(c,c) = t + c$, and firm 2's price $P_2(c,c) = t + c$. Firm 1 has a market share $m_1(c,c) = 1/2$. Therefore, firm 1's payoff given this outcome is

$$\pi_1^{FF} = \frac{t}{2} - f_1 = \frac{t}{2} - k(c - c_{1S})^2 .$$

If the implementation outcome is SS, firm 1's new marginal cost is $c_{1S} \leq c$, and firm 2's new marginal cost is $c_{2S} \leq c$. Firm 1's payoff given this outcome depends on the difference between c_{1S} and c_{2S}. If firm 2 becomes much more efficient than firm 1 such that $c_{2S} < c_{1S} - 3t$, then in the pricing subgame, in equilibrium, firm 2 prices his product so low that it is no longer profitable for firm 1 to sell in the market. If firm 1 becomes much more efficient than firm 2 such that $c_{1S} < c_{2S} - 3t$, then in the pricing subgame, in equilibrium, firm 1's price $P_1(c_{1S}, c_{2S}) = c_{2S} - t$. It is no longer profitable for firm 2 to sell in the market, and firm 1's market share is 1. If the two firms' new marginal costs are relatively close, then, in the pricing game, they share the market, and firm 1's price $P_1(c_{1S}, c_{2S}) = t + (2c_{1S} + c_{2S})/3$, and firm 2's price $P_2(c_{1S}, c_{2S}) = t + (c_{1S} + 2c_{2S})/3$. Firm 1 has a market share $m_1(c_{1S}, c_{2S}) = (c_{2S} - c_{1S})/6t + 1/2$. In summary, firm 1's payoff given this outcome is

$$\pi_1^{SS} = \begin{cases} 0 - f_1 & \text{if } c_{2S} + 3t < c_{1S} \leq c \\ \left(\frac{c_{2S} - c_{1S}}{6t} + 1/2\right)\left(t + \frac{2c_{1S} + c_{2S}}{3} - c_{1S}\right) - f_1 & \text{if } c_{2S} - 3t \leqslant c_{1S} \leqslant c_{2S} + 3t \\ c_{2S} - t - c_{1S} - f_1 & \text{if } 0 \leq c_{1S} < c_{2S} - 3t \end{cases},$$

where $f_1 = k(c - c_{1S})^2$.

Since this is a symmetric game, below we focus on solving those Nash equilibria of the game in which the two firms follow the same investment strategies, or the symmetric Nash equilibria of the game. Note that even if the two firms follow the same investment strategy, their implementation outcome can be different due to implementation uncertainty, and, therefore, they may have different marginal costs post IT investment.

Assumption: $18kt > \alpha$.

This assumption ensures that the marginal return to firms' IT investment decreases with the total investment amount. If this condition does not hold, then the cost of IT is so low that the marginal return to IT investment increases the more a firm invests in IT, and both firms always invest in IT until their marginal costs are equal to zero.

To highlight the role of implementation uncertainty, let us first look at a benchmark case in which IT implementation is successful with probability 1 ($\alpha = 1$), or no uncertainty. Next, we solve for firms' investment decision when the implementation outcome is uncertain. We then compare the findings with those of the benchmark model.

4.2.1 Benchmark: IT Investment Decision without Implementation Uncertainty

In the absence of implementation uncertainty, firm i obtains a new marginal cost c_{iS} after investing $f_i = k(c - c_{iS})^2$ in IT, where $i = 1, 2$. Firm i's payoff depends on the amount of his own and his opponent's IT investment. Applying Lemma 1, one can show that firm i's payoff

$$\pi_i(c_{iS}) = \begin{cases} 0 - k(c - c_{iS})^2 & \text{if } c_{-iS} + 3t < c_{iS} \leq c \\ \left(\frac{c_{-iS} - c_{iS}}{6t} + 1/2\right)\left(t + \frac{2c_{iS} + c_{-iS}}{3} - c_{iS}\right) - k(c - c_{iS})^2 & \text{if } c_{-iS} - 3t \leqslant c_{iS} \leqslant c_{-iS} + 3t \\ c_{-iS} - t - c_{iS} - k(c - c_{iS})^2 & \text{if } 0 \leq c_{iS} < c_{-iS} - 3t \end{cases}.$$

Evidently, firm i's objective function is not differentiable everywhere for $c_{iS} \in [0, c]$. Note that if a set of strategies $(\widehat{c_{1S}}, \widehat{c_{2S}})$ is a symmetric equilibrium of the game, then it satisfies that (necessary condition), for $i = 1, 2$,

$$\widehat{c_{iS}} = \underset{c_{iS} \in [0,c]}{\arg\max} \left(\frac{\widehat{c_{-iS}} - c_{iS}}{6t} + 1/2\right)\left(t + \frac{2c_{iS} + \widehat{c_{-iS}}}{3} - c_{iS}\right) - k(c - c_{iS})^2.$$

That is if $(\widehat{c_{1S}}, \widehat{c_{2S}})$ is a symmetric equilibrium of the game, then given $\widehat{c_{2S}}$, strategy $\widehat{c_{1S}}$ maximizes firm 1's profit at least among all strategies $c_{1S} \in [\widehat{c_{2S}} - 3t, \widehat{c_{2S}} + 3t]$. And the same applies to firm 2. Solving the two optimization problems simultaneously for $\widehat{c_{1S}}$ and $\widehat{c_{2S}}$, we obtain a set of investment strategies that may be a symmetric equilibrium of the game. Second, for this set of investment strategy to be an equilibrium, we also need that firm i cannot improve his payoff by deviating to a strategy c_i' such that $c_i' \in [0, c]$, and $c_i' \notin [\widehat{c_{-iS}} - 3t, \widehat{c_{-iS}} + 3t]$. That is for any $c_i' \in [0, c] \setminus [\widehat{c_{-iS}} - 3t, \widehat{c_{-iS}} + 3t]$,

$$E\left[\pi_i\left(c_i'\right)|\widehat{c_{-iS}}\right] \leq E\left[\pi_i\left(\widehat{c_{iS}}\right)|\widehat{c_{-iS}}\right].$$

The second step completes the conditions under which the set of strategies identified in the early step is a symmetric equilibrium of the game. Moreover, this two-step procedure captures any possible symmetric equilibrium of the game. One can show that, firm i's optimal investment strategy is as follows:

The Benchmark (BM) strategy: Firm i invests $f_i = \min\left\{1/36k, kc^2\right\}$, and obtains a new marginal cost $c_{iS} = \max\{c - 1/6k, 0\}$, where $i = 1, 2$.

Let Θ_0 denote the set of parameter values for (c, k, t) such that the BM investment strategy is optimal for any $(c, k, t) \in \Theta_0$. The detailed definition for Θ_0 is available in the Appendix. The following proposition summarizes the findings.

Proposition 1. *In the absence of implementation uncertainty, when $(c, k, t) \in \Theta_0$, in a symmetric equilibrium, each firm's optimal investment strategy is the BM strategy. If $c \geq 1/6k$, in the pricing stage, each firm sets his price $P_i = t + c - 1/6k$, and gains a profit*

$$\pi_i = \frac{t}{2} - \frac{1}{36k},$$

where $i = 1, 2$. If $c < 1/6k$, in the pricing stage, each firm sets his price *$P_i = t$, and gains a profit $\pi_i = t/2 - kc^2$.*

In a symmetric equilibrium, in the absence of implementation uncertainty, both firms successfully lower their marginal costs by the same amount through IT investment. Competition, nevertheless, forces them to pass the entire benefit from marginal cost reduction to consumers in the form of lower prices. Each firm retains the same profit margin and market share despite of their IT investment, which hurts their profits.

4.2.2 IT Investment Decision with Implementation Uncertainty

With implementation uncertainty, after investing $f_i = k(c - c_{iS})^2$ in IT, firm i obtains a new marginal cost $c_{iS} \in [0, c]$ with probability α, and retains his original marginal cost c with probability $1 - \alpha$, where $i = 1, 2$. Since each firm's objective function is not differentiable everywhere for $c_{iS} \in [0, c]$, the standard optimization method that assumes a smooth objective function (e.g., Lagrange Multiplier) cannot be applied directly to solve this game. Instead, we consider two separate cases. Case 1, we investigate whether there is a symmetric Nash equilibrium of the game in which, in equilibrium, $c_{1S}, c_{2S} \in [\max\{c - 3t, 0\}, c]$. This represents a relatively conservative investment strategy. Given these strategies, both firms have positive market shares irrespective of the implementation outcome. Case 2, when $c > 3t$, we investigate whether there is a symmetric Nash equilibrium of the game in which, in equilibrium, $c_{1S}, c_{2S} \in [0, c - 3t]$. When the market is more competitive (t is small), this represents an aggressive investment strategy. Given these strategies, if one firm succeeds at his IT investment while his opponent fails, the successful firm sets such a low price that the opponent cannot make a profit selling in the market.

Case 1: A NE of the game in which $c_{1S}, c_{2S} \in [\max\{c - 3t, 0\}, c]$

If a set of investment strategies $(\widehat{c_{1S}}, \widehat{c_{2S}})$, where $\widehat{c_{1S}}, \widehat{c_{2S}} \in [\max\{c - 3t, 0\}, c]$, is a symmetric equilibrium of the game, then it satisfies that (necessary condition): for $i = 1, 2$,

$$\widehat{c_{iS}} = \underset{c_{iS} \in [\max\{c-3t,0\},c]}{\arg\max} E\left[\pi_i\left(c_{iS}\right) | \widehat{c_{-iS}} \in [\max\{c-3t,0\}, c]\right]. \tag{2}$$

That is, if $(\widehat{c_{1S}}, \widehat{c_{2S}})$ is a symmetric equilibrium of the game, then each firm's investment strategy is a best response to his opponent's investment strategy at least in the range of $[\max\{c-3t,0\}, c]$.

One can show that, for any $c_{1S}, c_{2S} \in [\max\{c-3t,0\}, c]$, we have $|c_{1S} - c_{2S}| \leqslant 3t$, and $|c_{iS} - c| \leqslant 3t$, $i = 1, 2$. Therefore, firm 1 and 2's objective functions are continuous and differentiable, given $c_{1S}, c_{2S} \in [\max\{c-3t,0\}, c]$. Now one can solve the two optimization problems defined by (2) simultaneously for firm 1 and 2, and obtain a set of investment strategies that can be a symmetric equilibrium of the game.

When $c - 3t \leqslant 0$, this set of strategies is indeed a NE of the game (i.e., sufficient condition). When $c - 3t > 0$, we need to verify that firm i is unable to improve his profit by deviating to an investment strategy in the range of $[0, c-3t)$, given his opponent's strategy. That is for any $c_i' \in [0, c-3t)$,

$$E\left[\pi_i\left(c_i'\right) | \widehat{c_{-iS}}\right] \leqslant E\left[\pi_i\left(\widehat{c_{iS}}\right) | \widehat{c_{-iS}}\right],$$

where $i = 1, 2$. This step completes the conditions under which the set of investment strategy identified in the previous step is an equilibrium given the entirety of the firms' strategy space. Furthermore, one can show that this two-step procedure captures any symmetric equilibrium of the game in which $c_{1S}, c_{2S} \in [\max\{c-3t,0\}, c]$ if it exists. Two sets of investment strategies can be optimal in an equilibrium depending on the range of parameter values.

The Responsive (R) Investment Strategy: Firm i invests

$$f_i = k\left(\frac{3\alpha t}{(-1+\alpha)\alpha + 18kt}\right)^2,$$

in IT, and, if his IT implementation is successful, his new marginal cost is

$$c_{iS} = c - \frac{3\alpha t}{(-1+\alpha)\alpha + 18kt},$$

where $i = 1, 2$.

The Responsive Limit (RL) Investment Strategy: Firm i invests $f_i = kc^2$ in IT, and, if his IT implementation is successful, his new marginal cost is $c_{iS} = 0$.

Both Responsive and Responsive Limit strategies are relatively conservative investment strategies: the investment amounts are moderate such that the two firms share the market in every possible outcome of the IT implementation: SS, SF, FS and FF. The Responsive Limit strategy represents the boundary of the Responsive strategy where the investment amount reaches its maximum– the new marginal cost in the event of a successful implementation is reduced to zero. Further investment is ruled out as marginal cost cannot be negative.

Let Θ_1 denote the set of parameter values for (c, k, α, t) such that the Responsive investment strategy is optimal for any $(c, k, \alpha, t) \in \Theta_1$. The detailed definition for Θ_1 is available in the Appendix. The following propositions summarize the findings.

Proposition 2. *When $(c, k, \alpha, t) \in \Theta_1$, in a symmetric equilibrium, the firms' optimal investment strategy is the Responsive investment strategy, and the expected profit is*

$$E(\pi_i) = \frac{t(324k^2t^2 + \alpha^2(1 + 18kt) - \alpha^4 - 36k\alpha t)}{2((-1 + \alpha)\alpha + 18kt)^2}$$

where $i = 1, 2$.

Proposition 3. *When $c < 3t$* and *$\alpha/(18t) < k < \alpha/(6c) + \alpha(1 - \alpha)/(18t)$, in a symmetric equilibrium, the firms' optimal investment strategy is the Responsive Limit strategy, and the expected profit is*

$$E(\pi_i) = \frac{t}{2} - \frac{c^2(9kt - (1 - \alpha)\alpha)}{9t}$$

where $i = 1, 2$.

We discuss the range of parameter values that characterizes each symmetric equilibrium at the end of this section.

Case 2: A NE of the game in which $c_{1S}, c_{2S} \in [0, c - 3t]$

When the market is more competitive, or $3t < c$, the two firms may pursue an aggressive investment strategy such that $c_{1S}, c_{2S} \in [0, c - 3t]$. In this case, if firm i's IT implementation succeeds while his opponent's does not, firm i's new marginal cost is so much lower than his opponent's that his opponent cannot profit from selling in the market. Firm i sets his price $P_i = c - t$, and has a market share equal to 1. Thus, in this case, $\pi_1^{SF} = (c - t - c_{1S}) - f_1$, $\pi_1^{FS} = 0 - f_1$, and $\pi_2^{FS} = (c - t - c_{2S}) - f_2$, $\pi_2^{SF} = 0 - f_2$. π_i^{SS} depends on the difference between c_{1S} and c_{2S}. When c_{1S}, c_{2S} are relatively close such that $|c_{1S} - c_{2S}| \leqslant 3t$,

$$\pi_i^{SS} = \left(\frac{c_{-iS} - c_{iS}}{6t} + 1/2\right)\left(t + \frac{2c_{iS} + c_{-iS}}{3} - c_{iS}\right) - k(c - c_{iS})^2. \tag{3}$$

If a set of strategies $(\widehat{c_{1S}}, \widehat{c_{2S}})$, where $\widehat{c_{1S}}, \widehat{c_{2S}} \in [0, c - 3t]$, is a symmetric equilibrium of the game, then it satisfies the following condition (i.e., necessary condition): for $i = 1, 2$,

$$\widehat{c_{iS}} = \underset{c_{iS} \in [0, c-3t]}{\arg\max}\ E\left[\pi_i\left(c_{iS}\right)|\widehat{c_{-iS}} \in [0, c-3t]\right],$$

where π_1^{SF}, π_1^{FS}, π_2^{FS}, and π_2^{SF} are defined in the previous paragraph, and π_i^{SS} is defined in (3). Solving the two optimization problems simultaneously, one can identify investment strategies that can be a symmetric equilibrium of the game. Second, if the identified investment strategies are a symmetric equilibrium of the game, then, given his opponent's strategy, firm i is unable to improve his profit by deviating to an investment strategy $c_i^{'}$, such that $c_i^{'} \in [0, c]$, but $c_i^{'} \notin [c_{-iS} - 3t, c_{-iS} + 3t]$. This step completes the conditions under which the investment strategy identified in the previous step is optimal given the entirety of the firms' strategy space (i.e., $c_{iS} \in [0, c]$). Furthermore, one can show that this two-step procedure captures any symmetric equilibrium of the game in which firms' investment policy falls in the range $[0, c-3t]$, if it exists. One can show that two sets of strategies can be optimal:

The Aggressive (A) Investment Strategy: Firm i invests

$$f_i = \frac{\alpha^2(3-2\alpha)^2}{36k},$$

in IT, and, if the IT implementation is successful, firm i's new marginal cost is

$$c_{iS} = c - \frac{\alpha(3-2\alpha)}{6k},$$

where $i = 1, 2$.

The Aggressive Limit (AL) Investment Strategy: Firm i invests $f_i = kc^2$ in IT, and, if the IT implementation is successful, firm i's new marginal cost is $c_{iS} = 0$, where $i = 1, 2$.

When the market is more competitive, or $3t < c$, the Aggressive and Aggressive Limit strategies both involve high levels of IT investment designed to facilitate 100% market share for the successful firm when the opponent's IT implementation fails. The Aggressive Limit strategy represents the boundary of the Aggressive strategy where the investment amount reaches the maximum– the new marginal cost in the event of a successful implementation is reduced to zero. Further investment is ruled out as marginal cost cannot be negative.

Let Θ_2 denote the set of parameter values for (c, k, α, t) such that the Aggressive investment strategy is optimal. And let Θ_3 denote the set of parameter values for (c, k, α, t) such that the Aggressive Limit strategy is optimal. The detailed definitions for Θ_2 and Θ_3 are available in the

Appendix. The following propositions summarize the findings.

Proposition 4. *When $c > 3t$, and $(c, k, \alpha, t) \in \Theta_2$, in a symmetric equilibrium, the firms' optimal investment strategy is the Aggressive investment strategy, and the expected profit is*

$$E(\pi_i) = \frac{(\alpha^2(9 - 2\alpha(9 - 4\alpha)) + 18k(1 - 2\alpha)^2 t)}{36k}$$

where $i = 1, 2$.

Proposition 5. *When $c > 3t$, and $(c, k, \alpha, t) \in \Theta_3$, in a symmetric equilibrium, the firms' optimal investment strategy is the Aggressive Limit strategy, and the expected profit is*

$$E(\pi_i) = -c(ck + (-1 + \alpha)\alpha) + \frac{t}{2}(1 - 2\alpha)^2.$$

In summary, the firms' optimal investment strategy in a symmetric equilibrium depends on the range of parameter values. Figure 3 shows one such example, assuming $c = 1/4$, and $k = 1/2$. The horizontal axis represents the probability of IT implementation success (α). The vertical axis represents the level of differentiation between the two firms–a large t represents a more differentiated and, hence, less competitive market. The valid region is the region above the gray area, or $18kt > \alpha$. Given these parameter values, when the probability of project success (α) is low, and the level of competition is not too high (Region I), the firms' optimal investment strategy is the Responsive investment strategy. When the probability of project success is high, and the level of competition is relatively low (Region II), the firms' optimal investment strategy is the Responsive Limit strategy. When the probability of project success is low, and the level of competition is high (Region III), the firms' optimal investment strategy is the Aggressive investment strategy. When the probability of project success is relatively high, and the level of competition is high (Region IV), the firms' optimal investment strategy is the Aggressive Limit strategy. There is no symmetric equilibrium of the game in Region V. We discuss how firms' IT investment and profit vary with the parameter values in the next section.

4.3 Uncovering the Drivers of IT Investment

The objective of this paper is to understand (i) the impact of competitive pressure on firms' incentive to invest in IT and how it changes when the outcome of IT implementation is uncertain and (ii) the impact of IT investment on firm profits. As we established in the previous section, firms' optimal investment policy depends on the range of parameter values. In this section, we discuss

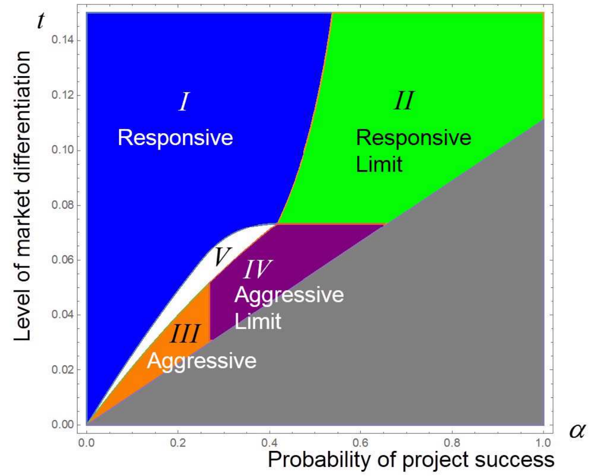

Figure 3: Equilibrium investment strategies for different α and t. Plot for $c = 0.25$, $k = 0.5$.

how firms' optimal investment strategy and their profits may vary with the nature of the market that they operate in or the characteristics of the technology that they are adopting. Through this discussion, we highlight the role of competition and implementation uncertainty in driving firms' IT investment.

4.3.1 The Role of Implementation Uncertainty

IT implementation projects are plagued by intrinsically high failure rates. This section discusses how such uncertainty impacts firms' investment incentives and profits. While trade journals and academic literature often emphasize the adverse consequences of IT project failure and caution about adopting high-risk IT (see for example Flyvbjerg and Budzier (2011)), we demonstrate in this section that implementation uncertainty can improve firm profits and reduce investment risk.

To understand the role of implementation uncertainty in shaping firms' IT investment and profits, we begin with the benchmark case in which there is no such uncertainty, or when $\alpha = 1$. Subsequently, we will introduce implementation uncertainty and discuss its impact on firms' investment decisions and profits.

In the absence of implementation uncertainty, the quandary that firms face while making their IT investment decisions resembles that of a Prisoner's Dilemma. If firm i's opponent does not invest in IT, and so $c_{-iS} = c$, it would always be beneficial for firm i to invest in IT to lower his marginal cost, since

$$\frac{\partial E(\pi_i | c_{-iS} = c)}{\partial c_{iS}} |_{c_{iS}=c} < 0,$$

for any $\alpha > 0$, $t > 0$. This is because the amount of IT investment required for a small reduction in marginal costs is minimal, since f is a convex function of the amount of marginal cost reduction. Once the firm is able to achieve a lower marginal cost, he directly benefits from a higher profit margin on each sale and a larger market share.

If firm i invests in IT, Figure 4 shows the opponent's (firm 2) best response as a function of firm i's (firm 1) investment strategy. The response function is downward sloping. Thus, if firm i invests more, his opponent would invest less in IT in response, and firm i is able to obtain a lower marginal cost and gain market share. Therefore, the firms enter an arm's race in IT investment with the objective of lowering their marginal costs. In a symmetric equilibrium, in the absence of implementation uncertainty, both firms successfully lower their marginal costs by the same amount. Competition, nevertheless, forces them to pass the entire gain from marginal cost reduction to consumers in the form of lower prices. Each firm retains the same profit margin and market share despite their IT investment, which hurts their profits.

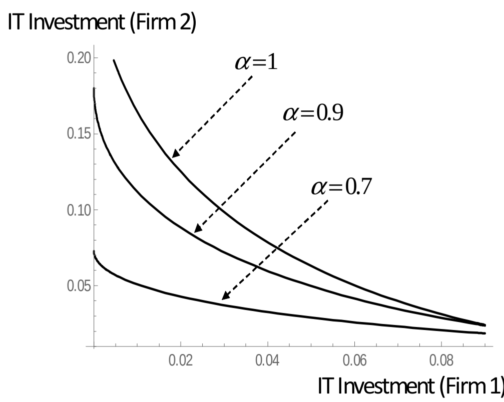

Figure 4: Best response function showing investment by firm 2 as a function of the investment level of firm 1. Plot for $c = 0.75$, $k = 0.5$, $t = 0.2$.

Next, let us consider the case in which IT implementation may fail. The uncertain outcome of IT implementation impacts firms' investment incentives and profitability in two ways:

First, a firm is less motivated to invest in IT when his investment is unlikely to be successful. More importantly, as shown in Figure 4, firm i also becomes less responsive to his competitor's investment as α approaches zero, since his competitor's IT investment is less likely to succeed. Recall that in the absence of implementation uncertainty, competition forces firms to enter an arm's race in IT investment, even though such decisions hurt both firms' profits. The uncertain outcome of IT implementation discourages firms from undercutting their opponents through marginal cost reduction. Therefore, implementation uncertainty mitigates the impact of competition: firms invest less as the probability of a successful implementation (α) decreases, and their profit improves.

Second, when the outcome of firms' IT implementation is uncertain, one firm can achieve a lower marginal cost than his competitor even though both firms invest the same amount in IT. This occurs when one firm's IT project is successful while the other's IT project fails. Thus implementation uncertainty creates a new possibility of differentiation in marginal costs. This differentiation effect changes the return to firms' IT investment. In particular, implementation outcomes SF and FS create marginal cost based differentiation. Each outcome occurs with probability $\alpha(1-\alpha)$, which peaks at $\alpha = 1/2$ and declines as α approaches 1 or 0. One can show that, in a symmetric equilibrium,

$$\frac{1}{2}\left(\pi_i^{SF} + \pi_i^{FS}\right) > \pi_i^{SS} = \pi_i^{FF}, i = 1, 2.$$

Thus, a firm prefers a probabilistic outcome in which only one firm's IT investment is successfully implemented, even though he may or may not be the successful one, than one in which both succeed or fail. The firm has more to gain as the more efficient firm than he has to lose as the less efficient firm in a differentiated outcome. Therefore, firms' expected profit improves when marginal cost based differentiation becomes more likely.

These two effects of implementation uncertainty move firms' IT investment and profitability in the same direction in some cases, and in opposing directions in other cases. The overall impact of implementation uncertainty depends on which effect dominates, which then depends on the characteristics of the market and the nature of the IT being adopted. Below we illustrate with two examples.

Figure 5 illustrates how firms' equilibrium investment policy and expected profit change with implementation uncertainty (or α), when the market is more differentiated and so less competitive (i.e., t is relatively high). When the probability of a successful implementation (α) is relatively low, the optimal investment strategy is the Responsive (R) strategy (Blue curve); and when such probability is relatively high, the optimal investment strategy is the Responsive Limit (RL) strategy (Green curve). Figure 6 shows how firms' equilibrium investment policy and expected profit change with α when the market is more competitive (or t is small). When the probability of a successful implementation (α) is relatively low, the optimal investment strategy is the Responsive (R) strategy (Blue curve); and when such probability is moderate, the optimal investment strategy is the Aggressive (A) strategy (Orange curve); and as α approaches 1/2, the optimal investment strategy is the Aggressive Limit (AL) strategy (Brown curve). Note that our assumption $18kt > \alpha$ implies that $\alpha < 0.45$ in this example.

Interestingly, according to Figure 5(b), when a firm's IT investment is more likely to succeed,

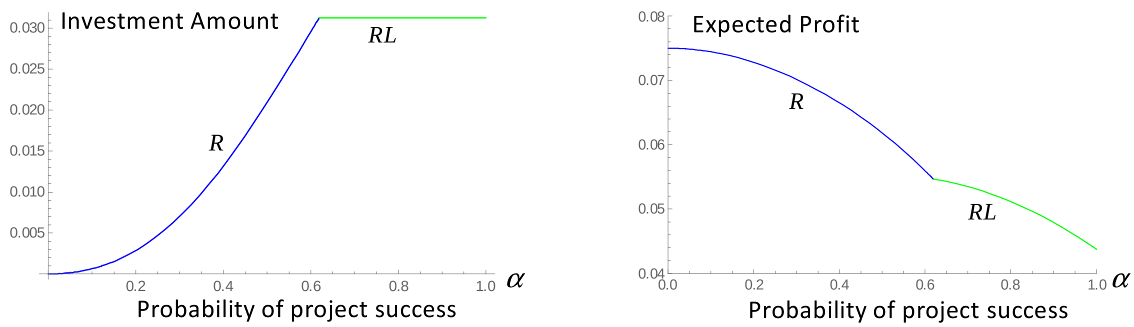

Figure 5: (a) IT investment with α; (b) Expected profit with α, when the market is not competitive; Plots for $c = 0.25$, $k = 0.5$, $t = 0.15$.

his profit suffers. The firm, nevertheless, continues to increase his IT investment (Figure 5(a)) even though he anticipates lower returns. This interesting pattern is driven by both effects of implementation uncertainty. When α is not too large and firms' optimal investment strategy is the Responsive strategy, the first effect dominates. Implementation uncertainty mitigates the impact of competition on firms' IT investment decisions. This mitigation becomes weaker as α increases. Accordingly, firms become more motivated to invest in IT as α increases, and their profit suffers.

The differentiation effect is evident when α is relatively close to 1, and firms' equilibrium investment strategy is the Responsive Limit strategy, in which both firms keep their IT investment constant at maximum. Even though their investment amounts do not change, firms' expected profit decreases when the project is more likely to succeed. This is because the probability of achieving marginal cost based differentiation decreases as α increases and approaches 1.

The impact of the differentiation effect is even more striking in more competitive markets. In Figure 6, as α approaches 1/2, the likelihood of realizing the differentiated outcome increases. Firms' investment strategy changes to take advantage of the increasing chance of achieving marginal cost based differentiation. As seen in Figure 6(a), firms' optimal investment strategy changes from Responsive to Aggressive strategy as α increases. With the Aggressive investment strategy, firms rapidly increase their IT investment, which leads to drastically improved expected profits.

The above findings are formalized in the following Proposition.

Proposition 6: *Comparative Statics: Role of Implementation Uncertainty (α).*

In a symmetric equilibrium, (i) when firms follow the Responsive investment strategy, the investment level (f) increases with the probability of IT implementation success α, and the expected profit decreases with α when α is relatively close to 1, and may increase or decrease with α otherwise.

(ii) When firms follow the Responsive Limit or Aggressive Limit investment strategy, the investment level (f) does not change with the probability of IT implementation success α, and the

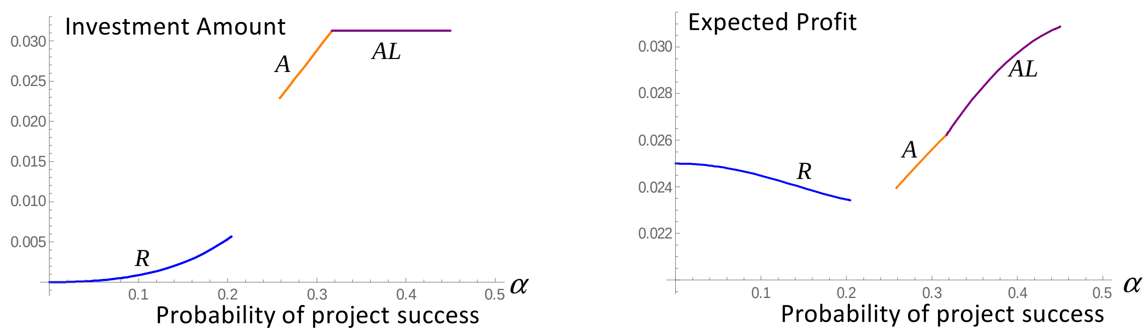

Figure 6: (a) IT investment with α; (b) Expected profit with α, when the market is competitive. Plots for $c = 0.25$, $k = 0.5$, $t = 0.05$.

expected profit increases with α as α increases and approaches 1/2 from the left ($\alpha \nearrow 1/2$), and decreases with α when $\alpha > 1/2$.

Interestingly, the differentiation effect impacts firms' investment strategy and profits quite differently in different markets. Comparing Figures 5 and 6, one can see that as α approaches 1/2, in less competitive markets (5(a) and (b)), firms follow the conservative Responsive strategy. Firms' equilibrium profit decreases as α approaches 1/2. Whereas, in more competitive markets (6(a) and (b)), firms follow the Aggressive investment strategy. Firms' profit increases as α approaches 1/2. It appears that firms in more competitive markets may be more capable of recouping returns to their IT investment than firms in less competitive markets. This will be the subject of our discussion in the next subsection.

Impact of Implementation Uncertainty on Investment Risk Prior empirical work has suggested IT investment risk as another factor for explaining patterns of IT investment returns and connected IT project uncertainty with IT investment risks (Dewan et al. 2007). In this subsection, we discuss how IT implementation uncertainty impacts firms' IT investment risks. We show that while conventional wisdom often associates high project uncertainty with risky investment, according to our model, IT implementation uncertainty can increase or decrease investment risks.

We use a standard measure of investment risk, *Coefficient of Variation* (CV), which is calculated as the ratio of the standard deviation (σ) of a firm's profit under each implementation outcome (i.e., SF, SS, FS, FF) to the mean value of absolute return on IT investment (μ). Coefficient of Variation is a common measure for investment risks in the finance literature and business practice (Markowitz 1952; Ferri and Jones 1979). Intuitively, Coefficient of Variation measures the variance of firms' equilibrium profit adjusted for expected level of profit (or $CV = \sigma/\mu$).

In our context, the investment risk is driven by the difference in a firm's payoff across different

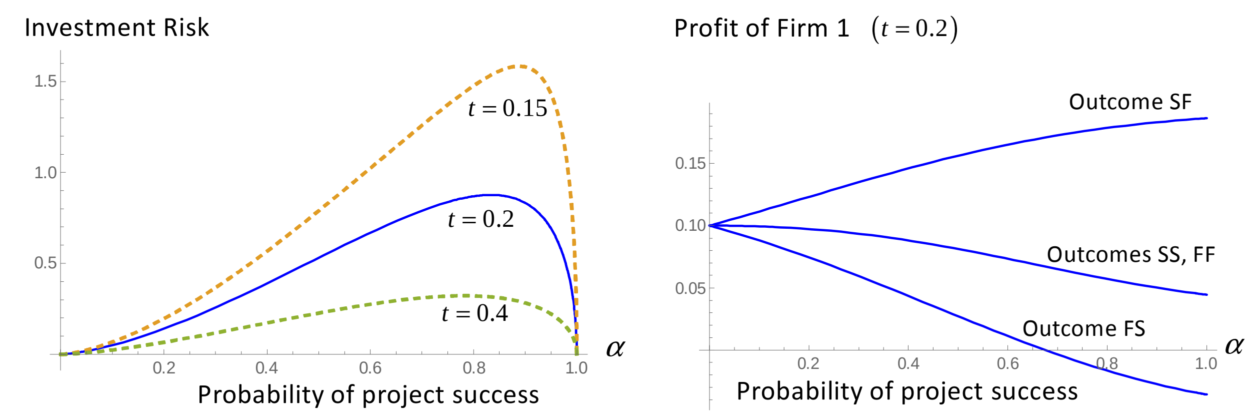

Figure 7: Impact of implementation uncertainty (α) on (a) investment risk (CV) for different levels of t (b) Profit of firm 1 for $t = 0.2$. Plots for $c = 2.5$, $k = 0.5$.

implementation outcomes and the probability distribution of the four implementation outcomes. The investment risk is higher when a firm's payoffs given different implementation outcomes are more divergent, or when the extreme outcomes (i.e., the ones with the highest or lowest payoffs) are more likely to occur.

Figure 7(a) shows that investment risk is non-monotone with increasing probability of a successful implementation: investment risk first increases and then decreases with α. To understand this pattern, note that implementation uncertainty not only changes the probability distribution among different implementation outcomes, but also mitigates the impact of competition. When implementation uncertainty is high (α close to zero), the mitigation effect is strong. Both firms are less motivated to invest, and their payoffs given different implementation outcomes fall in a very narrow range. Accordingly, their investment risk is low when implementation uncertainty is high (α small). As α increases and moves away from zero, the mitigation effect becomes weaker. Competition forces firms to invest more in IT, and each firm's payoffs given different implementation outcomes become more divergent (Figure 7(b)), contributing to increasing investment risk. The investment risk decreases eventually, since the extreme implementation outcomes become less likely as α approaches 1.

Moreover, as shown in Figure 7(a), IT investment risk increases as the market becomes more competitive (t decreases). Therefore, our findings suggest that IT investment risk be evaluated in a competitive context. Competition changes firms' payoff distribution across different implementation outcomes, and possibly leads to more divergent payoffs. This finding is consistent with the empirical evidence showing that IT investment risks differ greatly across industries (Dewan et al. 2007).

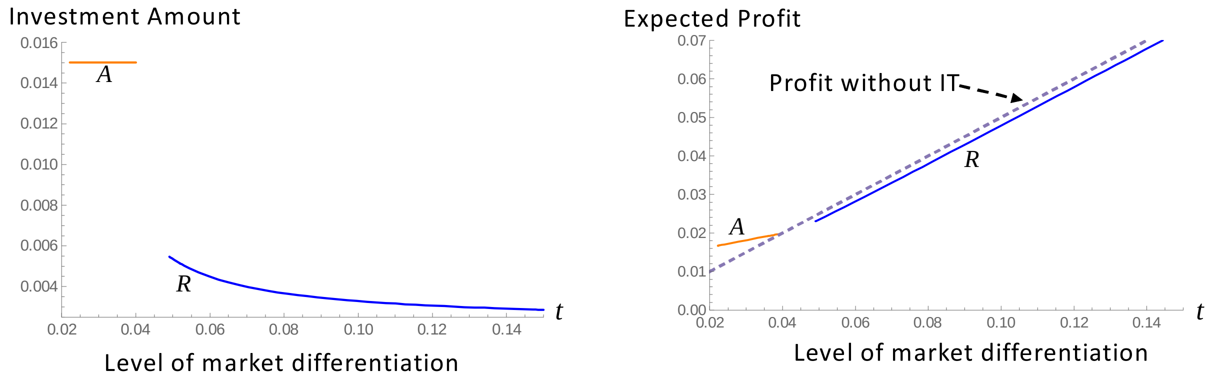

Figure 8: (a) IT investment with t; (b) Expected profit with t. Plots for $c = 0.22$, $k = 0.45$, $\alpha = 0.2$.

4.3.2 The Role of Competition

This section discusses the impact of market competition on firms' IT investment and profit. While conventional wisdom suggests that firms in more competitive markets are less able to recoup the return to their IT investment (see, for example, Brynjolfsson and Hitt 1996), we show that this no longer holds when the outcome of IT implementation is uncertain.

Figure 8 shows how a firm's equilibrium investment policy and expected profit change with the level of market differentiation (or t). Recall that more differentiation in the market, or larger t, corresponds to less competition in the market. When t is relatively low, the optimal investment strategy is the Aggressive (A) strategy (Orange curve); when t is moderate or high, the optimal investment strategy is the Responsive (R) strategy (Blue curve).

In general, firms in highly competitive markets (t close to zero) invest more to lower their marginal costs. As the market becomes less competitive, the equilibrium investment levels decline. A firm's expected profit (solid line in Figure 8(b)) increases with lower levels of market competition. The dashed line in Figure 8(b) plots $t/2$, or a firm's equilibrium profit if neither firm has the opportunity to invest in IT. Thus, it provides a benchmark for investigating the impact of IT on firms' profitability. Interestingly, in highly competitive markets (t close to zero), firms' expected profit is either above or close to the benchmark values when both firms have the opportunity to invest in IT. In contrast, in less competitive markets, firms' expected profit is always below the benchmark profit levels. Are firms in highly competitive markets more capable of taking advantage of their IT investment?

When the market is weakly differentiated, or t is small, a small difference in marginal cost (i.e., $c_{-i} - c_i$) allows the more efficient firm to obtain a larger market share. This is because, when both firms compete in the market, firm i's market share is

$$m_i = \frac{c_{-i} - c_i}{6t} + 1/2,$$

as shown in Lemma 1. Therefore, firms in weakly differentiated markets are more motivated to invest in IT. In the example of Figure 8, when t is small, in a symmetric equilibrium, both firms follow the Aggressive investment strategy. Given this strategy, if one firm succeeds at his IT investment while his opponent does not, the successful firm's new marginal cost is so low that his competitor cannot make a profit selling in the market. As we show in Figure 2, the successful firm enjoys lucrative returns if he has a significant cost advantage over his competitor, and this improves the expected profit. This is a risky strategic approach though, involving high levels of IT investment and potentially significant returns.

As t increases, however, gaining market share against a competitor becomes more costly since a firm has to offer even lower prices to lure customers, which requires much lower marginal costs and more IT investment. The heavy IT investment requirement renders the above strategic approach unworthy in a highly differentiated market. The equilibrium investment strategies in highly differentiated (or less competitive) markets are more conservative. When firms follow the Responsive investment strategy, in equilibrium, both firms have positive market shares post IT investment irrespective of the implementation outcome. Firms invest out of strategic necessity to fence off competition rather than to gain market share.

The following proposition formalizes our findings.

Proposition 7: *Comparative Statics: Role of Competition (t).*

In a symmetric equilibrium, (i) when firms follow the Responsive investment strategy, the investment level (f) decreases with the degree of differentiation (t), and the expected profit increases with t, and is strictly below $t/2$.

(ii) When firms follow the Responsive Limit, Aggressive Limit or Aggressive investment strategy, the investment level (f) does not change with the degree of differentiation (t). The expected profit increases with t. When firms follow the Aggressive or Aggressive Limit strategy, in equilibrium, firms' expected profit can be greater than $t/2$.

4.3.3 Interaction between Competition and Uncertainty

Proposition 1 shows that, in the absence of implementation uncertainty ($\alpha = 1$), in a symmetric equilibrium, firms invest the same amount in IT no matter how competitive the market is (the

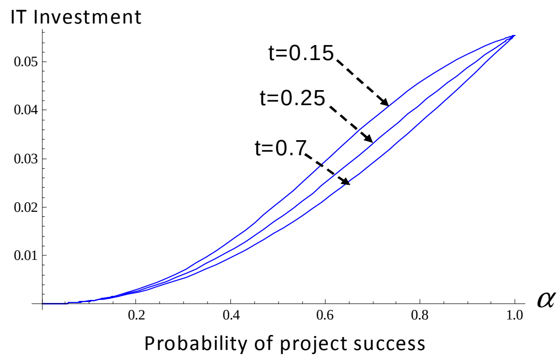

Figure 9: IT investment level with different α and t. Plot for $c = 1$, $k = 0.5$.

investment level is independent of t). With an increasing risk of IT implementation failure ($\alpha < 1$), would firms in different markets respond differently? Figure 9 shows how firms' IT investment responds to implementation uncertainty in different markets parameterized by different values of t. In general, firms in all markets reduce their IT investment in response to increased chance of a project failure. Firms in less competitive markets retreat faster than firms in more competitive markets, even though they are likely to be in a better position to withstand risk. Since all firms face the same IT cost function ($f = k \triangle c^2$), the different investment incentives are largely attributed to the difference in the upside gain from their IT investment. Uncertainty creates a possibility of differentiation based on marginal cost. For a fixed marginal cost reduction, firms in more competitive markets are able to capture more gain: not only do they have a higher margin on each sale, they also gain a larger market share if a firm becomes more efficient than his competitor through the IT investment. Firms in less competitive markets also benefit from a higher profit margin, but it is much harder for them to gain market share against competition. Therefore, firms in less competitive industries may seem more cautious about investing in risky IT projects even though they have the same risk preference as firms in more competitive industries.

4.3.4 Effectiveness of IT in Reducing Marginal Costs

The parameter k measures the inverse effectiveness of IT investment in reducing marginal cost of production. The smaller k is, the greater is the degree of potential marginal cost reduction from a given level of IT investment. Several factors may impact the value of k in practice. k may decline as computer processing power becomes cheaper, as per Moore's Law, leading to a lower cost to the firm for a given amount of computational capacity for reducing marginal costs. The value of k may also depend on the business processes supported by IT. Technologies that support primary activities (e.g., manufacturing) in a firm may have a more direct impact on the

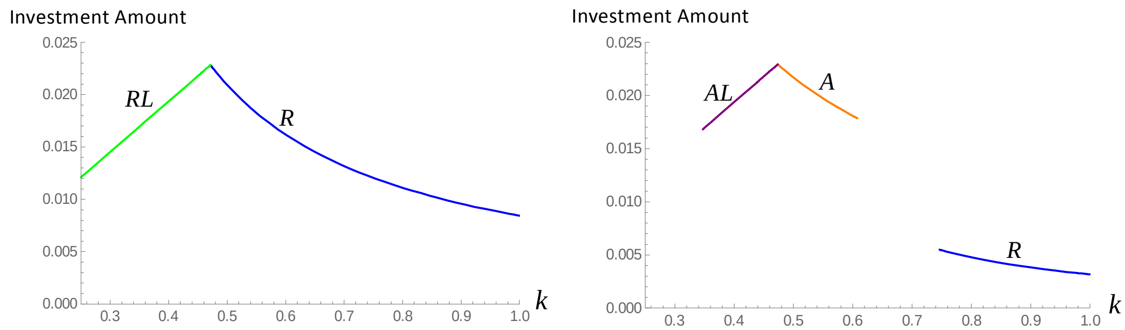

Figure 10: (a) IT investment with k when the market is not competitive ($c = 0.22$, $\alpha = 0.5$, $t = 0.15$.); (b) IT investment with k, when the market is competitive ($c = 0.22$, $\alpha = 0.25$, $t = 0.04$.).

firm's marginal production cost (smaller k) than those that sustain support activities (e.g., human resource, accounting). Figure 10 shows how a firm's IT investment changes with k when (a) the market is less competitive (large t) and (b) when the market is more competitive (small t).

If firms' equilibrium investment strategy is described by the Responsive or Aggressive strategy, their IT investment levels decrease with k. As IT investment becomes less effective in reducing marginal costs (k is larger), both firms reduce their IT investment. On the other hand, this finding implies that even though the cost of IT *declines* over time (or k decreases over time), firms' IT investment is likely to *increase* over time if firms' investment policy is described by the Responsive or Aggressive strategy. IT becomes a more attractive investment option as it is more effective in reducing production costs.

On the other hand, if firms' equilibrium investment strategy is described by the Responsive Limit or Aggressive Limit strategy, their IT investment levels increase with k. The Responsive Limit and Aggressive Limit strategy describes investment strategies that aim to lower firms' marginal costs to the lowest possible level. The more effective IT investment is in reducing costs, the less investment is required to reduce marginal cost by a fixed amount. Thus, a firm's investment level increases with k if the optimal investment strategy is described by the Responsive Limit and Aggressive Limit strategy. The following proposition formalizes this finding.

Proposition 8: *Comparative Statics: Effectiveness of IT (k).*

In a symmetric equilibrium, (i) when firms follow the Responsive or Aggressive investment strategy, the investment level (f) decreases with k. (ii) When firms follow the Responsive Limit or Aggressive Limit investment strategy, their investment level (f) increases with k.

5 Discussion

It is well documented that competition impacts firms' incentives to invest in IT. However, the direction in which competition drives IT investment has been less clear. While firms in competitive markets may be more motivated to invest in IT to improve their performance, firms in less competitive markets may be better able to appropriate the return from their investment. Furthermore, IT differs from many general-purpose technologies in that the outcome of IT implementation can be highly uncertain. In this paper, we study how competition may impact a firm's incentive to invest in IT with a focus on understanding the role of uncertainty regarding IT implementation. We employ the standard Hotelling framework to model two competing firms that have the opportunity to invest in IT that may reduce their marginal costs. The outcome of the IT implementation project is, however, uncertain.

First, we examine a benchmark model without implementation uncertainty and show that the quandary that firms face while making their IT investment decisions resembles that of a Prisoner's Dilemma game. Each firm benefits from investing in IT if his opponent does not. But if both firms invest in IT, in a symmetric equilibrium, they lower their marginal costs by the same amount. Competition forces them to pass the entire benefit from marginal cost reduction to consumers in the form of lower prices. Thus firms retain the same profit margin and market share with the added burden of IT investment, and this leads to lower profits. This finding holds irrespective of the level of competition in the market.

Next, we introduce IT implementation uncertainty and demonstrate that such uncertainty has two effects on firms' IT investment: first, the uncertain outcome of IT implementation creates a new possibility of differentiation in marginal costs: one firm may be able to achieve a lower marginal cost than his competitor even though both firms invest the same amount in IT. Second, the firms are less motivated to invest in IT when the implementation may not be successful. They also become less responsive to their opponent's investment, since the opponent's IT investment may not succeed.

The overall impact of implementation uncertainty on firms' IT investment strategy and their profits depends on the level of competition in the market and the type of IT being adopted. Firms in highly competitive markets are better able to take advantage of the differentiation effect—consumers in these markets are more fluid, and so a small cost advantage would allow a firm to gain a larger market share. For moderate or high-risk IT, firms in such competitive markets pursue an Aggressive investment strategy characterized by high levels of IT investment. They aim to achieve a significant cost advantage over their competitors when their implementation succeeds but their opponents' does not. The strategic trade-off that they face is no longer described by a Prisoner's Dilemma game. Instead, their expected profit increases when they have the opportunity to invest in IT.

Gaining market share is much more costly for firms in less competitive markets. Consumers tend to be more "sticky" and demand a bigger price discount for switching to a different vendor. This requires the firm to invest even more in IT to obtain lower costs, which may render this strategic approach unworthy. Therefore, firms in less competitive markets focus on remaining viable relative to their competitors' IT investment by investing conservatively. IT investment is considered a competitive necessity. In such markets, firms follow the Responsive investment strategy, and their expected profit is lower when they have the opportunity to invest in IT. Implementation uncertainty, nevertheless, mitigates the impact of competition on firms' investment incentive, and firms are less motivated to enter an arms race in IT investment when their investment is less likely to succeed. Indeed, firms invest less, and their expected profit improves when the probability of a successful implementation is lower.

5.1 Contributions

This paper makes three main contributions. First, this paper presents an initial effort to study the impact of competition on firms' IT investment when the outcome of IT implementation is uncertain. We examine a duopoly model, in which firms face an opportunity to invest in an information technology that may reduce their marginal costs if implemented successfully. Firms can change the level of their investment to affect their performance in the event of a successful implementation. Our model setup is consistent with the empirical evidence that associates firms' IT investment amount with their productivity gain (see, for example, Brynjolfsson and Hitt 1996), and allows our findings to address important gaps in the IS literature, as we elaborate below. Our modeling approach also distinguishes this paper from prior literature on strategic investment in non-exclusive technologies.

Second, our findings add to the literature on competition and firms' incentive to invest in IT. Prior literature suggests that competitive pressure and a firm's ability to generate returns affect their incentive to invest in IT. As discussed in the Introduction, this literature, however, makes opposite predictions on the direction in which competition drives IT investment: On one hand, firms in more competitive markets are under greater pressure to improve their performance and, thus, more motivated to invest in IT. On the other hand, firms in more competitive markets are less able to appropriate the returns from their investment and, hence, less motivated to invest in IT.

In this paper, we show that when the outcome of IT implementation is uncertain, IT investment creates an opportunity for new market differentiation. This new source of return was not considered in prior literature. Firms in more competitive markets are better able to take advantage of this differentiation to improve their competitive position. In these markets, customers are more price sensitive, and a small cost disadvantage would cause a firm to lose a large share of the market. Similarly, a small cost advantage would also help the firm gain a large market share. Indeed, for moderate or high-risk IT, firms in such competitive markets follow an Aggressive investment strategy characterized by high levels of IT investment. They aim to achieve a dominant market position through their IT investment when their implementation succeeds but their competitor's does not. This finding is consistent with empirical observations. For instance, in the highly competitive retail industry, Wal-Mart expanded rapidly by implementing technologies that were new and risky at that time, such as Universal Product Codes (UPC), Electronic Data Interchange (EDI), and Vendor Managed Inventory (VMI). Since the development of ecommerce, Amazon has followed a similar strategy of aggressive investment in technologies such as data-mining and robotics to establish a dominant position.

On the other hand, firms in less competitive markets are less able to take advantage of the differentiation effect and the opportunity to improve profitability because gaining market share is much more costly when consumers are less price sensitive and tend to stay with the same vendor. In such markets, firms follow a more conservative Responsive investment strategy. They invest only to stay on par with their competitors and to avoid being left behind with a less efficient process and a higher cost structure. The healthcare market, for instance, is more differentiated, since consumers are often loyal to their physicians, and those who have insurance have limited desire to switch providers because the cost is mostly covered by insurance. Consistent with the predictions of our theory, the healthcare industry has been slow to adopt Health Information Technology (HIT). Indeed, the government had to provide a mix of financial support and delay penalties to promote the adoption of HIT and Electronic Health Records (EHR) (see American Recovery and Reinvestment Act of 2009).

Therefore, our findings suggest that, for moderate or high-risk IT, firms in highly competitive industries are more motivated to invest in IT, and their extensive IT investment leads to higher expected profits.

Third, our findings also contribute to the ongoing discourse on IT investment and its impact on firms' profitability. The strategic value of adopting IT as a general-purpose technology has been the subject of much debate (see, for example, Carr 2003, Brown and Hagel 2003, McAfee and Brynjolfsson 2008). Empirical work thus far has provided mixed findings with some suggesting none or negative association between IT investment and firms' profitability (e.g., Brynjolfsson and Hitt 1996, Aral and Weill 2007, Ren and Dewan 2014) while others suggesting positive association (Mithas et al MISQ 2012).

Our theoretical findings suggest that higher IT investment does not necessarily lead to higher profits. The return depends on the nature of the IT being adopted and the level of competition that the adopting firm faces. Adoption of IT that requires straight-forward implementation with promised success (e.g., some desktop technologies) do not bring superior return. Firms' investment in these technologies is often motivated by "competitive necessity" to avoid the loss from forsaking the investment opportunity. Indeed, investment in these IT may see some of the lowest and often negative returns.

On the other hand, information technologies that have high implementation uncertainty (e.g., large enterprise systems), either because of the complexity of the technology or the required organizational transformation, carry much potential for improving a firm's competitive position and profitability. Firms in highly competitive markets are better able to leverage this opportunity, and, therefore, tend to invest intensively in these types of IT. Their profits post IT investment are likely to have a wide spread. Their expected profit increases when they have the opportunity to invest in a risky IT, and the upside gain from a successful implementation can be substantial.

Therefore, our theory calls for empirical work that differentiates firms' investment in different "types" of IT and that examines cross-industry difference in IT investment strategy and returns. Some recent work has made an attempt to disentangle the performance impact of different types of IT investment, including hardware (Rai et al 1997), software (Beccalli 2007, McAfee 2002), or IS personnel and training expenditure (Chatterjee et al 2001; Thouin et al 2008). Our findings highlight the importance of the implementation process, and suggest that the complexity and uncertainty associated with the implementation process as well as cross-industry differences may dictate the pattern of firms' IT investment policy and their anticipated returns from their IT investment.

5.2 Managerial Implications

Our findings provide several key managerial insights. While prior literature argues that non-exclusive technologies that are available to all competing firms cannot be a source of competitive advantage and, therefore, supranormal returns (Carr 2003), in this paper, we show that the risky nature of IT implementation creates a possibility of differentiation — one firm may be able to achieve a lower marginal cost than his competitor even though both firms invest the same amount in IT. Such differentiation can lead to supranormal returns, and thus successful implementation of a risky IT can become a source of competitive advantage. Firms in highly competitive industries are better able to take advantage of this benefit.

Therefore, our theory suggests that, when making IT investment decisions, firms need to consider the level of market competition that they face as well as the nature of the technology that they are adopting. The strategic value of different types of IT differ, and the complexity of IT implementation is key to understanding the strategic potential of an IT. Moreover, whereas Carr (2003) argues that managers should focus on spending less on IT due to its commodification, we show that firms in competitive industries should invest more in new and innovative information technologies. Executives need to ensure that their managers feel comfortable adopting high-risk technologies that have the potential to be transformative. Managers in highly competitive industries should not be heavily penalized for occasional failure in IT implementation especially when the project is inherently risky.

On the other hand, an IT with a guaranteed implementation success (e.g., some desktop technologies) improves a firm's productivity but does not enhance a firm's competitive position in the market. Managers have to invest in these technologies for fear of being left behind with a less efficient process and a higher cost structure. Investment in such IT is perceived more as a competitive necessity for a firm to stay on par with its competitors rather than an avenue for getting ahead of the competition. Indeed, firms often anticipate some of the lowest returns from such IT investment.

Therefore, given a portfolio of IT options, client firms may wish to prioritize their investment focus depending on the market condition that they are in and the strategic objective of their investment. Firms in highly competitive markets are better able to take advantage of the differentiation benefit.

For social planners that are concerned about firms' motivation to adopt efficiency enhancing IT, we find that firms in more competitive markets are more motivated to invest in IT. Social planners that aim to improve total welfare through promoting IT adoption need to incentivize firms in less competitive markets. Moreover, the high uncertainty regarding the outcome of an IT implementation discourages firms' IT investment. This uncertainty may be caused by a number of reasons, including client firms' lack of understanding on the technology or their lack of expertise in adapting to the technology. Social welfare can be improved by measures that help reduce such uncertainty, for instance, programs that help transfer knowledge from IT vendors to client firms, or from successful adopters of an IT to prospective adopters.

6 Conclusion

This paper can be extended in a number of directions. We study a horizontal differentiation model with two firms, one on each end of a unit line. This model allows us to parameterize the level of market competition with just one variable t, and examine the impact of competition on firms' IT investment in a simple setup. Future work may extend the model to describe other forms of market competition, for instance, vertical differentiation and markets with more than two firms. In this paper, we also focus on a symmetric game, assuming both firms share the same cost structure initially and level of IT expertise. Since this is the first paper that studies the impact of implementation uncertainty and competition on firms' IT investment, such a standard setup allows us to isolate and highlight these two effects without introducing additional complexity. Future research is encouraged to incorporate dimensions of firm heterogeneity that may closely describe certain industrial environment.

Firms' motivation to invest in IT and the return to their IT investment have been an enduring topic in the IS literature. Nevertheless, how competition drives IT investment and its return remains unclear. Through a formal theoretical model, this paper demonstrates that firms' IT investment is motivated by the pressure to fence off competition as well as the aim to improve profitability. In particular, we highlight the role of implementation uncertainty in determining returns and investment incentives. Our theoretical findings are consistent with empirical observations and provide several key insights for future empirical work and business practice.

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7 Appendix

Lemma 1. *If* $|c_1 - c_2| < 3t$, *then both firms have positive market shares in equilibrium. Their optimal pricing strategy is characterized by*

$$P_1(c_1, c_2) = t + \frac{2c_1 + c_2}{3},$$
$$P_2(c_1, c_2) = t + \frac{c_1 + 2c_2}{3},$$

and their market shares are $m_1(c_1, c_2) = \frac{c_2 - c_1}{6t} + 1/2$ and $m_2(c_1, c_2) = \frac{c_1 - c_2}{6t} + 1/2$. *If* $|c_1 - c_2| \geqslant 3t$, *then the more efficient firm (i.e., with a lower marginal cost), say firm* i, *sets the price* $P_i = c_{-i} - t$. *All consumers buy from firm* i, *and firm* $-i$ *has a zero market share in equilibrium, i.e.,* $m_i = 1, m_{-i} = 0$.

Proof. Consumers' decision: adopt Firm 1's product if (Firm 1 is at $x = 0$)

$$U - P_2 - t(1-x)^2 < U - P_1 - tx^2 \Rightarrow$$
$$P_1 + tx^2 < P_2 + t(1-x)^2$$
$$x < \frac{P_2 - P_1 + t}{2t}$$

Given consumers' decision, Firm 1's pricing decision can be described as:

$$\max_{P_1} \frac{P_2 - P_1 + t}{2t}(P_1 - c_1)$$
$$s.t., 0 \leq \frac{P_2 - P_1 + t}{2t} \leq 1$$

Given consumers' decision, Firm 2's pricing decision can be described as:

$$\max_{P_2} \left(1 - \frac{P_2 - P_1 + t}{2t}\right)(P_2 - c_2)$$
$$s.t., 0 \leq \frac{P_2 - P_1 + t}{2t} \leq 1$$

One can show that, when $-3t \leq c_2 - c_1 \leq 3t$, the equilibrium pricing is

$$P_1 = t + \frac{c_2 + 2c_1}{3},$$
$$P_2 = t + \frac{c_1 + 2c_2}{3}.$$

Each firm has a market share

$$m_1 = \frac{c_2 - c_1}{6t} + \frac{1}{2},$$
$$m_2 = \frac{c_1 - c_2}{6t} + \frac{1}{2}.$$

When $c_1 < c_2 - 3t$, in equilibrium, $P_1 = c_2 - t$, and $m_1 = 1$. Firm 2 cannot make a profit selling in the market. When $c_2 < c_1 - 3t$, in equilibrium, $P_2 = c_1 - t$, and $m_2 = 1$. Firm 1 cannot make a profit selling in the market.

Proposition 1. *In the absence of implementation uncertainty, when $(c, k, t) \in \Theta_0$, in a symmetric equilibruim, each firm's optimal investment strategy is the BM strategy. In the pricing stage, each firm sets his price $P_i = t + c - 1/6k$, and gains a profit*

$$\pi_i = \frac{t}{2} - \frac{1}{36k},$$

where $i = 1, 2$.

Proof. In the absence of implementation uncertainty, firm i obtains a new marginal cost c_{iS} with probability 1 when he invests $f_i = k\left(c - c_{iS}\right)^2$ in IT. Firm i's payoff depends on his own and his opponent's new marginal costs and can be described as follows:

$$\pi_i\left(c_{iS}\right) = \begin{cases} 0 - k(c - c_{iS})^2 & \text{if } c_{-iS} + 3t < c_{iS} \le c \\ \left(\frac{c_{-iS} - c_{iS}}{6t} + 1/2\right)\left(t + \frac{2c_{iS} + c_{-iS}}{3} - c_{iS}\right) - k(c - c_{iS})^2 & \text{if } c_{-iS} - 3t \le c_{iS} \le c_{-iS} + 3t \\ c_{-iS} - t - c_{iS} - k(c - c_{iS})^2 & \text{if } 0 \le c_{iS} < c_{-iS} - 3t \end{cases}.$$

If a set of investment strategies (c^*_{1S}, c^*_{2S}) is a symmetric equilibrium of the game, then it satisfies two sets of conditions: one, for $i = 1, 2$,

$$c^*_{iS} = \arg\max_{c_{iS}} \left(\frac{c^*_{-iS} - c_{iS}}{6t} + 1/2\right)\left(t + \frac{2c_{iS} + c^*_{-iS}}{3} - c_{iS}\right) - k(c - c_{iS})^2. \tag{4}$$

Two, given his opponent's investment strategy (or c^*_{-iS}), firm i cannot improve his strategy by deviating to an investment strategy c'_i such that $c'_i \in [0, c]$, and $c'_i \notin \left[c^*_{-iS} - 3t, c^*_{-iS} + 3t\right]$. That is for any $c'_i \in [0, c]$, and $c'_i \notin \left[c^*_{-iS} - 3t, c^*_{-iS} + 3t\right]$,

$$E\left[\pi_i\left(c'_i\right)|c^*_{-iS}\right] \le E\left[\pi_i\left(c^*_{iS}\right)|c^*_{-iS}\right].$$

Solve (4) for firm 1 and 2 simultanuously, we have

$$c_{1S}^* = c_{2S}^* = c - 1/6k.$$

In addition, if (c_{1S}^*, c_{2S}^*) is a symmetric equilibrium of the game, then when $c_{-iS}^* > 3t$, for any $c_i' \in \left[0, c_{-iS}^* - 3t\right]$, $E\left[\pi_i\left(c_i'\right)|c_{-iS}^*\right] \leq E\left[\pi_i\left(c_{iS}^*\right)|c_{-iS}^*\right]$. That is

$$c_{-iS}^* - t - c_i' - k(c - c_i')^2 \leq E\left[\pi_i\left(c_{iS}^*\right)|c_{-iS}^*\right].$$

$$s.t., 0 \leq c_i' \leq c - 1/6k - 3t$$

Or

$$k(c - c_i')^2 + c_i' + \frac{3t}{2} - c + \frac{5}{36k} \geq 0$$

$$s.t., 0 \leq c_i' \leq c - 1/6k - 3t$$

One can show that this condition holds if (1) $c - \frac{1}{2k} \leq 0$, and $kc^2 + \frac{3t}{2} - c + \frac{5}{36k} \geq 0$; or (2)

$$0 < c - \frac{1}{2k} \leq c - 1/6k - 3t \Leftrightarrow 9kt \leq 1 \wedge 2kc > 1,$$

and $13.5kt > 1$; or (3)

$$c - \frac{1}{2k} > c - 1/6k - 3t \Leftrightarrow 9kt > 1,$$

and $18kt \geq 1$. Therefore, the condition holds if $2kc \leq 1$ and $kc^2 + \frac{3t}{2} - c + \frac{5}{36k} \geq 0$, or $1/13.5 < kt \leq 1/9 \wedge 2kc > 1$, or $9kt > 1$. Denote this range of parameter values by

$\Theta_0 = \left\{(c, k, t)\,|(2kc \leq 1 \wedge kc^2 + \frac{3t}{2} - c + \frac{5}{36k} \geq 0) \text{ or } (1/13.5 < kt \leq 1/9 \wedge 2kc > 1) \text{ or } 9kt > 1\right\}$.

Furthermore, if $c_{-iS}^* + 3t < c$, for any $c_i' \in [c_{-iS} + 3t, c]$, $E\left[\pi_i\left(c_i'\right)|c_{-iS}^*\right] \leq E\left[\pi_i\left(c_{iS}^*\right)|c_{-iS}^*\right]$. That is,

$$0 - k(c - c_i')^2 \leq E\left[\pi_i\left(c_{iS}^*\right)|c_{-iS}^*\right].$$

Clearly, this condition holds since $E\left[\pi_i\left(c_{iS}^*\right)|c_{-iS}^*\right] \geq 0$.

Therefore, given the range of parameter values in Θ_0, each firm's optimal investment strategy is the BM strategy: when $c \geqslant 1/6k$, each firm obtains a new marginal cost equal to $c - 1/6k$ by investing $1/36k$ in IT. In the pricing stage, applying Lemma 1, we know that in equilibrium, the two firms split the market with equal market shares. Firm i's price $P_i = t + c - 1/6k$, and his profit is $\pi_i = \frac{t}{2} - \frac{1}{36k}$, where $i = 1, 2$. When $c < 1/6k$, each firm obtains a new marginal cost equal to 0 by investing kc^2 in IT. In the pricing stage, applying Lemma 1, we know that in equilibrium, the two firms split the market with equal market shares. Firm i's price $P_i = t$, and his profit is $\pi_i = \frac{t}{2} - kc^2$, where $i = 1, 2$.

Proposition 2. *When $(c, k, \alpha, t) \in \Theta_1$, in a symmetric equilibrium, the firms' optimal investment strategy is the Responsive investment strategy, and the expected profit is*

$$E(\pi_i) = \frac{t(324k^2t^2 + \alpha^2(1 + 18kt) - \alpha^4 - 36k\alpha t)}{2((-1 + \alpha)\alpha + 18kt)^2}$$

where $i = 1, 2$.

Proposition 3. *When* $c < 3t$ and $\alpha/(18t) < k < \alpha/(6c) + \alpha(1-\alpha)/(18t)$, *in a symmetric equilibrium, the firms' optimal investment strategy is the Responsive Limit strategy, and the expected profit is*

$$E(\pi_i) = \frac{t}{2} - \frac{c^2(9kt - (1 - \alpha)\alpha)}{9t}$$

where $i = 1, 2$.

Proof of Prop 2 and 3. If a set of investment strategies $(\widehat{c_{1S}}, \widehat{c_{2S}})$, where $\widehat{c_{1S}}, \widehat{c_{2S}} \in [\max\{c - 3t, 0\}, c]$, is a symmetric equilibrium of the game, then a necessary condition is that firm i's investment strategy, $\widehat{c_{iS}}$, is a best response to his opponent's investment strategy at least for $\forall c_{iS} \in [\max\{c - 3t, 0\}, c]$, or the following condition holds: for $i = 1, 2$,

$$\widehat{c_{iS}} = \arg\max_{c_{iS}} E\left[\pi_i\left(c_{iS}\right) | \widehat{c_{-iS}} \in [\max\{c - 3t, 0\}, c]\right], \tag{5}$$

$$s.t., c_{iS} \in [\max\{c - 3t, 0\}, c]. \tag{6}$$

(We will check the sufficient condition later on.)

One can show that, for any $c_{1S}, c_{2S} \in [\max\{c - 3t, 0\}, c]$, we have $|c_{1S} - c_{2S}| \leq 3t$, and $|c_{iS} - c| \leq 3t$, $i = 1, 2$. Therefore, firm 1 and 2's objective functions are continuous and differentiable, given $c_{1S}, c_{2S} \in [\max\{c - 3t, 0\}, c]$. In particular, firm 1's profit given each implementation outcome is:

$$\pi_1^{SF} = \left(\frac{c - c_{1S}}{6t} + 1/2\right)\left(t + \frac{2c_{1S} + c}{3} - c_{1S}\right) - f_1,$$

$$\pi_1^{FS} = \left(\frac{c_{2S} - c}{6t} + 1/2\right)\left(t + \frac{2c + c_{2S}}{3} - c\right) - f_1,$$

$$\pi_1^{FF} = \frac{t}{2} - f_1 = \frac{t}{2} - k\left(c - c_{1S}\right)^2, \text{ and}$$

$$\pi_1^{SS} = \left(\frac{c_{2S} - c_{1S}}{6t} + 1/2\right)\left(t + \frac{2c_{1S} + c_{2S}}{3} - c_{1S}\right) - f_1,$$

where $f_1 = k\left(c - c_{1S}\right)^2$. Firm 2's profit given each implementation outcome can be derived similarly.

One can show that each firm's objective function defined in (5) is strictly concave when $18kt > \alpha$. We now can solve the two optimization problems defined by (5) simultaneously for firm 1 and 2, and obtain a set of investment strategies that can be a symmetric equilibrium of the game. This gives:

The Responsive (R) Investment Strategy: Firm i invests

$$f_i = k\left(\frac{3\alpha t}{(-1+\alpha)\alpha + 18kt}\right)^2,$$

in IT, and, if his IT implementation is successful, his new marginal cost is

$$c_{iS} = c - \frac{3\alpha t}{(-1+\alpha)\alpha + 18kt},$$

where $i = 1, 2$.

Note that $c_{iS} \in [\max\{c - 3t, 0\}, c]$. One can show that

$$c - \frac{3\alpha t}{(-1+\alpha)\alpha + 18kt} \geqslant 0 \Leftrightarrow k \geqslant \alpha/(6c) + \alpha(1-\alpha)/(18t).$$

Therefore, when $c - 3t < 0$, and $k \geqslant \alpha/(6c) + \alpha(1-\alpha)/(18t)$, the Responsive investment strategy is optimal for each firm given $c_{iS} \in [0, c]$ (i.e., sufficient condition), $i = 1, 2$, and hence is the NE of the game.

When $c - 3t < 0$, and $\alpha/(18t) < k < \alpha/(6c) + \alpha(1-\alpha)/(18t)$, define the following boundary solution:

The Responsive Limit (RL) Investment Strategy: Firm i invests $f_i = kc^2$ in IT, and, if his IT implementation is successful, his new marginal cost is $c_{iS} = 0$.

Therefore, when $c - 3t < 0$, and $\alpha/(18t) < k < \alpha/(6c) + \alpha(1-\alpha)/(18t)$, the Responsive Limit investment strategy is optimal for each firm given $c_{iS} \in [0, c]$ (i.e., sufficient condition), $i = 1, 2$, and hence is the NE of the game.

When $c - 3t \geqslant 0$, one can show that

$$c - \frac{3\alpha t}{(-1+\alpha)\alpha + 18kt} \geqslant c - 3t \Leftrightarrow k \geqslant \alpha\left(2 - \alpha\right)/18t.$$

To characterize the sufficient conditions for an NE, we need to verify that firm i is unable to improve his profit by deviating to an investment strategy in the range of $[0, c-3t)$, given his opponent's strategy. That is for any $c_i' \in [0, c-3t)$,

$$E\left[\pi_i\left(c_i'\right)|\widehat{c_{-iS}}\right] \leq E\left[\pi_i\left(\widehat{c_{iS}}\right)|\widehat{c_{-iS}}\right],$$

where $i = 1, 2$.

Specifically, when $c - 3t \geqslant 0$, and $k \geqslant \alpha\left(2-\alpha\right)/18t$, for the Responsive strategy to be an NE, we need to verify that for any $c_i' \in [0, c-3t)$,

$$E\left[\pi_i\left(c_i'\right)|\widehat{c_{-iS}} = c - \frac{3\alpha t}{(-1+\alpha)\alpha + 18kt}\right] \leq E\left[\pi_i\left(\widehat{c_{iS}} = c - \frac{3\alpha t}{(-1+\alpha)\alpha + 18kt}\right)|\widehat{c_{-iS}} = c - \frac{3\alpha t}{(-1+\alpha)\alpha + 18kt}\right],$$

where $i = 1, 2$. Define A as the set of parameter values for (c, k, α, t) that satisfy the above inequality.

When $c - 3t \geqslant 0$, and $k < \alpha\left(2-\alpha\right)/18t$, the boundary solution: each firm i invests to lower the marginal cost till $c_{iS} = c - 3t$ is suboptimal. This is because for $i = 1, 2$,

$$\partial \frac{E\left[\pi_i\left(c_i\right)|\widehat{c_{-iS}} = c - 3t\right]}{c_i}|_{c_i = c-3t} < 0.$$

Therefore, when $c - 3t \geqslant 0$, and $\alpha/(18t) < k < \alpha\left(2-\alpha\right)/18t$, there is no NE of the game in which firms' equilibrium investment strategies are such that $c_{1S}, c_{2S} \in \left[\max\left\{c-3t, 0\right\}, c\right]$.

Define Θ_1 as the set of parameter values for (c, k, α, t), such that the following conditions are satisfied:

$\left\{(c, k, \alpha, t)\,|c < 3t, \text{ and } k \geqslant \alpha/(6c) + \alpha(1-\alpha)/(18t)\right\} \cup$

$\left\{(c, k, \alpha, t)\,|\,(c, k, \alpha, t) \in A, \text{ and } c - 3t \geqslant 0, \text{ and } k \geqslant \alpha\left(2-\alpha\right)/18t\right\}.$

Therefore, when $(c, k, \alpha, t) \in \Theta_1$, the firms' optimal investment strategy in a symmetric equilibrium is the Responsive investment strategy. When $c < 3t$ and $\alpha/(18t) < k < \alpha/(6c) + \alpha(1-\alpha)/(18t)$, the firms' optimal investment strategy in a symmetric equilibrium is the Responsive Limit strategy.

Finally, one can show that the above two-step procedure captures any symmetric equilibrium of the game in which $c_{1S}, c_{2S} \in \left[\max\left\{c-3t, 0\right\}, c\right]$ if it exists. This is because if it exists, it has to be a solution of (5) (or necessary condition).

Firms' expected profits in a symmetric equilibrium given these strategies can be derived by substituting the investment strategies into the objective function. This concludes the proof.

Proposition 4. *When $c > 3t$, and $(c, k, \alpha, t) \in \Theta_2$, in a symmetric equilibrium, the firms'* *optimal investment strategy is the Aggressive investment strategy, and the expected profit is*

$$E(\pi_i) = \frac{(\alpha^2(9 - 2\alpha(9 - 4\alpha)) + 18k(1 - 2\alpha)^2 t)}{36k}$$

where $i = 1, 2$.

Proposition 5. *When* $c > 3t$*, and* $(c, k, \alpha, t) \in \Theta_3$*, in a symmetric equilibrium, the firms' optimal investment strategy is the Aggressive Limit strategy, and the expected profit is*

$$E(\pi_i) = -c(ck + (-1 + \alpha)\alpha) + \frac{t}{2}(1 - 2\alpha)^2.$$

Proof of Prop 4 and 5. When the market is more competitive, or $c > 3t$, the two firms may pursue an aggressive investment strategy such that $c_{1S}, c_{2S} \in [0, c - 3t]$. In this case, if firm i's IT implementation succeeds while his opponent's does not, firm i's new marginal cost is so much lower than his opponent's that his opponent cannot profit from selling in the market. Firm i sets his price $P_i = c - t$, and has a market share equal to 1. Thus, in this case, $\pi_1^{SF} = (c - t - c_{1S}) - f_i$, $\pi_1^{FS} = 0 - f_i$, and $\pi_2^{FS} = (c - t - c_{2S}) - f_i$, $\pi_2^{SF} = 0 - f_i$. π_i^{SS} depends on the difference between c_{1S} and c_{2S}. When c_{1S}, c_{2S} are relatively close such that $|c_{1S} - c_{2S}| \leq 3t$,

$$\pi_i^{SS} = \left(\frac{c_{-iS} - c_{iS}}{6t} + 1/2\right)\left(t + \frac{2c_{iS} + c_{-iS}}{3} - c_{iS}\right) - k(c - c_{iS})^2. \tag{7}$$

If a set of investment strategies $(\widehat{c_{1S}}, \widehat{c_{2S}})$, where $\widehat{c_{1S}}, \widehat{c_{2S}} \in [0, c - 3t]$, is a symmetric equilibrium of the game, then it satisfies the following condition (i.e., necessary condition): for $i = 1, 2$,

$$\widehat{c_{iS}} = \underset{c_{iS} \in [0, c-3t]}{\arg\max}\ E\left[\pi_i\left(c_{iS}\right) | \widehat{c_{-iS}} \in [0, c - 3t]\right] \tag{8}$$

$$= \underset{c_{iS} \in [0, c-3t]}{\arg\max}\ \left(\alpha^2 \pi_i^{SS} + \alpha(1 - \alpha)\pi_i^{SF} + \alpha(1 - \alpha)\pi_i^{FS} + (1 - \alpha)^2 \pi_i^{FF}\right), \tag{9}$$

where π_1^{SF}, π_1^{FS}, π_2^{FS}, and π_2^{SF} are defined in the previous paragraph, and π_i^{SS} is defined in (7). We know that

$$\pi_1^{FF} = \frac{t}{2} - f_1 = \frac{t}{2} - k\left(c - c_{1S}\right)^2.$$

That is firm i's investment strategy $\widehat{c_{iS}}$ is at least a best response for any $c_{iS} \in [0, c - 3t]$ (necessary condition).

One can show that each firm's objective function defined in (8) is strictly concave when $18kt > \alpha$. Solving the two optimization problems simultaneously, one can identify investment strategies that can be a symmetric equilibrium of the game. This gives:

The Aggressive (A) Investment Strategy: Firm i invests

$$f_i = \frac{\alpha^2(3-2\alpha)^2}{36k},$$

in IT, and, if the IT implementation is successful, firm i's new marginal cost is

$$c_{iS} = c - \frac{\alpha(3-2\alpha)}{6k},$$

where $i = 1, 2$.

One can show that

$$0 \leq c - \frac{\alpha(3-2\alpha)}{6k} \leq c - 3t \Leftrightarrow$$
$$18kt \leq \alpha(3-2\alpha) \leq 6kc.$$

When $\alpha(3-2\alpha) > 6kc$, define the following boundary solution:

The Aggressive Limit (AL) Investment Strategy: Firm i invests $f_i = kc^2$ in IT, and, if the IT implementation is successful, firm i's new marginal cost is $c_{iS} = 0$, where $i = 1, 2$.

Second, to characterize the sufficient conditions under which the above identified investment strategies are a symmetric equilibrium of the game, we need to verify that, given his opponent's strategy, firm i is unable to improve his profit by deviating to an investment strategy $c_i^{'}$, such that $c_i^{'} \in [0, c]$, but $c_i^{'} \notin [\widehat{c_{-iS}} - 3t, \widehat{c_{-iS}} + 3t] \cap [0, c-3t]$.

Specifically, when $c > 3t$ and $18kt \leq \alpha(3-2\alpha) \leq 6kc$, for the Aggressive investment strategy to be an NE of the game, we need to verify that for any $c_i' \in [0, c] \,/\, [\widehat{c_{-iS}} - 3t, \widehat{c_{-iS}} + 3t] \cap [0, c-3t]$, the following inequality holds:

$$E\left[\pi_i\left(c_i'\right)|\widehat{c_{-iS}} = c - \frac{\alpha(3-2\alpha)}{6k}\right] \leq E\left[\pi_i\left(\widehat{c_{iS}} = c - \frac{\alpha(3-2\alpha)}{6k}\right)|\widehat{c_{-iS}} = c - \frac{\alpha(3-2\alpha)}{6k}\right],$$

where $i = 1, 2$. Define B as the set of parameter values for (c, k, α, t) that satisfy the above inequality. Define Θ_2 as the set of parameter values for (c, k, α, t) that satisfy

$\{(c, k, \alpha, t) |\ (c, k, \alpha, t) \in B \text{ and } c > 3t \text{ and } 18kt \leq \alpha(3-2\alpha) \leq 6kc\}$.

Therefore, when $(c, k, \alpha, t) \in \Theta_2$, the firms' optimal investment strategy is the Aggressive investment strategy.

When $c > 3t$ and $\alpha(3-2\alpha) > 6kc$, for the Aggressive Limit investment strategy to be an NE of the game, we need to verify that for any $c_i' \in [0, c] \,/\, [\widehat{c_{-iS}} - 3t, \widehat{c_{-iS}} + 3t] \cap [0, c - 3t]$,

$$E\left[\pi_i\left(c_i'\right)|\widehat{c_{-iS}} = c - \frac{\alpha(3-2\alpha)}{6k}\right] \leq E\left[\pi_i\left(\widehat{c_{iS}} = c - \frac{\alpha(3-2\alpha)}{6k}\right)|\widehat{c_{-iS}} = c - \frac{\alpha(3-2\alpha)}{6k}\right],$$

where $i = 1, 2$. Define C as the set of parameter values for (c, k, α, t) that satisfy the above inequality. Define Θ_3 as the set of parameter values for (c, k, α, t) that satisfy:

$\{(c, k, \alpha, t) \,|\, (c, k, \alpha, t) \in C$ and $c > 3t$ and $\alpha(3 - 2\alpha) > 6kc\}$. Therefore, when $(c, k, \alpha, t) \in \Theta_3$, the firms' optimal investment strategy is the Aggressive Limit investment strategy.

Finally, one can show that this two-step procedure captures any symmetric equilibrium of the game in which firms' investment policy falls in the range $[0, c - 3t]$, if it exists. This is because if it exists, it has to be a solution of (8) (or necessary condition).

Firms' expected profits in a symmetric equilibrium given these strategies can be derived by substituting the investment strategies into the objective function. This concludes the proof.

Proposition 6: *Comparative Statics: Role of Implementation Uncertainty (α).*

In a symmetric equilibrium, (i) when firms follow the Responsive investment strategy, the investment level (f) increases with the probability of IT implementation success α, and the expected profit decreases with α when α is relatively close to 1, and may increase or decrease with α otherwise.

(ii) When firms follow the Responsive Limit or Aggressive Limit investment strategy, the investment level (f) does not change with the probability of IT implementation success α, and the expected profit increases with α as α increases and approaches 1/2 from the left ($\alpha \nearrow 1/2$), and decreases with α when $\alpha > 1/2$.

Proof of Proposition 6

(i) According to the Responsive investment strategy, for $i = 1, 2$,

$$f_i = k\left(\frac{3\alpha t}{(-1+\alpha)\alpha + 18kt}\right)^2.$$

Thus,

$$\frac{\partial f_i}{\partial \alpha} = \frac{18k\alpha t^2(-\alpha^2 + 18kt)}{((-1+\alpha)\alpha + 18kt)^3},$$

which is positive when $18kt > \alpha$. In a symmetric equilibrium, the expected profit is defined by

$$E(\pi_i) = \frac{t(324k^2t^2 + \alpha^2(1 + 18kt) - \alpha^4 - 36k\alpha t)}{2((-1+\alpha)\alpha + 18kt)^2}.$$

Thus,

$$\frac{\partial E(\pi_i)}{\partial \alpha} = \frac{\alpha t((-1+\alpha)\alpha^2 - 54k(-1+\alpha)\alpha t - 324k^2t^2)}{((-1+\alpha)\alpha + 18kt)^3}.$$

Therefore, the equilibrium expected profit decreases with α when α is relatively close to 1, but can increase or decrease with α otherwise.

(ii) According to the Responsive Limit or Aggressive Limit investment strategy, for $i = 1, 2$, $f_i = kc^2$. Therefore, when firms follow the Responsive Limit or Aggressive Limit investment strategy, the investment level (f) does not change with the probability of IT implementation success α. When firms' optimal investment strategy is the Responsive Limit strategy, their expected profit is defined by

$$E(\pi_i) = \frac{t}{2} - \frac{c^2(9kt - (1-\alpha)\alpha)}{9t}.$$

Thus,

$$\frac{\partial E(\pi_i)}{\partial \alpha} = -\frac{c^2(-1+2\alpha)}{9t}.$$

When firms' optimal investment strategy is the Aggressive Limit strategy, their expected profit is

$$E(\pi_i) = -c(ck + (-1+\alpha)\alpha) + \frac{t}{2}(1-2\alpha)^2.$$

Thus,

$$\frac{\partial E(\pi_i)}{\partial \alpha} = (2t - c)(-1+2\alpha).$$

Note that if the equilibrium investment strategy is the Aggressive Limit strategy, then $c > 3t$. Therefore, when firms follow the Responsive Limit or Aggressive Limit investment strategy, the investment level (f) does not change with the probability of IT implementation success α, and the expected profit increases with α as α increases and approaches 1/2 from the left ($\alpha \nearrow 1/2$), and decreases with α when $\alpha > 1/2$.

Proposition 7: *Comparative Statics: Role of Competition (t).*

In a symmetric equilibrium, (i) when firms follow the Responsive investment strategy, the investment level (f) decreases with the degree of differentiation (t), and the expected profit increases with t, and is strictly below $t/2$.

(ii) When firms follow the Responsive Limit, Aggressive Limit or Aggressive investment strategy, the investment level (f) does not change with the degree of differentiation (t), and the expected profit increases with t.

Proof of Proposition 7

(i) In a symmetric equilibrium, when firms follow the Responsive investment strategy, the investment level is

$$f_i = k\left(\frac{3\alpha t}{(-1+\alpha)\alpha + 18kt}\right)^2,$$

where $i = 1, 2$. Thus,

$$\frac{\partial f_i}{\partial t} = \frac{18k\alpha^3 t(-1+\alpha)}{((-1+\alpha)\alpha + 18kt)^3},$$

which is negative when $18kt > \alpha$. The expected profit is defined by

$$E(\pi_i) = \frac{t(324k^2t^2 + \alpha^2(1+18kt) - \alpha^4 - 36k\alpha t)}{2((-1+\alpha)\alpha + 18kt)^2}.$$

Thus,

$$\frac{\partial E(\pi_i)}{\partial t} = \frac{1}{2} - \frac{(-1+\alpha)^2\alpha^4}{((-1+\alpha)\alpha + 18kt)^3}.$$

Clearly, $\frac{\partial E(\pi_i)}{\partial t} < \frac{1}{2}$ when $18kt > \alpha$. Note that, based on the Proof of Prop 2, a necessariy condition that the Responsive strategy is optimal is: $18kt \geqslant \alpha\,(2-\alpha)$. One can show that

$$\frac{(-1+\alpha)^2\alpha^4}{((-1+\alpha)\alpha + 18kt)^3} \leq \frac{(-1+\alpha)^2\alpha^4}{((-1+\alpha)\alpha + \alpha\,(2-\alpha))^3} = (1-\alpha)^2\alpha < \frac{1}{4}.$$

Therefore, the above derivative is positive, and hence the expected profit increases with t given this condition.

(ii) In a symmetric equilibrium, when firms follow the *Responsive Limit or Aggressive Limit* investment strategy, the investment level is, for $i = 1, 2$, $f_i = kc^2$, which does not change with the degree of differentiation (t). The expected profit given the Responsive Limit strategy is

$$E(\pi_i) = \frac{t}{2} - \frac{c^2(9kt - (1-\alpha)\alpha)}{9t}.$$

Thus,

$$\frac{\partial E(\pi_i)}{\partial t} = \frac{1}{2} + \frac{c^2\alpha\,(-1+\alpha)}{9t^2}$$

Note that the Responsive Limit strategy is optimal when $c < 3t$. Therefore, the above derivative is positive, and the expected profit increases with t when $c < 3t$.

The expected profit given the Aggressive Limit strategy is

$$E(\pi_i) = -c(ck + (-1+\alpha)\alpha) + \frac{t}{2}(1-2\alpha)^2,$$

which increases with t.

When firms follow the *Aggressive* investment strategy, the investment level is

$$f_i = \frac{\alpha^2(3-2\alpha)^2}{36k},$$

which does not change with the degree of differentiation (t). The expected profit is

$$E(\pi_i) = \frac{(\alpha^2(9-2\alpha(9-4\alpha)) + 18k(1-2\alpha)^2 t)}{36k},$$

which increases with t. This concludes the proof.

Proposition 8: *Comparative Statics: Effectiveness of IT (k).*

In a symmetric equilibrium, (i) when firms follow the Responsive or Aggressive investment strategy, the investment level (f) decreases with k. (ii) When firms follow the RL or AL investment strategy, their investment level (f) increases with k.

Proof of Proposition 8

(i) In a symmetric equilibrium, when firms follow the Responsive investment strategy, the investment level

$$f_i = k\left(\frac{3\alpha t}{(-1+\alpha)\alpha + 18kt}\right)^2.$$

Thus,

$$\frac{\partial f_i}{\partial k} = \frac{9\alpha^2 t^2((-1+\alpha)\alpha - 18kt)}{((-1+\alpha)\alpha + 18kt)^3},$$

which is negative when $18kt > \alpha$. When firms follow the Aggressive investment strategy, the investment level

$$f_i = \frac{\alpha^2(3-2\alpha)^2}{36k},$$

which decreases with k.

(ii) When firms follow the RL or AL investment strategy, their investment level $f_i = kc^2$, which increases with k.

This concludes the proof.