Sequential IT Investment: Can the Risk of IT Implementation Failure be Your Friend?

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Abstract

An extensive literature has studied the benefits for a firm to be the first to invest in innovative technologies such as Information Technologies (ITs). However, investment in innovative technologies often faces high levels of uncertainty. How would such uncertainty affect a pioneering firm's incentive to invest? Do late adopters benefit from information about the pioneer's investment? In this paper, we investigate these questions in a context where firms engage in sequential investment in an innovative IT. This paper differs from prior literature in two main aspects: First, IT adoption is nonexclusive and available to all client firms. Second, IT implementation can fail. Moreover, we focus on IT implementation failure caused by client firms' organization-specific factors (e.g., organizational processes and people) such that a late adopter faces a similar risk of implementation failure as an early adopter. Such uncertainty has led to persistently high IT implementation failure rates that are well documented in prior literature. We use a standard Hotelling model with two competing firms to examine firms' incentive to sequentially invest in IT given the risk of IT implementation failure. One firm (the Leader) makes his IT investment decision before his competitor (the Follower). Our results show that the probability of IT implementation failure impacts firms' payoff through three distinct effects: first-mover advantage mitigation effect, competition mitigation effect, and uncertainty-driven cost-based differentiation effect, although these three effects may drive the firms' investment and profit in opposite directions. The follower enjoys an information advantage as a second mover since he can make his investment decision contingent on knowledge of the Leader's IT investment strategy and implementation outcome. However, having more information can benefit or hurt the follower, depending on the nature of the IT being adopted and the extent of market competition. Finally, we find that a spaced-out IT investment schedule in which the follower makes his investment decision after the Leader's investment strategy and implementation outcome are known leads to the highest industry-wide IT investment and social surplus.

1. Introduction

An extensive literature has studied the advantages for a firm to be the first to invest in an innovative technology such as Information Technologies (ITs). It finds that first-mover advantages may arise from technological leadership due to the learning or experience curve or patent protection, preemption of scarce resources including input factors and product characteristics space, network externalities, and consumer preferences among competing products that are driven by the order of entry. On the other hand, investment in innovative technologies often faces high levels of uncertainty. Such uncertainty may arise from the uncertain outcome of implementing the new technology (Xin and Choudhary 2018), the uncertain future demand, supply uncertainty or competitive uncertainty regarding the nature and intensity of future competition (Wernerfelt and Karnani 1987). How would uncertainty affect a pioneering firm's incentive to invest? Do late adopters benefit from information about the pioneer's investment?

These questions are of substantial importance as IT-driven innovation has become the engine of economic growth. In this paper, we investigate these questions in a context where firms engage in sequential investment in an innovative IT. This paper differs from prior literature in two main aspects: First, we study IT as a general purpose technology that can be adopted by multiple client firms. That is, adoption of IT-enabled innovation is not exclusive. In contrast, much of the prior literature focuses on innovations that result in exclusive intellectual property rights such as patent protection and assumes that all returns go exclusively to the winner of the patent race (e.g., Bessen and Maskin 2009; Green and Scotchmer 1995). In addition, we focus on IT investments carried out with the objective of reducing marginal costs rather than creating new products. For instance, Supply Chain Management (SCM) systems have been adopted broadly by organizations to reduce production costs.

Second, we focus on a different type of uncertainty that is specific to IT adoption: IT implementation can fail. Moreover, we focus on IT implementation failure caused by client firms' organization-specific factors such that a late adopter faces a similar risk of implementation failure as an early adopter. As we shall discuss below, organization-specific factors are the main causes of IT implementation failure and have led to persistently high failure rates. Nonetheless, a late adopter may have an information advantage since he can make his investment decision after knowing the early adopter's investment strategy and implementation outcome, and make contingent adjustment. The question remains as to how the late adopter's information advantage may affect the early and late adopter's IT investment incentive and payoff.

There is ample evidence that IT implementation faces persistently high failure rates. Specifically, studies have found that despite decades of practice and learning, IT implementation failure rates simply do not decrease (Nelson 2007; Dwivedi et al. 2015). Complex enterprise systems such as Enterprise Resource

Planning (ERP) systems still face an implementation failure rate in the range of 50-75% (Forbes 2016). The collapse of Target Canada is largely blamed on their failure of implementing the ERP system even though they had chosen SAP's ERP system, a gold standard in retail that is used by many other retail chains around the world including Indigo in Canada and Dansk supermarket chain in Denmark, and partnered with Accenture, a veteran in SAP implementation. Even carefully chosen technologies and implementation partners cannot free client organizations from the risk of implementation failure.

An extensive literature has studied the reasons behind the persistently high failure rates of IT implementation. It finds that the main causes of persistent IT project failure usually have little to do with the technology itself. Instead, they are related to organizational processes and people that are unique to each client organization (Nelson 2007). While technology deficiencies can cause implementation problems, these can be mitigated through patches released by the IT vendor or by mediating institutions such as consultants who provide the technical know-how for implementing the technology as they enjoy economies of scale in learning across a large number of projects (Attewell 1992). In contrast, with organization-specific factors, the mediating institutions provide little help and may even be at a disadvantage compared to the organization's own IT department because of their unfamiliarity with the organization (Levina and Ross 2003). Indeed, it is common to see the same IT being successfully implemented by one organization but unsuccessfully by another (e.g., Target Canada's ERP implementation). Cooper and Zmud (1990) find that the IT implementation outcome depends on the dialectic interplay among diverse interests of stakeholders, the outcome of which is highly unpredictable before the completion of the implementation and is usually organization-specific. Therefore, by focusing on IT implementation failure caused by organization-specific factors, our analysis applies well to those ITs whose technical development is relatively mature, for instance, many enterprise systems such as SCM, salesforce automation and so on.

In this paper, we examine firms' incentive to invest in an IT and their anticipated returns in a sequential investment setting when IT implementation can fail. Specifically, we consider a standard Hotelling model in which two competing firms are horizontally differentiated. There is an opportunity to invest in an IT to reduce firms' marginal production cost. Following prior literature, we assume that a higher IT investment leads to a lower new marginal cost if the IT is implemented successfully[1]. However, the outcome of firms' IT implementation is uncertain. If a firm implements the IT successfully, then he achieves a lower marginal cost. If a firm's IT implementation fails, then he retains his original marginal cost but bears the cost of the

[1] Prior empirical work has shown that higher levels of IT investment generally lead to larger productivity gains (see for example, the seminal paper of Brynjolfsson and Hitt 1996).

IT investment. Both firms face the same probability of achieving implementation success, no matter in what sequence they invest in IT.

One firm (the Leader) makes his IT investment decision before his competitor (the Follower). The sequential nature of firms' IT investment may arise for many reasons, for example, if one firm becomes aware of the IT before his competitor. It is well-known that the successful deployment of American Airline's online reservation system SABRE (Semi-automated Business Research Environment) was the result of a chance meeting between a high-ranking IBM salesman and American Airline's then president on a flight from Los Angeles to New York City. The technologies that IBM had developed for a previous project turned out to suit American Airline's needs very well. The sequential nature of firms' IT investment may also be the results of firms' limited "attention budget" (Radner 2003). A client firm usually does not have the capacity to constantly look out for new IT to adopt as soon as they become available. It is more likely that a firm visits IT investment decisions only when triggered by certain organization-specific events such as periodic budget planning, changes in business needs, availability of organizational resources (e.g., budget or talent), or when the current system is due for a major upgrade. Therefore, it is likely that some firms may consider investing in an IT before other firms. A comprehensive discussion about the causes of firms' sequential IT investment is beyond the scope of this paper. The focus of our analysis is on how the risk of implementation failure impacts the first or second-mover's investment incentives and payoff if client firms make the IT investment decision sequentially.

The Follower has the opportunity to invest in the same IT and faces the same risk of implementation failure as the Leader, but has an information advantage: the Follower may know the Leader's investment strategy and implementation outcome before making his own IT investment decision. To disentangle the impact of these two types of information on the Leader and Follower's investment incentives and payoff, we consider two different cases of sequential IT investment: Case 1, the Follower makes his IT investment decision after knowing the Leader's IT investment strategy but before knowing the Leader's implementation outcome. We label this case as "outcome unknown". Case 2, the Follower makes his IT investment decision after knowing the Leader's IT investment strategy and implementation outcome. We label this case as "outcome known".

The sequence of moves happens as follows. The Leader makes his IT investment decision first. In Case 1, the Follower observes the Leader's IT investment strategy and makes his own investment decision before knowing the Leader's implementation outcome. In Case 2, the Follower makes his IT investment decision after observing the Leader's investment strategy and implementation outcome. After both firms have completed their IT implementation, they observe each other's implementation outcome and new marginal costs. The two firms then announce their prices simultaneously. Consumers observe the prices offered by both firms and make a purchase decision. Trade takes place.

Our results show that the probability of IT implementation failure impacts firms' payoff through three distinct effects: the first-mover advantage mitigation effect, competition mitigation effect, and uncertainty-driven cost-based differentiation effect, although these three effects may drive the firms' investment and profit in opposite directions. Interestingly, in competitive markets, when IT is very effective in reducing production costs, the Leader's profit first decreases and then increases as IT implementation becomes more likely to succeed. His IT investment, however, increases continuously despite the non-monotonic return to his IT investment. In contrast, the Follower's IT investment first increases and then decreases with the probability of implementation success. Furthermore, the follower enjoys an information advantage as a second mover since he can make his investment decision after knowing the Leader's IT investment strategy and implementation outcome and make contingent adjustment. However, having more information can benefit or hurt the follower, depending on the nature of the IT being adopted and the extent of market competition. Finally, we find that a spaced-out IT investment schedule, in which the Follower makes his investment decision after the Leader's investment strategy and implementation outcome are known, leads to the highest industry-wide IT investment and social surplus. We discuss the contributions of this paper at the end.

2. Literature Review

This paper is related to several streams of prior literature: (1) literature on first-mover advantage, (2) economics literature on firms' incentive to invest in innovation and, (3) Information Systems (IS) literature on strategic IT investment.

We begin with the literature on first-mover advantage. Lieberman and Montgomery (1988) define first-mover advantage as the excess profits that accrue to pioneering firms. An extensive literature has examined the sources of first-mover advantage. They have identified several factors that give rise to first mover advantage: technological leadership due to the learning or experience curve (Spence 1981) or patent protection (Reinganum 1983), preemption of scarce resources including input factors and product characteristics space (Schmalensee 1978), network externalities, and consumer preferences among competing products that are driven by the order of entry (e.g., Carpenter and Nakamoto 1989). They have also identified factors that may benefit firms that move later: free riding on first-mover investments through spillovers and imitation, benefits from reduction in uncertainty over time – either technological or market uncertainty, leveraging new disruptive technologies, and reduction in the cost of investment over time.

Lieberman and Montgomery (1988, 1998) and Kerin, Varadarajan and Peterson (1992) provide great reviews of this literature. Our paper differs from this literature in that we consider new factors that are specific to IT investment and differ from those considered in prior literature. Specifically, 1) adoption of IT is nonexclusive, and 2) IT implementation can fail, and late adopters face a risk that is similar to the first-mover's risk (or no spillover or imitation).

The second stream of literature spans a range of topics related to firms' incentive to invest in innovation. This literature has identified a number of factors that may impact firms' incentive to invest in innovation including the degree of knowledge spillover between early and late investors (Choi 1993 and D'Aspremont and Jacquemin 1998), the level of market competition (Schumpeter 1942 and Arrow 1962), information asymmetry (Spulber 1995 and Christen 2005), ownership structure of the firms (Matsumura and Matsushima 2004), and the uncertainty regarding the investment outcome (Reinganum 1983). In general, the findings depend on whether the innovation leads to exclusive intellectual property rights (e.g., patent protection) or not and whether it is a product- or process-based innovation. This paper is related to the sub-stream of the literature that studies firms' investment in non-exclusive process-based innovations with the objective to reduce production cost.

Only a few papers in this sub-stream have considered the possibility of investment failure on firms' incentive to invest in a sequential investment game (Hoppe 2000 and Fudenberg and Tirole 1984). Hoppe (2000) examines firms' technology adoption decision when the value of the technology is uncertain, but the Leader's adoption of the technology reveals its value so that, there is no uncertainty for the Follower. Moreover, the cost of technology adoption decreases over time, and the technology requires a lumpy investment so that the firm can only choose whether or not to adopt but cannot change the level of investment. Fudenberg and Tirole (1984) develop a reduced form model to examine firms' incentive to invest in cost reducing R&D in a sequential move game. In their model, the amount of cost reduction from successful investment is exogenously determined whereas the probability of success depends on the amount of investment. Further, if only one firm succeeds, then it is assumed to have monopoly power. In contrast, in our model, the amount of cost reduction from successful IT implementation depends on the amount of investment. The Leader and follower face the same probability of implementation failure and IT investment cost. Firms compete in a horizontal differentiation model, and both may have positive market shares even if only one firm's IT investment is successful. A separate literature has examined the timing of firms' R&D investment (e.g., Reinganum 1983, 1989). The relative timing of firms' IT investment is not relevant in our model since none of the key factors in our model changes with time, and the model remains the same as far as the sequence of firms' decisions and the information structure remain the same.

Several papers in the IS literature have examined firms' incentive to invest in IT and their anticipated returns in a competitive market. Most have not considered the possibility of IT implementation failure, which is the focus of this paper. For instance, Thatcher and Pingry (2004) examine firms' price and quality choices in a duopoly model given four different types of cost structures. They find that marginal cost-saving IT investments increase profits, productivity and consumer welfare while the impact of investments to save fixed and quality-related costs remains ambiguous. Zhu and Weyant (2003) study firms' decision to adopt a technology in a Cournot duopoly game when one firm knows his competitor's cost structure but his competitor does not know his cost structure (information asymmetry). The technology adoption requires a single lumpy investment. They find that informational advantage can mitigate cost disadvantage depending on the relative degree of information asymmetry. Demirhan et al. (2005, 2007) analyze the role of declining IT costs on firms' incentive to invest in IT to improve product quality in a duopoly game. Demirhan et al. (2005) find that both firms increase quality with the reduction in IT costs in price-sensitive markets. Demirhan et al. (2007) analyze the impact of consumers' switching cost in addition to declining IT costs on firms' IT investments. They find that declining IT costs reduce first-mover's profits, but it retains market leadership when switching costs are endogenous. Barua et al. (1991) develop a reduced form model of firms' IT investment to improve product quality in a duopoly setting. They compare the outcome of a simultaneous game to a sequential game and find that the profits of each competitor is greater in the sequential game. They also show that the first mover invests less in the sequential move game than in the simultaneous game.

Only one paper has considered the possibility of IT implementation failure. Xin and Choudhary (2018) analyze a simultaneous IT investment game to study the role of implementation uncertainty. Our paper differs from Xin and Choudhary (2018) in several aspects: First, we study a sequential IT investment game. As we shall show in Section 5, the possibility of implementation failure impacts the first-mover and second-mover's IT investment and profit very differently. Such a differential impact is absent in a simultaneous investment game. Second, when IT implementation can fail, the follower has an information advantage as he can make his investment decision after the Leader's investment strategy and implementation outcome are known and make contingent adjustment to maximize his expected payoff. Our results show that such an information advantage has a very complex impact on investment incentives and may benefit or hurt the follower. In contrast, both firms have the same information on their competitors in a simultaneous move game. Finally, we show that the sequence of IT investment has important welfare implications, which is again absent in a simultaneous move game.

3. Model

We analyze a model of duopoly competition in which both firms may invest in IT to reduce their marginal cost of production. We use the horizontal differentiation framework of Hotelling (1929) and d'Aspremont et al. (1979). The two firms are located at the ends of a unit line, and consumers are uniformly distributed along the line. Without loss of generality, we assume that the Leader firm is located at 1, and the Follower firm is located at 0. The distance between the location of a consumer and that of a firm represents the difference between the consumer's preferred product and the firm's product offering. We model the disutility that a consumer incurs from buying a product that does not fit her preference perfectly (or consumer misfit costs) as a quadratic function of the distance between the consumer and the seller. That is, if a consumer located at x buys from the Leader firm (or from the Follower firm), then she incurs a misfit cost of $t(1-x)^2$ (or tx^2). t represents the degree of differentiation between the two competing products and is often used as a measure for the intensity of market competition in prior literature (e.g., Villas-Boas and Schmidt-Mohr (1999)). When t is small, the products are less differentiated (or more substitutable) since consumers do not have strong preferences for one product over the other (or $|tx^2 - t(1-x)^2|$ is small). Thus, lower t implies more intense competition. The payoff that a consumer gains from purchasing one unit of the product from the Follower firm is $U - tx^2 - p_F$, and that from the Leader firm is $U - t(1-x)^2 - p_L$, where U is the maximum utility that a consumer derives from the products, and p_L and p_F are prices of the Leader and the Follower respectively. We retain a common assumption for horizontal models that U is large enough so that the market is always fully covered (otherwise the firms become local monopolists).

Given the current technology, both firms incur a constant marginal production cost c_O. There is an opportunity to invest in an IT to reduce firms' marginal costs. The outcome of the IT implementation is uncertain, however. With probability α, the IT implementation succeeds, in which case firm *i* is able to reduce his marginal cost to c_i given an IT investment $f_i = k(c_O - c_i)^2$, where $0 \le c_i \le c_O$, $k > 0$, and *i*=*L* or *F*. This cost of IT investment function implies that firms' return to their IT investment decreases the more that they invest in IT. k is a scaling parameter, representing the inverse effectiveness of converting IT investment into reduction in marginal costs. With probability $(1-\alpha)$, the IT implementation fails, in which case the firm retains his original marginal cost c_O but bears the cost of the IT investment.

The two firms make their IT investment decisions sequentially: the Leader firm makes his IT investment decision before the Follower firm. As we have discussed previously, we consider two alternative schedules of firms' sequential IT investment:

Case 1: the Follower makes his IT investment decision after knowing the Leader's investment strategy (i.e., IT investment amount) but before knowing the Leader's implementation outcome. We label this case the "outcome unknown" case.

Case 2: the Follower makes his IT investment decision after knowing the Leader's investment strategy and implementation outcome. We label this case the "outcome known" case.

The strategic interaction between the two firms happens in two stages (see Figure 1). In the investment stage, the Leader makes his IT investment decision first. In Case 1, the Follower observes the Leader's IT investment strategy (i.e., IT investment amount) and makes his own IT investment decision before knowing the Leader's implementation outcome. In Case 2, the Follower makes his IT investment decision after observing both the Leader's investment strategy and implementation outcome. After both firms have completed their IT implementation, they observe each other's implementation outcome and new marginal costs. Note that there are four possible implementation outcomes: (i) both firms have succeeded (ss), (ii) both firms have failed (ff), (iii) the Leader succeeded, while the Follower failed (sf), and (iv) the Leader failed, while the Follower succeeded (fs). Next, in the pricing stage, the two firms announce their prices simultaneously. Consumers observe the prices offered by both firms and make a purchase decision. Trade takes place.

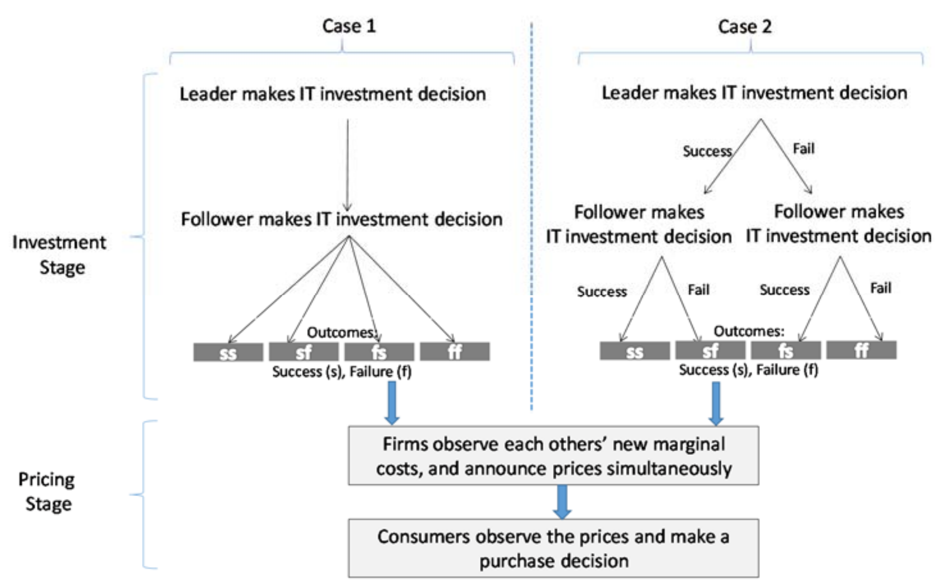

Figure 1: Sequential IT investment game: Case 1 "Outcome unknown" and Case 2 "outcome known"

We assume $c_O < 3t$. This assumption ensures that both firms have positive market shares irrespective of the implementation outcome and thus, allows us to focus on interior solutions. We also assume that $kt > 1/6$.

This assumption ensures that the marginal return to firms' IT investment decreases with the total investment amount.

We focus on the Subgame Perfect Nash Equilibrium of the sequential investment game and solve for the firms' strategies through backward induction. We first analyze the pricing stage and solve for the equilibrium pricing strategy and the two firms' profit given each implementation outcome. Next, we focus on the investment stage and solve for the firms' optimal investment strategy given the two alternative sequential investment schedules.

4 Equilibrium IT Investment and Pricing Strategies

4.1 Pricing stage

We begin with the pricing stage of the game. Both firms have completed their IT implementation and observed each other's implementation outcome and new marginal costs. Firm *i*'s profit as a function of his pricing strategy $p_{i,j}$ given implementation outcome *j* can be represented as: $\pi_{i,j} = m_{i,j}\left(p_{i,j} - c_{i,j}\right) - f_i$, where $m_{i,j}$ is firm *i*'s market share given implementation outcome *j*, and firm *i*'s IT investment $f_i = k(c_O - c_i)^2$, where c_i is firm *i*'s new marginal cost if his IT implementation succeeds, $i \in \{L, F\}$, $j \in \{ss, sf, fs, ff\}$. Firm *i*'s market share given implementation outcome *j* can be computed by considering the indifferent consumers ($x_{i,j}$) who obtains equal payoff from buying either seller's product, or mathematically,

$$U - tx_{i,j}^{\ 2} - p_{F,j} = U - t(1 - x_{i,j})^2 - p_{L,j} \qquad \Leftrightarrow x_{i,j} = \frac{p_{L,j} - p_{F,j} + t}{2t} \tag{1}$$

The market share of the Follower is $m_{F,j} = x_{i,j}$, and the market share of the Leader is $m_{L,j} = 1 - x_{i,j}$.

The two firms simultaneously set their profit maximizing prices given each other's new marginal costs. One can show that firm *i*'s optimal pricing strategy given implementation outcome *j* is $p_{i,j} = t + (2c_{i,j} + c_{-i,j})/3$, and his market share $m_{i,j} = 1/2 + (c_{-i,j} - c_{i,j})/(6t)$. Consequently, firm *i*'s profit given implementation outcome *j* can be represented as a function of his own marginal cost ($c_{i,j}$) and that of his competitor's ($c_{-i,j}$) as follows:

$$\pi_{i,j} = \left(c_{-i,j} - c_{i,j} + 3t\right)^2 \Big/ (18t) - k(c_O - c_i)^2 \tag{2}$$

4.2 Investment Stage

Now we focus on the investment stage of the game and solve for the firms' optimal investment decisions. Note that in the event of a failed implementation, each firm retains his original marginal cost despite the IT investment, or $c_{L,fs} = c_{L,ff} = c_O$, and $c_{F,sf} = c_{F,ff} = c_O$. On the other hand, in the event of a successful implementation, each firm obtains a new and lower marginal cost. Let c_L denote the Leader's new marginal cost, and c_F the Follower's new marginal cost. Then, $c_{L,ss} = c_{L,sf} = c_L$, and $c_{F,ss} = c_{F,fs} = c_F$. Since the IT investment amount $f_i = k(c_O - c_i)^2$, there is a one-to-one mapping between a firm's IT investment amount, f_i, and his new marginal cost when IT implementation succeeds, c_i, where $i = L, F$. Effectively, the firm's problem of finding the optimal investment amount (f_i) is equivalent to finding a new marginal cost in the event of a successful implementation (c_i) so as to maximize the firm's expected profit. Therefore, below we formulate the firms' investment decisions as a decision to find the optimal new marginal cost in the event of a successful implementation (c_i) so as to maximize his expected profit.

As we have discussed previously, we examine the firms' optimal IT investment strategy given the two alternative schedules of firms' sequential IT investment: Case 1, sequential investment with the Leader's implementation outcome unknown to the follower (Section 4.2.1), and Case 2, sequential investment with the Leader's implementation outcome known to the follower (Section 4.2.2).

4.2.1 Investment Strategy for Case 1--Sequential investment with "outcome unknown"

In this case, the Leader makes his IT investment decision (f_L^U) first. The Follower decides his investment amount (f_F^U) after observing the Leader's investment amount but before knowing the Leader's implementation outcome. Therefore, firm *i*'s decision problem can be formulated as:

$$\max_{c_i^U} E(\pi_i^U) = \max_{c_i^U} \left(\alpha^2 \pi_{i,ss}^U + \alpha(1-\alpha)\pi_{i,sf}^U + (1-\alpha)\alpha\pi_{i,fs}^U + (1-\alpha)^2 \pi_{i,ff}^U \right)$$

$$s.t., c_i^U \in [0, c_O],$$

where $\pi_{i,j}^U$ denotes firm *i*'s payoff given implementation outcome j in this "outcome unknown" Case 1, $i \in \{L, F\}$, and $j = ss, sf, fs, ff$. Firm *i*'s payoff given each implementation outcome can be derived from (2).

Given the sequence of IT investment decisions in this case, we first solve for the Follower's investment problem given the Leader's investment amount. Next, we solve for the Leader's optimal IT investment amount given the Follower's response to the Leader's IT investment. The following Proposition 1 describes the firms' optimal IT investment decisions and their new marginal costs if IT implementation is successful.

We present the firms' expected profits and social welfare in this case in the Appendix. All proofs are included in the Appendix.

PROPOSITION 1: *The two firms' optimal investment strategies in the sequential investment game under the "outcome unknown" Case 1 are:*

The Leader invests $f_L^U = k\left(\frac{3\alpha t\left(\alpha^2-\alpha^3-36k\alpha t+324k^2t^2\right)}{\alpha^5-36k\alpha^4 t-\alpha^3+54k\alpha^2 t-972k^2\alpha t^2+5832k^3t^3}\right)^2$ *in IT, and if the implementation succeeds, his new marginal cost is* $c_L^U = c_O - \frac{3\alpha t\left(\alpha^2-\alpha^3-36k\alpha t+324k^2t^2\right)}{\alpha^5-36k\alpha^4 t-\alpha^3+54k\alpha^2 t-972k^2\alpha t^2+5832k^3t^3}$. *The Follower invests* $f_F^U = k\left(\frac{3\alpha t\left(\alpha+2\alpha^2-18kt\right)\left(18kt-(1-\alpha)\alpha\right)}{\alpha^3-\alpha^5-54k\alpha^2 t+36k\alpha^4 t+972k^2\alpha t^2-5832k^3t^3}\right)^2$ *in IT, and if the implementation succeeds, his new marginal cost is* $c_F^U = c_O - \frac{3\alpha t\left(\alpha+2\alpha^2-18kt\right)\left(18kt-(1-\alpha)\alpha\right)}{\alpha^3-\alpha^5-54k\alpha^2 t+36k\alpha^4 t+972k^2\alpha t^2-5832k^3t^3}$.

4.2.2 Investment stage for Case 2: Sequential Investment with "outcome known"

In this case, the Leader makes his investment decision (f_L^K) first. The Follower makes his investment decision after observing the Leader's investment amount and implementation outcome. The Leader's IT implementation may have succeeded or failed, and the Follower can make contingent investment decisions based on the Leader's implementation outcome. Denote by $f_{F,s}^K$ the Follower's investment amount if the Leader's IT implementation has succeeded, and by $f_{F,f}^K$ the Follower's investment amount if the Leader's IT implementation has failed. In addition, we denote by $c_{F,ss}^K$ (or $c_{F,fs}^K$) the Follower's new marginal cost in the event of a successful IT implementation given that the Leader's IT implementation has succeeded (or failed). The Follower's investment problem can now be described as:

$$\max_{c_{F,ss}^K}\left(\alpha\pi_{F,ss}^K+(1-\alpha)\pi_{F,sf}^K\right) \text{ if the Leader's IT implementation has succeeded, or}$$

$$\max_{c_{F,fs}^K}\left(\alpha\pi_{F,fs}^K+(1-\alpha)\pi_{F,ff}^K\right) \text{ if the Leader's IT implementation has failed,}$$

$$s.t., c_{F,ss}^K, c_{F,fs}^K \in [0, c_O].$$

$\pi^K_{F,j}$ denotes the Follower's payoff given implementation outcome *j* in this "outcome known" Case 2, and *j=ss, sf, fs, ff*. The Follower's payoff given each implementation outcome can be derived from (2). This allows us to solve for the Follower's optimal IT investment amount given the Leader's IT investment and implementation outcome. One can show that the Follower's optimal IT investment strategy is such that his new marginal cost in the event of a successful implementation $c^K_{F,ss} = \frac{c^K_L + 3(\alpha - 6c_O k)t}{\alpha - 18kt}$ if the Leader's IT implementation has succeeded, or $c^K_{F,fs} = \frac{c_O\alpha + 3(\alpha - 6c_O k)t}{\alpha - 18kt}$ if the Leader's IT implementation has failed.

The Leader anticipates the Follower's response to his IT investment and implementation outcome while making his own IT investment decision. The Leader's IT investment decision can be described as follows:

$$\max_{c^K_L} E(\pi^K_L) = \max_{c^K_L}\left(\alpha^2\pi^K_{L,ss} + \alpha(1-\alpha)\pi^K_{L,sf} + (1-\alpha)\alpha\pi^K_{L,fs} + (1-\alpha)^2\pi^K_{L,ff}\right)$$
$$s.t., c^K_L \in [0, c_O],$$

Where $\pi^K_{L,j}$ denotes the Leader's payoff given implementation outcome *j* in this "outcome known" Case 2, and *j=ss, sf, fs, ff*. The Leader's payoff given each implementation outcome can be derived from (2).

The following Proposition 2 formally describes the firms' optimal investment decisions and their new marginal costs if their implementation is successful in this "outcome known" Case 2. We present the firms' expected profits and social welfare in this case in the Appendix.

PROPOSITION 2: *The two firms' optimal investment strategies in the sequential investment game under the "outcome known" Case 2 are:*

The Leader invests $f^K_L = k\left(\frac{3pt\left(36k\alpha t - (1-\alpha)\alpha^2 - 324k^2t^2\right)}{18k(3-2\alpha)\alpha^2 t - (1-\alpha)\alpha^3 - 972k^2\alpha t^2 + 5832k^3t^3}\right)^2$ *in IT, and if the implementation succeeds, then his new marginal cost is* $c^K_L = c_O - \frac{3pt\left(36k\alpha t - (1-\alpha)\alpha^2 - 324k^2t^2\right)}{18k(3-2\alpha)\alpha^2 t - (1-\alpha)\alpha^3 - 972k^2\alpha t^2 + 5832k^3t^3}$. *The Follower invests* $f^K_{F,s} = k\left(\frac{6\alpha^2t^2\left(27k\alpha t - (1-\alpha)\alpha^2 - 162k^2t^2\right)}{18k(3-2\alpha)\alpha^2 t - (1-\alpha)\alpha^3 - 972k^2\alpha t^2 + 5832k^3t^3}\right)^2$ *in IT if the Leader's IT implementation has succeeded and achieves a new marginal cost* $c^K_{F,ss} = c_O - \frac{6\alpha^2t^2\left(27k\alpha t - (1-\alpha)\alpha^2 - 162k^2t^2\right)}{18k(3-2\alpha)\alpha^2 t - (1-\alpha)\alpha^3 - 972k^2\alpha t^2 + 5832k^3t^3}$ *if the Follower's IT* *implementation succeeds. The Follower invests* $f_{F,f}^{K}=k\left(\frac{3\alpha t}{\alpha-18kt}\right)^{2}$ *in IT if the Leader's IT implementation has failed and achieves a new marginal cost* $c_{F,fs}^{K}=c_{O}-\frac{3\alpha t}{\alpha-18kt}$ *if the Follower's IT implementation succeeds.*

5. Uncovering the Role of IT Implementation Failure and Information in a Sequential IT Investment Game

The objective of our research is to understand the impact of IT implementation failure rate on the Leader and Follower's IT investment incentives and profits. As we have discussed previously, being a second mover, the Follower has an information advantage in the sense that he may be informed of the Leader's IT investment amount and implementation outcome before making his own investment decision and thus, has the opportunity to make contingent adjustment. In this section, we disentangle the impact of these two types of information on the Leader and Follower's investment strategy and payoff. Specifically, we focus on the Follower's knowledge about the Leader's IT investment strategy in Section 5.1. We show that the Leader enjoys a first-mover advantage, while the follower suffers from a second-mover disadvantage when the Follower makes his investment decision after knowing the Leader's investment strategy. The possibility of IT implementation failure mitigates the Leader's first-mover advantage. However, both the Leader and the Follower may be better off when IT implementation can fail than when it cannot.

In Section 5.2, we focus on the Follower's knowledge about the Leader's implementation outcome. Interestingly, we find that the Leader enjoys a stronger first-mover advantage when the Follower makes his investment decision after the Leader's implementation outcome is known. The Leader's gain does not necessarily mean the follower's loss, however. Such knowledge can also improve the Follower's profit under some conditions. Lastly, we examine the welfare implication of firms' sequential IT investment schedule (Section 5.3). We show that a spaced-out IT investment schedule in which the follower makes his investment decision after the Leader's investment strategy and implementation outcome are known leads to the highest industry-wide IT investment and social surplus.

5.1 Role of Information: Follower's knowledge about Leader's IT investment strategy

In this section, we first demonstrate that the Leader enjoys a first-mover advantage when the Follower makes his investment decision after knowing the Leader's IT investment amount. We begin with a benchmark model in which IT implementation does not fail, or $\alpha=1$. This allows us to focus on understanding the nature of the Leader's first-mover advantage without the complexity of IT implementation failure. In this regard, we compare firms' IT investment and profits when the Follower makes his IT investment decision after knowing the Leader's investment amount but before knowing the Leader's implementation outcome (Case 1) with those when the Leader and follower make their investment decision simultaneously. Next, we introduce the possibility of IT implementation failure and examine how it impacts the Leader's advantage as a first mover or the Follower's disadvantage as a second mover.

5.1.1 Benchmark model without the possibility of implementation failure

Consider a benchmark model in which IT implementation does not fail, or $\alpha = 1$. The firms' optimal IT investment strategy and profit in this benchmark model can be derived by applying Proposition 1 while assuming $\alpha = 1$. Xin and Choudhary (2018) solve firms' optimal IT investment strategy and profits when both firms make their IT investment decision simultaneously. According to their paper, the firms' equilibrium IT investment amount is $f_i^S = k\left(\frac{3\alpha t}{18kt-(1-\alpha)\alpha}\right)^2$, and their profit is $E(\pi_i^S) = \frac{t(324k^2t^2+\alpha^2(1+18kt)-\alpha^4-36k\alpha t)}{2(18kt-(1-\alpha)\alpha)^2}$. Comparing the firms' investment strategy and profits in the simultaneous move game with those in the benchmark sequential move game Case 1, we obtain the following results regarding the impact of the Follower's knowledge about the Leader's investment amount on the Leader and Follower's investment strategy and payoff.

> **PROPOSITION 3:** *When IT implementation always succeeds ($\alpha = 1$),*
>
> *a) the Leader invests more in IT and expects a higher profit than the Follower in the sequential IT investment game, and thus, the Leader enjoys a first-mover advantage;*
>
> *b) the Leader invests more in IT and expects a higher profit, while the Follower invests less and expects a lower profit in the sequential IT investment game Case 1 "outcome unknown" than in the simultaneous investment game;*
>
> *c) the Leader and Follower both have lower profit when they have the opportunity to invest in IT than when they do not have such an opportunity.*

The Leader's advantage as a first mover in the sequential move game arises from his ability to impact the Follower's return to IT investment and ultimately, payoff through his own IT investment. Specifically, when the two firms make their investment decisions sequentially, the Leader's IT investment has a stronger impact on the Follower's investment decision and payoff because the Follower makes his IT investment decision after the Leader's investment is already known. In contrast, in a simultaneous move game, both firms have equal impact on each other's investment decision. Figure 2 shows how the Follower responds to the Leader's investment amount in a sequential investment game. The best response function is downward sloping. That is, if the Leader invests more, the Follower would respond with a lower IT investment. When IT implementation always succeeds, a higher IT investment allows the Leader to achieve a lower new marginal cost, a larger market share and profit margin than the Follower. Therefore, the Leader leverages his first-mover advantage and invests heavily in IT (Proposition 3). The Leader's heavy IT investment lowers the Follower's marginal return to his IT investment, and so the Follower responds with a lower IT investment. Ultimately, the Leader achieves an advantage in marginal cost and a higher profit compared to the Follower.

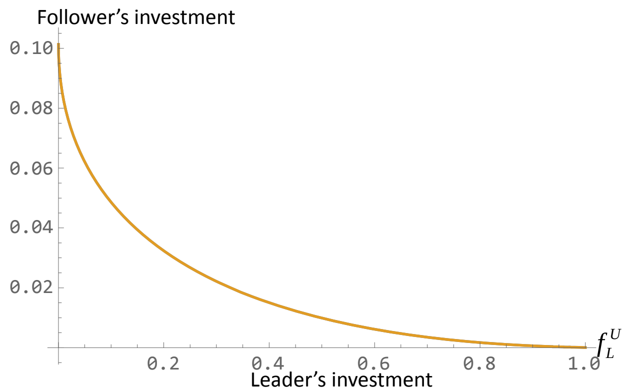

Figure 2: Follower's investment with Leader's investment in Case 1 where α=1, c_O=0.95, k=0.47, and t=0.5.

Interestingly, although the Leader benefits from being the first mover in IT investment, he is worse off when the two firms have the opportunity to invest in IT compared to not having such an opportunity. When IT implementation always succeeds, both firms lower their marginal costs successfully through IT investment. Competition, however, forces them to pass the majority of their efficiency gain on to customers in the form of lower prices. While the Leader still gains a larger market share and lower marginal cost than the Follower with the help of his first-mover advantage, this gain is insufficient to offset the cost of IT investment. Therefore, both the Leader and the Follower face a lower profit when they have the opportunity to invest in IT than when they do not (Proposition 3c). Next, we consider the effect of IT implementation failure.

5.1.2 Impact of IT implementation failure

When IT implementation can fail, overall, the Leader still enjoys a first-mover advantage: He invests more in IT and anticipates a higher expected profit than the Follower. Nonetheless, the possibility of IT implementation failure introduces intriguing changes to the firms' investment incentives and profits. Figures 3 and 4 show how the Leader and Follower's IT investment and profit change with the probability of IT implementation success when the market is competitive, and IT investment is very effective in reducing marginal costs (or *kt* is small). The dashed lines show firms' IT investment and profit in a simultaneous move game. Interestingly, when IT implementation is more likely to succeed, the Leader's profit first decreases and then increases. His IT investment, however, increases continuously despite the non-monotonic return to his IT investment. On the other hand, whereas the Leader increases his IT investment monotonically as the probability of implementation success increases, the Follower's IT investment first increases and then decreases. In contrast, in the simultaneous case, the firms' investment and profits change monotonically with the probability of implementation success. These results are formalized in Proposition 4.

PROPOSITION 4: *When the Follower knows only the Leader's IT investment amount before making his own IT investment decision (Case 1) and as the probability of implementation success (α) decreases,*

a) the Leader's IT investment always decreases. However, his expected profit may change non-monotonically, decrease first and then increase, when the market is competitive, and IT is very effective in reducing firms' marginal costs (or kt is small); when kt is large, his expected profit always increases.

b) the Follower's IT investment may change non-monotonically, increase first and then decrease, when the market is competitive, and IT is very effective in reducing firms' marginal costs (or kt is small); when kt is large, his IT investment always decreases. However, his expected profit always increases.

c) the Leader always invests more and expects a higher expected profit than the Follower.

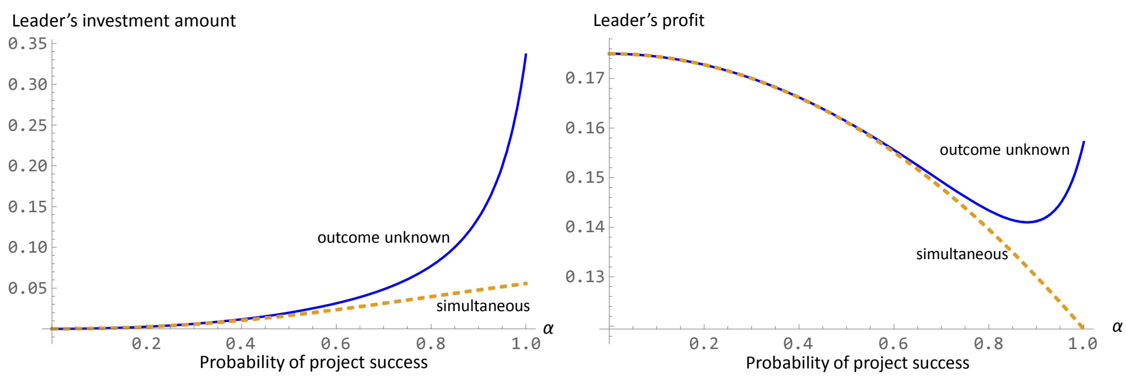

Figure 3: Leader's investment amount and profit with probability of IT implementation success in Case 1 "outcome unknown" and simultaneous case where c_O=1, k=0.5, and t=0.35.

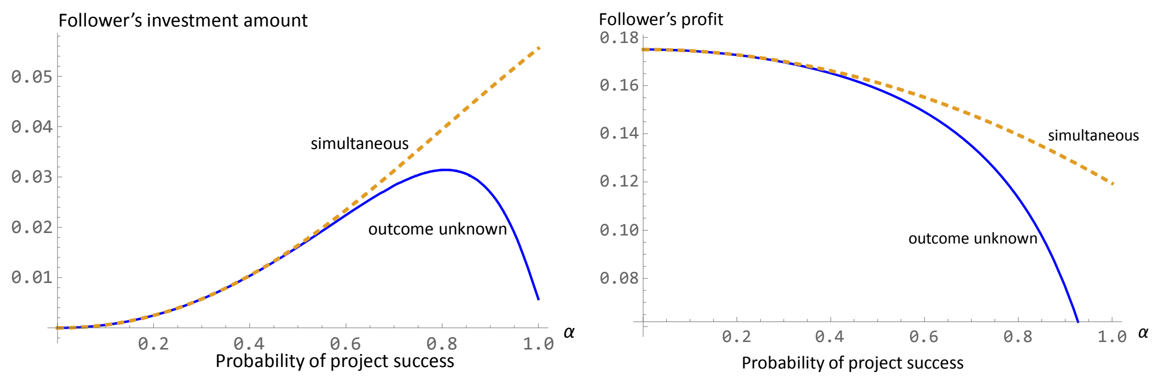

Figure 4: Follower's investment amount and profit with probability of IT implementation success in Case 1 "outcome unknown" and simultaneous case where c_O=1, k=0.5, and t=0.35.

The intriguing pattern of firms' IT investment and profit is driven by three different effects:

First-mover advantage mitigation effect: Recall that without the possibility of implementation failure (or $\alpha = 1$), the Leader leverages his advantage as the first mover and invests extensively in IT and achieves a higher profit than the follower. The Leader's heavy IT investment reduces the Follower's return to his IT investment. The Follower invests less and anticipates a lower profit.

When $\alpha < 1$, the Leader's IT implementation may fail while the Follower's IT implementation may succeed. Thus, the Leader becomes less motivated to invest in IT the less likely that he is able to take advantage of the IT successfully (or α decreases). In contrast, the Follower becomes more motivated to invest in IT when $\alpha < 1$ because a lower investment by the Leader improves the Follower's return to his IT investment. Therefore, the possibility of implementation failure mitigates the Leader's advantage as a first mover.

Competition mitigation effect: Both firms become less motivated to invest in IT as the probability of implementation success (α) decreases. They also become less responsive to their competitor's IT investment because their competitor's implementation is likely to fail. Recall that in the absence of the possibility of implementation failure ($\alpha = 1$), competition forces both firms to invest in IT even though both firms face lower profits after IT investment (Proposition 3c). The possibility of implementation failure discourages firms from entering a race in IT investment that hurts both firms' profits. As a result, both firms' IT investment amounts decrease, and their profits increase as the probability of implementation success (α) decreases.

Implementation Uncertainty-driven Cost-based Differentiation Effect: The possibility of implementation failure creates a new opportunity for marginal cost-based differentiation. This happens when one firm's IT implementation fails but the other's implementation succeeds (or differentiated implementation outcome), and such cost differentiation does not depend on the firms making different levels of IT investment. This effect can benefit a firm if the firm's IT implementation succeeds, but can hurt him otherwise. The overall impact of the uncertainty-driven cost-based differentiation effect depends on the probability of implementation success (α) and on whether the firm is the Leader or the Follower. One can show that the Follower is always better off given a differentiated implementation outcome (i.e., sf or fs), even though his implementation may have failed, than an outcome in which both firms succeed (i.e., ss). On the other hand, the Leader is better off given a differentiated implementation outcome (i.e., sf or fs) than an outcome in which both firms succeed only when α is low. When α is large, however, he is worse off.[2]

Evidently, these three effects may drive firms' IT investment and profit in opposite directions. In particular, the first-mover advantage mitigation effect and the uncertainty-driven cost differentiation effect predict that the Follower's IT investment increases as IT implementation failure becomes more likely, while the competition mitigation effect predicts the opposite. The first-mover advantage mitigation effect predicts that the Leader's profit suffers as IT implementation failure becomes more likely, while the competition mitigation effect predicts the opposite. The overall impact of IT implementation failure rate depends on which effect dominates.

When the market is competitive, and IT investment is very effective in reducing production cost (or *kt* is small), the first-mover advantage mitigation effect dominates when the probability of implementation success is relatively high (α close to 1). This is because the Leader's first-mover advantage is most prominent when firms' IT investment is most likely to succeed. As the probability of implementation success decreases, the Leader invests less, which improves the Follower's return to his IT investment. In addition, the Follower may benefit from the uncertainty-driven cost differentiation effect. The Follower then responds with an elevated level of IT investment. As the two firms' IT investment becomes closer, the first-mover advantage mitigation effect becomes weaker. The competition mitigation effect then dominates when the probability of implementation success is relatively low. In this case, both firms' IT investment decreases as IT implementation success becomes unlikely (α decreases), and their profits improve.

On the other hand, when the market is not competitive (or is highly differentiated), or IT investment is relatively ineffective in reducing production cost (or *kt* is large), the competition mitigation effect dominates for any α. This is because market differentiation weakens the Leader's first-mover advantage: To win new customers in a highly differentiated market, the Leader has to offer even lower prices, which requires higher

[2] Note that this result differs from those in Xin and Choudhary (2018), which studies symmetric firms making simultaneous IT investment. In contrast to our findings above, they find that both firms always benefit from the cost-based differentiation effect.

IT investment to reduce costs. The high IT investment cost discourages the Leader's IT investment. Lower IT investment by the Leader then improves the Follower's incentive to invest in IT. As the Leader's first-mover advantage diminishes with more market differentiation, so does the first-mover advantage mitigation effect caused by implementation failure rates. Similarly, the Leader's first-mover advantage weakens when IT investment is ineffective in reducing production cost since higher IT investment costs are required to reduce marginal costs. The uncertainty-driven cost differentiation effect is also weaker due to the high IT investment cost required to gain market share or to reduce marginal cost. In this case, the competition mitigation effect becomes dominant. Both firms' IT investment decreases as IT implementation success becomes unlikely (α decreases), and their profits improve.

5.2 Role of Information: Follower's knowledge about Leader's IT implementation outcome

When IT implementation may fail, can the Follower benefit from knowing the Leader's implementation outcome in addition to the Leader's investment amount before making his own IT investment decision? How would the Follower's knowledge about the Leader's implementation outcome impact the Leader's IT investment and profit? To answer these questions, we compare the Leader and Follower's IT investment and profit when the Follower makes his IT investment decision after knowing the Leader's investment amount and implementation outcome (Case 2) with those when the Follower makes his IT investment decision after only knowing the Leader's investment amount (Case 1). Proposition 5 formalizes our findings.

> **PROPOSITION 5:** *Effect of the Follower's knowledge about the Leader's implementation outcome:*
>
> *a) The Leader invests more and expects a higher profit when the Follower knows the Leader's IT investment amount and implementation outcome (Case 2) than when the Follower knows only the Leader's IT investment amount before making his own IT investment decision (Case 1).*
>
> *b) The Follower may benefit or be hurt by knowledge about the Leader's implementation outcome before making his own IT investment decision. Such knowledge may improve the Follower's profit when the probability of implementation success is high, and the extent of market competition is high; such knowledge may hurt the follower's profit otherwise.*

The Leader benefits from the Follower's knowledge about the Leader's implementation outcome because such knowledge creates an additional source of first-mover advantage and allows the Leader to influence the Follower's IT investment decision more directly. As we have discussed previously, the Leader's first-mover advantage in our context arises from the Leader's ability to change the Follower's return to his IT investment with the Leader's own IT investment. Note that the Leader's IT investment matters to the Follower only if the Leader's IT implementation succeeds. When the Follower makes his investment decision without knowing the Leader's implementation outcome, the Follower discounts the impact of the Leader's IT investment on his own payoff function because the Leader's IT investment may fail. Therefore, a higher IT investment by the Leader discourages the Follower from investing in IT, but not by much. In contrast, when the Follower makes his investment decision after knowing the Leader's implementation has succeeded, the Follower takes full account of the impact of the Leader's investment on his payoff. Thus, an increase in the Leader's IT investment leads to a larger decrease in the Follower's return to his IT investment in this case. This effect strengthens the Leader's advantage as a first mover and improves the Leader's IT investment incentives and expected profit.

In contrast, the Follower's knowledge about the Leader's implementation outcome can either benefit or hurt the Follower.

Information Benefit: Having such information allows the Follower to vary his IT investment contingent on the outcome of the Leader's IT implementation so that his investment decision maximizes his expected payoff given the specific scenario. If the Leader's implementation fails, then the Follower's IT investment decision is independent of the Leader's investment amount. If the Leader's implementation succeeds, then the Follower makes his investment decision taking full account of the impact of the Leader's investment on his payoff. In contrast, without such information, the Follower makes his investment decision based on an expected outcome, and his investment amount does not maximize the Follower's expected payoff given either of the Leader's implementation outcomes (i.e., success or failure). Indeed, the Follower's expected profit is always higher when he makes his investment decision after instead of before knowing the Leader's investment outcome, if we hold the Leader's IT investment constant.

Information Loss: As we have discussed previously, this information creates an additional source of first-mover advantage for the Leader and causes the Leader to increase his IT investment amount, which hurts the Follower's profit when the Leader's IT implementation succeeds.

Therefore, having information about the Leader's implementation outcome can either benefit or hurt the Follower, depending on the extent of the benefit compared to the extent of the loss. As we shall discuss below, the tradeoff relies on the probability of implementation success and the extent of market competition.

<u>Impact of Implementation Failure Rate on the Follower's Payoff</u>

Figure 5 shows how the follower's expected profit changes with the probability of implementation success (α) when the Follower makes his investment decision with or without the knowledge of the Leader's implementation outcome. The left and right plots show the follower's expected profit given different ranges of α. Evidently, the follower's knowledge about the leader's implementation outcome hurts the follower's profit when α is relatively low, but can benefit the follower's profit when α is close to 1.

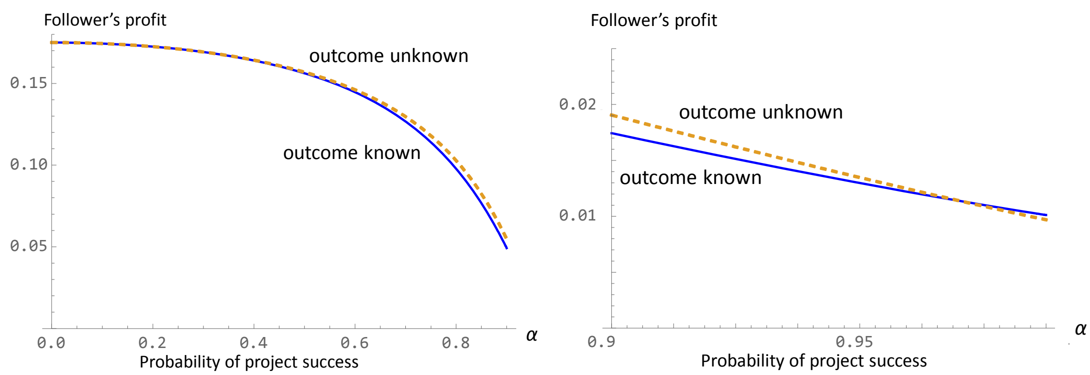

Figure 5: Follower's expected profit with low probability of implementation success on the left and with high probability of implementation success on the right in Case 1 "outcome unknown" and Case 2 "outcome known" where c_O=1, k=0.491, and t=0.34**.**

Why would a higher probability of implementation success allow the Follower to gain from knowing the Leader's implementation outcome? Recall that when the Follower makes his IT investment decision after knowing the Leader's implementation outcome, the Leader enjoys a stronger advantage as a first mover, but only when the Leader's implementation succeeds. As α increases initially, the Leader' implementation is more likely to succeed, and the enhanced first-mover advantage effect becomes stronger. Therefore, the Leader becomes more motivated to invest in IT, which hurts the Follower's profit. Even though the Follower gains from his ability to make contingent investment decisions relative to the Leader's implementation outcome, such gain is less than the Follower's loss from a worsened second-mover disadvantage. Thus, the Follower is worse off from knowing the Leader's implementation outcome when α is not large.

In contrast, as α approaches 1, the Follower may benefit from knowing the Leader's implementation outcome before making his own investment decision. This is because as α approaches 1, the Leader's first-mover advantage arising from the Follower's knowledge about the Leader's implementation outcome diminishes. As α approaches 1, even if the Follower does not know the Leader's implementation outcome when making his investment decision, he does not discount the impact of the Leader's investment on his own payoff by much because the Leader's investment is most likely to succeed. Therefore, the Leader's IT investment has a similar effect on the follower's payoff function whether the follower knows the leader's implementation outcome or not. Indeed, as shown in Figure 6, the Leader's IT investment strategy in these two cases converges as α approaches 1. This limits the Follower's loss from being a second mover. On the other hand, the Follower continues to gain from the ability to make contingent IT investment decisions based on the Leader's implementation outcome, especially when the Leader's implementation has failed, as the Follower would need to drastically change his investment strategy to take advantage of the unlikely outcome (see Figure 6). Without such information, however, the Follower has to make a costly compromise in his investment decision. As a result, the Follower's information gain can outweigh the loss when α is close to 1.

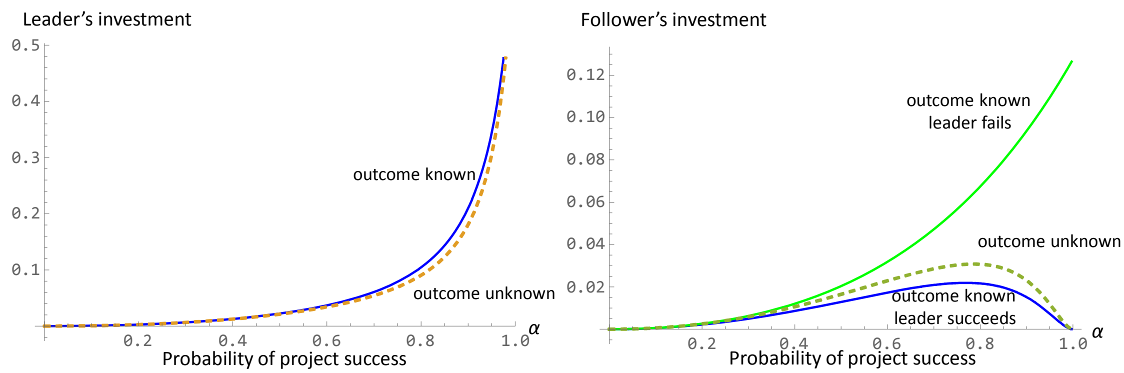

Figure 6: Investment of the Leader and the Follower with probability of project implementation success in Case 1 "outcome unknown" and Case 2 "outcome known" where c_O=1, k=0.491, and t=0.34.

Note that the Leader's first-mover advantage arises either from the Follower's knowledge about the Leader's investment amount or from his knowledge about the Leader's implementation outcome. The impact of implementation failure rate on these two types of first-mover advantage is quite different. As we have discussed above, in the latter case, the Leader's first-mover advantage weakens as α approaches 1, whereas in the former case, the Leader's first-mover advantage strengthens as α approaches 1. This difference is driven by the unique mechanism underlying how each type of information enables the Leader's first-mover advantage.

Impact of Market Competition on the Follower's Payoff

Figures 7 shows how the Follower's expected profit changes with the extent of market competition (t) when the Follower makes his investment decision with or without the knowledge of the Leader's implementation outcome. Interestingly, the Follower can benefit from having such information, but only if the market is more competitive (or the level of differentiation t is small). When the market is less competitive (or t is large), however, the Follower is worse off from having information about the Leader's implementation outcome.

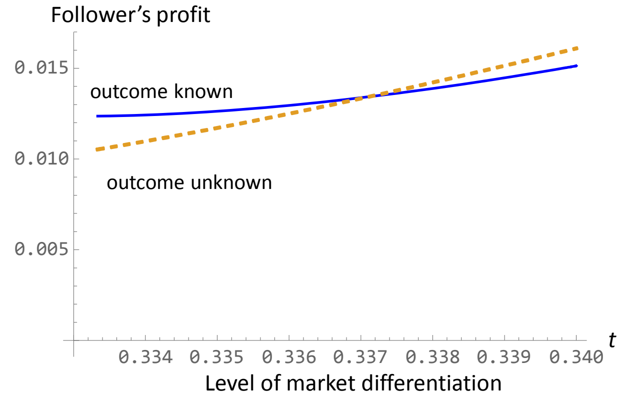

Figure 7: Follower's profit with Level of market differentiation in Case 1 "outcome unknown" and Case 2 "outcome known" where c_O=1, k=0.47, and α=0.95**.**

Why would a competitive market allow the Follower to gain from knowing the Leader's implementation outcome? When the market is more competitive (or t is small), gaining market share requires smaller price differences and so less IT investment to reduce marginal costs. Consequently, both the Leader and the Follower are more motivated to invest in IT to improve their profit margin and market share when t is small. When the Leader's implementation outcome is known to the Follower before the Follower's investment decision, the Follower responds with a lower IT investment if the Leader's implementation succeeds, since the Leader's higher IT investment lowers the Follower's return to his IT investment; if the Leader's IT investment fails, nonetheless, the Follower responds with a dramatically higher IT investment when t is small to improve his profit margin and gain market share. This leads to the Follower's more divergent investment strategies contingent on the Leader's implementation outcome given a highly competitive market. In this case, not knowing the Leader's implementation outcome becomes more costly to the Follower because the Follower would have to compromise between these two diverging forces. Therefore, the Follower's gain from knowing the Leader's implementation outcome is the highest when the market is highly competitive (t is small).

On the other hand, as the market becomes more differentiated (t increases), the Follower's gain from knowing the Leader's implementation outcome decreases because the Follower's investment strategies given the Leader's different implementation outcomes converge. To see this, note that as t increases, it becomes more costly to sway customers and gain market share because it requires offering lower prices and committing to higher IT investment to lower marginal costs. This reduces the Leader's return to his IT investment. As the Leader scales back his IT investment with a larger t, given that the Leader's implementation has succeeded, the Follower's return to his IT investment improves, and the Follower is motivated to invest more in IT. Given that the Leader's implementation has failed, however, the Follower becomes less motivated to invest in IT as t increases since market differentiation makes it more costly to gain market share. Thus, the Follower's IT investment given the Leader's different implementation outcomes converge.

While the Follower's gain from knowing the Leader's implementation outcome decreases, the Follower continues to suffer from a worsened second-mover disadvantage arising from his knowledge of the Leader's implementation outcome. Therefore, when the market is more differentiated, the Follower's information gain is not large enough to overcome his disadvantage as a second mover, and the Follower expects a lower profit if he makes his investment decision after knowing the Leader's implementation outcome. The effect of market competition on firms' investment strategies is formalized in Proposition 6.

PROPOSITION 6: *As the market becomes more competitive (lower* t *):*

a) the Leader invests more in both sequential investment cases: when the Follower knows only the Leader's IT investment amount (Case 1) and when the Follower knows the Leader's IT investment amount and implementation outcome (Case 2) before making his own IT investment decision;

b) the Follower may invest more or less in Case 1;

c) the Follower invests more when the Leader's implementation fails, and invests less when the Leader's implementation succeeds in Case 2.

5.3 Social welfare

We have thus far focused on firms' IT investment and profit when they make their IT investment decisions sequentially. In this subsection, we examine how the sequence of firms' IT investment may affect social welfare. To this extent, we compare social welfare, consumer surplus and industry profit under three different sequences of firms' IT investment: 1) the sequential investment Case 1 with the Leader's implementation outcome unknown to the Follower before the Follower's investment decision; 2) the sequential investment Case 2 with the Leader's implementation outcome known to the Follower; 3) simultaneous investment game. Proposition 7 formalizes our findings.

PROPOSITION 7: *Among the three sequences of firms' IT investment: the sequential investment Case 1 "outcome unknown", sequential investment Case 2 "outcome known" and the simultaneous investment game,*

a) Social welfare is the highest in the sequential investment Case 2 "outcome known";

b) Industry-wide profit is higher in the simultaneous game than in the sequential investment game (i.e., Case 1 or Case 2); Industry-wide total IT investment is the highest in the sequential investment Case 2 "outcome known";

c) Consumer surplus is the highest in the sequential investment Case 2 "outcome known".

This result is somewhat counter-intuitive. Specifically, Case 2 leads to the most asymmetric investment incentives: the Leader has the strongest first-mover advantage when the Follower makes his investment decision after knowing the Leader's investment strategy and implementation outcome. He then leverages his first-mover advantage and invests heavily in IT. Indeed, the Leader's IT investment is the highest in this scenario. Such asymmetric incentives, however, may hurt social surplus because: First, the Leader's extensive investment can fail. On the contrary, since the Leader and the Follower face the same probability of implementation failure, an IT investment schedule that induces a more even distribution of investment incentives may offer an intuitively more appealing diversification. Second, the Leader may be able to achieve a much lower marginal cost than the Follower if his extensive IT investment is implemented successfully. This allows the Leader to offer lower prices and gain market share against the Follower. The Leader's dominant market position may increase the total misfit cost because many more consumers end up buying a product that is cheaper but not a good fit for their needs, which hurts social surplus.

To understand why social surplus is the highest under the most spaced out IT investment schedule in which the Follower makes his IT investment decision after the Leader's investment amount and implementation outcome are both known (Case 2) despite these potential costs, we separate social surplus into two components, total industry profit and consumer surplus. Proposition 7b shows that total industry profit is lower when the two firms make sequential investment decisions. In contrast, Proposition 7c shows that consumer surplus is the highest in the "outcome known" Case 2. Therefore, the increase in social surplus in Case 2 is largely driven by increase in consumer surplus.

Why would consumers benefit the most when the firms space out their IT investment decisions? When IT implementation can fail, the Leader and Follower's IT investment has four possible outcomes: both investment succeeds, both fails, and one succeeds and one fails. Consumer surplus does not change if both firms' IT investment fails. Given the other three outcomes, however, the efficiency gain by the cost Leader, the firm with the lower marginal cost post IT investment, is the highest when the Follower makes his IT investment after knowing the Leader's investment outcome (i.e., Case 2). Specifically, if the Leader's investment succeeds, we know that the Leader invests the most in IT and achieves the lowest new marginal cost when the Follower makes his IT investment after knowing the Leader's investment outcome (i.e., Case 2). If the Leader's investment fails while the Follower's succeeds, the Follower invests the most in IT and achieves the lowest new marginal cost when the Follower makes his IT investment decision after knowing that the Leader's investment has failed. Indeed, the industry-wide IT investment is the highest in the "outcome known" Case 2, creating an opportunity for substantial efficiency gains. Competition then forces firms to pass much of their efficiency gains on to consumers in the form of lower prices. Even though the total consumer misfit cost may increase in Case 2, consumers' gain from lower prices in this case more than compensate for their loss in total misfit cost.

6. Discussion and Conclusion

6.1 Contributions

This paper makes three main contributions.

First, when IT implementation can fail, the Follower enjoys an information advantage as a second mover since he can make his investment decision after knowing the Leader's IT investment strategy and implementation outcome and make contingent adjustment to maximize his own payoff. Would such an information advantage benefit the Follower? How would it affect the Leader's IT investment and profit? Our analysis on these two questions generates genuine economic insights not considered in prior literature.

Our results show that it depends on the type of information that the Follower has about the Leader's IT investment. (a) The **Follower's knowledge about the Leader's investment strategy** (amount of investment) creates a first-mover advantage for the Leader, whereas a second-mover disadvantage for the Follower. This is because the Leader has a stronger ability to impact the Follower's return to IT investment and ultimately, payoff when the Follower makes his IT investment decision after the Leader's investment is already known. In contrast, if the follower makes his investment decision simultaneously as the Leader, both firms have equal impact on each other's investment decision. Therefore, in the sequential game, the Leader leverages his first-mover advantage and invests heavily in IT to lower his marginal cost and gain market share. The Leader's heavy IT investment lowers the Follower's expected return to his IT investment. The Follower responds with a lower IT investment and anticipates a lower expected profit.

(b) The **Follower's knowledge about the Leader's implementation outcome** creates an additional source of first-mover advantage for the Leader. However, the Leader's gain does not necessarily mean the Follower's loss in this case. The Follower may also benefit from having such knowledge under some conditions, depending on the nature of the IT being adopted and the level of market competition.

In particular, recall that the Leader's first-mover advantage arises from his ability to use his investment to influence the Follower's return to IT investment. The Leader's IT investment only affects the Follower's payoff if the Leader's IT implementation succeeds. If the Leader's implementation fails, then the Follower's payoff is independent of the Leader's investment decision. When the Follower makes his investment decision without knowing the Leader's implementation outcome, the Follower discounts the impact of the Leader's IT investment on his own payoff because the Leader's IT investment may fail. In contrast, when the Follower makes his investment decision after knowing that the Leader's implementation has succeeded, the Follower takes full account of the impact of the Leader's investment on his payoff. Thus, an increase in the Leader's IT investment leads to a larger decrease in the Follower's return to IT investment when the Follower knows that the Leader's investment has succeeded. This effect strengthens the Leader's advantage as a first mover and worsened the Follower's disadvantage as a second mover, which hurts the Follower's profit.

On the other hand, knowing the Leader's implementation outcome allows the Follower to make contingent investment decisions to maximize his expected payoff. In contrast, without such knowledge, the Follower makes his investment decision based on an expected outcome, and his investment amount does not maximize his expected payoff given either of the Leader's implementation outcomes (success or failure). Thus, such ability to make contingent investment decisions may improve the Follower's return to IT investment. Indeed, we show that this information benefit outweighs the loss from a worsened second-mover disadvantage, and so the Follower benefits from knowing the Leader's implementation outcome before making his own IT investment decision when the market is more competitive, and IT implementation is likely to succeed.

Second, our results show that when competing firms adopt an IT sequentially, the possibility of IT implementation failure influences the Leader and Follower's investment strategy and profit differently. In particular, it has three possibly opposing effects.

- **First-mover advantage mitigation effect:** The possibility of implementation failure mitigates the Leader's first-mover advantage. As the probability of implementation success decreases, the Leader is less motivated to invest in a risky IT, which increases the Follower's marginal return to his investment. The Follower then responds with higher IT investment and sees increased expected profit.

- **Competition mitigation effect:** The possibility of implementation failure mitigates the competitive pressure for both firms to invest in IT. Without the risk of implementation failure, competition forces firms to invest in IT even though they have to pass the majority of the efficiency gain on to consumers in the form of lower prices. As the probability of implementation success decreases, both firms become less motivated to invest or respond to their competitor's investment in an IT whose implementation is likely to fail. Their profits, nonetheless, improve with the release of such competitive pressure.

- **Uncertainty-driven cost-based differentiation:** The possibility of implementation failure creates a new opportunity for uncertainty-driven cost-based differentiation. This happens when one firm's IT implementation fails but the other's implementation succeeds and does not depend on the firms making different IT investment amounts. This effect can benefit a firm if the firm's IT implementation succeeds, but can hurt him otherwise. The tradeoff depends on the probability of implementation success.

Evidently, these three effects may drive firms' IT investment and profit in opposite directions. In particular, the first-mover advantage mitigation effect and the uncertainty-driven cost differentiation effect predict that the Follower's IT investment increases as IT implementation failure becomes more likely, while the competition mitigation effect predicts the opposite. The first-mover advantage mitigation effect predicts that the Leader's profit suffers as IT implementation failure becomes more likely, while the competition mitigation effect predicts the opposite. The overall impact of IT implementation failure rate on the Leader and Follower's IT investment and profit depends on which effect dominates, which then depends on the nature of the IT and the level of market competition.

When the market is competitive, and IT investment is very effective in reducing production cost, the first-mover advantage mitigation effect dominates when the probability of implementation success is relatively high. This is because the first-mover advantage is most prominent when firms' IT investment is most likely to succeed. As the probability of implementation success decreases, the Leader invests less, which improves the Follower's return to his IT investment. In addition, the Follower may benefit from the uncertainty-driven cost differentiation effect. The Follower then responds with an elevated level of IT investment. As the probability of implementation success decreases further, and the two firms' IT investment becomes closer, the first-mover advantage mitigation effect weakens. The uncertainty-driven cost differentiation effect is also weaker when IT implementation is more likely to fail. Instead, the competition mitigation effect dominates. In this case, both firms' IT investment decreases as IT implementation success becomes unlikely, and their profits improve.

On the other hand, when the market is not competitive (or is highly differentiated), or IT investment is relatively ineffective in reducing production cost, the competition mitigation effect dominates. This is because market differentiation weakens the Leader's first-mover advantage: To win new customers in a highly differentiated market, the Leader has to offer even lower prices, which requires higher IT investment to reduce costs. The high IT investment cost discourages the Leader's IT investment. Lower investment by the Leader then improves the Follower's incentive to invest in IT. As the Leader's first-mover advantage diminishes with more market differentiation, so does the first-mover advantage mitigation effect. Similarly, the Leader's first-mover advantage weakens when IT investment is ineffective in reducing production cost since higher IT investment costs are required to reduce marginal costs. The uncertainty-driven cost differentiation effect is also weaker due to the high IT investment cost required to gain market share or to reduce marginal cost. In this case, the competition mitigation effect becomes dominant.

Third, we show that a spaced-out IT investment schedule in which the Follower makes his investment decision after the Leader's investment strategy and implementation outcome are both known leads to the highest industry-wide IT investment and social surplus.

The gain in social surplus in this sequential investment case is mainly driven by the increase in consumer surplus arising from higher levels of industry-wide IT investment. The intuition is as follows. A spaced-out sequential adoption schedule creates asymmetric incentives: The Leader faces a higher return from his IT investment due to his first-mover advantage and hence, increases his investment significantly. On the other hand, the Follower's overall IT investment does not decrease much, even though he faces the second-mover disadvantage. This is because the spaced-out sequential investment schedule creates an information advantage for the Follower since the Follower makes his IT investment decision after knowing the Leader's investment strategy and implementation outcome and so can make contingent adjustment to maximize his expected payoff. Higher levels of industry-wide IT investment create an opportunity for more efficiency gains. Competition then forces firms to pass much of the efficiency gains on to consumers in the form of lower prices. Although the total industry profit is lower, the gain in consumer surplus from such a spaced-out investment schedule more than compensates for the loss in total industry profit.

6.2 Managerial Implications

Our results have several managerial implications. First, our findings show that part of the Leader's first-mover advantage arises from his ability to influence the Follower's investment decisions via awareness of the Leader's investment actions. Therefore, early IT adopters should publically announce their investment decisions early in order to influence potential followers. This insight is consistent with the frequent public announcement that firms make about their IT investment. For example, Amazon announced its miniature Unmanned Air Vehicle (UAV) service back in December of 2013 (source Wikipedia) even though the project still had a long way to go before full implementation. This service plans to increase the efficiency of the deliveries by using UAVs to deliver purchases to customers. The company continues to invest in this remarkable technology and showcases progress on its website under the brand "Prime Air"[3]. Google X announced its competing investment in "Project Wing" in August 2014.

Second, our findings suggest that before the Leader's investment outcome is known, the Follower invests more in IT if the project failure rate is relatively high as such uncertainty can mitigate the Follower's disadvantage as a second mover. Consistent with this insight, we see that in the case of self-driving technology, Alphabet (the parent company of Google) led the early investment effort. Although Alphabet's investment in this area has not yet realized an actual impact on the company's profit, several companies (Uber, Tesla and most large auto firms), despite of being second-movers, are making very sizable investments in the same area.

[3] https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011 (accessed on March 5, 2018)

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