Online Appendix A

In this online appendix, we examine three extensions of the main model to show that our key findings are robust to changes in these assumptions. The three extensions are:

1) Extension 1: Allowing the leader to benefit from his IT investment before the follower completes his IT implementation;
2) Extension 2: The follower having a higher probability of implementation success than the leader;
3) Extension 3: Assuming a large enough market so that the market is not fully covered without firms' IT investment.

All proofs to the results in these three extensions are in Online Appendix B.

Extension 1: Non-negligible IT Implementation Duration

In the main model, we assume that IT implementation completes in a relatively short period of time so that the leader does not have much to gain during the follower's IT implementation. In this extension, we relax this assumption and allow the leader to benefit from his IT investment, if implemented successfully, before the follower completes his IT implementation. This setup is suitable for those scenarios in which IT implementation takes a non-negligible period of time. Nonetheless, we find that all the key findings of our main model continue to hold.

Specifically, in this extension, the leader makes his IT investment decision first.

- In Case 1 with outcome unknown, the follower observes the leader's IT investment and makes his own IT investment decision before knowing the leader's implementation outcome. Next, the leader completes his IT implementation and obtains a new and lower marginal cost if the implementation is successful. The leader and the follower compete in the market before the follower completes his IT implementation: The firms observe each other's marginal costs and announce their prices simultaneously. (Note that the follower's marginal cost remains c_0.) Consumers observe both firms' prices and make a purchase decision. We call this stage of market competition the First Pricing Stage. After the follower's IT implementation completes, the leader and the follower compete again in the market: The firms observe each other's marginal costs and announce their prices simultaneously. Consumers observe both firms' prices and make a purchase decision. We call this stage of market competition the Second Pricing Stage.
- In case 2 with outcome known, after the leader's IT implementation completes, the follower makes his IT investment decision knowing both the leader's investment amount and implementation outcome. Then, the leader and the follower compete in the market before the follower's IT implementation completes: The firms observe each other's marginal costs and announce their prices. Consumers observe both firms' prices and make a purchase decision. Again, we call this stage of market competition the First Pricing Stage. After the follower's IT implementation completes, the leader and follower compete in the market again, i.e., the second pricing stage.

Figure E1.1 illustrates the sequence of interaction between the two firms. We do not consider the firms' profits before the leader completes his IT implementation because during this time, both firms have the same marginal cost c_0, which is unrelated to their IT investment. The length of the first pricing stage is e $(0 \leq e < 1)$, and that of the second pricing stage is $1 - e$. Note that this extension allows flexibility on the duration of the follower's IT implementation through e. A fraction e of all consumers participates in the market in the first pricing stage, and the remaining fraction $1 - e$ of all consumers participates in the market in the second pricing stage. For simplicity of exposition, we assume no discounting.

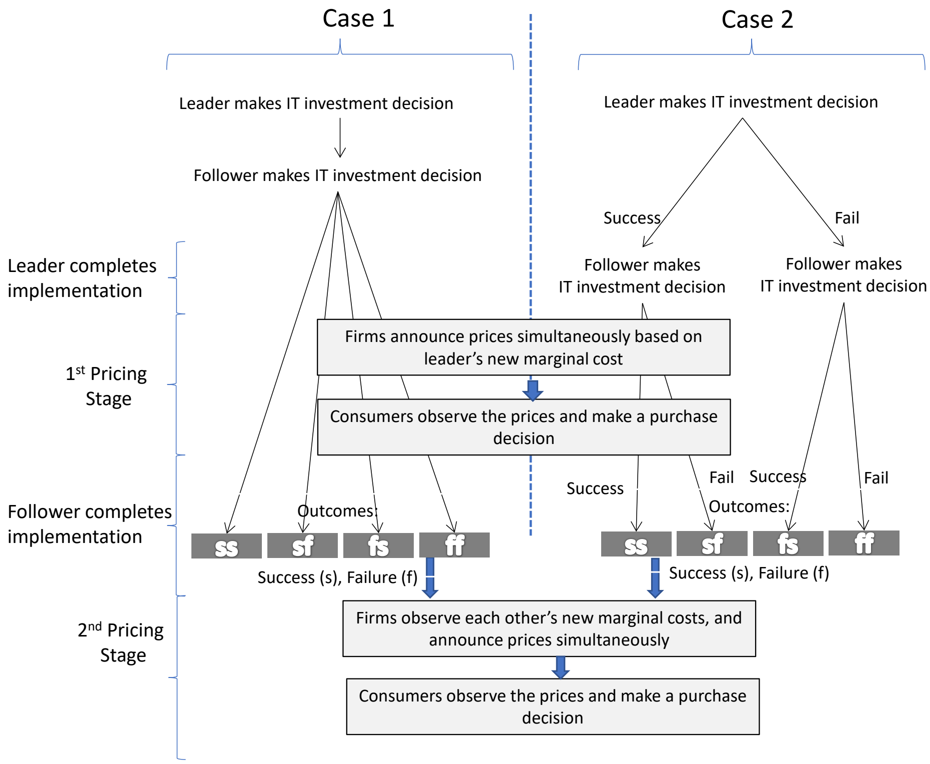

Figure E1.1: Sequential IT investment game: Case 1 "outcome unknown" and Case 2 "outcome known"

We continue to use the main model's assumption that $k \cdot t > 1/6$ which ensures the concavity of the firms' expected profit function and that the firms' new marginal costs given a successful implementation are between 0 and c_O. We solve this extension through backward induction. The following two lemmas summarize our findings on the firms' optimal IT investment in Case 1 and 2 respectively. All proofs are in Online Appendix B.

LEMMA E1.1 *The two firms' optimal IT investment strategies in the "outcome unknown" Case 1 are:*

The leader invests $f_L^U = k\left(\frac{3t\alpha\left(324k^2t^2-36(1-e)kt\alpha-(1-e)^2\alpha^2\left((1-e)\alpha-1\right)\right)}{5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha^2)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2)}\right)^2$ *in IT.*

The follower invests $f_F^U = k\left(\frac{3(1-e)t\alpha\left(324k^2t^2-18kt\alpha(2-e+\alpha)+(1-e)\alpha^2\left(1+\alpha-2(1-e)\alpha^2\right)\right)}{5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha^2)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2)}\right)^2$ *in IT.*

LEMMA E1.2 *The two firms' optimal IT investment strategies in the "outcome known" Case 2 are:*

The leader invests $f_L^K = k\left(\frac{3t\alpha(324k^2t^2-36(1-e)kt\alpha+(1-e)^2\alpha^2(1-(1-e)\alpha))}{5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)}\right)^2$ *in IT.*

The follower invests $f_{F,s}^K = k\left(\frac{3t\alpha(324k^2t^2-36(1-e)kt\alpha+(1-e)^2\alpha^2(1-(1-e)\alpha))}{5832k^3t^3+324(2e-3)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)}\right)^2$ *in IT if the leader's IT implementation has succeeded. The follower invests* $f_{F,f}^K = k\left(\frac{3(1-e)t\alpha}{18kt-(1-e)\alpha}\right)^2$ *in IT if the leader's IT implementation has failed.*

How do the firms' IT investment and profits change when the leader can take advantage of his IT investment before the follower completes his IT implementation? Interestingly, given this additional opportunity to take advantage of his IT investment, the leader may invest less in IT, but his expected profit improves. Indeed, the leader can be better off given the opportunity to invest in IT than without such an opportunity. These results are formalized in the following proposition.

PROPOSITION E1.1 *When the leader can take advantage of his IT investment before the follower completes his IT implementation, the leader expects a higher profit. His investment decreases in Case 2. Moreover, the leader can be better off given the opportunity to invest in IT than without such an opportunity.*

The intuition is as follows. Recall that the firms' IT investment is partially driven by competitive pressure even though it may not lead to higher expected profits. The leader's ability to take advantage of his IT investment before the follower completes his IT implementation creates a window of opportunity for the leader to monopolize the benefit of IT investment without concerning the follower's action, which alleviates the competitive pressure on the leader to invest more in IT, resulting in lower IT investment and higher expected profit.

Nonetheless, the key findings of the main model continue to hold in this extension. The following proposition shows that consistent with the findings of the main model, in this extension, the firms' IT investment and profit may change non-monotonically with the probability of implementation success α. This is driven by three distinct effects caused by the risk of implementation failure: i.e., the first-mover advantage mitigation effect, competition mitigation effect and uncertainty-driven cost-based differentiation effect. These three effects may drive the firms' IT investment and profit in opposite directions.

PROPOSITION E1.2: *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.*
b) *the follower's IT investment may change non-monotonically. However, his expected profit always increases.*

Figure E1.2 shows how the leader's and the follower's IT investment and profit change with the probability of implementation success (α). Note that the leader can be better off given the opportunity to invest in IT (i.e., when α is close to 1) than not having such an opportunity (i.e., when $\alpha=0$).

Consistent with the findings of the main model, in this extension, 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 the firms' IT investment is most likely to succeed. As the probability of implementation success decreases, the leader invests less, and his profit decreases, which improves the follower's return to 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 and expects a higher profit. 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, and their profits improve.

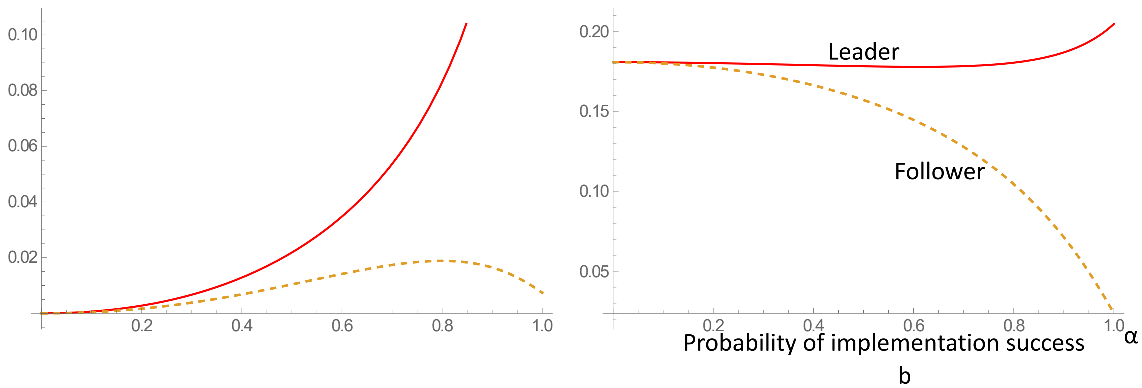

Figure E1.2 Firms' IT investment and profit in Case 1 "outcome unknown" where c_O=1, k=0.461, *e*=0.2, and t=0.362.

Furthermore, the following proposition shows that consistent with the findings of the main model, in this extension, the follower's knowledge about the leader's IT investment amount before making his own investment decision benefits the leader but hurts the follower. In contrast, the follower's knowledge about the leader's IT implementation outcome before making his own investment decision benefits the leader and may benefit or hurt the follower's profit. The intuition behind this finding is consistent with that of the main model and so is omitted to avoid repetition.

PROPOSITION E1.3: *Effect of the follower's knowledge about the leader's IT investment:*

a) The leader invests more and expects a higher profit than the follower when the follower makes his IT investment decision after knowing the leader's IT investment amount (Case 1).

b) 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 (Case 1) before making his own IT investment decision.

c) The follower's expected profit may be higher or lower in Case 2 than in Case 1.

Extension 2: The follower having a higher probability of implementation success than the leader

In this extension, we assume that the follower has a higher probability of implementation success than the leader. It is conceivable that the probability of successfully implementing an IT may increase over time. Denote by α_L the leader's probability of implementation success, and by α_F the follower's probability of implementation success, where $0 < \alpha_L < \alpha_F < 1$. Firms know each other's probabilities of implementation success. We preserve the remaining setup of the main model. Our results show that the key findings of our main model continue to hold in this extension.

The following two lemmas summarize the firms' optimal IT investment strategies in Case 1, in which the follower knows only the leader's IT investment amount before making his own IT investment decision (i.e., outcome unknown), and in Case 2, in which the follower makes his IT investment decision after observing both the leader's investment amount and implementation outcome (i.e., outcome known).

LEMMA E2.1 *When the follower has a higher probability of implementation success than the leader, and the follower knows only the leader's IT investment amount before making his own IT investment decision (Case 1 "outcome unknown"), the two firms' optimal IT investment in the sequential investment game is as follows.*

The leader invests $f_L^U = k\left(\frac{3t\left(324k^2t^2-\alpha_F(36kt-(1-\alpha_F)\alpha_F)\right)\alpha_L}{(18kt-\alpha_L)(18kt-\alpha_F)^2-\alpha_F^2(36kt-\alpha_F)\alpha_L^2}\right)^2$ *in IT. The follower invests* $f_F^U = k\left(\frac{3t\alpha_F\left(18kt(18kt-\alpha_L(1+\alpha_L))-2(\alpha_F\alpha_L)^2-\alpha_F(18kt-\alpha_L-\alpha_L{}^2)\right)}{(18kt-\alpha_L)(18kt-\alpha_F)^2-\alpha_F^2(36kt-\alpha_F)\alpha_L^2}\right)^2$ *in IT.*

LEMMA E2.2 *When the follower has a higher probability of implementation success than the leader, and the follower makes his IT investment decision after knowing both the leader's IT investment amount and implementation outcome (Case 2 "outcome known"), the two firms' optimal investment strategies in the sequential investment game are as follows.*

The leader invests $f_L^K = k\left(\frac{3\alpha_L t(324k^2t^2-36kt\alpha_F+(1-\alpha_F)\alpha_F{}^2)}{5832k^3t^3-324k^2t^2(2\alpha_F+\alpha_L)-(1-\alpha_F)\alpha_F{}^2\alpha_L+18k\alpha_F(\alpha_F+2\alpha_L-2\alpha_F\alpha_L)t}\right)^2$ *in IT. If the leader's IT implementation fails, the follower invests* $f_{F,f}^K = k\left(\frac{3t\alpha_F}{18kt-\alpha_F}\right)^2$ *in IT. If the leader's IT implementation succeeds, the follower invests*

$$f_{F,s}^K = k\left(\frac{6t\alpha_L\left(324k^2t^2-\alpha_F(36kt-(1-\alpha_F)\alpha_F)\right)}{18kt(18kt-\alpha_F)^2-(324k^2t^2-(36kt-\alpha_F)(1-\alpha_F)\alpha_F)\alpha_L}\right)^2 \text{ in IT.}$$

Next, we examine how the follower's higher probability of implementation success may impact the two firms' IT investment amounts and profits. First, we show that interestingly, the follower's higher success probability may hurt his profit and lead to higher or lower IT investment. Second, we show that the key findings of our main model continue to hold in this extension: The probability of IT implementation failure impacts the firms' IT investment and profit through three distinct effects, which may drive the firms' IT investment and profit in opposite directions. Moreover, the follower's knowledge about the leader's IT investment amount before making his own investment decision creates a first-mover advantage for the leader and a disadvantage for the follower. In contrast, the follower's knowledge about the leader's IT implementation outcome before making his own investment decision may benefit both the leader and the follower.

First, we use α_Δ to denote the difference between the two firms' implementation success probabilities, or $\alpha_\Delta = \alpha_F - \alpha_L$**.** The following proposition summarizes how the firms' IT investment amounts and profits change with α_Δ. Interestingly, as the follower enjoys a higher probability of implementation success than the leader, his profit can decrease, and both the leader and the follower's IT investment can increase or decrease. The leader can still expect a higher profit than the follower under some conditions despite the follower's advantage of a higher implementation success rate.

PROPOSITION E2.1 *When the follower has a higher probability of implementation success than the leader, in the sequential investment game,*

1) *In both Cases 1 and 2, the leader's IT investment can increase or decrease with α_Δ. The leader's expected profit decreases with α_Δ.*
2) *In the outcome unknown Case 1, the follower's investment amount and expected profit can increase or decrease with α_Δ. In the outcome known Case 2, if the leader's IT implementation has failed, then the follower's IT investment and profit increase with α_Δ; if the leader's IT implementation has succeeded, then the follower's IT investment and profit can increase or decrease with α_Δ.*
3) *In both Cases 1 and 2, the leader's expected profit can be higher than the follower's expected profit under certain conditions.*

The intuition is as follows. The leader continues to have a first-mover advantage in this extension. When $\alpha_\Delta > 0$, the follower enjoys a different advantage arising from having a higher probability of implementation success. The impact of α_Δ on the firms' IT investment and profit depends on the tradeoff between the leader's first-mover advantage and the follower's advantage of a higher implementation success probability. In some cases, the leader would increase his IT investment to offset the follower's advantage, whereas, in the other cases, the leader would not.

Specifically, in the outcome unknown Case 1, if the leader's probability of implementation success is high, then his first-mover advantage is strong. In this case, when the follower has a higher probability of implementation success, the leader increases his IT investment to (partially) offset the follower's advantage. The follower's response then depends on the level of market competition. In a highly competitive market (Figure E2.1a), the leader's higher IT investment can lower the follower's return to IT investment, leading to lower IT investment and lower expected profit for the follower even as the follower's advantage in implementation success probability (α_Δ) increases. The leader also expects a lower profit as α_Δ increases since competition forces the firms to pass most of the efficiency gains on to customers in the form of lower prices while the leader's extensive IT investment escalates his cost. In a less competitive market, the leader's higher IT investment is insufficient to offset the follower's advantage since gaining market share requires larger price differences and more costly IT investment. The follower responds with higher IT investment and expects a higher profit (see Figure E2.1b). The leader expects a lower profit as α_Δ increases. On the other hand, if the leader's probability of implementation success is relatively low, then his first-mover advantage is relatively weak. In this case, when the follower enjoys a higher probability of implementation success, the leader lowers his IT investment, and his expected profit declines. In contrast, the follower increases his IT investment, and his expected profit improves (see Figure E2.1c).

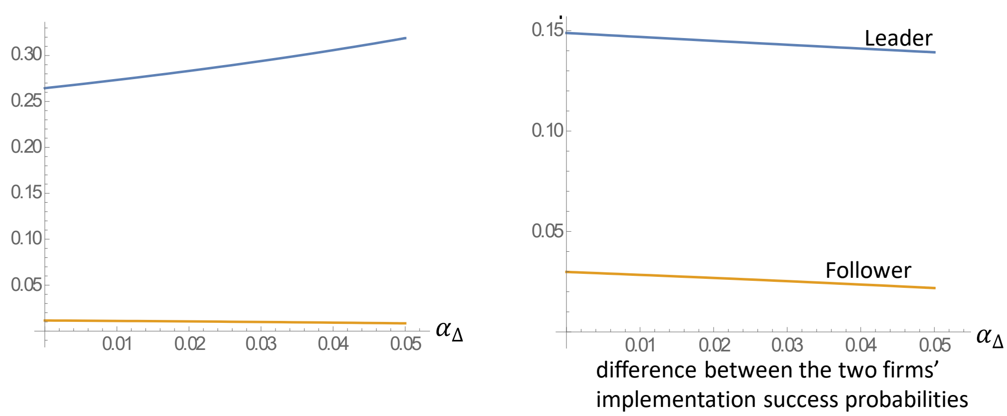

Figure E2.1a: Firms' IT investment and expected profits in Case 1 with respect to α_Δ for $k = 0.482$, $c_O = 1, t = 0.346$, $\alpha_L = 0.95$

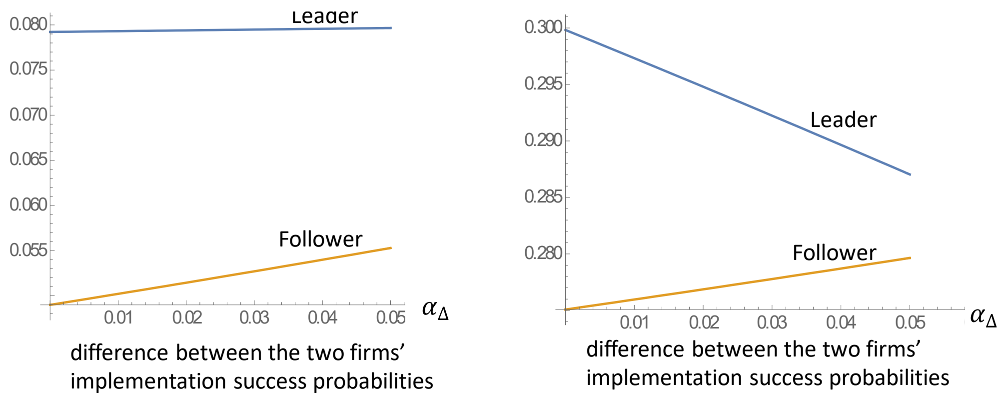

Figure E2.1b: Firms' IT investment and expected profits in Case 1 with respect to α_Δ for $k = 0.482,\ c_O = 1, t = 0.7,\ \alpha_L = 0.95$

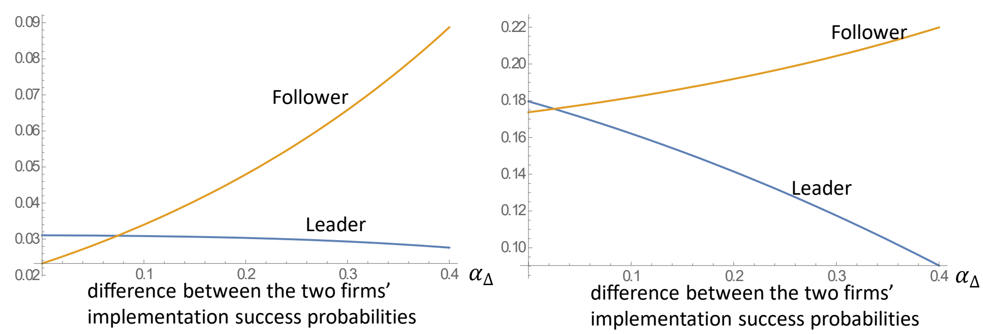

Figure E2.1c: Firms' IT investment and expected profits in Case 1 with respect to α_Δ for $k = 0.482,\ c_O = 1, t = 0.4,\ \alpha_L = 0.6$

In the outcome known Case 2, the leader has a stronger first-mover advantage than in the outcome unknown Case 1. Hence, in Case 2, as α_Δ increases, the leader increases his IT investment to offset the follower's advantage as far as α_Δ is not too high. When α_Δ is high, and the follower's advantage is very strong, the leader's IT investment decreases with α_Δ. In both cases, the leader's expected profit decreases with α_Δ. As for the follower, if the leader's IT investment has failed, the follower's IT investment and profit always increase with α_Δ. If the leader's IT investment has succeeded, the follower's IT investment and profit change with α_Δ in a similar pattern as in Case 1 with outcome unknown: The follower's IT investment and profit increase with α_Δ as far as the market is not too competitive or the leader's probability of implementation success is not too high. Otherwise, the follower's investment and profit can decrease with α_Δ. The intuition is similar to that in Case 1 and so is omitted for brevity.

Second, we verify that the key findings of the main model continue to hold in this extension. Specifically, the following proposition shows that consistent with the findings of the main model, in Case 1 with outcome unknown, the firms' IT investment and profit may change non-monotonically with the probability of implementation success. This is driven by three distinct effects caused by the risk of implementation failure: i.e., the first-mover advantage mitigation effect, competition mitigation effect and uncertainty-driven cost-based differentiation effect. These three effects may drive the firms' IT investment and profit in opposite directions.

PROPOSITION E2.2 *When the follower has a higher probability of implementation success than the leader, in Case 1 with outcome unknown, if one keeps* α_Δ *constant, then as both firms' probabilities of implementation success decrease,*

a) the leader's IT investment always decreases. However, his expected profit may change non-monotonically.

b) the follower's IT investment and expected profit may increase or decrease.

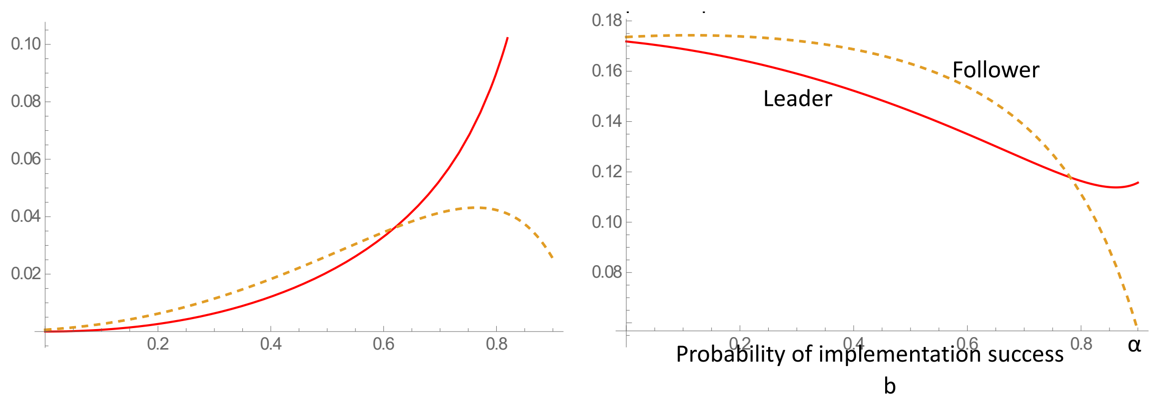

Figure E2.2: Firms' IT investment and profits in Case 1 with respect to α for $k = 0.482$, $c_0 = 1, t = 0.346$, $\alpha_\Delta = 0.1$

Figure E2.2 shows how the leader's and the follower's IT investment and profit change with the probability of implementation success holding α_Δ constant. Consistent with the findings of the main model, the first-mover advantage mitigation effect dominates when both firms' probabilities of implementation success are relatively high (close to 1). This is because the leader's first-mover advantage is most prominent when his IT investment is most likely to succeed. As both firms' probabilities of implementation success (α) decrease, the first-mover advantage is weaker. The leader invests less, and his profit decreases, which improves the follower's return to 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 and expects a higher profit. As the two firms' IT investment becomes closer, the first-mover advantage mitigation effect becomes weaker. The competition mitigation effect then dominates: both firms' IT investment decreases as IT implementation success becomes increasingly unlikely, and their profits improve. As the probability of implementation success decreases further (close to zero), the cost-based differentiation effect may dominate under some conditions: In this case, the leader's IT implementation is most likely to fail, but the follower has a higher probability of achieving the cost-based differentiation than the leader (i.e., $\alpha_F(1-\alpha_L)>\alpha_L(1-\alpha_F)$). As a result, the follower's expected profit may increase with the probability of implementation success when the leader's probability of implementation success is close to zero.

Furthermore, the following proposition shows that consistent with the findings of the main model, in this extension, the follower's knowledge about the leader's IT investment amount before making his own investment decision benefits the leader but hurts the follower. In contrast, the follower's knowledge about the leader's IT implementation outcome before making his own investment decision may benefit both the leader and the follower. The intuition behind these findings is consistent with that of the main model and so is omitted to avoid repetition.

PROPOSITION E2.3 *When the follower has a higher probability of implementation success than the leader,*

a) The leader invests more and expects a higher profit, while the follower invests less and expects a lower profit when the follower makes his IT investment decision after knowing the leader's IT investment amount (Case 1) than when both firms make their investment decisions simultaneously.

b) The leader invests more and expects a higher profit in Case 2 than in Case 1.

c) The follower's profit may be higher or lower in Case 2 than in Case 1.

Extension 3: Partial Market Coverage

In the main model, we assume that the market is always fully covered, in which case one firm's gain would mean the other firm's loss in sales. In this extension, we relax this assumption and assume that the market is large enough so that it is not fully covered without IT investment, and IT investment may allow the firms to serve new customers that they would not be able to serve otherwise.

Specifically, we assume that consumers are distributed on a straight line between 0 and $2n+1$. The leader is located at $n+1$, and the follower is located at n, where $n > 0$. Assume a measure $2nw/(2nw+1)$ of consumers are uniformly distributed on the two ends of the market, i.e., between 0 and n, and between $n+1$ and $2n+1$, where $0 < w \leq 1$. The remaining measure $1/(2nw+1)$ of the consumers are uniformly distributed between n and $n+1$. This is a very flexible setup. When $w = 1$, consumers are uniformly distributed between 0 and $2n+1$. As w decreases, more consumers are located between the two firms, which makes competition in the overlapping middle market more important to each firm. We continue to use the main model's assumption that $k \cdot t > 1/6$ which ensures the concavity of the firms' expected profit function and that the firms' new marginal costs given a successful implementation are between 0 and c_O. We further assume that $n > 2$ to ensure the market is not fully covered.

As in the main model, we solve this extension through backward induction. That is, we first solve the firms' optimal pricing strategies given new marginal costs. Then we solve their optimal investment strategies. The detailed analysis is in Online Appendix B. Lemmas E3.1 and E3.2 in Online Appendix B summarize the firms' optimal investment strategies.

The following proposition shows that when the market is not fully covered without IT investment, both firms can be better off given the opportunity to invest in IT than without such an opportunity (i.e., no prisoner's dilemma). IT investment gives both firms the opportunity to lower costs and serve new customers that they would not be able to serve otherwise. This improves both firms' expected profits.

PROPOSITION E3.1 *In both the outcome unknown Case 1 and outcome known Case 2, both firms can be better off having the opportunity to invest in IT than not having such an opportunity.*

Nonetheless, the key findings of the main model continue to hold in this extension. In particular, the following proposition shows that consistent with the findings of the main model, in this

α . This is driven by three distinct effects caused by the risk of implementation failure: i.e., the first-mover advantage mitigation effect, competition mitigation effect and uncertainty-driven cost-based differentiation effect. These three effects may drive the firms' IT investment and profit in opposite directions.

PROPOSITION E3.2 *When the follower makes his IT investment decision after knowing the leader's IT investment amount (Case 1), as the probability of implementation success (α) decreases,*

a) the leader's expected profit may increase or decrease.

b) the follower's IT investment may increase or decrease.

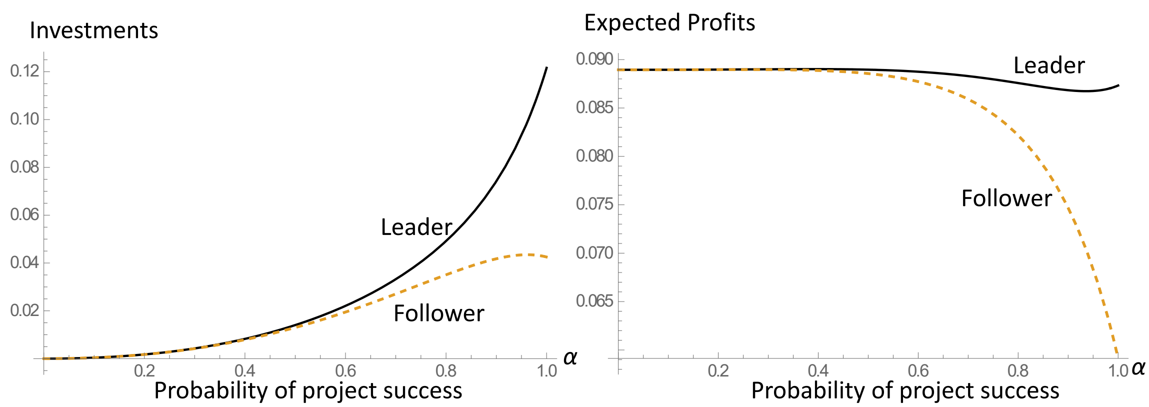

Figure E3.1 Firms' IT investment and profit in Case 1 "outcome unknown" where c_O=1, k=0.461, U=1.37, w=0.183, n=2.05 and t=0.362.

Figure E3.1 shows how the leader's and the follower's IT investment and expected profit may change with the probability of implementation success (α). The risk of implementation failure has a similar impact on the firms' IT investment and profit in this extension as in the main model. Consistent with the findings of the main model, 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 the firms' IT investment is most likely to succeed. As the probability of implementation success decreases, the leader invests less, and his profit decreases, which improves the follower's return to 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 and expects a higher profit. 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 further), and their profits improve. As the probability of implementation success decreases further (close to zero), the cost-based differentiation effect may dominate under some conditions: The follower's expected profit may increase with the probability of implementation success since the follower always benefits from the cost-based differentiation effect.

Next, the following proposition shows that consistent with the findings of the main model, in this extension, the follower's knowledge about the leader's IT investment amount before making his own investment decision benefits the leader but hurts the follower. In contrast, the follower's knowledge about the leader's IT implementation outcome before making his own investment decision may benefit or hurt the follower's profit. The intuition behind this finding is consistent with that of the main model, and so is omitted for brevity.

PROPOSITION E3.3 *Effect of the follower's knowledge about the leader's IT investment:*

a) The leader expects a higher profit than the follower when the follower makes his IT investment decision after knowing the leader's IT investment amount (Case 1).

b) The follower's profit may be higher or lower in Case 2 than in Case 1.

Online Appendix B

Proofs for Extension 1

LEMMA E1.1: Sequential IT investment with "outcome unknown" Case 1

Firm i's decision problem in Case 1 "outcome unknown" can be formulated as:

$$\max_{c_i^U} E(\pi_i^U)$$
$$= \max_{c_i^U} \begin{pmatrix} \alpha^2(e\pi_{i,s,t1}^U + (1-e)\pi_{i,ss,t2}^U) + \alpha(1-\alpha)(e\pi_{i,s,t1}^U + (1-e)\pi_{i,sf,t2}^U) \\ +(1-\alpha)\alpha(e\pi_{i,f,t1}^U + (1-e)\pi_{i,fs,t2}^U) + (1-\alpha)^2(e\pi_{i,f,t1}^U + (1-e)\pi_{i,ff,t2}^U) - k(c_O - c_i)^2 \end{pmatrix}$$

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

where $\pi_{i,k,t1}^U$ denotes firm i's payoff given leader's implementation outcome k during the first pricing stage $t1$ (or after the leader's implementation completes but before the follower's implementation completes), and $\pi_{i,j,t2}^U$ denotes firm i's payoff given both firms' implementation outcome j during the second pricing stage $t2$ (after the follower's implementation completes), $i \in \{L, F\}$, $k = s, f$, and $j = ss, sf, fs, ff$.

The two firms' expected profits can be characterized as follows:

$$E(\pi_L^U) = \frac{\begin{pmatrix} 9t^2 - 6\left(c_L^U - c_F^U(1-e)\right)t\alpha + \alpha\left({c_L^U}^2 + c_F^U(1-e)(c_F^U - 2c_L^U\alpha)\right) - \\ 2\alpha(c_F^U + c_L^U - c_F^U e - 3et - (c_F^U + c_L^U)(1-e)\alpha)c_O + \alpha(2 - e - 2(1-e)\alpha)c_O^2 \end{pmatrix}}{18t} - k(c_O - c_L^U)^2$$

$$E(\pi_F^U) = \frac{\begin{pmatrix} 9t^2 + 6\left(c_L^U - c_F^U(1-e)\right)t\alpha + \alpha\left({c_L^U}^2 + c_F^U(1-e)(c_F^U - 2c_L^U\alpha)\right) - \\ 2\alpha(c_F^U + c_L^U - c_F^U e + 3et - (c_F^U + c_L^U)(1-e)\alpha)c_O + \alpha(2 - e - 2(1-e)\alpha)c_O^2 \end{pmatrix}}{18t} - k(c_O - c_F^U)^2$$

By taking the first derivative of the follower's expected profit with respect to the follower's new marginal cost in the event of a successful implementation, c_F^U, and solving the first order condition, we get $c_F^U(c_L^U) = \frac{c_O(18kt-(1-e)(1-\alpha)\alpha)-(1-e)\alpha(c_L^U\alpha+3t)}{18kt-(1-e)\alpha}$, which is the response function of the follower conditional on the leader's investment level. We used the D function in Mathematica to obtain derivatives of a function with respect to (w.r.t.) a variable and the SOLVE function in Mathematica to solve for the first order condition in this proof and in the subsequent proofs. Then, we substitute the follower's response function into the leader's expected profit. By taking the first derivative of the leader's expected profit w.r.t. the leader's new marginal cost if his implementation is successful, c_L^U, and solving the first order condition, we get the leader's new marginal cost if his implementation is successful as

$$c_L^U = c_O - \frac{3t\alpha\left(324k^2t^2-36(1-e)kt\alpha-(1-e)^2\alpha^2\left((1-e)\alpha-1\right)\right)}{5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha^2)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2)}.$$

Next, we check the second order condition. Take the second order derivative of $E(\pi_L^U)$ w.r.t. c_L^U, and we get

$$\frac{\partial^2 E(\pi_L^U)}{\partial {c_L^U}^2} = \frac{(36kt-2\alpha)(18kt-(1-e)\alpha)^2-72kt(1-e)^2\alpha^4+2(1-e)^3\alpha^5}{-18t(18kt-(1-e)\alpha)^2}.$$

We have $-18t$ is negative given $t > 0$ and $(18kt - (1-e)\alpha)^2$ is positive. Thus, the denominator of $\frac{\partial^2 E(\pi_L^U)}{\partial {c_L^U}^2}$ is negative.

Moreover, the numerator $(36kt - 2\alpha)(18kt - (1-e)\alpha)^2 - 72kt(1-e)^2\alpha^4 + 2(1-e)^3\alpha^5 = 1944k^2t^2\alpha(6kt-1) + 1296k^2t^2e\alpha + 72(1-e)\alpha^2(1-(1-e)\alpha^2)kt + (1-e)^2\alpha^2(36kt - 2\alpha(1-(1-e)\alpha^2))$, which is positive, given $kt > \frac{1}{6}$, $0 \le e < 1$ and $0 < \alpha < 1$. Thus, the numerator of $\frac{\partial^2 E(\pi_L^U)}{\partial {c_L^U}^2}$ is positive. Therefore, $\frac{\partial^2 E(\pi_L^U)}{\partial {c_L^U}^2} < 0$, and the second order condition is satisfied.

Then we substitute the leader's new marginal cost into the follower's response function and get the follower's new marginal cost if his implementation is successful

$$c_F^U = c_O - \frac{3(1-e)t\alpha\left(324k^2t^2-18kt\alpha(2-e+\alpha)+(1-e)\alpha^2\left(1+\alpha-2(1-e)\alpha^2\right)\right)}{5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha^2)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2)}.$$

Next, we check the second order condition. Take the second derivative of $E(\pi_F^U)$ with respect to c_F^U, and we get $\frac{\partial^2 E(\pi_F^U)}{\partial {c_F^U}^2} = -\frac{18kt-\alpha(1-e)}{9t}$. We have that $18kt - \alpha(1-e)$ and $9t$ are positive, given $kt > \frac{1}{6}$, $t > 0$, $0 \le e < 1$ and $0 < \alpha < 1$. Thus, $\frac{\partial^2 E(\pi_F^U)}{\partial {c_F^U}^2} < 0$, and the second order condition is satisfied.

Then, we substitute the firms' new marginal costs in the event of a successful implementation into the investment functions and get the optimal investment levels of the leader and the follower:

$$f_L^U = k(c_O - c_L^U)^2 = k\left(\frac{3t\alpha\left(324k^2t^2-36(1-e)kt\alpha-(1-e)^2\alpha^2\left((1-e)\alpha-1\right)\right)}{5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha^2)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2)}\right)^2 \text{ and}$$

$$f_F^U = k(c_O - c_F^U)^2 = k\left(\frac{3(1-e)t\alpha\left(324k^2t^2-18kt\alpha(2-e+\alpha)+(1-e)\alpha^2\left(1+\alpha-2(1-e)\alpha^2\right)\right)}{5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha^2)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2)}\right)^2.$$

We discuss how the firms' optimal investment strategies change with model parameters in Proposition E1.2.

This concludes the proof. ■

LEMMA E1.2: Sequential IT investment with "outcome known" Case 2

In the "outcome known" case, the leader's expected profit can be characterized as follows:

$$E(\pi_L^K) = \frac{(1-\alpha)t((1-e)^2\alpha^2(1+3(1-e)\alpha) - 36(1-e)k\alpha(1+(1-e)\alpha)t + 324k^2t^2)}{18t} - k(c_O - c_L^K)^2$$

And the follower's expected profit depending on the outcome of the leader's implementation can be characterized as follows:

$E(\pi_{F,s}^K) = \frac{(1-e)\left(c_O{}^2(1-\alpha)+c_{F,ss}^K{}^2\alpha-2c_O(1-\alpha)(c_L^K+3t)+(c_L^K+3t)(c_L^K-2c_{F,ss}^K\alpha+3t)\right)}{18t} - k(c_O - c_{F,ss}^K)^2$, if the leader's implementation is successful; $E(\pi_{F,f}^K) = \frac{(1-e)\left((c_{F,fs}^K-c_O)^2\alpha+6(c_O-c_{F,fs}^K)\alpha t+9t^2\right)}{18t} - k(c_O - c_{F,fs}^K)^2$, if the leader's implementation is unsuccessful.

By taking the first derivative of the follower's expected profits, $E(\pi_{F,s}^K)$ and $E(\pi_{F,f}^K)$ with respect to the follower's new marginal costs if his implementation is successful, $c_{F,s}^K$ and $c_{F,f}^K$, and solving the first order conditions, we get $c_{F,s}^K = \frac{18c_Okt-(1-e)\alpha(c_L^K+3t)}{18kt-(1-e)\alpha}$ and $c_{F,f}^K = c_O - \frac{3(1-e)t\alpha}{18kt-(1-e)\alpha}$, which are the response functions of the follower conditional on the leader's investment level and implementation outcome.

Then, we substitute the follower's response functions into the leader's expected profit. By taking the first derivative of the leader's expected profit w.r.t. the leader's new marginal cost if his implementation is successful, c_L^K, and solving the first order condition, we get

$$c_L^K = c_O - \frac{3t\alpha(324k^2t^2-36(1-e)kt\alpha+(1-e)^2\alpha^2(1-(1-e)\alpha))}{5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)}.$$

Then we substitute the leader's new marginal cost if his implementation is successful into the follower's response functions and get the follower's new marginal costs if his implementation is successful $c_{F,s}^K = c_O - \frac{3t\alpha(324k^2t^2-36(1-e)kt\alpha+(1-e)^2\alpha^2(1-(1-e)\alpha))}{5832k^3t^3+324(2e-3)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)}$ and $c_{F,f}^K = c_O - \frac{3(1-e)t\alpha}{18kt-(1-e)\alpha}$.

Next, we check the second order conditions. We take the second order derivative of $E(\pi_{F,s}^K)$ w.r.t. $c_{F,s}^K$ and the second order derivative of $E(\pi_{F,f}^K)$ w.r.t. $c_{F,f}^K$, and get $\frac{\partial^2 E(\pi_{F,s}^K)}{\partial c_{F,s}^K{}^2} = \frac{\partial^2 E(\pi_{F,f}^K)}{\partial c_{F,f}^K{}^2} = -\frac{18kt-\alpha(1-e)}{9t}$. $18kt-\alpha(1-e)$ and $9t$ are positive, given $kt > 1/6$, $0 \le e < 1$, and $t > 0$. Thus, $\frac{\partial^2 E(\pi_{F,s}^K)}{\partial c_{F,s}^K{}^2} < 0$ and $\frac{\partial^2 E(\pi_{F,f}^K)}{\partial c_{F,f}^K{}^2} < 0$, and these second order conditions are satisfied.

In addition, we take the second order derivative of $E(\pi_L^K)$ w.r.t. to c_L^K, and get

$$\frac{\partial^2 E(\pi_L^K)}{\partial c_L^{K2}} = \frac{-324k^2t^2(18kt-(3-2e)\alpha)-(1-e)\alpha^2((1-e)^2\alpha^2+(1-e)(18kt-\alpha)+36kt(1-(1-e)\alpha))}{9t(18kt-(1-e)\alpha)^2}.$$

The denominator of $\frac{\partial^2 E(\pi_L^K)}{\partial c_L^{K2}}$ is positive, since $9t$ is positive given $t > 0$, and $(18kt-(1-e)\alpha)^2$ is positive. Moreover, $-324k^2t^2(18kt-(3-2e)\alpha)$ is negative and $-(1-e)\alpha^2((1-e)^2\alpha^2 + (1-$

$e)(18kt-\alpha)+36kt(1-(1-e)\alpha))$ is negative given $0<\alpha<1$, $0\leq e<1$ and $k>\frac{1}{6t}$. Thus, the numerator is negative. Hence, $\frac{\partial^2 E(\pi_L^K)}{\partial c_L^{K^2}}$ is negative, and the second order condition is satisfied.

Finally, we substitute the firms' new marginal costs in the event of a successful implementation into the investment functions and get the optimal investment levels of the leader and the follower:

$$f_L^K=k(c_O-c_L^K)^2=k\left(\frac{3t\alpha(324k^2t^2-36(1-e)kt\alpha+(1-e)^2\alpha^2(1-(1-e)\alpha))}{5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)}\right)^2,$$

$$f_{F,s}^K=k(c_O-c_{F,s}^K)^2=k\left(\frac{3t\alpha(324k^2t^2-36(1-e)kt\alpha+(1-e)^2\alpha^2(1-(1-e)\alpha))}{5832k^3t^3+324(2e-3)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)}\right)^2,$$

$$f_{F,f}^K=k(c_O-c_{F,f}^K)^2=k\left(\frac{3(1-e)t\alpha}{18kt-(1-e)\alpha}\right)^2.$$

This concludes the proof. ■

Figure EA1 illustrates how the firms' optimal investment levels may change with the probability of implementation success (α) given c_0=1, k=0.461, e=0.2, and t=0.362 in the outcome known Case 2. The leader's investment level f_L^K generally increases with α. This is consistent with our observation in Case 1 (see Proposition E1.2) and in the main model. The follower's investment level if the leader's implementation fails, $f_{F,f}^K$, generally increases with α as the follower takes advantage of a higher probability of implementation success. But the follower's investment level if the leader's implementation succeeds, $f_{F,s}^K$, can first increase and then decrease with α.

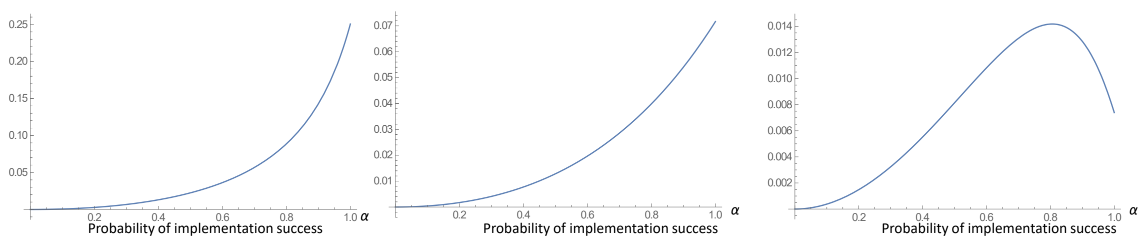

Figure EA1: Firms' investment amounts in Case 2 "outcome known" where c_O=1, k=0.461, e=0.2, and t=0.362.

Proof of PROPOSITION E1.1:

$e=0$, we have the baseline setup where the two firms' implementations complete at the same time.

We take the first derivative of the leader's profit in Case 1 with respect to e.

$$\frac{\partial E(\pi_L^U)}{\partial e}=\frac{\begin{pmatrix}(1-e)\alpha^2((1-e)\alpha^2(1-(1-e)\alpha^2)+(1-e)\alpha^3(1-(1-e)\alpha)+18kt(18kt-\alpha(2-e+\alpha)))\\(23328k^3t^3-324k^2t^2\alpha(13-9e-4\alpha)+18(1-e)kt\alpha^2(3(4-e)-3\alpha-8(1-e)\alpha^2)\\-(1-e)^2\alpha^3(3-\alpha(1+2(1-e)\alpha)))\end{pmatrix}}{2(324(3-2e)k^2t^2\alpha+(1-e)^2\alpha^3(1-(1-e)\alpha^2)-18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2)-5832k^3t^3)^2}$$

The denominator of $\frac{\partial E(\pi_L^U)}{\partial e}$ is positive because $(324(3-2e)k^2t^2\alpha+(1-e)^2\alpha^3(1-(1-e)\alpha^2)-18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2)-5832k^3t^3)^2$ is positive.

$(1-e)\alpha^2$ is positive and $(1-e)\alpha^2(1-(1-e)\alpha^2)+(1-e)\alpha^3(1-(1-e)\alpha)+18kt(18kt-\alpha(2-e+\alpha))$ is positive, given $kt>1/6$, $0<\alpha<1$ and $0\le e<1$. Thus, the 1st and the 2nd factors in the numerator of $\frac{\partial E(\pi_L^U)}{\partial e}$ are positive, given $kt>1/6$, $0<\alpha<1$ and $0\le e<1$.

The remaining portion of the numerator of $\frac{\partial E(\pi_L^U)}{\partial e}$, $23328k^3t^3-324k^2t^2\alpha(13-9e-4\alpha)+18(1-e)kt\alpha^2(3(4-e)-3\alpha-8(1-e)\alpha^2)-(1-e)^2\alpha^3(3-\alpha(1+2(1-e)\alpha))$, is also positive. This is because this expression is a polynomial function of k, t, e and α. Take the 3rd derivative of this expression w.r.t. k, and we get $139968t^3$, which is positive, given $t>0$. Next, we take the 2nd derivative of this expression w.r.t. k, and evaluate it at $k=\frac{1}{6t}$. This gives $648(36-(13-9e)\alpha+4\alpha^2)t^2$, which is positive given $0<\alpha<1$, $0\le e<1$ and $t>0$. Thus, the 2nd derivative of the expression w.r.t. k is positive given $k\ge\frac{1}{6t}$, $0<\alpha<1$, $0\le e<1$ and $t>0$. Then, we take the 1st derivative of this expression w.r.t. k, and evaluate it at $k=\frac{1}{6t}$. This gives $18(108-78\alpha-3(1-e)\alpha^3-8(1-e)^2\alpha^4+54e\alpha+21\alpha^2+3e^2\alpha^2+15(1-e)\alpha^2)t$, which is positive, given $0<\alpha<1$, $0\le e<1$ and $t>0$. Thus, the 1st derivative of this expression w.r.t. k, is positive, given $k\ge\frac{1}{6t}$, $0<\alpha<1$ and $t>0$, implying this expression increases with k given $k\ge\frac{1}{6t}$, $0<\alpha<1$ and $t>0$. Finally, evaluating this expression at $k=\frac{1}{6t}$, we have it is equal to $108-9(13-9e)\alpha+9(8-(5-e)e)\alpha^2-3(4-e)(1-e)\alpha^3-23(1-e)^2\alpha^4+2(1-e)^3\alpha^5$, which is positive given $0<\alpha<1$ and $0\le e<1$. This can be shown again by taking the 1st derivative of this expression w.r.t. e, which is $\alpha(81-45\alpha-6e\alpha^2-6(1-e)^2\alpha^4+18e\alpha+15\alpha^2+46(1-e)\alpha^3)$, which is positive given $0<\alpha<1$ and $0\le e<1$, implying this expression increases with e given $0<\alpha<1$ and $0\le e<1$. This expression is equal to $(108-117\alpha+9\alpha^2)+(63\alpha^2-12\alpha^3-23\alpha^4)+2\alpha^5$ given $e=0$, which is positive given $0<\alpha<1$. Thus, the remaining portion of the numerator of $\frac{\partial E(\pi_L^U)}{\partial e}$, $23328k^3t^3-324k^2t^2\alpha(13-9e-4\alpha)+18(1-e)kt\alpha^2(3(4-e)-3\alpha-8(1-e)\alpha^2)-(1-e)^2\alpha^3(3-\alpha(1+2(1-e)\alpha))$, is positive given $k>\frac{1}{6t}$, $0<\alpha<1$, and $0\le e<1$. Therefore, the numerator of $\frac{\partial E(\pi_L^U)}{\partial e}$ is positive.

Hence, $\frac{\partial E(\pi_L^U)}{\partial e}>0$, and the leader's profit in Case 1 in this extension ($e>0$) is higher than in the baseline setup ($e=0$).

Next, we take the first order derivative of the leader's profit in Case 2 with respect to e.

$$\frac{\partial E(\pi_L^K)}{\partial e}$$

$$= (1-e)\alpha^2 t \frac{\begin{pmatrix} 44079842304u^8 + (-1+e)^6\alpha^8(3+\alpha)(1+(-1+e)\alpha)^2 + 18(-1+e)^5 u\alpha^7(3+\alpha)(1+(-1+e)\alpha)(9-2e+7(-1+e)\alpha) + \\ 5832(-1+e)^3u^3\alpha^5(219+e(-158+21e)-202\alpha+2(159-55e)e\alpha+2(-1+e)(-10+19e)\alpha^2) + \\ 324(-1+e)^4u^2\alpha^6(103+3(-16+e)e-124\alpha+6(30-7e)e\alpha+2(-1+e)(-8+21e)\alpha^2+8(-1+e)^2\alpha^3) + \\ 104976(-1+e)^2u^4\alpha^4(3(95+\alpha(-59+2\alpha))-4e(70+\alpha(-75+4\alpha))+2e^2(29+\alpha(-67+5\alpha)))+612220032(-33+25e)u^7\alpha - \\ 34012224u^6\alpha^2(-117+14\alpha+e(176-26\alpha+e(-63+16\alpha)))-1889568(-1+e)u^5\alpha^3(-233+79\alpha+2e(145-71\alpha+e(-41+38\alpha))) \end{pmatrix}}{2((-1+e)\alpha+18u)^3((-1+e)^3\alpha^4-18(-3+e)(-1+e)\alpha^2u+324(3-2e)\alpha u^2-5832u^3+(-1+e)^2\alpha^3(1+36u))^2}$$

where $u = k \cdot t$.

$2((-1+e)\alpha+18u)^3$ is positive given $u = kt > \frac{1}{6}$. The other factor in the denominator of $\frac{\partial E(\pi_L^K)}{\partial e}$ is also positive. Thus, the denominator of $\frac{\partial E(\pi_L^K)}{\partial e}$ is positive.

The numerator in the 2nd factor in $\frac{\partial E(\pi_L^K)}{\partial e}$ is a polynomial function of $u, e,$ and α, and is positive given $u > \frac{1}{6}$, $0 < \alpha < 1$, $0 \le e < 1$. This result that this expression, which is a polynomial function of $u, e,$ and α, is positive can be shown by taking the 8th derivative of this expression w.r.t. u, which is 1777299241697280 and positive. Next, we take the 7th derivative of this expression w.r.t. u and evaluate it at $u = \frac{1}{6}$, which is equal to $3085588961280(96 - 33\alpha + 25e\alpha)$, which is positive given $0 < \alpha < 1$ and $0 \le e < 1$. Thus, the 7th derivative of the expression w.r.t. u is positive given $u \ge \frac{1}{6}$, $0 < \alpha < 1$ and $0 \le e < 1$. Then, we consecutively take the 6th, the 5th, the 4th, the 3rd, the 2nd and the 1st derivative of this expression w.r.t. u and show that these derivatives are all positive given $u = \frac{1}{6}$, and $0 < \alpha < 1$ and $0 \le e < 1$. Thus, these derivatives, including the 1st derivative, are positive, given $u \ge \frac{1}{6}$, $0 < \alpha < 1$ and $0 \le e < 1$, implying this expression increases with u given $u \ge \frac{1}{6}$, $0 < \alpha < 1$ and $0 \le e < 1$. Next, we consecutively take higher order derivatives of the expression w.r.t. e and show that the derivatives are positive given $u = \frac{1}{6}$, implying that the expression increases with e given $u = \frac{1}{6}$, $0 \le e < 1$, and $0 < \alpha < 1$. Finally, the expression evaluated at $u = \frac{1}{6}$ and $e = 0$ is $(1-\alpha)(2748 + (1-\alpha)(10957 + (1-\alpha)(2647 + (9892 + 3481\alpha^2 + 310\alpha^4 + \alpha^7)(1-\alpha) + 3562\alpha^2 + 508\alpha^4 + 2\alpha^6 + 16\alpha^7)))$ and positive given $0 < \alpha < 1$. Therefore, this expression, which is the numerator in the 2nd factor in $\frac{\partial E(\pi_L^K)}{\partial e}$, is positive, given $u > \frac{1}{6}$, $0 < \alpha < 1$, $0 \le e < 1$ and $t > 0$.

Thus, the 2nd factor in $\frac{\partial E(\pi_L^K)}{\partial e}$ is positive. Moreover, $(1-e)\alpha^2 t$ is positive, given $0 < \alpha < 1$, $0 \le e < 1$ and $t > 0$. Therefore, all factors in $\frac{\partial E(\pi_L^K)}{\partial e}$ are positive. Hence, $\frac{\partial E(\pi_L^K)}{\partial e} > 0$.

We take the first order derivative of the leader's investment amount in Case 2 with respect to e.

$$\frac{\partial f_L^K}{\partial e} = \frac{-\begin{pmatrix} 324(1-e)k^2t^3\alpha^5(36kt(9kt-(1-e)\alpha)+(1-e)^2\alpha^2(1-(1-e)\alpha)) \\ (36kt((27kt-2\alpha)e+2e^2\alpha)+324k^2t^2-(1-e)^3\alpha^2(1-2\alpha)) \end{pmatrix}}{(5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha))^3}$$

$324(1-e)k^2t^3\alpha^5$ is positive and $36kt(9kt-(1-e)\alpha)+(1-e)^2\alpha^2(1-(1-e)\alpha)$ is positive given $kt>1/6$, $0<\alpha<1$, and $0\le e<1$. In addition, $36kt\big((27kt-2\alpha)e+2e^2\alpha\big)>0$ and $324k^2t^2-(1-e)^3\alpha^2(1-2\alpha))>0$, given $kt>1/6$, $0<\alpha<1$, and $0\le e<1$. Thus, the numerator of $\frac{\partial f_L^K}{\partial e}$ is negative (notice the negative sign in front).

Next, consider the denominator of $\frac{\partial f_L^K}{\partial e}$. $5832k^3t^3-324k^2t^2\alpha(3-2e)=324k^2t^2\big(18kt-\alpha(3-2e)\big)>0$, given $kt>1/6$, $0<\alpha<1$, and $0\le e<1$. $-(1-e)^2\alpha^3(1-(1-e)\alpha)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)=(1-e)\alpha^2\Big(36kt(1-(1-e)\alpha)+(1-e)\big(18kt-\alpha(1-(1-e)\alpha)\big)\Big)>0$ given $kt>1/6$, $0<\alpha<1$, and $0\le e<1$. Therefore, the denominator of $\frac{\partial f_L^K}{\partial e}$, is positive, given $kt>\frac{1}{6}$, $t>0$, $0<\alpha<1$, and $0\le e<1$.

Thus, the denominator of $\frac{\partial f_L^K}{\partial e}$ is positive. Hence, $\frac{\partial f_L^K}{\partial e}<0$. Thus, the leader's investment in Case 2 in this extension ($e>0$) is lower than in the baseline setup ($e=0$).

With the parameter sets, $k=0.461, c_O=1, t=0.362, e=0.2$, the leader's profit without investing in IT is $t/2=0.181$. We can check that the leader's profit $E(\pi_L^U|\alpha=0.85)=0.183$ in the outcome unknown case, and $E(\pi_L^K|\alpha=0.85)=0.185$ in the outcome known case. Thus, the leader's profits can be higher in Case 1 and Case 2 than in the case where the firms do not invest in IT.

This concludes the proof. ■

Proof of PROPOSITION E1.2:

a) The first derivative of the leader's investment level with respect to the probability of success is

$$\frac{\partial f_L^U}{\partial \alpha} = \frac{\begin{pmatrix} 18kt^2\alpha\left(324k^2t^2+36(-1+e)kt\alpha+(-1+e)^2\alpha^2\left(1+(-1+e)\alpha\right)\right) \\ (1889568k^5t^5+419904(-1+e)k^4t^4\alpha+ \\ 11664(-1+e)^2k^3t^3\alpha^2\left(3+\alpha(-2+2e+3\alpha)\right)+ \\ 18(-1+e)^4kt\alpha^4\left(1+2\alpha(-3+e+4\alpha)\right)+324(-1+e)^3k^2t^2\alpha^3 \\ \left(4+3\alpha(-3+2e+4\alpha)\right)+(-1+e)^5\alpha^6\left(-1+\alpha\left(2+(-1+e)\alpha\right)\right)) \end{pmatrix}}{\begin{pmatrix} 5832k^3t^3+324(-3+2e)k^2t^2\alpha-(-1+e)^2\alpha^3\left(1+(-1+e)\alpha^2\right)- \\ 18(-1+e)kt\alpha^2\left(3-e+2(-1+e)\alpha^2\right) \end{pmatrix}^3}$$

We previously proved that $5832k^3t^3 - 324(3-2e)k^2t^2\alpha - (1-e)^2\alpha^3(1-(1-e)\alpha) + 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)$ is positive given $k > \frac{1}{6t}$, $0 < \alpha < 1$, and $0 \le e < 1$. Thus, the denominator of $\frac{\partial f_L^U}{\partial \alpha}$ is positive.

Moreover, $18kt^2\alpha > 0$, $324k^2t^2 - 36(1-e)\alpha kt = 36kt(9kt-(1-e)a)) > 0$, and $(1-e)^2\alpha^2(1-(1-e)\alpha) > 0$, given $0 < \alpha < 1$, $0 \le e < 1$ and $kt > \frac{1}{6}$. Thus, the 1st and the 2nd factors in the numerator of $\frac{\partial f_L^U}{\partial \alpha}$ are positive.

The 3rd factor of the numerator of $\frac{\partial f_L^U}{\partial \alpha}$, or $1889568k^5t^5 - 419904(1-e)k^4t^4\alpha + 11664(1-e)^2k^3t^3\alpha^2(3+\alpha(2e+3\alpha-2)) + (1-e)^5\alpha^6(1-\alpha(2-(1-e)\alpha)) + 18(1-e)^4kt\alpha^4(1+2\alpha(e+4\alpha-3)) - 324(1-e)^3k^2t^2\alpha^3(4-3\alpha(3-2e-4\alpha))$, is a polynomial function of k, e, t, and α, and is positive given $k > \frac{1}{6t}$, $0 \le e < 1$, $0 < \alpha < 1$ and $t > 0$. To show that this expression is positive given $k > \frac{1}{6t}$, $0 \le e < 1, 0 < \alpha < 1$ and $t > 0$, we apply a similar procedure as the one used repeatedly in the proof of Proposition E1.1 and the proofs of Lemma 1 and Lemma 2 (see Appendix) by consecutively taking higher order derivatives of the expression w.r.t. k and show that the derivatives are positive, given $k \ge \frac{1}{6t}$, $0 \le e < 1, 0 < \alpha < 1$ and $t > 0$. Next, we consecutively take higher order derivatives of the expression w.r.t. e, and show that the derivatives are positive given $k = \frac{1}{6t}$, implying that the expression increases with e given $k = \frac{1}{6t}$, $0 \le e < 1, 0 < \alpha < 1$ and $t > 0$. Finally, the expression evaluated at $k = \frac{1}{6t}$ and $e = 0$ is $3(81 + 40\alpha^4 - 108\alpha) + 18\alpha^2 + 23\alpha^6 + \alpha^8 + (1-\alpha)(144\alpha^2 + 126\alpha^4 + 2\alpha^6)$ and positive given $0 < \alpha < 1$. Therefore, this expression, which is the 3rd factor of the numerator of $\frac{\partial f_L^U}{\partial \alpha}$, is positive given $k > \frac{1}{6t}$, $0 \le e < 1, 0 < \alpha < 1$ and $t > 0$. The details are omitted to avoid repetition, but available upon request.

Thus, the numerator of $\frac{\partial f_L^U}{\partial \alpha}$ is positive, given $0 < \alpha < 1$, $0 \le e < 1$ and $k > \frac{1}{6t}$.

Hence, $\frac{\partial f_L^U}{\partial \alpha}$ is positive.

With the parameter set, $k = 0.461, c_O = 1, t = 0.362, e = 0.01$, in the outcome unknown case the first derivative of the leader's profit with respect to the probability of implementation success $\frac{\partial E(\pi_L^U)}{\partial \alpha} = 0$ at $\alpha = 0.854$. Further, we check that $E(\pi_L^U | \alpha = 0.7) = 0.155$, $E(\pi_L^U | \alpha = 0.85) = 0.148$, and $E(\pi_L^U | \alpha = 0.9) = 0.150$ in the outcome unknown case. Thus, the leader's profit can first decrease and then increase as the probability of implementation success decreases.

b)

We rewrite the expression of the follower's profit as: $E(\pi_F^U) = \frac{t(LT)}{2(LL)^2}$, where $LT = l_0 + l_1\alpha + l_2\alpha^2 + l_3\alpha^3 + l_4\alpha^4 + l_5\alpha^5 + l_6\alpha^6 + l_7\alpha^7 + l_8\alpha^8 + l_9\alpha^9 + l_{10}\alpha^{10} + l_{11}\alpha^{11}$, $LL = -5832k^3t^3 + 324(3-2e)k^2t^2\alpha + (1-e)^2\alpha^3(1-(1-e)\alpha^2) - 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2)$, $l_0 = 34012224k^6t^6$, $l_1 = -3779136(3-2e)k^5t^5$, $l_2 = 104976k^4t^4(15-20e+6e^2+18(1+(2-e)e)kt)$, $l_3 =$

$11664k^3t^3(9(6+e(5-e(11-3e)))kt-2(1-e)(5-(5-e)e))$, $l_4=-324(1-e)k^2t^2(25e-15-11e^2+e^3+18(14+e(10-3(5-e)e))kt+1944(1-e)k^2t^2)$, $l_5=36(1-e)^2kt(4e-3-e^2+9(16+e(10-(9-e)e))kt+972(4-3e)k^2t^2)$, $l_6=(1-e)^2((1-e)^2-18(1-e)(9+e(5-2e))kt-648(1-e)(19-9e)k^2t^2+5832(1+4(2-e)e)k^3t^3)$, $l_7=-(1-e)^3(e+e^2-2-36(1-e)(14-3e)kt+324(1+4e(5-2e))k^2t^2)$, $l_8=-2(1-e)^4(4-4e+9(1-4(4-e)e)kt-1296k^2t^2)$, $l_9=-(1-e)^5(5e+288kt-2)$, $l_{10}=(1-e)^6(7+72kt)$, $l_{11}=-4(1-e)^7$.

The first derivative of the follower's profit with respect to the probability of success is

$\frac{\partial E(\pi_F^U)}{\partial\alpha}=\frac{t(LL*LTD-2\,LT*LLD)}{2(LL)^3}$, where $LLD=-324(3-2e)k^2t^2+36(1-e)kt\alpha(3-e-4(1-e)\alpha^2)-(1-e)^2\alpha^2(3-5(1-e)\alpha^2)$, $LTD=l_1+2l_2\alpha+3l_3\alpha^2+4l_4\alpha^3+5l_5\alpha^4+6l_6\alpha^5+7l_7\alpha^6+8l_8\alpha^7+9l_9\alpha^8+10l_{10}\alpha^9+11l_{11}\alpha^{10}$.

We previously proved that, $-LL>0$, i.e., $5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)$ is positive given $k>\frac{1}{6t}$, $0<\alpha<1$, and $0\le e<1$. Thus, the denominator of $\frac{\partial E(\pi_F^U)}{\partial\alpha}$, which is the cubic of LL, is negative.

The numerator of $\frac{\partial E(\pi_F^U)}{\partial\alpha}$ is a polynomial function of $k, e, t,$ and α, and is positive given $k>\frac{1}{6t}$, $0\le e<1, 0<\alpha<1$ and $t>0$. To show that this expression is positive given $k>\frac{1}{6t}$,$0\le e<1, 0<\alpha<1$ and $t>0$, we apply a similar procedure as the one used repeatedly in the proof of Proposition E1.1 and the proofs of Lemma 1 and Lemma 2 (see Appendix) by consecutively taking higher order derivatives of the expression w.r.t. k and show that the derivatives are positive given $k\ge\frac{1}{6t}$,$0\le e<1, 0<\alpha<1$ and $t>0$. Next, we consecutively take higher order derivatives of the expression w.r.t. e, and show that the derivatives are positive given $k=\frac{1}{6t}$ implying that the expression increases with e given $k=\frac{1}{6t}$, $0\le e<1, 0<\alpha<1$ and $t>0$. Finally, the expression evaluated at $k=\frac{1}{6t}$ and $e=0$ is $27+(1-\alpha)(27(125+(13.25+355(1/4-\alpha(1-\alpha))+(258+543\alpha^2)(1-\alpha))(1-\alpha))+(16416\alpha^4+3960\alpha^7+268\alpha^9+4\alpha^{12}+(61\alpha^6+94\alpha^9)(1+\alpha))(1-\alpha)+3224\alpha^6+1275\alpha^9+64\alpha^{12})$ and also positive given $0<\alpha<1$. Thus, the expression is positive given $k>\frac{1}{6t}$,$0\le e<1, 0<\alpha<1$ and $t>0$. The details are omitted to avoid repetition, but available upon request.

Hence, $\frac{\partial E(\pi_F^U)}{\partial\alpha}<0$, and the follower's expected profit increases as α decreases.

With the parameter set, $k=0.461, c_O=1, t=0.362, e=0.01$, in the outcome unknown case the first derivative of the follower's investment level with respect to the probability of success $\frac{\partial f_F^U}{\partial\alpha}=0$ at $\alpha=0.787$. Further, we can check that $f_F^U|_{\alpha=0.7}=0.0296$, $f_F^U|_{\alpha=0.8}=0.0319$, and $f_F^U|_{\alpha=0.9}=0.0243$ in the outcome unknown case. Thus, the follower's investment level can first increase and then decrease as the probability of implementation success decreases.

This concludes the proof. ■

Proof of PROPOSITION E1.3:

a) The difference between the leader's investment level and the follower's investment level in Case 1 is:

$$f_L^U - f_F^U = \frac{9kt^2\alpha^2\begin{pmatrix}(324k^2t^2 - 36(1-e)kt\alpha + (1-e)^2\alpha^2(1-(1-e)\alpha))^2 - \\ (1-e)^2(324k^2t^2 - 18kt\alpha(2-e+\alpha) + (1-e)\alpha^2(1+\alpha-2(1-e)\alpha^2))^2\end{pmatrix}}{(-5832k^3t^3 + 324(3-2e)k^2t^2\alpha + (1-e)^2\alpha^3(1-(1-e)\alpha^2) + 18(-1+e)kt\alpha^2(3-e-2(1-e)\alpha^2))^2}$$

It is easy to see that the dominator of $f_L^U - f_F^U$ is positive. The 1st factor in the numerator of $f_L^U - f_F^U$, i.e., $9kt^2\alpha^2(1-e)^2$, is positive, given $k > \frac{1}{6t}$, $t > 0$, $0 \leq e < 1$, and $0 < \alpha < 1$.

The 2nd factor in the numerator of $f_L^U - f_F^U$, $(324k^2t^2 - 36(1-e)kt\alpha + (1-e)^2\alpha^2(1-(1-e)\alpha))^2 - (1-e)^2(324k^2t^2 - 18kt\alpha(2-e+\alpha) + (1-e)\alpha^2(1+\alpha-2(1-e)\alpha^2))^2$, is a polynomial function of k, e, t, and α, and is positive given $k > \frac{1}{6t}$, $0 \leq e < 1, 0 < \alpha < 1$ and $t > 0$. To show that this expression is positive given $k > \frac{1}{6t}$, $0 \leq e < 1, 0 < \alpha < 1$ and $t > 0$, we apply a similar procedure as the one used repeatedly in the proof of Proposition E1.1 and the proofs of Lemma 1 and Lemma 2 (see Appendix) by consecutively taking higher order derivatives of the expression w.r.t. k and show that the derivatives are positive given $k \geq \frac{1}{6t}$, $0 \leq e < 1, 0 < \alpha < 1$ and $t > 0$. Next, we consecutively take higher order derivatives of the expression w.r.t. e, and show that the derivatives are positive given $k = \frac{1}{6t}$, implying that the expression increases with e given $k = \frac{1}{6t}$, $0 \leq e < 1, 0 < \alpha < 1$ and $t > 0$. Finally, the expression evaluated at $k = \frac{1}{6t}$ and $e = 0$ is $\alpha^2(3 - 2\alpha(1-\alpha))(18 - 12\alpha - \alpha^2 - 2\alpha^4)$ and also positive given $0 < \alpha < 1$. Therefore, this expression, which is the 2nd factor in the numerator of $f_L^U - f_F^U$, is positive given $k > \frac{1}{6t}$, $0 \leq e < 1, 0 < \alpha < 1$ and $t > 0$. The details are omitted to avoid repetition, but available upon request.

Thus, the numerator of $f_L^U - f_F^U$ is positive. Hence, $f_L^U > f_F^U$, and the leader's investment level is higher than the follower's investment level in Case 1.

The difference between the leader's expected profit and the follower's expected profit in Case 1 is:

$$E(\pi_L^U) - E(\pi_F^U) = \frac{\begin{pmatrix}\alpha^2(-2834352(-2+e)ekt^5 - 104976e(15+e(-18+5e))kt^4\alpha - 2916(-1+e)kt^3(e(58+e(-53+11e)) - 36(-1+e)kt)\alpha^2 - 324(-1+e)^2kt^2(e(27+e(-17+2e)) \\ +18(6-5e)kt)\alpha^3 + 36(-1+e)^2kt(2(-3+e)(-1+e)e + 9(-1+e)(-13+7e)kt + 81(5+12(-2+e)e)kt^2)\alpha^4 + 2(-1+e)^3(-(-1+e)e \\ +27(-4+e)(-1+e)kt + 486(3+2e(-5+2e))kt^2)\alpha^5 + (-1+e)^4(4+99e^2kt + 36(5-18kt)kt - 2e(2+207kt))\alpha^6 - 2(-1+e)^5(-2+3e+72kt)\alpha^7 \\ -4(-1+e)^6(1+27kt)\alpha^8 - 4(-1+e)^7\alpha^9)\end{pmatrix}}{(5832kt^3 + 324(-3+2e)kt^2\alpha - (-1+e)^2\alpha^3(1+(-1+e)\alpha^2) + 18kt\alpha^2(3-4e+e^2-2(-1+e)^2\alpha^2))^2}$$

where $kt = k \cdot t$. It is easy to see that the dominator of $E(\pi_L^U) - E(\pi_F^U)$ is positive.

The numerator of $E(\pi_L^U) - E(\pi_F^U)$ is a polynomial function of kt, e, and α, and is positive given $kt > \frac{1}{6}$, $0 \leq e < 1, 0 < \alpha < 1$ and $t > 0$. To show that this expression is positive given $kt > \frac{1}{6}$, $0 \leq e < 1$, and $0 < \alpha < 1$, we apply a similar procedure as the one used repeatedly in the proof of Proposition E1.1 and the proofs of Lemma 1 and Lemma 2 (see Appendix) by consecutively taking higher order derivatives of the expression w.r.t. kt and show that the derivatives are positive given $kt \geq \frac{1}{6}$, $0 \leq e < 1$, and $0 < \alpha < 1$. Next, we consecutively take higher order derivatives of the expression w.r.t. e, and show that the derivatives are positive given $kt = \frac{1}{6}$, implying that the expression increases with e given $kt = \frac{1}{6}$, $0 \le e < 1, 0 < \alpha < 1$ and $t > 0$. Finally, the expression evaluated at $kt = \frac{1}{6}$ and $e = 0$ is $\alpha^4(3 - 2\alpha + 2\alpha^2)^2\,(17.5 - 12\alpha - 5\alpha^2 + 2(1/4 - \alpha^2(1-\alpha)))/2$ and positive given $0 < \alpha < 1$. Therefore, this expression, which is the numerator of $E(\pi_L^U) - E(\pi_F^U)$, is positive given $kt > \frac{1}{6}$, $0 \le e < 1$, and $0 < \alpha < 1$. The details are omitted to avoid repetition, but available upon request.

Hence, $E(\pi_L^U) - E(\pi_F^U) > 0$, and the leader's expected profit is higher than the follower's expected profit in Case 1.

b)

The difference between the leader's investment level in the outcome known case and that in the outcome unknown case is

$$f_L^K - f_L^U = R0\left(\frac{1}{\begin{pmatrix}324(3-2e)k^2t^2\alpha - 5832k^3t^3 + (1-e)^2\alpha^3(1-(1-e)\alpha) - \\ 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)\end{pmatrix}^2} - \frac{1}{\begin{pmatrix}324(3-2e)k^2t^2\alpha - 5832k^3t^3 + (1-e)^2\alpha^3(1-(1-e)\alpha^2) - \\ 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2)\end{pmatrix}^2}\right)$$

where R0=$9kt^2\alpha^2\left(324k^2t^2 - 36(1-e)kt\alpha + (1-e)^2\alpha^2(1-(1-e)\alpha)\right)^2$

$9kt^2\alpha^2$ is positive, given $k > \frac{1}{6t}$, $0 < \alpha < 1$ and $t > 0$, and $\left(324k^2t^2 - 36(1-e)kt\alpha + (1-e)^2\alpha^2(1-(1-e)\alpha)\right)^2$ is positive. Thus, R0 is positive.

We have that $324(3-2e)k^2t^2\alpha - 5832k^3t^3 + (1-e)^2\alpha^3(1-(1-e)\alpha^2) - 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2) - \left(324(3-2e)k^2t^2\alpha - 5832k^3t^3 + (1-e)^2\alpha^3(1-(1-e)\alpha) - 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)\right) = -(1-e)^2(1-\alpha)\alpha^3(36kt-(1-e)\alpha)$, which is negative, given $0 < \alpha < 1$, $0 \le e < 1$ and $k > \frac{1}{6t}$. Thus, $324(3-2e)k^2t^2\alpha - 5832k^3t^3 + (1-e)^2\alpha^3(1-(1-e)\alpha^2) - 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2) < 324(3-2e)k^2t^2\alpha - 5832k^3t^3 + (1-e)^2\alpha^3(1-(1-e)\alpha) - 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)$, given $0 < \alpha < 1$, $0 \le e < 1$ and $kt > \frac{1}{6}$.

In addition, $324(3-2e)k^2t^2\alpha - 5832k^3t^3 + (1-e)^2\alpha^3(1-(1-e)\alpha) - 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha) = -324k^2t^2(18kt-(3-2e)\alpha) - (1-e)\alpha^2(18kt(3-e-2(1-e)\alpha) - (1-e)\alpha(1-(1-e)\alpha)$, which is negative, given $0 < \alpha < 1$, $0 \le e < 1$ and $k > \frac{1}{6t}$. This means that $324(3-2e)k^2t^2\alpha - 5832k^3t^3 + (1-e)^2\alpha^3(1-(1-e)\alpha^2) - 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2) < 324(3-2e)k^2t^2\alpha\ -5832k^3t^3 + (1-e)^2\alpha^3(1-(1-e)\alpha) - 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha) < 0$.

Therefore, if we compare the two terms in the 2nd factor in $f_L^K - f_L^U$, we get

$$\frac{1}{\begin{pmatrix}324(3-2e)k^2t^2\alpha - 5832k^3t^3 + (1-e)^2\alpha^3(1-(1-e)\alpha) - \\ 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)\end{pmatrix}^2} > \frac{1}{\begin{pmatrix}324(3-2e)k^2t^2\alpha - 5832k^3t^3 + (1-e)^2\alpha^3(1-(1-e)\alpha^2) - \\ 18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2)\end{pmatrix}^2}.$$

Thus, the 2nd factor in $f_L^K - f_L^U$ is positive. Hence, $f_L^K - f_L^U > 0$.

The difference between the leader's expected profit in the outcome known case and that in the outcome unknown case is

$$E(\pi_L^K)-E(\pi_L^U)=\frac{\begin{pmatrix}(1-e)^2 t(1-\alpha)\alpha^5(36kt-(1-e)\alpha)\\ \left(324k^2t^2-36(1-e)kt\alpha+(1-e)^2\alpha^2(1-(1-e)\alpha)\right)^2\end{pmatrix}}{\begin{pmatrix}2(18kt+(-1+e)\alpha)^2(5832k^3t^3-324(3-2e)k^2t^2\alpha-\\ (1-e)^2\alpha^3(1-(1-e)\alpha)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha))\\ (5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha^2)+\\ 18kt\alpha^2(3-4e+e^2-2(1-e)^2\alpha^2))\end{pmatrix}}$$

$36kt-(1-e)\alpha$ is positive, given $kt>1/6$, $0<\alpha<1$ and $0\leq e<1$. Moreover, all other terms in the numerator of $E(\pi_L^K)-E(\pi_L^U)$ are positive, given $0<\alpha<1$, $t>0$, and $0\leq e<1$. Thus, the numerator of $E(\pi_L^K)-E(\pi_L^U)$ is positive.

We previously proved that $324(3-2e)k^2t^2\alpha-5832k^3t^3+(1-e)^2\alpha^3(1-(1-e)\alpha^2)-18(1-e)kt\alpha^2(3-e-2(1-e)\alpha^2)<324(3-2e)k^2t^2\alpha-5832k^3t^3+(1-e)^2\alpha^3(1-(1-e)\alpha)-18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)<0$ in the proof for $f_L^K-f_L^U>0$. This means that $5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha)+18(1-e)kt\alpha^2(3-e-2(1-e)\alpha)>0$, and $5832k^3t^3-324(3-2e)k^2t^2\alpha-(1-e)^2\alpha^3(1-(1-e)\alpha^2)+18kt\alpha^2(3-4e+e^2-2(1-e)^2\alpha^2)>0$. Moreover, $2(18kt+(-1+e)\alpha)^2$ is positive. Thus, the denominator of $E(\pi_L^K)-E(\pi_L^U)$ is positive. Hence, $E(\pi_L^K)-E(\pi_L^U)>0$.

c) With the parameter set, $k=0.4902, c_O=1, t=0.34, e=0.01$, the follower's profit $E(\pi_F^U|\alpha=0.985)=0.0075$ and $E(\pi_F^U|\alpha=0.995)=0.0022$ in the outcome unknown case; and the follower's profit $E(\pi_F^K|\alpha=0.985)=0.0073$ and $E(\pi_F^K|\alpha=0.995)=0.0023$ in the outcome known case. Thus, the follower's profit can be higher in Case 1 than in Case 2, or it can be higher in Case 2 than in Case 1.

This concludes the proof. ■

Proofs for Extension 2

Proof of Lemma E2.1: Sequential IT investment with “outcome unknown” Case 1

Firms’ decision problem in the “outcome unknown” case can be formulated as:

$$\max_{c_L^U} E(\pi_L^U) = \max_{c_L^U} \left(\alpha_L \alpha_F \pi_{L,ss}^U + \alpha_L (1-\alpha_F) \pi_{L,sf}^U + (1-\alpha_L) \alpha_F \pi_{L,fs}^U + (1-\alpha_L)(1-\alpha_F) \pi_{L,ff}^U \right) - k(c_O - c_L^U)^2$$

$$\max_{c_F^U} E(\pi_F^U) = \max_{c_F^U} \left(\alpha_L \alpha_F \pi_{F,ss}^U + \alpha_L (1-\alpha_F) \pi_{F,sf}^U + (1-\alpha_L) \alpha_F \pi_{F,fs}^U + (1-\alpha_L)(1-\alpha_F) \pi_{F,ff}^U \right) - k(c_O - c_F^U)^2$$

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

where $\pi_{i,j}^U$ denotes firm i’s payoff given implementation outcome j in this “outcome unknown” Case 1, $i = L, F$ and $j = ss, sf, fs, ff$.

The two firms’ expected profits can be characterized as follows:

$$E(\pi_L^U) = \frac{9t^2 + (c_L^U - c_O)(c_L^U - 6t - c_O)\alpha_L + (c_F^U - c_O)\alpha_F \left(c_F^U + 6t - 2c_L^U\alpha_L + c_O(2\alpha_L - 1)\right)}{18t} - k(c_O - c_L^U)^2$$

$$E(\pi_F^U) = \frac{9t^2 + (c_L^U - c_O)(c_L^U + 6t - c_O)\alpha_L + (c_F^U - c_O)\alpha_F \left(c_F^U - 6t - 2c_L^U\alpha_L + c_O(2\alpha_L - 1)\right)}{18t} - k(c_O - c_F^U)^2$$

By taking the first derivative of the follower’s expected profit w.r.t. the follower’s new marginal cost if his implementation is successful, c_F^U, and solving the first order condition, we get $c_F^U(c_L^U) = \frac{\alpha_F(c_O - c_O c_L^U + c_L^U \alpha_L) + 3(\alpha_F - 6c_O k)t}{\alpha_F - 18kt}$, which is the response function of the follower conditional on the leader’s investment level. We used the D function in Mathematica to obtain derivatives of a function w.r.t. a variable and the SOLVE function in Mathematica to solve the first order condition in this proof and in the subsequent proofs. Then, we substitute the follower’s response function into the leader’s expected profit. By taking the first derivative of the leader’s expected profit w.r.t. the leader’s new marginal cost if his implementation is successful, c_L^U, and solving the first order condition, we get the leader’s new marginal cost if his implementation is successful:

$c_L^U = c_O - \frac{3t\left(324k^2t^2 - \alpha_F(36kt - (1-\alpha_F)\alpha_F)\right)\alpha_L}{(18kt - \alpha_L)(18kt - \alpha_F)^2 - \alpha_F^2(36kt - \alpha_F)\alpha_L^2}$. Then we substitute the leader’s new marginal cost into the follower’s response function and get the follower’s new marginal cost if his implementation is successful $c_F^U = c_O - \frac{3t\alpha_F\left(18kt(18kt - \alpha_L(1+\alpha_L)) - 2(\alpha_F\alpha_L)^2 - \alpha_F(18kt - \alpha_L - \alpha_L^2)\right)}{(18kt - \alpha_L)(18kt - \alpha_F)^2 - \alpha_F^2(36kt - \alpha_F)\alpha_L^2}$.

Next, we check the second order conditions. We take the second order derivative of $E(\pi_L^U)$ with respect to c_L^U, $\frac{\partial^2 E(\pi_L^U)}{\partial {c_L^U}^2} = \frac{(18kt - \alpha_F)^2(18kt - \alpha_L) - {\alpha_F}^2{\alpha_L}^2(36kt - \alpha_F)}{-9t(18kt - \alpha_F)^2}$ and the second order derivative of $E(\pi_F^U)$ with respect to c_F^U, $\frac{\partial^2 E(\pi_F^U)}{\partial {c_F^U}^2} = \frac{18kt - \alpha_F}{-9t}$.

$(18kt - \alpha_F)^2(18kt - \alpha_L) - {\alpha_F}^2{\alpha_L}^2(36kt - \alpha_F) = 324k^2t^2(18kt - (2\alpha_F + \alpha_L)) + 36kt\alpha_F\alpha_L(1 - \alpha_F\alpha_L) + \alpha_F^2(18kt - \alpha_L + \alpha_F\alpha_L^2)$, which is positive, and $-9t(18kt - \alpha_F)^2$ is negative given $kt > 1/6$

and $0 < \alpha_L < \alpha_F < 1$. Thus, $\frac{\partial^2 E(\pi_L^U)}{\partial {c_L^U}^2}$ is negative. In addition, the numerator of $\frac{\partial^2 E(\pi_F^U)}{\partial {c_F^U}^2}$, i.e., $18kt - \alpha_F$, is positive, and the denominator, i.e., $-9t$ is negative, given $kt > 1/6$, $t > 0$ and $0 < \alpha_F < 1$.

Hence, the second order conditions are satisfied, i.e., $\frac{\partial^2 E(\pi_F^U)}{\partial {c_F^U}^2} < 0, \frac{\partial^2 E(\pi_L^U)}{\partial {c_L^U}^2} < 0$.

We substitute the firms' new marginal costs in the event of a successful implementation into the investment functions and get the optimal investment levels of the leader and the follower:

$$f_L^U = k(c_O - c_L^U)^2 = k\left(\frac{3t\left(324k^2t^2 - \alpha_F(36kt - (1-\alpha_F)\alpha_F)\right)\alpha_L}{(18kt-\alpha_L)(18kt-\alpha_F)^2 - \alpha_F^2(36kt-\alpha_F)\alpha_L^2}\right)^2,$$

$$f_F^U = k(c_o - c_F^U)^2 = k\left(\frac{3t\alpha_F\left(18kt(18kt-\alpha_L(1+\alpha_L)) - 2(\alpha_F\alpha_L)^2 - \alpha_F(18kt-\alpha_L-{\alpha_L}^2)\right)}{(18kt-\alpha_L)(18kt-\alpha_F)^2 - \alpha_F^2(36kt-\alpha_F)\alpha_L^2}\right)^2.$$

We discuss how the firms' optimal investment strategies change with model parameters in Proposition E2.1.

This concludes the proof. ■

Proof of Lemma E2.2: Sequential IT investment with "outcome known" Case 2

In the "outcome known" case, the leader's expected profit can be characterized as follows:

$$E(\pi_L^K) = \frac{\alpha_L\alpha_F(c_{F,ss}^K - c_L^K + 3t)^2 + \alpha_L(1-\alpha_F)(c_O - c_L^K + 3t)^2 + (1-\alpha_L)\alpha_F(c_{F,fs}^k - c_O + 3t)^2 + (1-\alpha_L)(1-\alpha_F)(3t)^2}{18t} - k(c_O - c_L^K)^2.$$

And the follower's expected profit depending on the outcome of the leader's implementation can be characterized as follows:

$E(\pi_{F,s}^K) = \frac{\alpha_F(c_L^K - c_{F,ss}^K + 3t)^2 + (1-\alpha_F)(c_L^K - c_O + 3t)^2}{18t} - k(c_O - c_{F,ss}^K)^2$, if the leader's implementation is successful; $E(\pi_{F,f}^K) = \frac{\alpha_F(c_O - c_{F,fs}^K + 3t)^2 + (1-\alpha_F)(3t)^2}{18t} - k(c_O - c_{F,fs}^K)^2$, if the leader's implementation is unsuccessful.

By taking the first derivative of the follower's expected profits, $E(\pi_{F,s}^K)$ and $E(\pi_{F,f}^K)$ w.r.t. the follower's new marginal costs if his implementation is successful, $c_{F,s}^K$ and $c_{F,f}^K$, and solving the first order conditions, we get $c_{F,ss}^K = \frac{c_L^K + 3(\alpha_F - 6c_O k)t}{\alpha_F - 18kt}$ and $c_{F,fs}^K = \frac{c_O\alpha_F + 3(\alpha_F - 6c_O k)t}{\alpha_F - 18kt}$, which are the response functions of the follower conditional on the leader's investment level and implementation outcome.

Then, we substitute the follower's response functions into the leader's expected profit. By taking the first derivative of the leader's expected profit w.r.t. the leader's new marginal cost if his implementation is successful, c_L^K, and solving the first order condition, we get $c_L^K = c_O - \frac{3\alpha_L t(324k^2t^2 - 36kt\alpha_F + (1-\alpha_F){\alpha_F}^2)}{5832k^3t^3 - 324k^2t^2(2\alpha_F + \alpha_L) - (1-\alpha_F){\alpha_F}^2\alpha_L + 18k\alpha_F(\alpha_F + 2\alpha_L - 2\alpha_F\alpha_L)t}$. Next, we substitute the leader's new marginal cost if his implementation is successful into the follower's response functions and get the follower's new marginal costs if his implementation is successful $c_{F,s}^K = c_O - \frac{6t\alpha_L\left(324k^2t^2-\alpha_F(36kt-(1-\alpha_F)\alpha_F)\right)}{18kt(18kt-\alpha_F)^2-(324k^2t^2-(36kt-\alpha_F)(1-\alpha_F)\alpha_F)\alpha_L}$ and $c_{F,f}^K = c_O - \frac{3t\alpha_F}{18kt-\alpha_F}$.

Next, we check the second order conditions. We take the second order derivative of $E(\pi_{F,s}^K)$ w.r.t. $c_{F,s}^K$ and second order derivative of $E(\pi_{F,f}^K)$ w.r.t. $c_{F,f}^K$, $\frac{\partial^2 E(\pi_{F,s}^K)}{\partial {c_{F,s}^K}^2} = \frac{\partial^2 E(\pi_{F,f}^K)}{\partial {c_{F,f}^K}^2} = -\frac{18kt-\alpha_F}{9t}$.

$18kt - \alpha_F > 0$, and $9t > 0$ given $kt > 1/6$, $t > 0$ and $0 < \alpha_F < 1$. Thus, the second order conditions are satisfied, i.e., $\frac{\partial^2 E(\pi_{F,s}^K)}{\partial {c_{F,s}^K}^2} < 0, \frac{\partial^2 E(\pi_{F,f}^K)}{\partial {c_{F,f}^K}^2} < 0$.

We take the second order derivative of $E(\pi_L^K)$ w.r.t. c_L^K,

$$\frac{\partial^2 E(\pi_L^K)}{\partial {c_L^K}^2} = -\frac{(18kt-\alpha_F)^2(18kt-\alpha_L)-\alpha_F{}^2\alpha_L(36kt-\alpha_F)}{9t(18kt-\alpha_F)^2}.$$

We previously proved $(18kt - \alpha_F)^2(18kt - \alpha_L) - \alpha_F{}^2\alpha_L{}^2(36kt - \alpha_F)$ is positive given $kt > 1/6$, $t > 0$ and $0 < \alpha_L < \alpha_F < 1$ (see proof of Lemma E2.1). In addition, $9t$ and $(18kt - \alpha_F)^2$ are positive, given $t > 0$. Thus, the second order condition is satisfied, i.e., $\frac{\partial^2 E(\pi_L^K)}{\partial {c_L^K}^2} < 0$.

We substitute the firms' new marginal costs in the event of a successful implementation into the investment functions and get the optimal investment levels of the leader and the follower:

$$f_L^K = k(c_O - c_L^K)^2 = k\left(\frac{3\alpha_L t(324k^2t^2-36kt\alpha_F+(1-\alpha_F)\alpha_F{}^2)}{5832k^3t^3-324k^2t^2(2\alpha_F+\alpha_L)-(1-\alpha_F)\alpha_F{}^2\alpha_L+18k\alpha_F(\alpha_F+2\alpha_L-2\alpha_F\alpha_L)t}\right)^2,$$

$$f_{F,s}^K = k(c_o - c_{F,s}^K)^2 = k\left(\frac{6t\alpha_L\left(324k^2t^2-\alpha_F(36kt-(1-\alpha_F)\alpha_F)\right)}{18kt(18kt-\alpha_F)^2-(324k^2t^2-(36kt-\alpha_F)(1-\alpha_F)\alpha_F)\alpha_L}\right)^2,$$

$$f_{F,f}^K = k(c_o - c_{F,f}^K)^2 = k\left(\frac{3t\alpha_F}{18kt-\alpha_F}\right)^2.$$

We discuss how the firms' optimal investment strategies change with model parameters in Proposition E2.1.

This concludes the proof. ■

Proof of Proposition E2.1:

We define $\alpha_F = \alpha_L + \alpha_\Delta$.

1) With the following set of parameters, $k = 0.482, c_O = 1, t = 0.346, \alpha_L = 0.7$, the first derivative of the leader's investment level with respect to α_Δ in Case 1 $\frac{\partial f_L^U}{\partial \alpha_\Delta} = 0$ when $\alpha_\Delta = 0.1$. We further check that $f_L^U|_{\alpha_\Delta=0.01} = 0.0524$, $f_L^U|_{\alpha_\Delta=0.1} = 0.0527$, and $f_L^U|_{\alpha_\Delta=0.2} = 0.0522$. Thus, f_L^U can increase first and then decrease as α_Δ increases.

With the following set of parameters, $k = 0.482, c_O = 1, t = 0.346, \alpha_L = 0.5$, the first derivative of the leader's investment level with respect to α_Δ in Case 2, $\frac{\partial f_L^K}{\partial \alpha_\Delta} = 0$ when $\alpha_\Delta = 0.25$. We further check that $f_L^K|_{\alpha_\Delta=0.01} = 0.0218, f_L^K|_{\alpha_\Delta=0.25} = 0.0223$, and $f_L^K|_{\alpha_\Delta=0.5} = 0.0207$. Thus, f_L^K can increase first and then decrease as α_Δ increases.

Given $u = kt$, $\alpha_F = d + \alpha$ and $\alpha_L = \alpha$, the leader's expected profit in Case 1:

$$E(\pi_L^U) = \frac{t(4\alpha^2(d+\alpha)^4 + 324u^2(18u-(1-\alpha)\alpha) - 36u(d+\alpha)(18u-(1-\alpha)\alpha) + (1-36u)(d+\alpha)^2(18u-(1-\alpha)\alpha) - (d+\alpha)^3(54u-\alpha(3+\alpha)))}{648u^2(18u-\alpha) + 2\alpha^2(d+\alpha)^3 - 72u(d+\alpha)(18u-\alpha) - 2(d+\alpha)^2(\alpha - 18u(1-2\alpha^2))}$$

The first derivative of the leader's expected profit with respect to d in Case 1:

$$\frac{\partial E(\pi_L^U)}{\partial d} = \frac{\begin{pmatrix} 2t(d+\alpha)(18(d+\alpha(2+\alpha))u - 324u^2 - \alpha(d+\alpha)(1+\alpha(1-2(d+\alpha)))) \\ (23328u^3 - \alpha(d+\alpha)^2(3-\alpha-2d\alpha-2\alpha^2) - 18(d+\alpha)(8\alpha^3 - 3(4-\alpha)\alpha - d(3-8\alpha^2))u - 324(9d+(13-4\alpha)\alpha)u^2) \end{pmatrix}}{(2\alpha^2(d+\alpha)^3 + 72(d+\alpha)(\alpha-18kt)u - 648(\alpha-18kt)u^2 - 2(d+\alpha)^2(\alpha-18u+36\alpha^2u))^2}$$

where $u = k \cdot t$.

It is easy to see that the denominator of $\frac{\partial E(\pi_L^U)}{\partial d}$ is positive.

The 1st factor in the numerator, i.e., $2t(d+\alpha)$, is positive, given $0 < d+\alpha < 1$ and $t > 0$.

We have $18u(d+\alpha(2+\alpha)) - 324u^2 = -18u(18u - d - \alpha(2+\alpha)) < 0$, and $-\alpha(d+\alpha_L)\left(1+\alpha(1-2(d+\alpha))\right) < 0$, given $0 < \alpha < d+\alpha < 1$ and $u > \frac{1}{6}$. Thus, the 2nd factor in the numerator, i.e., $18u(d+\alpha(2+\alpha)) - 324u^2 - \alpha(d+\alpha_L)(1+\alpha(1-2(d+\alpha)))$, is negative, given $0 < \alpha < d+\alpha < 1$ and $u > \frac{1}{6}$.

The 3rd factor in the numerator of $\frac{\partial E(\pi_L^U)}{\partial d}$, i.e., $23328u^3 - \alpha(d+\alpha)^2(3-\alpha-2d\alpha-2\alpha^2) - 18(d+\alpha)(8\alpha^3 - 3(4-\alpha)\alpha - d(3-8\alpha^2))u - 324(9d+(13-4\alpha)\alpha)u^2$, is a polynomial function of $d, u,$ and α, and is positive given $0 < \alpha < d+\alpha < 1$ and $u > \frac{1}{6}$. To show that this expression is positive given $0 < \alpha < d+\alpha < 1$ and $u > \frac{1}{6}$, we apply a similar procedure as the one used repeatedly in the proof of Proposition E1.1 and the proofs of Lemma 1 and Lemma 2 (see Appendix) by consecutively taking higher order derivatives of the expression w.r.t. u and show that the derivatives are positive, given $0 < \alpha \le d+\alpha < 1$ and $u \ge \frac{1}{6}$. Next, we consecutively take higher order derivatives of the expression w.r.t. d, and show that the derivatives are positive given $u = \frac{1}{6}$, implying that the expression increases with d given $0 < \alpha \le d+\alpha < 1$ and $u = \frac{1}{6}$. Finally, the expression evaluated at $u = \frac{1}{6}$ and $d = 0$ is $(1-\alpha)(78 - 39\alpha + 33\alpha^2 + 21\alpha^3 - 2\alpha^4)$ and positive given $0 < \alpha < 1$. Therefore, this expression, which is the 3rd factor in the numerator of $\frac{\partial E(\pi_L^U)}{\partial d}$, is positive given $0 < \alpha < d+\alpha < 1$ and $u > \frac{1}{6}$. The details are omitted to avoid repetition, but available upon request.

Thus, the numerator of $\frac{\partial E(\pi_L^U)}{\partial d}$ is negative. Hence, $\frac{\partial E(\pi_L^U)}{\partial d}$ is negative, that is the leader's expected profit in Case 1 decreases as d increases.

The leader's expected profit in Case 2 is

$$E(\pi_L^K) = \frac{\alpha(3+\alpha)(d+\alpha)^6 - k_1(d+\alpha)^2 + 9u\,k_2/2 - k_2(d+\alpha) - k_3(d+\alpha)^5 + k_4(d+\alpha)^3 + (d+\alpha)^4 k_5}{2(d-k_6)^2(324u^2k_6 + \alpha(d+\alpha)^3 - 36u(d+\alpha)k_6 - (d+\alpha)^2(36u\alpha - k_6))}$$

where
$k_1 = 1944u^2(18u(6u-1)+\alpha-\alpha^2)$, $k_2 = 23328u^3(18u-\alpha+\alpha^2)$, $k_3 = 2(\alpha+72u\alpha-27u+\alpha^2)$, $k_4 = 72u(9u(63u-2)+\alpha-9u\alpha-(1+9u)\alpha^2)$, $k_5 = (18(1-144u)u + (72u+1296u^2-1)\alpha + (1+72u)\alpha^2)$, $k_6 = 18u-\alpha$, and $u = kt$.

The first derivative of the leaders' expected profit with respect to d in Case 2 is:

$$\frac{\partial E(\pi_L^K)}{\partial d} = \frac{t\begin{pmatrix}(d-k_6)(-k_2-2k_1(d+\alpha)+3k_4(d+\alpha)^2+4k_5(d+\alpha)^3-5k_3(d+\alpha)^4+6\alpha(3+\alpha)(d+\alpha)^5)(324k_6u^2-36k_6u(d+\alpha)+\alpha(d+\alpha)^3+(d+\alpha)^2(k_6-36u\alpha)) \\ -(d-k_6)\left(\frac{9k_2u}{2}-k_2(d+\alpha)-k_1(d+\alpha)^2+k_4(d+\alpha)^3+k_5(d+\alpha)^4-k_3(d+\alpha)^5+\alpha(3+\alpha)(d+\alpha)^6\right)\left(-36k_6u+3\alpha(d+\alpha)^2+2(d+\alpha)(k_6-36u\alpha)\right)- \\ (9k_2u-2k_2(d+\alpha)-k_1(d+\alpha)^2+k_4(d+\alpha)^3+k_5(d+\alpha)^4-k_3(d+\alpha)^5+\alpha(3+\alpha)(d+\alpha)^6)(324k_6u^2-36k_6u(d+\alpha)+\alpha(d+\alpha)^3+(d+\alpha)^2(k_6-36u\alpha))\end{pmatrix}}{2(d-k_6)^3(324k_6u^2-36k_6u(d+\alpha)+\alpha(d+\alpha)^3+(d+\alpha)^2(k_6-36u\alpha))^2}$$

The 1st factor in the denominator of $\frac{\partial E(\pi_L^K)}{\partial d}$, i.e., $2(d-k_6)^3 = -2(18kt-d-\alpha)^3$, is negative, given $kt > \frac{1}{6}, 0 < \alpha + d < 1$. Moreover, the 2nd factor in the denominator is positive. Thus, the denominator of $\frac{\partial E(\pi_L^K)}{\partial d}$ is negative.

The numerator of $\frac{\partial E(\pi_L^K)}{\partial d}$ is a polynomial function of $d, u,$ and α, and is positive given $0 < \alpha < d + \alpha < 1$ and $u > \frac{1}{6}$. To show that this expression is positive given $0 < \alpha < d + \alpha < 1$ and $u > \frac{1}{6}$, we apply a similar procedure as the one used repeatedly in the proof of Proposition E1.1 and the proofs of Lemma 1 and Lemma 2 (see Appendix) by consecutively taking higher order derivatives of the expression w.r.t. u and show that the derivatives are positive given $0 < \alpha \le d + \alpha < 1$ and $u \ge \frac{1}{6}$. Next, we consecutively take higher order derivatives of the expression w.r.t. d, and show that the derivatives are positive given $u = \frac{1}{6}$, implying that the expression increases with d given $0 < \alpha \le d + \alpha < 1$ and $u = \frac{1}{6}$. Finally, the expression evaluated at $u = \frac{1}{6}$ and $d = 0$ is $(1-\alpha)\alpha(2748 + (1-\alpha)(23496 - 22431\alpha + 16935\alpha^2 - 10524\alpha^3 + 4299\alpha^4 - 1128\alpha^5 + 312\alpha^6 + 15\alpha^7 - 18\alpha^8 + \alpha^9))$ and also positive given $0 < \alpha < 1$. Thus, this expression, which is the numerator of $\frac{\partial E(\pi_L^K)}{\partial d}$, is positive given $0 < \alpha < d + \alpha < 1$ and $u > \frac{1}{6}$. The details are omitted to avoid repetition, but available upon request.

Hence, $\frac{\partial E(\pi_L^K)}{\partial d} < 0$, and the leader's expected profit in Case 2 decreases as d increases.

2) With the following set of parameters, $k = 0.482, c_O = 1, t = 0.346, \alpha_L = 0.91$, the first derivative of the follower's investment level with respect to α_Δ in Case 1 $\frac{df_F^U}{d\alpha_\Delta} = 0$ at $\alpha_\Delta = 0.06$. We further check that $f_F^U|_{\alpha_\Delta=0.01} = 0.0219$, $f_F^U|_{\alpha_\Delta=0.06} = 0.0224$, and $f_F^U|_{\alpha_\Delta=0.08} = 0.0222$. Thus, f_F^U can increase first and then decrease as α_Δ increases.

With the following set of parameters, $k = 0.482, c_O = 1, t = 0.346, \alpha_L = 0.86$, The first derivative of the follower's expected profit with respect to α_Δ in Case 1: $\frac{\partial E(\pi_F^U)}{\partial \alpha_\Delta} = 0$ at $\alpha_\Delta = 0.025$. We further check that $E(\pi_F^U|_{\alpha_\triangle=0}) = 0.08406$, $E(\pi_F^U|_{\alpha_\triangle=0.025}) = 0.0841$, and $E(\pi_F^U|_{\alpha_\triangle=0.14}) = 0.0827$. Thus, $E(\pi_F^U)$ can increase first and then decrease as α_Δ increases.

We take the first derivative of the follower's expected profit if leader's implementation failed in Case 2, w.r.t. α_Δ is:

$$\frac{\partial E(\pi_{F,f}^K)}{\partial \alpha_\triangle} = \frac{(\alpha_\Delta+\alpha_L)(36kt-\alpha_\Delta-\alpha_L)}{2(18kt-\alpha_\Delta-\alpha_L)^2}.$$

$36kt - \alpha_\Delta - \alpha_L$ and $\alpha_\Delta + \alpha_L$ are positive, given $kt > \frac{1}{6}$ and $0 < \alpha_L < \alpha_L + \alpha_\Delta < 1$. Moreover, $(18kt - \alpha_\Delta - \alpha_L)^2$ is positive. Thus, $\frac{\partial E(\pi_{F,f}^K)}{\partial \alpha_\triangle} > 0$.

We take the first derivative of the follower's IT investment level if the leader's implementation failed in Case 2, with respect to α_Δ is:

$$\frac{\partial f_{F,f}^K}{\partial \alpha_\triangle} = \frac{324(\alpha_\Delta+\alpha_L)k^2t^2}{(18kt-\alpha_\Delta-\alpha_L)^3}.$$

$18kt - \alpha_\Delta - \alpha_L$ is positive, given $kt > \frac{1}{6}$ and $0 < \alpha_L + \alpha_\Delta < 1$. Moreover, $(\alpha_\Delta + \alpha_L)k^2t^2$ is positive given $0 < \alpha_L + \alpha_\Delta < 1$. Thus, $\frac{\partial f_{F,f}^K}{\partial \alpha_\triangle} > 0$.

With the following set of parameters, $k = 0.482, c_O = 1, t = 0.346, \alpha_L = 0.86$, the first derivative of the follower's investment level with respect to α_Δ when the leader's implementation succeeded in Case 2, $\frac{\partial f_{F,s}^K}{\partial \alpha_\triangle} = 0$ at $\alpha_\Delta = 0.092$. We further check that $f_{F,s}^K|_{\alpha_\triangle=0} = 0.0194$,$f_{F,s}^K|_{\alpha_\triangle=0.1} = 0.0210$, and $f_{F,s}^K|_{\alpha_\triangle=0.2} = 0.0166$. Thus, $f_{F,s}^K$ can increase first and then decrease as α_Δ increases.

With the following set of parameters, $k = 0.482, c_O = 1, t = 0.346, \alpha_L = 0.75$, the first derivative of the follower's profit with respect to α_Δ when the leader's implementation succeeded in Case 2, $\frac{\partial E(\pi_{F,s}^K)}{\partial \alpha_\triangle} = 0$ at $\alpha_\Delta = 0.192$. We further check that $E(\pi_{F,s}^K|_{\alpha_\triangle=0.1}) = 0.0847$,$E(\pi_{F,s}^K|_{\alpha_\triangle=0.2}) = 0.0853$, and $E(\pi_{F,s}^K|_{\alpha_\triangle=0.25}) = 0.0849$. Thus, $E(\pi_{F,s}^K)$ can increase first and then decrease as α_Δ increases.

3) With the following set of parameters, $k = 0.482, c_O = 1, t = 0.346, \alpha_L = 0.7$, $E(\pi_F^U|\alpha_F = 0.73) = 0.132742$, $E(\pi_L^U|\alpha_F = 0.73) = 0.140492$, $E(\pi_F^U|\alpha_F = 0.75) = 0.134283$, $E(\pi_L^U|\alpha_F = 0.75) = 0.136303$. Thus, when $\alpha_F = 0.73$ and $\alpha_F = 0.75$, $E(\pi_L^U) > E(\pi_F^U)$.

With the same set of parameters, $E(\pi_F^K|\alpha_F = 0.73) = 0.129797$, $E(\pi_L^K|\alpha_F = 0.73) = 0.142612$, $E(\pi_F^K|\alpha_F = 0.75) = 0.131022$, $E(\pi_L^K|\alpha_F = 0.75) = 0.138586$. Thus, when $\alpha_F = 0.73$ and $\alpha_F = 0.75$, $E(\pi_L^K) > E(\pi_F^K)$.

This concludes the proof. ■

Proof of Proposition E2.2:

a) We first substitute $\alpha_L = \alpha$ and $\alpha_F = \alpha + \alpha_\Delta$. Then we get the first derivative of the leader's new marginal cost in the event of a successful implementation in Case 1 with respect to α is:

$$\frac{\partial c_L^U}{\partial \alpha} = \frac{\begin{pmatrix} 3t(\alpha\left(36kt + 2\left(-1+\alpha_\Delta+\alpha\right)\left(\alpha_\Delta+\alpha\right)+\left(\alpha_\Delta+\alpha\right)^2\right) \\ \left(5832k^3t^3 - 324k^2t^2\left(2\alpha_\Delta+3\alpha\right)+\alpha\left(\alpha_\Delta+\alpha\right)^2\left(-1+\alpha\left(\alpha_\Delta+\alpha\right)\right)+18kt\left(\alpha_\Delta+\alpha\right)\left(\alpha_\Delta+3\alpha-2\alpha^2\left(\alpha_\Delta+\alpha\right)\right)\right)+ \\ \left(-324k^2t^2+36kt\left(\alpha_\Delta+\alpha\right)+\left(-1+\alpha_\Delta+\alpha\right)\left(\alpha_\Delta+\alpha\right)^2\right) \\ \left(5832k^3t^3 - 324k^2t^2\left(2\alpha_\Delta+3\alpha\right)+\alpha\left(\alpha_\Delta+\alpha\right)^2\left(-1+\alpha\left(\alpha_\Delta+\alpha\right)\right)+18kt\left(\alpha_\Delta+\alpha\right)\left(\alpha_\Delta+3\alpha-2\alpha^2\left(\alpha_\Delta+\alpha\right)\right)\right)- \\ \alpha\left(-324k^2t^2+36kt\left(\alpha_\Delta+\alpha\right)+\left(-1+\alpha_\Delta+\alpha\right)\left(\alpha_\Delta+\alpha\right)^2\right)(-972k^2t^2+2\alpha_\Delta^3\alpha+108kt\alpha-3\alpha^2- \\ 144kt\alpha^3+5\alpha^4+4\alpha_\Delta\left(-18kt+\alpha\right)\left(-1+3\alpha^2\right)+d^2\left(-1+9\alpha\left(-8kt+\alpha\right)\right))) \end{pmatrix}}{\left(5832k^3t^3 - 324k^2t^2\left(2\alpha_\Delta+3\alpha\right)+\alpha\left(\alpha_\Delta+\alpha\right)^2\left(-1+\alpha\left(\alpha_\Delta+\alpha\right)\right)+18kt\left(\alpha_\Delta+\alpha\right)\left(\alpha_\Delta+3\alpha-2\alpha^2\left(\alpha_\Delta+\alpha\right)\right)\right)^2}$$

The denominator of $\frac{\partial c_L^U}{\partial \alpha}$ is positive.

The numerator of $\frac{\partial c_L^U}{\partial \alpha}$ is a polynomial function of $\alpha, \alpha_\Delta, t,$ and k, and is negative given $0 < \alpha < \alpha + \alpha_\Delta < 1$, $t > 0$ and $k > \frac{1}{6t}$. To show that this expression is negative given $0 < \alpha < \alpha + \alpha_\Delta < 1$, $t > 0$ and $k > \frac{1}{6t}$, we apply a similar procedure as the one used repeatedly in the proof of Proposition E1.1 and the proofs of Lemma 1 and Lemma 2 (see Appendix) by consecutively taking higher order derivatives of the expression w.r.t. k and show that the derivatives are negative given $0 < \alpha \le \alpha + \alpha_\Delta < 1$, $t > 0$ and $k \ge \frac{1}{6t}$. Next, we consecutively take higher order derivatives of the expression w.r.t. α_Δ, and show that the derivatives are negative given $k = \frac{1}{6t}$, implying that the expression decreases with α_Δ given $0 < \alpha \le \alpha + \alpha_\Delta < 1$ and $k = \frac{1}{6t}$. Finally, the expression evaluated at $k = \frac{1}{6t}$ and $\alpha_\Delta = 0$ is $-3t(((1/4 - \alpha(1-\alpha))(66 + 78(1-\alpha))\alpha^2 + (324 - (66 + 78(1-\alpha))\alpha^2)/4 + (162 + 24\alpha^4 + \alpha^6)(1-\alpha)^2))$ and also negative given $t > 0$ and $0 < \alpha < 1$. Therefore, this expression, which is the numerator of $\frac{\partial c_L^U}{\partial \alpha}$, is negative given $0 < \alpha < \alpha + \alpha_\Delta < 1$, $t > 0$ and $k > \frac{1}{6t}$. The details are omitted to avoid repetition, but available upon request.

Hence, $\frac{\partial c_L^U}{\partial \alpha} < 0$.

$$c_O - c_L^U = \frac{3\alpha_L t(36kt(9kt-\alpha_F)+(1-\alpha_F)\alpha_F^2)}{324k^2t^2(18kt-(2\alpha_F+\alpha_L))+\alpha_F(18kt(2\alpha_L(1-\alpha_F\alpha_L))+\alpha_F(18kt-\alpha_L)+\alpha_F^2\alpha_L^2)}.$$

We have that $36kt(9kt - \alpha_F) + (1-\alpha_F)\alpha_F^2$ is positive and $3\alpha_L t$ is positive given $0 < \alpha_L < \alpha_F < 1$, $t > 0$ and $k > \frac{1}{6t}$. Thus, the numerator of $c_O - c_L^U$ is positive.

In addition, we have $324k^2t^2(18kt-(2\alpha_F+\alpha_L))$ is positive and $\alpha_F(18kt(2\alpha_L(1-\alpha_F\alpha_L))+\alpha_F(18kt-\alpha_L)+{\alpha_F}^2{\alpha_L}^2)$ is positive given $0<\alpha_L<\alpha_F<1$ and $k>\frac{1}{6t}$. Thus, the denominator of $c_O-c_L^U$ is positive. Hence, $c_O-c_L^U$ is positive.

Given $f_L^U=k(c_O-c_L^U)^2$, $\frac{\partial f_L^U}{\partial\alpha}=-2k(c_O-c_L^U)\frac{\partial c_L^U}{\partial\alpha}$. Moreover, given $c_O-c_L^U>0$ and $\frac{\partial c_L^U}{\partial\alpha}<0$, $\frac{\partial f_L^U}{\partial\alpha}>0$.

With the following set of parameters, $k=0.482, c_O=1, t=0.346, \alpha_\Delta=0.1$, $\frac{\partial E(\pi_L^U)}{\partial\alpha}=0$ at $\alpha=0.8614$. We further check that $E(\pi_L^U)|_{\alpha=0.7}=0.1252$, $E(\pi_L^U)|_{\alpha=0.86}=0.1138$ and $E(\pi_L^U)|_{\alpha=0.9}=0.1157$. This means $E(\pi_L^U)$ can first decrease and then increase as α increases.

b) With the following set of parameters, $k=0.482, c_O=1, t=0.346, \alpha_\Delta=0.1$, $\frac{\partial f_F^U}{\partial\alpha}=0$ at $\alpha=0.7635$. We further check that $f_F^U|_{\alpha=0.6}=0.0346$, $f_F^U|_{\alpha=0.76}=0.04314$ and $f_F^U|_{\alpha=0.9}=0.02538$. Thus, the follower's investment f_F^U can first increase and then decrease when α increases.

With the following set of parameters, $k=0.482, c_O=1, t=0.346, \alpha_\Delta=0.1$, $\frac{\partial E(\pi_F^U)}{\partial\alpha}=0$ at $\alpha=0.1131$. We further check that $E(\pi_F^U)|_{\alpha=0.01}=0.1737$, $E(\pi_F^U)|_{\alpha=0.11}=0.1743$ and $E(\pi_F^U)|_{\alpha=0.2}=0.1738$. Thus, the follower's expected profit $E(\pi_F^U)$ can first increase and then decrease when α increases.

This concludes the proof. ■

Proof of Proposition E2.3:

a) The leader's new marginal cost in the event of a successful implementation in the simultaneous investment game is

$$c_L^S=c_O-\frac{3\alpha_L t(18kt-\alpha_F-{\alpha_F}^2)}{(18kt-\alpha_F)(18kt-\alpha_L)-{\alpha_F}^2{\alpha_L}^2}.$$

$18kt-\alpha_F-{\alpha_F}^2$ is positive and $3\alpha_L t$ is positive given $0<\alpha_L<\alpha_F<1$, $t>0$ and $kt>\frac{1}{6}$.

In addition, $(18kt-\alpha_F)(18kt-\alpha_L)>4$ and ${\alpha_F}^2{\alpha_L}^2<1$, given $0<\alpha_L<\alpha_F<1$ and $kt>\frac{1}{6}$. Thus, $(18kt-\alpha_F)(18kt-\alpha_L)-{\alpha_F}^2{\alpha_L}^2>0$.

Thus, $\frac{3\alpha_L t(18kt-\alpha_F-{\alpha_F}^2)}{(18kt-\alpha_F)(18kt-\alpha_L)-{\alpha_F}^2{\alpha_L}^2}$ is positive given $0<\alpha_L<\alpha_F<1$, $t>0$ and $kt>\frac{1}{6}$. Hence, $c_L^S<c_O$

$$c_L^S-c_L^U=\frac{6t\alpha_L(18kt-\alpha_F)\alpha_F^2((9kt-\alpha_F)(18kt-\alpha_L)+\alpha_L^2(9kt-\alpha_F^2))}{((18kt-\alpha_L)(18kt-\alpha_F)^2-\alpha_F^2\alpha_L^2(36kt-\alpha_F))((18kt-\alpha_F)(18kt-\alpha_L)-\alpha_F^2\alpha_L^2)}$$

$6t\alpha_L(18kt-\alpha_F)\alpha_F^2$ is positive and $(9kt-\alpha_F)(18kt-\alpha_L)+\alpha_L^2(9kt-\alpha_F^2)$ is positive given $0<\alpha_L<\alpha_F<1$, $t>0$ and $kt>\frac{1}{6}$. Thus, the numerator of $c_L^S-c_L^U$ is positive.

In addition, $(18kt-\alpha_L)(18kt-\alpha_F)^2-\alpha_F^2\alpha_L^2(36kt-\alpha_F)=324k^2t^2(18kt-(2\alpha_F+\alpha_L))+\alpha_F^2(18kt-\alpha_L)+36kt\alpha_F\alpha_L(1-\alpha_F\alpha_L)+\alpha_F^3\alpha_L^2$, which is positive, given $0<\alpha_L<\alpha_F<1$, $t>0$ and $kt>\frac{1}{6}$. Moreover, we previously proved that $(18kt-\alpha_F)(18kt-\alpha_L)-\alpha_F^2\alpha_L^2$ is positive, given $0<\alpha_L<\alpha_F<1$, $t>0$ and $kt>\frac{1}{6}$. Thus, the denominator of $c_L^S-c_L^U$ is positive.

Hence, $c_L^S-c_L^U>0$.

Since, $f_L^U=k(c_O-c_L^U)^2$ and $f_L^S=k(c_O-c_L^S)^2$, we have $f_L^U-f_L^S=k(2c_O-c_L^U-c_L^S)(c_L^S-c_L^U)$. We have proved that $c_L^S<c_O$, $c_L^U<c_O$, and $c_L^S-c_L^U>0$. Hence, $f_L^U>f_L^S$.

The leader's expected profit in the simultaneous investment game is

$$E(\pi_L^S)=\frac{t\begin{pmatrix}\alpha_F^3(972k^2t^2-108kt\alpha_L+3\alpha_L^2+\alpha_L^4)-36kt\alpha_F(324k^2t^2-36kt\alpha_L+(1+18kt)\alpha_L^2-\alpha_L^3)+\\(-1+36kt)\alpha_F^2(-324k^2t^2+36kt\alpha_L-(1+18kt)\alpha_L^2+\alpha_L^3)+\\324k^2t^2(324k^2t^2-36kt\alpha_L+(1+18kt)\alpha_L^2-\alpha_L^3)-\alpha_F^4\alpha_L^2(-54kt+3\alpha_L+\alpha_L^2)\end{pmatrix}}{2\left(\alpha_F^2\alpha_L^2+18kt(-18kt+\alpha_L)-\alpha_F(-18kt+\alpha_L)\right)^2}$$

$$E(\pi_L^S)-E(\pi_L^U)=\frac{-2t\alpha_F^4\alpha_L^2(9kt(2\alpha_F+\alpha_L-\alpha_L^2)-\alpha_F\alpha_L(1-\alpha_F\alpha_L)-162k^2t^2)^2}{\begin{pmatrix}(18kt(\alpha_F+\alpha_L)-\alpha_F\alpha_L(1-\alpha_F\alpha_L)-324k^2t^2)^2\\\left(324k^2t^2\left(18kt-(2\alpha_F+\alpha_L)\right)+18kt\alpha_F\alpha_F+\alpha_F\alpha_L(1-\alpha_F\alpha_L)(36kt-\alpha_F)\right)\end{pmatrix}}$$

We have that the 1st factor in the numerator of $E(\pi_L^S)-E(\pi_L^U)$, i.e., $-2t\alpha_F^4\alpha_L^2$, is negative, given $t>0$ and $0<\alpha_L<\alpha_F<1$. Moreover, the 2nd factor in the numerator is positive. Thus, the numerator of $E(\pi_L^S)-E(\pi_L^U)$ is negative.

The 2nd factor in the denominator, i.e., $324k^2t^2\left(18kt-(2\alpha_F+\alpha_L)\right)+18kt\alpha_F\alpha_F+\alpha_F\alpha_L(1-\alpha_F\alpha_L)(36kt-\alpha_F)$, is positive given $0<\alpha_L<\alpha_F<1$, $t>0$ and $kt>\frac{1}{6}$. Moreover, the 1st factor in the denominator is positive. Thus, the denominator of $E(\pi_L^S)-E(\pi_L^U)$ is positive. Hence, $E(\pi_L^S)-E(\pi_L^U)<0$.

The follower's new marginal cost in the event of a successful implementation in the simultaneous investment game is

$$c_F^S=c_O-\frac{3t\alpha_F\left(18kt-\alpha_L-\alpha_L^2\right)}{18kt(18kt-\alpha_F)-\alpha_F^2\alpha_L^2-\alpha_L(18kt-\alpha_F)}.$$

We previously proved that $c_L^S<c_O$. Given $c_L^S=c_F^S$, we have, $c_F^S<c_O$.

$$c_F^S-c_F^U=\frac{-6t\alpha_F^3\alpha_L^2((9kt-\alpha_F)(18kt-\alpha_L)+\alpha_L^2(9kt-\alpha_F^2))}{\begin{pmatrix}18kt\left(18kt-(\alpha_F+\alpha_L)\right)+\alpha_F\alpha_L(1-\alpha_F\alpha_L)\\((18kt-\alpha_L)(18kt-\alpha_F)^2-\alpha_F^2\alpha_L^2(36kt-\alpha_F))\end{pmatrix}}$$

The 1st factor in the numerator of $c_F^S - c_F^U$, i.e., $-6t\alpha_F^3\alpha_L^2$, is negative, given $0 < \alpha_L < \alpha_F < 1$, and $t > 0$. In addition, $(9kt - \alpha_F)(18kt - \alpha_L) + \alpha_L^2(9kt - \alpha_F^2)$ is positive given $0 < \alpha_L < \alpha_F < 1$, $t > 0$ and $kt > \frac{1}{6}$. Thus, the numerator of $c_F^S - c_F^U$ is negative.

Moreover, we previously proved $(18kt - \alpha_L)(18kt - \alpha_F)^2 - \alpha_F^2\alpha_L^2(36kt - \alpha_F)$ is positive, given $0 < \alpha_L < \alpha_F < 1$, $t > 0$ and $kt > \frac{1}{6}$. Moreover, $18kt\big(18kt - (\alpha_F + \alpha_L)\big) + \alpha_F\alpha_L(1 - \alpha_F\alpha_L)\big)$ is positive, given $0 < \alpha_L < \alpha_F < 1$, $t > 0$ and $kt > \frac{1}{6}$. Thus, the denominator of $c_F^S - c_F^U$ is positive. Therefore, $c_F^S - c_F^U < 0$.

$$c_O - c_F^U = \frac{3\alpha_F t(18kt(18kt - (\alpha_F + \alpha_L + \alpha_L{}^2)) + \alpha_F\alpha_L(1 + \alpha_L(1 - 2\alpha_F)))}{324k^2t^2(18kt - (2\alpha_F + \alpha_L)) + \alpha_F(18kt(2\alpha_L(1 - \alpha_F\alpha_L)) + \alpha_F(18kt - \alpha_L) + \alpha_F{}^2\alpha_L{}^2)}$$

We have that $324k^2t^2(18kt - (2\alpha_F + \alpha_L)) + \alpha_F(18kt(2\alpha_L(1 - \alpha_F\alpha_L)) + \alpha_F(18kt - \alpha_L) + \alpha_F{}^2\alpha_L{}^2)$ is positive, given $0 < \alpha_L < \alpha_F < 1$, $t > 0$ and $kt > \frac{1}{6}$. Thus, the denominator of $c_O - c_F^U$ is positive.

In addition, $3\alpha_F t$, $18kt(18kt - (\alpha_F + \alpha_L + \alpha_L{}^2))$ and $\alpha_F\alpha_L(1 + \alpha_L(1 - 2\alpha_F))$ are all positive, given $0 < \alpha_L < \alpha_F < 1$, $t > 0$ and $kt > \frac{1}{6}$. Thus, the numerator of $c_O - c_F^U$ is positive. Hence, $c_O - c_F^U > 0$.

Given $f_F^U = k(c_O - c_F^U)^2$ and $f_F^S = k(c_O - c_F^S)^2$, we have $f_F^U - f_F^S = k(2c_O - c_F^U - c_F^S)(c_F^S - c_F^U)$.

Given that $c_O - c_F^U > 0$, $c_F^S - c_F^U < 0$ and $c_O - c_F^S > 0$, we have $f_F^U < f_F^S$.

The follower's expected profit in the simultaneous investment game is

$$E(\pi_F^S) = \frac{\begin{pmatrix} 324k^2t^2\left(324k^2t^2 - 36kt\alpha_L + (1-36kt)\alpha_L^2 + 3\alpha_L^3\right) - 36kt\alpha_F\left(324k^2t^2 - 36kt\alpha_L + (1-36kt)\alpha_L^2 + 3\alpha_L^3\right) \\ -\alpha_F^3\left(324k^2t^2 - 36kt\alpha_L + (1-36kt)\alpha_L^2 + 3\alpha_L^4\right) - \alpha_F^4(-1+\alpha_L)\alpha_L^3 + \\ \alpha_F^2\left(324k^2t^2(1+18kt) - 36kt(1+18kt)\alpha_L + \left(1-18kt-648k^2t^2\right)\alpha_L^2 + 3\alpha_L^3 + 54kt\alpha_L^4\right) \end{pmatrix}}{2\left(\alpha_F^2\alpha_L^2 + 18kt(-18kt+\alpha_L) - \alpha_F(-18kt+\alpha_L)\right)^2}$$

$$E(\pi_F^S) - E(\pi_F^U) = \frac{\begin{pmatrix} 2t\alpha_F^2(18kt-\alpha_F)\alpha_L^2\left(162k^2t^2 + \alpha_F\alpha_L(1-\alpha_F\alpha_L) - 9kt\left(2\alpha_F + \alpha_L - \alpha_L^2\right)\right) \\ (1889568k^5t^5 - 104976k^4t^4\left(\left((3-\alpha_F)\alpha_F + 3\alpha_L\right) - (2-\alpha_F)\alpha_F^3\alpha_L^2(1-\alpha_F\alpha_L)^2 - \right. \\ 162k^2t^2\alpha_F\left(12\alpha_L^2 - \alpha_F^3\left(2-5\alpha_L^2\right) + \alpha_F\alpha_L\left(18-\alpha_L-11\alpha_L^2\right) + \alpha_F^2\left(2-7\alpha_L(1+2\alpha_L)\right)\right) + \\ 9kt\alpha_F^2\alpha_L(1-\alpha_F\alpha_L)\left(12\alpha_L + \alpha_F\left(6-4\alpha_F-\alpha_L(3+7\alpha_L)\right)\right) - \\ \left. 2916k^3t^3\left(4\alpha_F^3 - 18\alpha_F\alpha_L - 4\alpha_L^2 - \alpha_F^2\left(6-\alpha_L(3+8\alpha_L)\right)\right)\right) \end{pmatrix}}{\begin{pmatrix} \left(-324k^2t^2 + 18kt(\alpha_F+\alpha_L) + \alpha_F\alpha_L(-1+\alpha_F\alpha_L)\right)^2 \\ \left(5832k^3t^3 - 324k^2t^2(2\alpha_F+\alpha_L) + \alpha_F^2\alpha_L(-1+\alpha_F\alpha_L) + 18kt\alpha_F\left(\alpha_F + 2\alpha_L - 2\alpha_F\alpha_L^2\right)\right)^2 \end{pmatrix}}$$

The two factors in the denominator of $E(\pi_F^S) - E(\pi_F^U)$ are positive. Thus, the denominator is positive.

The 1st factor in the numerator, i.e., $2t\alpha_F^2(18kt-\alpha_F)\alpha_L^2$, is positive, and the 2nd factor, $162k^2t^2+\alpha_F\alpha_L(1-\alpha_F\alpha_L)-9kt(2\alpha_F+\alpha_L-\alpha_L^2)=9kt\big(18kt-(2\alpha_F+\alpha_L(1-\alpha_L))\big)+\alpha_F\alpha_L(1-\alpha_F\alpha_L)$, which is positive, given $kt>1/6$, $t>0$, and $0<\alpha_L<\alpha_F<1$.

In addition, we use $\alpha_L=\alpha$ and $\alpha_F=\alpha+d$, and rewrite the 3rd factor of the numerator of $E(\pi_F^S)-E(\pi_F^U)$ as $1889568k^5t^5-104976k^4t^4\big((3-d)d+2(3-d)\alpha-\alpha^2\big)-\alpha^2(2-d-\alpha)(d+\alpha)^3\big(1-\alpha(d+\alpha)\big)^2+9kt\alpha(d+\alpha)^2\big(1-\alpha(d+\alpha)\big)\big(12\alpha-(d+\alpha)(4d+7\alpha(1+\alpha)-6)\big)-162k^2t^2(d+\alpha)\Big(12\alpha^2+(d+\alpha)^3(5\alpha^2-2)+\alpha(d+\alpha)(18-\alpha-11\alpha^2)+(d+\alpha)^2\big(2-7\alpha(1+2\alpha)\big)\Big)+2916k^3t^3(4\alpha^2+18\alpha(d+\alpha)-4(d+\alpha)^3+(d+\alpha)^2(6-\alpha(3+8\alpha)))$. This expression, which is a polynomial function of k,t,α and d, is positive given $k>\frac{1}{6t}$, $t>0$, and $0<\alpha<\alpha+d<1$. To show that this expression is positive given $k>\frac{1}{6t}$, $t>0$, and $0<\alpha<\alpha+d<1$, we apply a similar procedure as the one used repeatedly in the proof of Proposition E1.1 and the proofs of Lemma 1 and Lemma 2 (see Appendix) by consecutively taking higher order derivatives of the expression w.r.t. k and show that the derivatives are positive given $k\geq\frac{1}{6t}$, $t>0$, and $0<\alpha\leq\alpha+d<1$. Next, we consecutively take higher order derivatives of the expression w.r.t. d, and show that the derivatives are positive given $k=\frac{1}{6t}$, implying that the expression increases with d given $0<\alpha\leq\alpha+d<1$ and $k=\frac{1}{6t}$. Finally, the expression evaluated at $k=\frac{1}{6t}$ and $d=0$ is $\frac{1}{2}(3-2(1-\alpha)\alpha)(3-\alpha-\alpha^2)(3+(1-\alpha)(51-3\alpha+15\alpha^2+10\alpha^3-\alpha^4+\alpha^5))$ and positive given $0<\alpha<1$. Therefore, this expression, which is the 3rd factor of the numerator of $E(\pi_F^S)-E(\pi_F^U)$, is positive given $kt>1/6$, $t>0$, and $0<\alpha_L<\alpha_F<1$. The details are omitted to avoid repetition, but available upon request.

Thus, the numerator of $E(\pi_F^S)-E(\pi_F^U)$ is positive. Hence, $E(\pi_F^S)-E(\pi_F^U)>0$.

b) The difference between the leader's new marginal cost if implementation is successful in Case 1 and Case 2:

$$c_L^U-c_L^K=\frac{3t\alpha_F^2(1-\alpha_L)\alpha_L^2(36kt-\alpha_F)(36kt(9kt-\alpha_F)+(1-\alpha_F)\alpha_F^2)}{\begin{pmatrix}(324k^2t^2(18kt-2\alpha_F-\alpha_L)+\alpha_F(\alpha_F^2\alpha_L^2+36kt(1-\alpha_F)\alpha_L+\alpha_F(18kt-(1-\alpha_F)\alpha_L-\alpha_F\alpha_L^2)))\\(324k^2t^2(18kt-(2\alpha_F+\alpha_L))+\alpha_F(18kt\,(2\alpha_L(1-\alpha_F\alpha_L))+\alpha_F(18kt-\alpha_L)+{\alpha_F}^2{\alpha_L}^2))\end{pmatrix}}$$

$3t\alpha_F^2(1-\alpha_L)\alpha_L^2(36kt-\alpha_F)$ and $36kt(9kt-\alpha_F)+(1-\alpha_F)\alpha_F^2$ are positive given $kt>1/6$, $t>0$, and $0<\alpha_L<\alpha_F<1$. Thus, the numerator of $c_L^U-c_L^K$ is positive.

We proved previously that the 2nd factor in the denominator, $324k^2t^2(18kt-(2\alpha_F+\alpha_L))+\alpha_F(18kt\,(2\alpha_L(1-\alpha_F\alpha_L))+\alpha_F(18kt-\alpha_L)+{\alpha_F}^2{\alpha_L}^2)$ is positive, given $kt>1/6$, $t>0$, and $0<\alpha_L<\alpha_F<1$. In addition, we have $324k^2t^2(18kt-2\alpha_F-\alpha_L)$ and $\alpha_F(\alpha_F^2\alpha_L^2+36kt(1-\alpha_F)\alpha_L+\alpha_F(18kt-(1-\alpha_F)\alpha_L-\alpha_F\alpha_L^2))$ are positive, given $kt>1/6$, $t>0$, and $0<\alpha_L<\alpha_F<1$. Thus, the 1st factor in the denominator is also positive, and the denominator is positive, given $kt>1/6$, $t>0$, and $0<\alpha_L<\alpha_F<1$. Hence, $c_L^U-c_L^K>0$.

$$c_O-c_L^K=\frac{3\alpha_Lt(36kt(9kt-\alpha_F)+(1-\alpha_F){\alpha_F}^2)}{324k^2t^2(18kt-2\alpha_F-\alpha_L)+\alpha_F(\alpha_F^2\alpha_L^2+36kt(1-\alpha_F)\alpha_L+\alpha_F(18kt-(1-\alpha_F)\alpha_L-\alpha_F\alpha_L^2))}$$

We proved previously that $324k^2t^2(18kt-2\alpha_F-\alpha_L)+\alpha_F(\alpha_F^2\alpha_L^2+36kt(1-\alpha_F)\alpha_L+\alpha_F(18kt-(1-\alpha_F)\alpha_L-\alpha_F\alpha_L^2))$ is positive, given $kt>1/6$, $t>0$, and $0<\alpha_L<\alpha_F<1$. Thus, the denominator of $c_O-c_L^K$ is positive.

In addition, $3\alpha_L t$ and $36kt(9kt-\alpha_F)+(1-\alpha_F)\alpha_F{}^2$ are positive, given $kt>1/6$, $t>0$, and $0<\alpha_L<\alpha_F<1$. Thus, the numerator of $c_O-c_L^K$ is positive. Hence, $c_O-c_L^K$ is positive.

Given $f_L^U=k(c_O-c_L^U)^2$ and $f_L^K=k(c_O-c_L^K)^2$, we have $f_L^U-f_L^K=k(2c_O-c_L^U-c_L^K)(c_L^K-c_L^U)$. Given that $c_O-c_L^K>0$, $c_L^U-c_L^K>0$, and $c_O-c_L^U>0$, $f_L^U-f_L^K<0$.

The difference between the leader's expected profits in Case 1 and Case 2:

$$E(\pi_L^U)-E(\pi_L^K)=\frac{-t\alpha_F^2(36kt-\alpha_F)(1-\alpha_L)\alpha_L^3(36kt(9kt-\alpha_F)+(1-\alpha_F)\alpha_F^2)^2}{\begin{pmatrix}2(18kt-\alpha_F)^2(324k^2t^2(18kt-(2\alpha_F+\alpha_L))+\alpha_F(18kt\,(2\alpha_L(1-\alpha_F\alpha_L))+\alpha_F(18kt-\alpha_L)+\alpha_F{}^2\alpha_L{}^2))\\(324k^2t^2(18kt-2\alpha_F-\alpha_L)+\alpha_F(\alpha_F^2\alpha_L^2+36kt(1-\alpha_F)\alpha_L+\alpha_F(18kt-(1-\alpha_F)\alpha_L-\alpha_F\alpha_L^2)))\end{pmatrix}}$$

$-t\alpha_F^2(36kt-\alpha_F)(1-\alpha_L)\alpha_L^3$ is negative, and $(36kt(9kt-\alpha_F)+(1-\alpha_F)\alpha_F^2)^2$ is positive given $kt>1/6$, $t>0$, and $0<\alpha_L<\alpha_F<1$. Thus, the numerator of $E(\pi_L^U)-E(\pi_L^K)$ is negative.

We proved previously that $324k^2t^2(18kt-(2\alpha_F+\alpha_L))+\alpha_F(18kt\,(2\alpha_L(1-\alpha_F\alpha_L))+\alpha_F(18kt-\alpha_L)+\alpha_F{}^2\alpha_L{}^2)$ and $324k^2t^2(18kt-2\alpha_F-\alpha_L)+\alpha_F(\alpha_F^2\alpha_L^2+36kt(1-\alpha_F)\alpha_L+\alpha_F(18kt-(1-\alpha_F)\alpha_L-\alpha_F\alpha_L^2))$ are positive given $kt>1/6$, $t>0$, and $0<\alpha_L<\alpha_F<1$. Moreover, $2(18kt-\alpha_F)^2$ is positive. Thus, the denominator of $E(\pi_L^U)-E(\pi_L^K)$ is positive.

Hence, $E(\pi_L^U)-E(\pi_L^K)<0$.

c) With the following set of parameter values: $k=0.4902, c_O=1, t=0.34$, we compare the followers' expected profits in Case 1 and Case 2:

$E(\pi_F^U|\alpha_L=0.98,\alpha_F=0.981)=0.00913$ and $E(\pi_F^K|\alpha_L=0.98,\alpha_F=0.981)=0.00875$. Thus, the follower's profit in Case 1 can be higher than that in Case 2.

$E(\pi_F^U|\alpha_L=0.98,\alpha_F=0.998)=0.00669$ and $E(\pi_F^K|\alpha_L=0.98,\alpha_F=0.998)=0.00673$. Thus, the follower's profit in Case 2 can be higher than that in Case 1.

This concludes the proof. ■

Proofs for Extension 3

<u>Sequential IT investment with "outcome unknown" Case 1</u>

In the pricing game, depending on the implementation outcome of the two firms, i.e., $j = ss, sf, fs, ff$, the firms' prices are $p_{L,j}^U$ and $p_{F,j}^U$ (for leader and follower respectively). For the consumers located between n and $n+1$, they consider either buying from the follower who is located at n or the leader who is located at $n+1$. The consumer's utility from buying the follower's product is $U - (x - n)\, t - p_{F,j}^U$ and that from buying the leader's product is $U - (n + 1 - x)\, t - p_{L,j}^U$. Thus, the indifferent consumer is at $\frac{p_{L,j}^U - p_{F,j}^U + t}{2t} + n$. Moreover, since the density of consumers is $1/(2nw + 1)$ between n and $n+1$, the demand for the follower is $\frac{p_{L,j}^U - p_{F,j}^U + t}{2t(2nw+1)}$ and the demand for the leader is $\frac{p_{F,j}^U - p_{L,j}^U + t}{2t(2nw+1)}$ among these consumers. Further, for the consumers located between 0 and n, they consider buying from the follower who is located at n or buying nothing. The consumer's utility from buying from the follower is $U - (n - x)\, t - p_{F,j}^U$, and is 0 if buying nothing. Thus, the indifferent consumer is at $n - \frac{U - p_{F,j}^U}{t}$. Similarly, for the consumers located between $n+1$ and $2n+1$, they consider buying from the leader who is located at $n+1$ or buying nothing. The consumer's utility from buying from the leader is $U - (x - n - 1)\, t - p_{L,j}^U$, and is 0 if buying nothing. Thus, the indifferent consumer is at $n + 1 + \frac{U - p_{L,j}^U}{t}$.[1] Since the density of consumers is $w/(2nw + 1)$ between 0 and n, and between $n+1$ and $2n+1$, the demand for the follower is $w\frac{U - p_{F,j}^U}{t(2nw+1)}$ and the demand for the leader is $w\frac{U - p_{L,j}^U}{t(2nw+1)}$ among these consumers. Therefore, the total consumer demand for the leader is $m_{L,j}^U = \frac{p_{F,j}^U - p_{L,j}^U + t}{2t(2nw+1)} + w\frac{U - p_{L,j}^U}{t(2nw+1)}$ and the total demand for the follower is $m_{F,j}^U = \frac{p_{L,j}^U - p_{F,j}^U + t}{2t(2nw+1)} + w\frac{U - p_{F,j}^U}{t(2nw+1)}$.

In outcome j, based on their marginal costs ($c_{L,ss}^U = c_{L,sf}^U = c_L^U$, $c_{F,ss}^U = c_{F,fs}^U = c_F^U$, $c_{L,fs}^U = c_{L,ff}^U = c_{F,sf}^U = c_{F,ff}^U = c_O$), Firm i's profit function is, $i \in \{L, F\}$:

$$\pi_{i,j}^U = (p_{i,j}^U - c_{i,j}^U)\left(\frac{p_{-i,j}^U - p_{i,j}^U + t}{2t(2nw + 1)} + w\frac{U - p_{i,j}^U}{t(2nw + 1)}\right)$$

[1] To be consistent with the main model, this extension assumes that the middle market between the two firms is fully covered. Otherwise, the two firms act as local monopolies.

We take the derivative of firm i's profit function with respect to $p_{i,j}^{U}$ and solve the first order condition $\frac{d\pi_{i,j}^{U}}{dp_{i,j}^{U}} = 0$. We get the firms' optimal prices: $p_{i,j}^{U}{}^{*} = \frac{(1+2w)(c_{-i,j}^{U}+2(1+2w)c_{i,j}^{U})}{(1+4w)(3+4w)} + \frac{t+2Uw}{1+4w}$. Substituting these prices back, we get firm i's profits, $i \in \{L, F\}$:

$$\pi_{i,j}^{U}{}^{*} = A(Bc_{-i,j}^{U} - Ec_{i,j}^{U} + D)^2$$

where, $A = \frac{1+2w}{2(1+4w)^2(3+4w)^2(t+2ntw)}$, $B = 1 + 2w$, $D = (3 + 4w)(t + 2Uw)$ and $E = (1 + 8w(1 + w))$.

In the investment stage, firm i's investment cost is $f_i^U = k(c_O - c_i^U)^2$. Given firm i's optimal profit under the four cases, $\pi_{i,j}^{U}{}^{*}$ where $j = ss, sf, fs, ff$, and the probability of the four cases, we can write firm i's optimization problem in the outcome unknown case as:

$$\max_{c_i^U} E(\pi_i^U) = \max_{c_i^U}\left(\alpha^2\pi_{i,ss}^{U}{}^{*} + \alpha(1-\alpha)\pi_{i,sf}^{U}{}^{*} + (1-\alpha)\alpha\pi_{i,fs}^{U}{}^{*} + (1-\alpha)^2\pi_{i,ff}^{U}{}^{*}\right) - f_i^U \quad \text{(E31)}$$

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

LEMMA E3.1 *In the "outcome unknown" Case 1, the leader's optimal investment amount is*

$$f_L^{U*} = k\left(\frac{A\,D((B-D)c_O+E)\alpha(A\,k\alpha(2D^2-B(B-D)\alpha)-k^2+A^2D\alpha^2(B^3\alpha-D(D^2-B(B-D)\alpha)))}{3A\,D^2k^2\alpha-k^3+A^2D^2k\alpha^2(2B^2\alpha^2-3D^2)+A^3D^2\alpha^3(D^4+B^4\alpha^2-2B^2D^2\alpha^2)}\right)^2;$$

and the follower's optimal investment amount is

$$f_F^{U*} = k\left(\frac{A\,D((B-D)c_O+E)\alpha(A\,D\,k\alpha(2D+B\alpha)-k^2+A^2D\alpha^2(B^2(B+D)\alpha^2-D^3-BD^2\alpha))}{3A\,D^2k^2\alpha-k^3+A^2D^2k\alpha^2(2B^2\alpha^2-3D^2)+A^3D^2\alpha^3(D^4+B^4\alpha^2-2B^2D^2\alpha^2)}\right)^2.$$

where $A = \frac{1+2w}{2(1+4w)^2(3+4w)^2(t+2ntw)}$, $B = 1 + 2w, D = (3 + 4w)(t + 2Uw)$ and $E = (1 + 8w(1 + w))$.

Proof of Lemma E3.1

Since the leader decides c_L^U and then the follower decides c_F^U, we first solve the follower's optimal investment decision given the leader's investment decision. We take the first derivative of $E(\pi_F^U)$ in Equation (E31) with respect to c_F^U, and get the first order condition (FOC):

$$\frac{\partial E(\pi_F^U)}{\partial c_F^U} = 2(k - ABD(1-\alpha)\alpha)c_O - 2(AD\alpha(E + Bc_L^U\alpha) + c_F^U(k - AD^2\alpha)) = 0,$$

which gives $c_F^U = \frac{c_O(k-A\,B\,D(1-\alpha)\alpha)-A\,D\,\alpha(E+Bc_L^U\alpha)}{k-A\,D^2\alpha}$. We used the D function in Mathematica to obtain derivatives of a function w.r.t. a variable and the SOLVE function in Mathematica to solve the first order condition in this proof and in the subsequent proofs.

Then we substitute this reaction function of the follower into the leader's expected profit $E(\pi_L^U)$ in Equation E31 and take the first derivative with respect to c_L^U, and obtain the FOC: $\frac{\partial E(\pi_L^U)}{\partial c_L^U} = 2(k(c_O - c_L^U) + AD(1-\alpha)\alpha(c_L^U D - E - Bc_O) + AD\alpha^2\left(1 - \frac{AB^2\alpha^2}{AD^2\alpha - k}\right)\left(c_L^U D - E - \frac{B\left((k - ABD(1-\alpha)\alpha)c_O - AD\alpha\left(E + Bc_L^U\alpha\right)\right)}{k - AD^2\alpha}\right) - \frac{A^2B^2D(1-\alpha)\alpha^3(E - Dc_O + \frac{B(-AD\alpha(E + Bc_L^U\alpha) + (k - ABD(1-\alpha)\alpha)c_O)}{k - AD^2\alpha})}{k - AD^2\alpha}) = 0.$

Solving the first order condition, we get the leader's optimal new marginal cost if the implementation is successful as

$$c_L^{U*} = c_O - \frac{A\,D((B-D)c_O+E)\alpha(A\,k\alpha(2D^2-B(B-D)\alpha)-k^2+A^2D\alpha^2(B^3\alpha-D(D^2-B(B-D)\alpha)))}{3A\,D^2k^2\alpha-k^3+A^2D^2k\alpha^2(2B^2\alpha^2-3D^2)+A^3D^2\alpha^3(D^4+B^4\alpha^2-2B^2D^2\alpha^2)}.$$

We substitute c_L^{U*} into the reaction function of the follower, and get the follower's optimal new marginal cost if the implementation is successful as

$$c_F^{U*} = c_O - \frac{A\,D((B-D)c_O+E)\alpha(A\,D\,k\alpha(2D+B\alpha)-k^2+A^2D\alpha^2(B^2(B+D)\alpha^2-D^3-BD^2\alpha))}{3A\,D^2k^2\alpha-k^3+A^2D^2k\alpha^2(2B^2\alpha^2-3D^2)+A^3D^2\alpha^3(D^4+B^4\alpha^2-2B^2D^2\alpha^2)}.$$

Next, we check the second order conditions. We take the second order derivative of $E(\pi_F^U)$ with respect to c_F^U, and get:

$$\frac{\partial^2 E(\pi_F^U)}{\partial c_F^{U2}} = -2k + 2\mathrm{A}\,\mathrm{E}^2\alpha = -\frac{(1+2w)\left(2kt(1+4w)^2(3+4w)^2-\alpha(1+8w(1+w))^2\right)+2kt(1+4w)^2(3+4w)^2 2w(n-1)}{(1+4w)^2(3+4w)^2(t+2ntw)}.$$

$2kt(1+4w)^2(3+4w)^2 - \alpha\left(1+8w(1+w)\right)^2 = (18kt-\alpha) + 16w((12kt-\alpha) + w(44kt-5\alpha)) + (128w^3+64w^4)(8kt-\alpha)$, which is positive, given $kt > \frac{1}{6}$, $0 < w < 1$ and $0 < \alpha < 1$. In addition, $(1+2w)$ is positive and $2kt(1+4w)^2(3+4w)^2 2w(n-1)$ is positive, given $kt > \frac{1}{6}$, $0 < w < 1$, $n > 2$ and $0 < \alpha < 1$. Thus, the numerator of $\frac{\partial^2 E(\pi_F^U)}{\partial c_F^{U2}}$ is positive.

Moreover, $(1+4w)^2(3+4w)^2(t+2ntw)$ is positive, given $t > 0$, $0 < w < 1$, and $n > 2$. Thus, the denominator of $\frac{\partial^2 E(\pi_F^U)}{\partial c_F^{U2}}$ is positive. Hence, $\frac{\partial^2 E(\pi_F^U)}{\partial c_F^{U2}}$ is negative (notice the negative sign in front).

In addition, we take the second order derivative of $E(\pi_L^U)$ with respect to c_L^U, and get $\frac{\partial^2 E(\pi_L^U)}{\partial c_L^{U2}} = -2k + 2\mathrm{AE}^2\alpha(1 + \frac{\mathrm{AB}^2\alpha^2(2k+\mathrm{A}(\mathrm{B}^2-2\mathrm{E}^2)\alpha)}{(k-\mathrm{AE}^2\alpha)^2})$.

$-2k + 2\mathrm{AE}^2\alpha(1 + \frac{\mathrm{AB}^2\alpha^2(2k+\mathrm{A}(\mathrm{B}^2-2\mathrm{E}^2)\alpha)}{(k-\mathrm{AE}^2\alpha)^2})$ is negative given $t > 0$, $k > \frac{1}{6t}$, $0 < w < 1$, $n > 2$ and $0 < \alpha < 1$. To show that this expression is negative given $t > 0$, $k > \frac{1}{6t}$, $0 < w < 1$, $n > 2$ and $0 < \alpha < 1$, we apply a similar procedure as the one used repeatedly in the proof of Proposition E1.1 and the proofs of Lemma 1 and Lemma 2 (see Appendix) by consecutively taking higher order derivatives of the expression w.r.t. k and show that the derivatives are negative given $t > 0$, $k \geq \frac{1}{6t}$, $0 \leq w < 1$, $n > 2$ and $0 < \alpha < 1$. Next, we consecutively take higher order derivatives of the expression w.r.t. w, and show that the derivatives are negative given $k = \frac{1}{6t}$, implying that the expression decreases with w given $k = \frac{1}{6t}$, $0 \leq w < 1$, $n > 2$ and $0 < \alpha < 1$. Finally, the expression evaluated at $k = \frac{1}{6t}$ and $w = 0$ is $-\frac{27-27\alpha+9\alpha^2-\alpha^3-6\alpha^4+\alpha^5}{(3-\alpha)^2}$ and negative given $0 < \alpha < 1$. Therefore, this expression is negative given $t > 0$, $k > \frac{1}{6t}$, $0 < w < 1$, $n > 2$ and $0 < \alpha < 1$. The details are omitted to avoid repetition, but available upon request.

Hence, $\frac{\partial^2 E(\pi_L^U)}{\partial c_L^{U2}}$ is negative, and the second order condition is met.

Finally, we substitute the firms' new marginal costs in the event of a successful implementation into the investment functions and get the optimal investment levels of the leader and the follower:

$$f_L^U = k(c_O - c_L^U)^2 = k\left(\frac{A\,D((B-D)c_O+E)\alpha(A\,k\alpha(2D^2-B(B-D)\alpha)-k^2+A^2D\alpha^2(B^3\alpha-D(D^2-B(B-D)\alpha)))}{3A\,D^2k^2\alpha-k^3+A^2D^2k\alpha^2(2B^2\alpha^2-3D^2)+A^3D^2\alpha^3(D^4+B^4\alpha^2-2B^2D^2\alpha^2)}\right)^2 \text{ and}$$

$$f_F^U = k(c_O - c_F^U)^2 = k\left(\frac{A\,D((B-D)c_O+E)\alpha(A\,D\,k\alpha(2D+B\alpha)-k^2+A^2D\alpha^2(B^2(B+D)\alpha^2-D^3-BD^2\alpha))}{3A\,D^2k^2\alpha-k^3+A^2D^2k\alpha^2(2B^2\alpha^2-3D^2)+A^3D^2\alpha^3(D^4+B^4\alpha^2-2B^2D^2\alpha^2)}\right)^2.$$

We discuss how the firms' optimal investment strategies change with model parameters in Proposition E3.2.

This concludes the proof. ■

Sequential IT investment with "outcome known" Case 2:

The firms' pricing game is identical to the outcome unknown case. Thus, firm i's profit, $i \in \{L, F\}$, in the case $j = ss, sf, fs, ff$, is:

$$\pi_{i,j}^{K\,*} = A(Bc_{-i,j}^K - Ec_{i,j}^K + D)^2$$

In the investment stage, the leader's investment cost is $f_L^K = k(c_O - c_L^K)^2$. Given his profit under the four cases, $j = ss, sf, fs, ff$, we can write the leader's optimal investment problem in the outcome known case as:

$$\max_{c_L^K} E(\pi_L^K) = \max_{c_L^K}\left(\alpha^2\pi_{L,ss}^{K\,*} + \alpha(1-\alpha)\pi_{L,sf}^{K\,*} + (1-\alpha)\alpha\pi_{L,fs}^{K\,*} + (1-\alpha)^2\pi_{L,ff}^{K\,*}\right) - f_L^K$$

The follower makes its investment decision after observing the outcome of the leader's implementation. The follower's investment cost is $f_{F,s}^K = k(c_O - c_{F,ss}^K)^2$ if the leader's implementation is successful, and $f_{F,f}^K = k(c_O - c_{F,fs}^K)^2$ if the leader's implementation is unsuccessful. Thus, we can write the follower's optimal investment problem in the outcome known case as:

$\max\limits_{c^K_{F,ss}} E(\pi^K_{F,s}) = \max\limits_{c^K_{F,ss}} (\alpha \pi^K_{F,ss}{}^* + (1-\alpha)\pi^K_{F,sf}{}^*) - f^K_{F,s}$, if the leader's implementation is successful;

and $\max\limits_{c^K_{F,fs}} E(\pi^K_{F,f}) = \max\limits_{c^K_{F,fs}} (\alpha \pi^K_{F,fs}{}^* + (1-\alpha)\pi^K_{F,ff}{}^*) - f^K_{F,f}$, if the leader's implementation is unsuccessful.

LEMMA E3.2 *In the "outcome known" Case 2, the leader's optimal investment amount is*

$$f^{K*}_L = k\left(\frac{A\,D(E+(B-D)c_O)\alpha(A\,k\,\alpha(2D^2+B(D-B)\alpha)-k^2+A^2D\,\alpha^2(B^3\alpha-D(D^2+B(D-B)\alpha)))}{3A\,D^2k^2\alpha-k^3+A^2D^2k\alpha^2(2B^2\alpha-3D^2)+A^3D^2\alpha^3(D^4+B^4\alpha-2B^2D^2\alpha)}\right)^2.$$

Given that the leader's implementation is not successful, the follower's optimal investment amount is

$$f^K_{F,f}{}^* = k\left(\frac{A\,D(E+(B-D)c_O)\alpha}{k-A\,D^2\alpha}\right)^2;$$

and given that the leader's implementation is successful, the follower's optimal investment amount is

$$f^K_{F,s}{}^* = k\left(\frac{A\,D(D+(B-D)c_O)\alpha(A\,D(B+2D)k\alpha-k^2+A^2D(B+D)\alpha^2(B^2\alpha-D^2))}{3A\,D^2k^2\alpha-k^3+A^2D^2k\alpha^2(2B^2\alpha-3D^2)+A^3D^2\alpha^3(D^4+B^4\alpha-2B^2D^2\alpha)}\right)^2.$$

Proof of Lemma E3.2

The follower decides $c^K_{F,ss}$ if the leader's implementation is successful or decides $c^K_{F,fs}$ if the leader's implementation is unsuccessful. We take the derivative of $E(\pi^K_{F,s})$ with respect to $c^K_{F,ss}$ and the derivative of $E(\pi^K_{F,f})$ with respect to $c^K_{F,fs}$, and get the FOCs: $\frac{\partial E(\pi^K_{F,f})}{\partial c^K_{F,fs}} = 2(c_O - c^K_{F,fs})k - 2AD(Bc_O - c^K_{F,fs}D + E)\alpha = 0$ and $\frac{\partial E(\pi^K_{F,s})}{\partial c^K_{F,ss}} = 2(c_O - c^K_{F,ss})k - 2AD(Bc^K_L - c^K_{F,ss}D + E)\alpha = 0$

Solving the FOCs, we get if the leader fails, the follower's optimal new marginal cost if his implementation is successful is $c^K_{F,fs}{}^* = c_O - \frac{A\,D(E+(B-D)c_O)\alpha}{k-A\,D^2\alpha}$, which does not depend on the leader's investment decision. If the leader succeeds, the follower's optimal new marginal cost if his implementation is successful is: $c^K_{F,ss} = \frac{c_O k - A\,D(E+Bc^K_L)\alpha}{k-A\,D^2\alpha}$, which depends on the leader's investment decision.

We substitute the follower's reaction functions into $E(\pi^K_L)$, and take the derivative with respect to c^K_L, and get the FOC:

$\frac{\partial E(\pi_L^K)}{\partial c_L^K} = 2(c_O - c_L^K)k(1-\alpha) + 2\alpha\Bigg((c_O - c_L^K)k - AD(Bc_O - c_L^K D + E)(1-\alpha) + \frac{AD\alpha(k+A(B-D)(B+D)\alpha)\big(AD(B+D)(Bc_L^K - c_L^K D + E)\alpha - (Bc_O - c_L^K D + E)k\big)}{(k-AD^2\alpha)^2}\Bigg) = 0.$

Solving the FOC, we get the leader's optimal new marginal cost if his implementation is successful:

$c_L^{K*} = c_O - \frac{A\,D(E+(B-D)c_O)\alpha(A\,k\,\alpha(2D^2+B(D-B)\alpha)-k^2+A^2D\,\alpha^2(B^3\alpha-D(D^2+B(D-B)\alpha)))}{3A\,D^2k^2\alpha-k^3+A^2D^2k\alpha^2(2B^2\alpha-3D^2)+A^3D^2\alpha^3(D^4+B^4\alpha-2B^2D^2\alpha)}$. Then, we substitute c_L^{K*} into the follower's response function, and get the following result: Given the leader's implementation has succeeded, the follower's optimal new marginal cost if his implementation is successful is:

$c_{F,ss}^{K}{}^* = c_O - \frac{A\,D(D+(B-D)c_O)\alpha(A\,D(B+2D)k\alpha-k^2+A^2D(B+D)\alpha^2(B^2\alpha-D^2))}{3A\,D^2k^2\alpha-k^3+A^2D^2k\alpha^2(2B^2\alpha-3D^2)+A^3D^2\alpha^3(D^4+B^4\alpha-2B^2D^2\alpha)}$. (Recall that $c_{F,fs}^{K}{}^* = c_O - \frac{A\,D(E+(B-D)c_O)\alpha}{k-A\,D^2\alpha}$.)

Next, we check the second order conditions. We take the second order derivative of $E(\pi_{F,s}^K)$ with respect to $c_{F,ss}^K$, and the second order derivative of $E(\pi_{F,f}^K)$ with respect to $c_{F,fs}^K$, and get $\frac{\partial^2 E(\pi_{F,s}^K)}{\partial c_{F,ss}^{K\,2}} = \frac{\partial^2 E(\pi_{F,f}^K)}{\partial c_{F,fs}^{K\,2}} = -2k + 2\mathrm{A}\,\mathrm{E}^2\alpha = -\frac{(1+2w)\left(2kt(1+4w)^2(3+4w)^2-\alpha(1+8w(1+w))^2\right)+2kt(1+4w)^2(3+4w)^2 2w(n-1)}{(1+4w)^2(3+4w)^2(t+2ntw)}$.

We previously proved that $(1+2w)\left(2kt(1+4w)^2(3+4w)^2-\alpha(1+8w(1+w))^2\right)+2kt(1+4w)^2(3+4w)^2 2w(n-1)$ is positive and $(1+4w)^2(3+4w)^2(t+2ntw)$ is positive given $t>0$, $kt>\frac{1}{6}$, $0<w<1$, $n>2$ and $0<\alpha<1$. Hence, $\frac{\partial^2 E(\pi_{F,s}^K)}{\partial c_{F,ss}^{K\,2}}$ and $\frac{\partial^2 E(\pi_{F,f}^K)}{\partial c_{F,fs}^{K\,2}}$ are negative, and the second order conditions are met.

In addition, we take the second order derivative of $E(\pi_L^K)$ with respect to c_L^K, and get $\frac{\partial^2 E(\pi_L^K)}{\partial c_L^{K2}} = -2k + 2\mathrm{AE}^2\alpha(1+\frac{\mathrm{AB}^2\alpha^2(2k+\mathrm{A}(\mathrm{B}^2-2\mathrm{E}^2)\alpha)}{(k-\mathrm{AE}^2\alpha)^2})$. We previously proved that $-2k + 2\mathrm{AE}^2\alpha(1+\frac{\mathrm{AB}^2\alpha^2(2k+\mathrm{A}(\mathrm{B}^2-2\mathrm{E}^2)\alpha)}{(k-\mathrm{AE}^2\alpha)^2})$ is negative given $t>0$, $kt>\frac{1}{6}$, $0<w<1$, $n>2$ and $0<\alpha<1$.

Therefore, $\frac{\partial^2 E(\pi_L^K)}{\partial c_L^{K2}} < 0$, and the second order condition is met.

We substitute the firms' new marginal costs in the event of a successful implementation into the investment functions and get the optimal investment levels of the leader and the follower:

$f_L^K = k(c_O - c_L^K)^2 = k(\frac{A\,D(E+(B-D)c_O)\alpha(A\,k\,\alpha(2D^2+B(D-B)\alpha)-k^2+A^2D\,\alpha^2(B^3\alpha-D(D^2+B(D-B)\alpha)))}{3A\,D^2k^2\alpha-k^3+A^2D^2k\alpha^2(2B^2\alpha-3D^2)+A^3D^2\alpha^3(D^4+B^4\alpha-2B^2D^2\alpha)})^2$,

$f_{F,s}^K = k(c_o - c_{F,ss}^K)^2 = k(\frac{A\,D(D+(B-D)c_O)\alpha(A\,D(B+2D)k\alpha-k^2+A^2D(B+D)\alpha^2(B^2\alpha-D^2))}{3A\,D^2k^2\alpha-k^3+A^2D^2k\alpha^2(2B^2\alpha-3D^2)+A^3D^2\alpha^3(D^4+B^4\alpha-2B^2D^2\alpha)})^2$,

$f_{F,f}^K = k(c_o - c_{F,fs}^K)^2 = k(\frac{A\,D(E+(B-D)c_O)\alpha}{k-A\,D^2\alpha})^2$.

Figure EA2 shows how the firms' optimal investment levels may change with the probability of implementation success (α) given c_0=1, k=0.461, w=0.1, U=1.37, n=2.05, and t=0.362. The leader's investment level generally increases with α, which is consistent with the finding of the main model. If the leader's implementation fails, the follower's IT investment level generally increases with α as the follower takes advantage of a higher probability of implementation success. However, if the leader's implementation succeeds, the follower's investment level $f_{F,s}^{K}$ can first increase and then decrease with α.

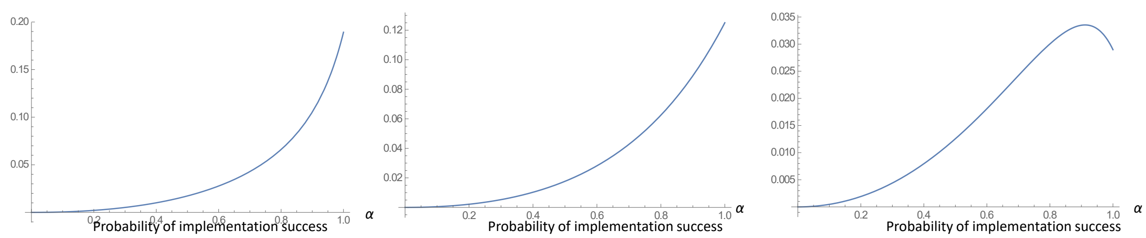

Figure EA2: Firms' investment amounts in Case 2 "outcome known" where c_O=1, k=0.461, w=0.1, U=1.37, n=2.05, and t=0.362.

This concludes the proof. ■

Proof of Proposition E3.1:

We just need to show that both firms can be better off given the opportunity to invest in the IT given certain parameter values, which satisfy all constraints.

Firm i's profit when the firms do not have an opportunity to invest in the IT, $i \in \{L, F\}$ is

$$\pi_i = (p_i - c_O)(\frac{p_{-i} - p_i + t}{2t(2nw + 1)} + w\frac{U - p_i}{t(2nw + 1)})$$

We take the derivative of firm i's profit function with respect to p_i and solve the first order conditions $\frac{\partial \pi_i}{\partial p_i} = 0$. We get the firms' optimal prices: ${p_i}^* = \frac{(1+2w)(1+2(1+2w))c_O}{(1+4w)(3+4w)} + \frac{t+2Uw}{1+4w}$.

Substitute ${p_i}^*$ into π_i, and we get ${\pi_i}^* = \frac{(1+2w)(t+2(U-c_O)w)^2}{2(1+4w)^2(t+2ntw)}$.

Consider the following parameter values: $k = 0.461, c_O = 1, t = 0.362, U = 1.37, w = 0.183$, and $n = 2.05$. This set of parameters satisfies the assumptions ensuring that the market is partially covered, and that the firms' new marginal costs given a successful implementation are between 0 and c_O in both Case 1 and Case 2 (i.e., $kt > 1/6$ and $n > 2$).

With the above set of parameters, the profits of the two firms are both ${\pi_i}^* = 0.088946$ when they do not have the opportunity to invest in the IT.

When the two firms have an opportunity to invest in the IT and $\alpha = 0.25$, with the above parameters, the leader's expected profit is $E(\pi_L^U|\alpha = 0.25) = 0.088983$ and the follower's expected profit is $E(\pi_F^U|\alpha = 0.25) = 0.088965$ in Case 1; the leader's expected profit is $E(\pi_L^K|\alpha = 0.25) = 0.088986$ and the follower's expected profit is $E(\pi_F^K|\alpha = 0.25) = 0.088963$ in Case 2.

Hence, both firms' profits can be higher when they have the opportunity to invest in the IT than when they do not. This concludes the proof. ■

Proof of Proposition E3.2:

We just need to show that the leader's expected profit and the follower's IT investment may increase or decrease with α given certain parameter values, which satisfy all the constraints.

Consider the same set of parameter values we used in the Proof of Proposition E3.1: $k = 0.461, c_O = 1, t = 0.362, U = 1.37, w = 0.183$, and $n = 2.05$. This set of parameter values satisfies all the assumptions of the model, as we have discussed earlier.

a) The leader's expected profit in Case 1 is $E(\pi_L^U|\alpha = 0.8) = 0.087576$, $E(\pi_L^U|\alpha = 0.95) = 0.086758$, and $E(\pi_L^U|\alpha = 0.99) = 0.087128$. This means that the leader's expected profit π_L^U can first decrease and then increase with α. This is also evident in Figure E3.1,

b) The follower's IT investment in Case 1 is $f_F^U|_{\alpha=0.8} = 0.035072$, $f_F^U|_{\alpha=0.95} = 0.043397$, and $f_F^U|_{\alpha=0.99} = 0.042965$. This means that the follower's IT investment f_F^U can first increase and then decrease with α. This is also evident in Figure E3.1.

This concludes the proof. ■

Proof of Proposition E3.3:

The difference between the expected profit of the leader and that of the follower in Case 1 is:

$$E(\pi_L^U) - E(\pi_F^U) = \frac{A^3B^3D\alpha^4(E + (B - D)c_O)^2(k - A\,D(B + D)(1 - \alpha)\alpha)^2 Z}{[k^3 - 3A\,D^2k^2\alpha + A^2D^2k\alpha^2(3D^2 - 2B^2\alpha^2) - A^3D^2\alpha^3(D^4 + B^4\alpha^2 - 2B^2D^2\alpha^2)]^2}$$

where $Z = 2k^2 - A\,D\,k\,\alpha(4D + 3B\,\alpha) + A^2D\,\alpha^2(2\,D^3 - B^3\alpha + 3B\,D^2\,\alpha)$.

It is easy to see the denominator of $E(\pi_L^U) - E(\pi_F^U)$ is positive. Moreover, $A^3B^3D\alpha^4$ is positive, given $A = \frac{1+2w}{2(1+4w)^2(3+4w)^2(t+2ntw)}$, $B = 1 + 2w, D = (3 + 4w)(t + 2Uw)$, $t > 0$, $U > 0$, $0 < w < 1$, $n > 2$ and $0 < \alpha < 1$. In addition, $(E + (B - D)c_O)^2$ and $(k - A\,D(B + D)(1 - \alpha)\alpha)^2$ are both positive.

Next, consider Z. With $B = 1 + 2w$, $A = \frac{1+2w}{2(1+4w)^2(3+4w)^2(t+2ntw)}$, $D = (3 + 4w)(t + 2Uw)$, and $E = (1 + 8w(1 + w))$ (Lemma E3.1), we can expand Z as

$(8k^2t^2(1 + 4w)^4(3 + 4w)^4(1 + 2nw)^2 - 2k\alpha(1 + 2w)(1 + 4w)^2(3 + 4w)^2(t + 2ntw)(1 + 8w(1 + w))(4 + 32w(1 + w) + \alpha(3 + 6w)) + 2(\alpha + 2\alpha w)^2(1 + 8w(1 + w))((1 + 8w(1 + w))^3 + \alpha(1 + 2w)(1 + 6w(1 + w))(1 + 16w(1 + w))))/(2(1 + 4w)^2(3 + 4w)^2(t + 2ntw))^2$.

The numerator of Z is a polynomial function of $k, w, t, n,$ and α, and is positive given $k > \frac{1}{6t}$, $0 < w < 1, 0 < \alpha < 1$ and $t > 0$. To show that this expression is positive given $k > \frac{1}{6t}$, $0 < w < 1, 0 < \alpha < 1$ and $t > 0$, we apply a similar procedure as the one used repeatedly in the proof of Proposition E1.1 and the proofs of Lemma 1 and Lemma 2 (see Appendix) by consecutively taking higher order derivatives of the expression w.r.t. k and show that the derivatives are positive given $k \geq \frac{1}{6t}$, $0 \leq w < 1, 0 < \alpha < 1$ and $t > 0$. Next, we consecutively take higher order derivatives of the expression w.r.t. w, and show that the derivatives are positive given $k = \frac{1}{6t}$, implying that the expression increases with w given $k = \frac{1}{6t}$, $0 \leq w < 1, 0 < \alpha < 1$ and $t > 0$. Finally, the expression evaluated at $k = \frac{1}{6t}$ and $w = 0$ is $18 - 12\alpha - 5\alpha^2 - \alpha/2 + 2\alpha(1/4 - \alpha(1-\alpha))$ and also positive given $0 < \alpha < 1$. Therefore, this expression, which is the numerator of Z, is positive given $k > \frac{1}{6t}$, $0 < w < 1, 0 < \alpha < 1$ and $t > 0$. The details are omitted to avoid repetition, but available upon request.

The denominator of Z, $(2(1+4w)^2(3+4w)^2(t+2ntw))^2$, is also positive. Thus, Z is positive, and the numerator of $E(\pi_L^U) - E(\pi_F^U)$ is positive.

Hence, $E(\pi_L^U) - E(\pi_F^U) > 0$.

b) We just need to show that the follower's expected profit in Case 2 can be higher or lower than his expected profit in Case 1 given certain parameter values, which satisfy all the constraints.

Consider the following set of parameter values: $k = 0.475, c_O = 1, t = 0.351, U = 1.37, w = 0.0017$, and $n = 4$. This set of parameters satisfies all of the model's assumptions ensuring that the market is partially covered, and that the firms' new marginal costs given a successful implementation are between 0 and c_O in both Case 1 and Case 2.

With this set of parameters, the follower's expected profit $E(\pi_F^U|\alpha = 0.985) = 0.00901$, and $E(\pi_F^U|\alpha = 0.995) = 0.00297$ in Case 1; and the follower's expected profit $E(\pi_F^K|\alpha = 0.985) = 0.00865$, and $E(\pi_F^K|\alpha = 0.995) = 0.00303$ in Case 2. Thus, given $\alpha = 0.985$, the follower's expected profit is higher in Case 1 with the leader's implementation outcome unknown. In contrast, given $\alpha = 0.995$, the follower's expected profit is higher in case 2 with the leader's implementation outcome known. That is, the follower may benefit from knowing the leader's IT implementation outcome or be hurt by it.

This concludes the proof. ■