

First versus Second-Mover Advantage with Information Asymmetry about the Profitability of New Markets

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Abstract

Is it better to move first, or second— to innovate, or to imitate? We show that if one player's information about the profitability of new markets is only modestly superior, the possibility of foreclosing the market can lead to a first-mover advantage. On the other hand, more extreme information superiority can reverse this, leading to a second-mover advantage. Knowing more surely what is the best choice, the better-informed player wants to delay to keep his information private and the less-informed player wants to delay to learn. Because of this, more accurate information can actually lead to inefficiency by increasing the incentive to delay, and exogenous costs of delay can aid efficiency by neutralizing that strategic incentive. In fact, in some circumstances a player may purposely coarsen his information to deter imitation.

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1 Introduction

Some companies are better than others at introducing new products or entering new geographic markets. One kind of advantage is technological—some companies can serve customers at lower cost. Another is informational—some companies are better at predicting which new products or markets will be profitable. If this advantage is known to rivals, however, it brings with it the peril of attracting imitation. Sony has generally played the role of leader in new markets, while Matsushita has been a follower (Boulding & Christen [2003]). Lu (2002), shows that later entrants in Japan tend to follow the entry mode of innovators. Baum & Haveman (1997) show that in the U.S. new hotels locate close to established hotels. Esty & Ghemawat (2002) study the particular case of superjumbo jet design in the 1990's, where both pre-emption and imitation were central concerns for Airbus and Boeing. At that time, it was uncertain whether "hub-and-spoke" or "point-to-point" would be more common in the future. "Hub-and-spoke" uses bigger and slower planes; "point-to-point" uses smaller but faster planes. Wrong choices in that industry take years to reverse, and each firm had to choose both which kind of plane to design and whether to first wait and see what the other was doing.¹

A firm with information that a new market will be profitable must choose its entry time to trade off the advantage of preemption against the disadvantage of disclosing its private information. Whether it is better to move first or second is an old question, the subject of an extensive literature that we will later discuss. Usually, it is framed as a choice between committing by moving first or outbidding by moving second—of whether actions are strategic substitutes or strategic complements.

Uncertainty is an important reason to delay. Uncertainty has two dimensions: when it is resolved, and whether it is asymmetric. Even when information is symmetric there is a second-mover advantage if the leader's choice causes uncertainty to be resolved—for example, through profits observed after entry. If, on the other hand, information is asymmetric, although the uncertainty is not resolved there can be a second mover advantage. The less-informed player may want to delay so as to observe and imitate the better-informed player's move. If imitation reduces profit, the better-informed player will want to delay to prevent it. The intuition is simple if the better-informed player has perfect information. If his information is superior but still imperfect, the situation is less clear, as we will see below.

There is a large literature on first and second mover advantages, but we will defer explaining its intricacies until after we have laid out our own model. Analyzing the effects of information quality on the strategic decision on delay when both information spillover and payoff externalities matter is our present topic. We will use a setting in which two firms decide which of two markets to enter. One firm has better but not perfect information about which market is better. The firms must decide whether to enter immediately or wait, but entry in the first period does not resolve

¹After an initial false start by Boeing, Airbus came up with its new plane, the big and slow A380, in 2005. The smaller and faster Boeing 787 took its first flight in 2009 (see Kohli & Venkatraman [2006] and <http://boeing.mediaroom.com/index.php?s=43&item=997>).

the underlying uncertainty. We describe the situation in terms of entering new geographic markets, but the model is equally suited to new products or any of the other of the varieties of innovation.

Whether it is best to move first or to move second depends on the quality of information. If the informed player's information is inaccurate, there is a first mover advantage for both players, the advantage of being able to foreclose the market. Both players know that the informed player's information is weak, so their main concern is to avoid competing in the same market. Choosing the same market does not necessarily put them both in the best market, however, since even the informed player's information is imperfect. Instead, they might both end up in the less profitable market, the worst possible outcome.

On the other hand, if the informed player's information is relatively accurate, the second-mover advantage dominates. Both players know that the informed player has a good chance of picking the big market, and this outweighs the disadvantage of competing in the same market. The uninformed player wants to imitate, and the informed player wants to evade imitation. There are both offensive and defensive reasons to delay. If duopoly competition is not severe, greater precision of information can lead to inefficiency because it increases the informed player's incentive to conceal his valuable information through delay. In this case, a cost of delay can raise welfare by countering that effect because the less-informed player is more patient to a cost of delay.

We also consider the case where a player can choose how informed to be. Does a player always want to have the most precise information? Oddly enough, a player might prefer to be less informed even if acquiring better information is costless. The reason is that very good information attracts imitation, whereas slightly superior information does not.

2 The Model

We will use the terminology of geographical markets rather than product markets in the model. An informed player (I) and an uninformed player (U) each will enter either the North (N) or South (S) market. One of which is bigger than the other, but which market is a bigger one is not known. There are two periods during which each player can enter. In the first period they choose simultaneously to enter North, enter South, or wait. If one player waits and the other does not, the waiting player can observe the other player's first-period choice before his own choice in the second period. The second mover cannot observe profits, however, which are received only at the end of the second period. Player i 's action set is thus $A = \{a_i, t_i\}$, where $i \in \{U, I\}$ denotes the player, $a_i \in L = \{N, S\}$ denotes the market entered, and $t = \{t_1, t_2\}$ denotes the period of entry.

Table 1 shows the ex-post payoffs, with $x < \alpha y$ for $0 < \alpha < 1$. A monopolist earns $x > 0$ or $y > x$ depending on whether its market is small or large. Each of two duopolists would earn α as much as a monopolist.²

²If being in a duopoly instead of a monopoly hurts a player's profits, as it would unless the two players' products were complements, then $0 < \alpha < 1$. If a duopoly industry earns less than a monopoly, as in the Cournot model with identical products, then $0 < \alpha < 0.5$. If consumers sufficiently value differentiated products, then $\alpha > 0.5$ and the

		Uninformed player	
		Big Market	Small Market
Informed player	Big Market	$\alpha y, \alpha y$	y, x
	Small Market	x, y	$\alpha x, \alpha x$

Table 1: Ex-Post Payoffs for Big and Small Markets
(for $y > x > 0$ and $0 < \alpha < 1$)

We will assume that $x < \alpha y$; that is, the single-firm duopoly profit in a big market is greater than the monopoly profit in a small market. Thus, the follower would be willing to crowd into a market despite the leader's presence if he were sure the market was big.

The common prior is that both markets are equally likely to be the big market. Before the first period, the informed player observes the private signal $\theta \in \Theta = \{N, S\}$ which correctly identifies the big market with probability $p \in (\frac{1}{2}, 1)$. As the precision, p , approaches $\frac{1}{2}$, the signal becomes useless; as it approaches 1, it becomes perfect. The uninformed player does not observe the informed player's signal, but he does know p .

The informed player's pure strategy is

$$s_I = (t_I(\theta), a_I(\theta|t_I = t_1), a_I(\theta|t_I = t_U = t_2), a_I(\theta|t_U = t_1, t_I = t_2)) \quad (1)$$

For given θ , the informed player decides when to enter and whether to follow his signal or not. If $a_I = \theta$, we will say that he "uses the signal". The uninformed player's strategy is

$$s_U = (t_U, a_U|(t_U = t_1), a_U|(t_I = t_U = t_2), a_U(a_I|t_I = t_1, t_U = t_2)) \quad (2)$$

since he observes no his own private signal. We will allow mixed-strategies for both players.

Let λ be the uninformed player's belief as to the probability that the informed player uses the signal in choosing a market. The strategy profile $s = \{s_U, s_I\}$ and λ is a perfect Bayesian equilibrium if $E\pi_I(s_I, s_U)$ and $E\pi_U(s_I, s_U)$ are maximized for given λ and $s = \{s_U, s_I\}$ and λ is consistent with s_I in terms of Bayesian updating.

Throughout this paper, one particular value of p is critical for determining the equilibrium, so let us define:

$$\bar{p} \equiv \frac{y - x\alpha}{(y - x)(\alpha + 1)} \quad (3)$$

It will turn out that for $p < \bar{p}$ there is a first-mover advantage and for $p > \bar{p}$ there is a second-mover advantage.

industry earns more as a duopoly, though each firm would still prefer to be a monopoly. We allow for both cases. The parameter α increases with: (1) the degree of product differentiation, (2) the degree to which the two goods are complements, and (3) the ability of the two players to collude when they are a duopoly. If the products are identical, then $\alpha \leq 0.5$, with perfect collusion having $\alpha = 0.5$, Bertrand competition having $\alpha = 0$, and Cournot competition having $0 < \alpha < 0.5$. If there is perfect collusion, then $0.5 \leq \alpha < 1$, depending on the degree of product differentiation and product complementarity.

3 Exogenous Timing of Entry

We will start by assuming that the sequence of entry is exogenous, a necessary prelude to the analysis of endogenous entry. This analysis is in order to derive both firms' best responses for each available outcome used in calculating the players' expected payoffs.³ The possible exogenous-timing games are (1) the players move simultaneously, (2) the uninformed player moves first, and (3) the informed player moves first.

If the uninformed player has no chance to observe I's choice, he has only prior belief about which is a big market. In this case, the informed player's best response is contingent on his belief as to the uninformed player's choice.

Lemma 1

Suppose that U has only prior belief about which is a big market. Let us denote by q I's belief that U selects "North". Then any $q \in [0, 1]$ is a consistent belief.

Proof: *In the appendix.*

The key reasoning is as follows. As the uninformed player should make a decision on timing of entry before round 1 starts, he has no chance to observe the informed player's signal. This implies that what the uninformed player should expect is not whether the informed player will select to "North" or "South", but whether he will follow the private signal or not. The uninformed player's expectation, based on the belief about both the true state and private signal, makes him indifferent between selecting "North" and "South" regardless of the informed player's best response contingent on his belief. Different equilibria will result depending on the informed player's belief.⁴ For the simple analysis, throughout this paper, we assume that $q = \frac{1}{2}$.⁵ As we assume no communication between players before making a choice, this would be a reasonable assumption.

Assumption 1

When U makes a choice without observing I's choice, I believes that $\Pr(a_U = N) = 0.5$.

Then both players' equilibrium behaviors in each exogenous ordering case can be described as follows.⁶

³When firms decide their timing of choice endogenously, they should consider their expected payoffs for all available outcomes which depend on both players' best responses.

⁴In all equilibria, it is same that the uninformed player is indifferent between his choices. Just the informed player's best responses contingent on his belief are different.

⁵Lemma A.1 (Page 19) describes the critical value of informed player's belief q^* which yields his different best response. The assumption that $q = \frac{1}{2}$ corresponds to the case where $q < q^*$ because $\frac{1}{2} < q^*$.

⁶If the informed player is indifferent between using and deviating from his signal for given p , we assume that he uses a signal. Also if the uninformed player is indifferent, for given p , between imitating and deviating from the informed player's choice, we assume that he imitates the informed player's choice.

Proposition 1.

1) Suppose that the choice of location is simultaneous. Then, the informed player uses his signal and the uninformed player chooses randomly between North and South.

2) Suppose that the choice of location is sequential.

2-1) If the uninformed player chooses first, the informed player uses the signal if it is accurate enough (if $\bar{p} \leq p < 1$), and otherwise (if $\frac{1}{2} < p < \bar{p}$) chooses the opposite of the uninformed player.

2-2) If the informed player chooses first, he uses the signal. The uninformed player imitates him if the signal is accurate enough (if $\bar{p} \leq p < 1$), but otherwise (if $\frac{1}{2} < p < \bar{p}$) he chooses the opposite.

Proof: In the appendix.

Proposition 1 says that when the informed player is the leader, he should use his signal rather than try to conceal it by randomization. The equilibrium is separating, so the uninformed player can infer the signal θ perfectly.

When the informed player is the follower, he has even less reason to randomize. He knows he is better informed, so it is natural for him to use the signal, but he must also consider the competition that arises when both players are in the same market. Hence, his information quality affects whether he uses his signal or not. If it is low, i.e., $p < \bar{p}$, he has more reason to worry that the signal is wrong. If the uninformed player already accidentally selected the location signalled by θ , the informed player will be reluctant to do the same because both players might end up in the small market.

On the other hand, if his information quality is high, i.e., $\bar{p} \leq p$, he has relatively strong confidence in the correctness of the signal. Even if the other player already chose the location signalled by θ , it is better to join him there in what is very likely the best market, because $\alpha y > x$. Hence, regardless of the uninformed player's choice of location, the informed player uses the signal.

Similar reasoning applies to the uninformed player's strategy. If and only if the informed player's information quality is low, the uninformed player thinks mainly of avoiding competition and diverges in his choice of market.

From (3), it can be checked that

$$\frac{\partial \bar{p}}{\partial y} = \frac{(\alpha - 1)x}{(\alpha + 1)(y - x)^2} < 0, \quad \frac{\partial \bar{p}}{\partial x} = \frac{(1 - \alpha)y}{(\alpha + 1)(y - x)^2} > 0, \quad \frac{\partial (\bar{p})}{\partial \alpha} = -\frac{x + y}{(\alpha + 1)^2(y - x)} < 0 \quad (4)$$

As the large market size y increases, the parameter set for which $p \in [\bar{p}, 1)$ increases. As y increases, each firm's payoff from being a duopolist in the large market increases, whereas the payoff x from being a small-market monopolist stays the same. Hence, the informed player puts more emphasis on being in the big market and has more reason to follow his signal. The uninformed player knows this, so he too relies more on the signal— which means that as y increases he becomes more eager to imitate the informed player. On the other hand, as x , the profit when a player operates as a monopolist in a small market, increases, the parameter set for which $p \in [\bar{p}, 1)$ falls. The loss from being in a small market decreases and each player's incentive to avoid competition

in one market grows relative to the incentive to be in a big market. As x rises, whichever player is the follower becomes more likely to diverge from the leader's choice. Finally, as α increases (as competition becomes less severe), each firm's payoff from being a duopolist in the same market increases. Hence, each firm's incentive to avoid being in the same market decreases. Hence, the parameter set of p for which the informed player sticks to his signal and the uninformed player wants to imitate the informed player's choice increases.

3.1 The Expected Payoffs

We wish to make the timing of entry over the two periods endogenous, and this requires setting out the possible payoffs from different timings. The informed player's expected payoff is one of two expressions, (5) or (6), depending on whether the uninformed player will have a chance to observe the informed player's choice or not. If the informed player goes first and the uninformed player second, the uninformed player can deduce the signal θ perfectly, so his action a_U is perfectly predictable. Hence, the informed player's expected payoff is:

$$\pi_I(t_U, t_I) = \sum_{w \in \{N, S\}} \Pr(w | \theta) \pi_I(a_I, a_U, w) \quad (5)$$

If, however, the uninformed player has no chance to infer the informed player's signal, he chooses a_U only using his prior. From Assumption 1, the informed player's expected payoff is:

$$\pi_I(t_U, t_I) = (0.5) \left(\sum_{w \in \{N, S\}} \Pr(w | \theta) \pi_I(a_I, a_U = N, w) + \sum_{w \in \{N, S\}} \Pr(w | \theta) \pi_I(a_I, a_U = S, w) \right) \quad (6)$$

These two equations cover the four possible combinations of timing. Payoff (5) is for $(t_U, t_I) = (t_2, t_1)$ and payoff (6) is for $(t_U, t_I) = (t_1, t_2)$, (t_2, t_2) and (t_1, t_1) . On the other hand, the uninformed player's expected payoff is:

$$\pi_U(t_U, t_I) = \sum_{\theta \in \{N, S\}} \sum_{w \in \{N, S\}} \Pr(w, \theta) \pi_U(a_I, a_U, w) \quad (7)$$

Here, his posterior belief should be about the true state w and I 's signal, $\Pr(w, \theta)$, because I has no chance to observe a_I and therefore no chance to infer θ before he makes a decision. Straightforward calculations yield the payoffs in Tables 1 and 2.

		t_I	
		t_1	t_2
t_1		$\frac{y+x\alpha-p(y-x)(1-\alpha)}{2}, \frac{(x-px+py)(\alpha+1)}{2}$	$\frac{(x+y)}{2}, \frac{(x+y)}{2}$
t_U			
	t_2	$(y + px - py), (x - px + py)$	$\frac{y+x\alpha-p(y-x)(1-\alpha)}{2}, \frac{(x-px+py)(\alpha+1)}{2}$

Table 2: Ex-Ante expected payoffs when the signal is imprecise: $\frac{1}{2} < p < \bar{p}$

		t_I	
	t_1		t_2
t_1		$\frac{y+x\alpha-p(y-x)(1-\alpha)}{2}, \frac{(x-px+py)(\alpha+1)}{2}$	$\frac{y+x\alpha-p(y-x)(1-\alpha)}{2}, \frac{(x-px+py)(\alpha+1)}{2}$
t_U	t_2	$\alpha(x-px+py), \alpha(x-px+py)$	$\frac{y+x\alpha-p(y-x)(1-\alpha)}{2}, \frac{(x-px+py)(\alpha+1)}{2}$

Table 3: Ex-Ante expected payoffs when the signal is precise: $\bar{p} \leq p < 1$

In following section, we will use Tables 2 and 3 to find the equilibrium when firms choose their timings of entry endogenously.

4 Endogenous Timing of Entry

In following, denote i 's ex-ante expected payoff when he enters as the leader, follower, or simultaneously by π_i^L , π_i^F , and π_i^S .

4.1 First-Mover and Second-Mover Advantage

When the signal is imprecise, $p < \bar{p}$, Table 2 tells us that:

$$\pi_U^S < \pi_U^F < \pi_U^L \text{ and } \pi_I^S < \pi_I^F < \pi_I^L \quad (8)$$

Each player's best response as follower is to choose a different location from the leader, even though we have assumed that it is better to be a duopolist in the big market than a monopolist in the small market ($\alpha y > x$). As the follower, he can operate as a monopolist in one market by diverging from the leader. This follower behavior is why equation (8) says that a player's expected profits are highest if he is the leader.

If the informed player is the leader, he uses his signal. Since the uninformed player diverges, the informed player more likely than not ends up as a monopolist in the big market. If he enters as the follower, however, he should diverge from the uninformed player even if that puts him in the market which he believes is likely to be small. Though if he chooses the signalled market the more likely outcome is duopoly in the big market, it might also be duopoly in the small market, the worst possible outcome.

The uninformed player's reasoning is similar. If he enters as the follower, he should choose a location opposite to the leader, even though he knows that the leader has chosen what is probably the big market. He would prefer to be the leader, since then he has probability .5 of ending up as a monopolist in the big market, compared to a probability of $1 - p$, which is less than .5, as the follower.

In this weak-information case, the expected payoff when sharing the market is possible is lower than that from being the follower. For either player, $\pi_U^S < \pi_U^F$ and $\pi_I^S < \pi_I^F$. If p is low, a player's confidence in the signal (his or the other player's) is so low that he puts more emphasis on avoiding competition. If both players choose locations simultaneously, they might both end up as monopolists, but they might not. Acting as the follower is better even if it reduces the chance of being in the big market because it at least prevents the possibility of sharing a small market. The best situation is to be the leader, the next-best is to be the follower, and the worst case is to enter simultaneously.

When information is precise, and $p \geq \bar{p}$, Table 3 tells us that:

$$\pi_U^S = \pi_U^L < \pi_U^F \quad \text{and} \quad \pi_I^L < \pi_I^S = \pi_I^F \quad (9)$$

Expression (9) says that if information precision is high, then each player does best as the follower. The informed player knows that if the uninformed player has a chance to observe his choice, he will choose the same location. For relatively high p , however, he has strong confidence in his signal and the payoff from being either a monopolist or a duopolist in the signalled market is high. Hence, he enters late to prevent his choice from being revealed and imitated. In fact, his payoff from simultaneous entry is just as high as from being the follower: $\pi_I^S = \pi_I^F$. If both players enter simultaneously, the uninformed player still has no chance to observe the informed player's choice, and the probability the informed player will end up sharing that market is .5.

As for the uninformed player, if the signal is relatively precise then his ideal is to observe the informed player's choice and imitate it. If he cannot, he is indifferent between being the leader or choosing simultaneously: $\pi_U^S = \pi_U^L$. In either case, he has no chance to observe the informed player's choice and to infer the signal. Hence, his expected profits are the same in both cases.

Remark 1

If information precision is relatively low ($p < \bar{p}$), there is a first mover advantage. On the other hand, if information precision is relatively high ($p \geq \bar{p}$), there is a second mover advantage.

If $p < \bar{p}$, a player would prefer to go first, but he will delay entry if he thinks the other player will enter first, so as to avoid ending up in the same market. If $p \geq \bar{p}$, the uninformed player would like to delay entry in order to observe the informed player's choice, but if he does delay, the informed player will also delay to prevent that observation. Both end up delaying because of the conflict between two types of second mover advantage: one from learning and the other from preventing learning.

4.2 The Equilibrium

Using the payoffs from Tables 2 and 3 we can characterize the endogenous timing of entry.

Proposition 2. *Suppose that entry timing is endogenous.*

1) *If information is precise enough, i.e., $p \geq \bar{p}$, the informed player enters in the second period, and the uninformed player is indifferent about when he enters.*

2) *If information is not precise enough, i.e., $p < \bar{p}$, there are two pure-strategy equilibria, one for each of two players entering first, and a mixed strategy equilibrium in which the uninformed player enters without delay with probability z and the informed player enters without delay with probability w :*

$$(z, w) = \left(\frac{(x - px + py)(\alpha - 1)}{(2x\alpha - y - x - 2px\alpha + 2py\alpha)}, \frac{(x - px + py)(\alpha - 1)}{(2x\alpha - y - x - 2px\alpha + 2py\alpha)} \right)$$

Proof: *In the appendix.*

The signal's precision is high if $p \geq \bar{p}$. The informed player delays entry and enters in period 2 to conceal his information. The uninformed player can only use his prior belief of .5, and his expected payoff is the same whenever and wherever he enters. The signal's precision is low if $p < \bar{p}$. There are two pure-strategy equilibria, in which the players enter sequentially into separate markets. Because the information quality is low the players hesitate to rely on it and are most concerned with avoiding competition. One player, at least, has incentive to delay, but his benefit is not from imitating the leader, but from diverging.

If $p < \bar{p}$ there is also the mixed strategy equilibrium, in which a player has no safe choice. Since the other player is mixing too, if he enters early he might end up competing in the same market, but the same thing could happen if he enters late. Entering early does have the advantage that if the other player enters late, the leader can preempt the signalled market (if he is the informed player) or have a .5 chance of preempting the signalled market (if he is the uninformed player). This must be balanced by a higher probability of ending up competing in the same market. Hence there is some probability of early entry greater than .5 for each player which leaves each of them indifferent about when to enter, and that is the equilibrium mixing probability.

The comparative statics on the mixing probabilities of choosing early entry yield that:

$$\frac{\partial z}{\partial p} = \frac{\partial w}{\partial p} = \frac{(1 - \alpha)(x + y)(y - x)}{(2x\alpha - y - x - 2px\alpha + 2py\alpha)^2} > 0 \quad (10)$$

$$\frac{\partial z}{\partial x} = \frac{\partial w}{\partial x} = \frac{(\alpha - 1)(2p - 1)y}{(x + y - 2x\alpha + 2px\alpha - 2py\alpha)^2} < 0 \quad (11)$$

$$\frac{\partial z}{\partial y} = \frac{\partial w}{\partial y} = \frac{(1 - \alpha)(2p - 1)x}{(2x\alpha - y - x - 2px\alpha + 2py\alpha)^2} > 0 \quad (12)$$

Inequality (10) says that when information precision increases, both players choose early entry with higher probability. The increase in information precision p makes choosing the signalled market more attractive. For both players to still be willing to choose the unsignalled market, it must be that choosing the signalled market results in greater probability of undesirable competition. The way this probability increases is for both of them to increase their probability of early entry until the likelihood of competition has risen enough for them to again be indifferent about their times of entry.

Inequalities (11) and (12) say that the probability of early entry falls with x , the size of the small market, and rises with y , the size of the big market. When the size of the small market increases, that increases the benefit from waiting and possibly being the only player to enter in period 2. As a result, the probability of early entry by the other player does not have to be so high to keep the player indifferent about his time of entry. The effect of an increase in the size of the big market is parallel: that increases the benefit from possibly being the only early entrant and the disadvantage of entering early and making the same choice as the other player must increase to balance that benefit.

Thus, we have shown that whether a first- or a second-mover advantage emerges depends on whether the preemption effect is dominant, so that the leader does not care about information leakage, or the information effect is dominant, so the leader's main concern is to prevent imitation. When knowledge of which market is best is imperfect, the presence of payoff externalities makes preemption possible even when both players would prefer a sure big market duopoly to small market monopoly.

4.3 Efficiency

Usually in information models, we analyze only ex ante efficiency— whether equilibrium decisions maximize the sum of expected payoffs given the information available to the players at the start of the game. Here, however, it is also possible that equilibrium leads to ex post efficiency— that equilibrium decisions maximize the sum of actual payoffs, as if decisions were made by a social planner who had no uncertainty. Here, of course, the uncertainty is over which market is big, and even the informed player's information is imperfect. Let us use the word “efficient” to mean “maximizing the sum of each firm's ex-post payoff,” since we have not specified demand precisely enough to discuss consumer welfare, which will depend on product variety and the loss from a market being unserved as well as on equilibrium prices.

In our model a player prefers to be a duopolist in the big market than a monopolist in the small market, i.e., $\alpha y > x$. If $2\alpha y > x + y$, that is, if $\alpha > \frac{x+y}{2y}$, it is efficient for both firms to be in the big market, since duopoly profits are large relative to monopoly profits and the difference between market sizes is large. Otherwise, efficiency requires that the firms choose different markets.

Suppose the informed player's information is imprecise ($p < \bar{p}$). From Proposition 2, the pure-strategy equilibria have sequential entry into two different markets. If $\alpha < \frac{x+y}{2y}$, this is the efficient outcome. Thus, if competition hurts profits enough or the markets are close enough in size, imprecise information results in the firms maximizing industry profits ex post, at least if the equilibrium is in pure strategies.

Ex ante, neither player knows with certainty which is a big market, so the best a planner maximizing industry profit can do is to either locate both firms at the signalled market or to put them in different markets. Locating in the same market is ex ante efficient if and only if

$2\alpha(py + (1 - p)x) \geq x + y$, which can be expressed in two ways $\alpha \geq \frac{x+y}{2[py+(1-p)x]}$ or $p \geq \frac{y+x-2x\alpha}{2\alpha(y-x)}$.⁷ If the planner has only the players' information about which market is big, expected profits from co-location will naturally be lower than when he knew perfectly which was big. Thus, the degree of product differentiation or duopoly cooperation α has to be bigger than in Proposition 3. That degree will now depend on the quality of information p too. The main key results of the analysis as to ex-ante efficiency can be summarized as follows.⁸

Proposition 3.

- 1) Suppose that duopoly profit is low relative to monopoly profit, so $\frac{x}{y} < \alpha < \frac{x+y}{2y}$. Then all pure-strategy equilibria are efficient. The mixed equilibrium is efficient only if $p \geq \bar{p}$.
- 2) Suppose that duopoly profit is high relative to monopoly profit, so $\frac{x+y}{2y} < \alpha$. Then improved information can lead to the inefficient equilibria.

Proof: In the appendix.

< Figure 1 here >

Figure 1 illustrates the possible equilibrium regions for the case where the monopoly profits are $x = 1$ in the small market and $y = 5$ in the large market. The values of p lie between .5 and 1, and values of the "duopoly/monopoly profit ratio" lie between x/y and 1, given our assumption that the duopoly profit in the big market is greater than the monopoly profit in the small market, i.e., $\alpha y > x$. The vertical line represents the boundary condition that $\alpha = \frac{x+y}{2y}$ and the two sloping lines represent $p = \bar{p}$ and $p = \frac{y+x-2x\alpha}{2\alpha(y-x)}$.

If we ignore mixed-strategy equilibria, the parameter set of α and p for which the equilibria are efficient (areas A1, A2, A4 and A5) increases as the information quality declines and duopoly relative to monopoly profits rise. In area A3, where the duopoly competition is not severe, ex-ante efficiency requires both firms to locate in the market signaled as big, but the informed player delays to conceal his precise information. The uninformed player enters randomly and they might end up in separate markets, which is inefficient. In this sense, more accurate information hurts efficiency.

5 Discussion

5.1 Delay Cost Can Raise Welfare

In previous sections, we have assumed that a delay in a entry does not incur any cost. Then what would happen if there is a delay cost? What would be its effects on the equilibrium and welfare?

⁷When both are in the same market, it is the big market with probability p and the small market with probability $1 - p$. Hence, $\pi_I = \pi_U = p\alpha y + (1 - p)\alpha x$ and $\pi_I + \pi_U = 2\alpha(py + (1 - p)x)$. If both are in the separate market, $\pi_I + \pi_U = x + y$. Finally, locating both firms in the same market is ex ante efficient if and only if $2\alpha(py + (1 - p)x) \geq x + y$.

⁸The detailed description of the ex-ante efficiency can be found in the appendix (Proof of Proposition 3).

If information quality is weak, such a cost has little impact because the first mover advantage dominates and the pure strategy equilibrium is a sequential entry. Hence a delay cost affects only on whether the sequential timing of entry can be sustained or not.⁹

What is more interesting is when information quality is high, i.e., $\bar{p} \leq p$. It was already checked that, in this case, if no cost is imposed, the second mover advantage dominates and both firms intend to delay a entry if possible. Now if a delay cost is imposed, a delay decision should be affected because a delay is allowed only if a net gain from a delay is positive. That is there can be a case in which a firm cannot delay although it wants to do so because of a too high cost, from which a sequential entry by both firms can be derived. From this reasoning, in this section, we focus on the equilibrium of the case in which information quality is high. Our results show that the existence of delay cost can improve ex-ante efficiency.

First, let us make some observations on which player gains more from a delay. If a delay cost is imposed, intuitively what matter would be who has the greater gain from a delay because the one with a greater gain can be more patient to a costly delay. Let d_U and d_I denote each player's gain from being the follower. The value d_U is the gain from delay that allows learning (imitating the choice of the informed player) and the value d_I is the gain from delay that preventing learning (preventing the uninformed player's imitation).

Lemma 2. *Suppose that $\bar{p} \leq p < 1$. There exists a value $\alpha^* = \frac{x+y}{2y} \in \left(\frac{x}{y}, 1\right)$ such that:*

1) *If $\alpha \in \left(\frac{x}{y}, \alpha^*\right)$, then $d_U < d_I$ for all $p \in [\bar{p}, 1)$. That is, the uninformed player has less benefit from delay.*

2) *If $\alpha \in (\alpha^*, 1)$, for $p \in \left[\bar{p}, \frac{y+x-2x\alpha}{2\alpha(y-x)}\right)$, $d_U < d_I$ and for $p \in \left(\frac{y+x-2x\alpha}{2\alpha(y-x)}, 1\right)$, $d_U > d_I$. For information weak enough, the informed player has the bigger benefit from delay, but for strong information, the uninformed player does.*

Proof: *In the appendix.*

As Lemma 2 says, both firms' gains from a delay are different according to given parameters sets. Then costly delay can yield the sequential timing of entry because both players' cutoff values of a delay cost below which a net positive gain is guaranteed, differ. That is, if $Min\{d_U, d_I\} < c < Max\{d_U, d_I\}$, the player with the lower delay benefit should enter in period 1 and the other can enter in period 2.¹⁰

⁹If a given delay cost is too high, the follower cannot sustain a delay and therefore the simultaneous timing of entry is derived. Also for a mixed strategy equilibrium, only the mixed probability changes to depend on c .

¹⁰If $c > Max\{d_U, d_I\}$, the two players both enter in period 1. If $c < Min\{d_U, d_I\}$, the unique equilibrium is a mixed strategy equilibrium. To see this, consider the pure strategy combinations. Suppose $(t_U, t_I) = (t_1, t_1)$. Then, the uninformed player has an incentive to deviate to $t_U = t_2$ in order to observe the informed player's choice. If $(t_U, t_I) = (t_2, t_1)$, however, the informed player has an incentive to deviate to $t_I = t_2$ to prevent the uninformed player from observing his choice. If they both enter in the second period, so $(t_U, t_I) = (t_2, t_2)$, the uninformed player has incentive to deviate to $t_U = t_1$ because delay does not allow him to observe the informed player's move, but it does incur cost c . But if $(t_U, t_I) = (t_1, t_2)$, the informed player might as well deviate to enter in the first period, since in this strong-information case he will follow his signal anyway and so his simultaneous move payoff is the same as his sequential move payoff except for the delay cost c . Thus, there is no pure strategy Nash equilibrium.

Now we see that there exist parameter sets for which a delay cost can increase welfare. According to Proposition 3, when duopoly competition is not severe, more accurate information can lead to inefficient equilibria because of the informed player's incentive to conceal information. The corresponding conditions are $\alpha \in \left(\frac{x+y}{2y}, 1\right)$ and $p \in \left(\frac{y+x-2x\alpha}{2\alpha(y-x)}, 1\right)$. In Lemma 2, for these parameter sets of α and p , $d_U > d_I$. Then, if $d_I < c < d_U$, the informed player should act as the leader and the uninformed player has a chance to observe and imitate the informed player's choice. Hence, the ex-ante efficiency can be attained. That is, when the duopoly competition is not severe and the informed player's information is quite accurate, the moderate but not too high delay cost can resolve the inefficiency and therefore function as a means to increase welfare.

5.2 Endogenous Information Quality and Incentive to be Less-informed.

Till now, we have assumed that one player is informed exogenously and the other is not. In this section, we extend our analysis to the case where the informed player can decide the information quality endogenously. The main question we want to ask is whether a player always wants to have the most precise information. In following, we show that interestingly, sometimes a player wants to be less-informed although more precise information can be acquired for free.

Suppose that one player has a chance of being informed without incurring any information cost. He can not only observe his own private signal, but also decide its precision. We assume that the other player does not have this chance of being informed.

From Proposition 2, a player can predict the equilibrium contingent on the information quality. If he picks the low quality information, i.e., $\frac{1}{2} < p < \bar{p}$, there exist multiple equilibria: $(t_{U1}, t_I) = (t_2, t_1)$, (t_1, t_2) and mixed equilibrium. If he picks the high quality information, i.e., $\bar{p} \leq p < 1$, in equilibrium always he should enter in round 2. As $\pi_I^{Mixed}|_{p < \bar{p}} < \pi_I(t_U = t_1, t_I = t_2)|_{p < \bar{p}} < \pi_I(t_U = t_2, t_I = t_1)|_{p < \bar{p}}$, we denote $(t_U, t_I) = (t_2, t_1)$ as the first-best outcome, $(t_U, t_I) = (t_1, t_2)$ as the second-best outcome and the mixed equilibrium as the worst outcome respectively.¹¹ The analysis yields the following result.

Proposition 4

Let $\bar{\alpha} = \frac{1}{y} \left(\sqrt{2} \sqrt{xy + y^2} - y \right)$. Suppose that a player expects the first-best outcome when $\frac{1}{2} < p < \bar{p}$. If the duopoly competition is severe, i.e., $0 < \alpha < \bar{\alpha}$, he will prefer to have worse information: $p = \bar{p} - \varepsilon$ instead of $p = \bar{p}$.

Proof: In the appendix.

< Figure 2 Here >

Figure 2 describes the informed player's expected payoff as a function of information quality p when he expects the first-best outcome. Choosing low quality information is a signal to the

¹¹For the multiple equilibria of this, both payoff- and risk-dominance criteria do not yield any dominant equilibrium. Hence we compare each equilibrium of this case with the equilibrium when $\bar{p} \leq p < 1$.

uninformed player that "there is not much for you to learn from me". Moreover if the duopoly competition is severe, the uninformed player should have less incentive to imitate the informed player because of a concern of being in the small market together. In this sense, the interior level of information quality $p = \bar{p} - \epsilon$ picked by a player is the best level consistent with not being mimicked by the uninformed player.¹² Figure 2 also implies that even when the competition is not severe sometimes being more-informed can make a player worse-off.: when $\alpha > \bar{\alpha}$, if the current information quality is $p = \bar{p} - \epsilon$, being more-informed to $\bar{p} \leq p < \hat{p}$ makes a player worse-off.

< Figure 3 Here >

On the other hand, if a player expects the second-best or worst outcome when $\frac{1}{2} < p < \bar{p}$, he picks the most precise information (See Figure 3). So whether the interior information quality will be picked or not depends on whether he expects that the equilibrium is more likely to be $(t_U, t_I) = (t_2, t_1)$. If the informed player has a chance to send a strong signal or a binding threat of entry in round 1, the uninformed player is more likely to pick round 2 because $\pi_U(t_U = t_1, t_I = t_1)|_{p < \bar{p}} < \pi_U(t_U = t_2, t_I = t_1)|_{p < \bar{p}}$.

In real world usually information is costly to acquire and moreover acquiring more precise information would be more costly. In the above analysis, we show that a player can intend to be less-informed although being more-informed does not incur any cost. Then the incentive to be less-informed would be more common in real world for the sake of saving a cost, especially if players face more competitive environment, as predicted in our model.

5.3 What If a Monopoly Profit in Small Market is Higher than a Duopoly Profit in Big Market?

So far we have assumed that a player would rather be a duopolist in the big market than a monopolist in the small market. Then what would happen if we assume instead that $\alpha y < x$? The equilibrium of this case can be described as follows.¹³

Proposition 5

Suppose that $\alpha y < x$. Then, for all $p \in (\frac{1}{2}, 1)$, there exist two pure-strategy equilibria $(t_U, t_I) = (t_2, t_1), (t_1, t_2)$ and one mixed-strategy equilibrium (z, w) where $z = \Pr(t_U = t_1)$ and $w = \Pr(t_I = t_1)$. The values (z, w) are identical to those found Proposition 2.

If $\alpha y < x$, the value of being in the big market even as a duopolist decreases. Especially for the uninformed player, the first mover advantage of preemption now outweighs the second mover advantage of learning for the uninformed player. The learning motive, in fact, collapses completely,

¹²If we assume that the uninformed player deviates from the informed player's choice when $p = \bar{p}$, the interior information quality picked by the informed player will be $p = \bar{p}$, which is a minor point.

¹³The detailed analysis is analogous to that used in the previous sections, so we skip it here.

because obtaining the benefit of learning requires that the follower become a duopolist. However it is inferior to being a monopolist even if the identity of the big market is learned perfectly. For the informed player, the best case is still to preempt a market his signal says. However, if the uninformed player already preempted a market his signal says, he has no more incentive to stick to it because operating as a monopolist in one market, even though it is a small market, is better. Hence for both players only the first mover advantage dominates, which induces the same result of the case where $\alpha y > x$ and information quality is low.

6 The Literature

A large literature exists on the war of attrition and pre-emption games in which entry does not result in any learning (see Argenziano & Schmidt-Dengler (2008) on pre-emption games, and Brunnermeier & Morgan (2010) on clock games). Bouis, Huisman & Kort (2009) add uncertainty in the form of changes in market demand, but this is observed even without entry, and its main interest is in changing the intervals between entry.

The next analytic step is for entry to reveal information. Gal-Or (1987) shows that a player with superior information on demand may prefer ex ante to move simultaneously rather than first, to avoid revealing his knowledge that demand is strong (though Mailath [1993] shows that if the well-informed player has the *option* of moving first, it will always take that option, since to delay reveals that it is trying to hide strong demand). Normann (1997, 2002) also look at what happens when one duopolist is better informed and he makes his quantity decision. Levin & Peck (2003) look at a different kind of asymmetric information: firms differ in their entry cost, and must decide when to enter a natural monopoly in a variant of the grab-the-dollar game. In all these models, the players are making decisions about how hard to compete in one market, not whether to compete at all, and the quality of the informed player's information is unimportant.

In other models, players are symmetric but the first player's move creates new information. In Rob (1991), entry reveals informational under payoff externality, but the players are not asymmetrically informed. The timing of actions is given exogenously, and the focus is on the second mover's advantage from learning. Rob does not analyze the possible advantage from moving second to prevent the other player from learning. Bolton & Harris (1999), Hirokawa & Sasaki (2001) and Hoppe (2000) also look at what happens when the first mover's move reveals something about the state of the world. In the present paper, what the second mover gets from observing the first mover's choice is not direct information about the unknown true state, but the first mover's information.

Appelbaum & Lim (1985), Spencer & Brander (1992), and Somma (1999) also deal with the topic of market preemption and delay. Their focus is the trade-off between precommitment and flexibility when uncertainty is resolved exogenously over time. Delay has option value, because the choice can be made after uncertainty is resolved. In our model, the uncertainty is not resolved till both firms make their choices.

Chamley and Gale (1994) and Zhang (1997) discuss strategic delay and the endogenous timing

of action when there are informational externalities but no payoff externalities. In Chamley and Gale (1994), a player has an incentive to delay his action for information updating. Zhang (1997) links this result to informational cascades, finding that the most-informed player is least willing to wait because he has the least to learn. In these models, as there are no payoff externalities, each player's main concern is whether the cost of delay is worth learning other players' information.

Yoon (2009) and Frisell (2003) consider endogenous timing of action game where there are both informational- and payoff externalities. Yoon (2009) analyzes a delay race where the worse-informed player delays to learn and a better-informed player delays to prevent learning. The payoff functions are different from the present paper's in that the worst outcome is to be incorrect alone. In our model, of market entry, the worst outcome is for both players to end up in a small market, having made the same mistake. That possible payoff is crucial to why the quality of information determines whether the advantage is to the first or the second mover. Frisell (2003) asks who will enter as the leader and follower when whether payoff externality is either positive or negative is given exogenously. The degree of information superiority does not affect the given payoff externality. Delay costs are crucial, but delay can be infinitely long. Also the simultaneous action is not considered. In our paper, on the other hand, one player cannot simply outwait the other. If he waits, the result can be simultaneous choices. As a result, a player who moves late must be concerned about ending up in the same market as his rival, even if he has prevented purposeful imitation. We find, in contrast to Frisell, that even if industry profits suffer heavily when both players are in the same market, the informed player may decide to move first if he is not much better informed.

7 Concluding Remarks

Often, a player must make a choice knowing that his choice may be imitated by another player. This choice might be of a new geographic market, as in our model, or of a new product, which could be modelled with exactly the same mathematics. Moving first may or may not deter entry into the market by the rival player, but it certainly will reveal information. Hence, in a setting of endogenous timing of entry, the decision on the timing of entry can be interpreted as the decision on the flow of private information. Of course, how is revealed information used by the other player affects the decision on the timing of entry. If the informed player's information is not strong, the attempt by both players to avoid crowding into one market results in the pure equilibrium in which they operate as monopolists in separate markets. On the other hand, if the informed player's information is relatively valuable, the rival player wants to learn it and imitate his choice. Hence, an informed player may well choose to delay entry to prevent imitation, which results in an equilibrium in which no learning is available. This kind of strategic delay by both players increases the probability that they end up in the same market. So the good information that causes the delay can actually end up reducing industry profits. In this case, however, the gain from preventing the other's learning is less than the gain from learning. Hence the existence of a delay cost can resolve the inefficiency caused from the informed player's incentive to conceal his information. If competition is quite severe, a firm's intention not to be imitated may increase. Hence, interestingly,

a player might choose to refuse free information— provided, of course, that his refusal is common knowledge. He will prefer to have the maximum level of information that prevents mimicking by his rival.

* If requested, some parts of the detailed proofs can be shortened in the final version.

8 Appendix

In the Appendix, "I" denotes the "informed player" and "U" denotes the "uninformed player".

8.1 Proof of Lemma 1

U has only prior belief about which is a big market if he has no chance to observe I's choice. In following, $E\pi_I(a_I = \theta)$ ($E\pi_I(a_I \neq \theta)$) is I's expected payoff when he follows (deviates from) his signal. Without loss of generality, suppose that $\theta = N$. Denote q as I's belief for that U selects "N". Then q can be interpreted as I's belief for that U selects what θ signals. Then

$$\begin{aligned} E\pi_I(a_I = \theta) &= q \left(\sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_I(a_I = \theta, a_U = N, w) \right) \\ &\quad + (1 - q) \left(\sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_I(a_I = \theta, a_U = S, w) \right) \\ &= q(p(\alpha y) + (1 - p)(\alpha x)) + (1 - q)(p(y) + (1 - p)(x)) \end{aligned}$$

$$\begin{aligned} E\pi_I(a_I \neq \theta) &= q \left(\sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_I(a_I \neq \theta, a_U = N, w) \right) \\ &\quad + (1 - q) \left(\sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_I(a_I \neq \theta, a_U = S, w) \right) \\ &= q(p(x) + (1 - p)(y)) + (1 - q)(p(\alpha x) + (1 - p)(\alpha y)) \end{aligned}$$

and

$$E\pi_I(a_I = \theta) - E\pi_I(a_I \neq \theta) = q(\alpha x - y - x + y\alpha) + (x - px + py - y\alpha - px\alpha + py\alpha)$$

As one extreme case, suppose that $q = 0$. (That is, I believes that U selects S when $\theta = N$.) Then,

$$E\pi_I(a_I = \theta) - E\pi_I(a_I \neq \theta)|_{q=0} = p(y - x - \alpha x + y\alpha) + x - y\alpha > 0$$

for $p \in (\frac{1}{2}, 1)$. Therefore, if $q = 0$, I follows his signal θ . As the other extreme case, suppose that $q = 1$. (I believes that U selects N when $\theta = N$.) Then,

$$E\pi_I(a_I = \theta) - E\pi_I(a_I \neq \theta)|_{q=1} = p(y - x - \alpha x + y\alpha) + \alpha x - y$$

So, if $q = 1$, there exists $p^* = \frac{y-x\alpha}{y-x-x\alpha+y\alpha}$ such that if $p \in (\frac{1}{2}, p^*)$, I deviates from θ and if $p \in [p^*, 1)$, I follows θ . As $E\pi_I(a_I = \theta) - E\pi_I(a_I \neq \theta)$ is a linear function of q with negative slope, the above analysis can be summarized as follows:

Lemma A.1.

Suppose that both firms make a choice simultaneously. Let $q = \Pr(a_U = N)$ be I's belief when U has only prior information. In following, $q^* = -\frac{x-px+py-y\alpha-px\alpha+py\alpha}{x\alpha-y-x+y\alpha}$.

- 1) If $q < q^*$ (if I believes that U is less likely to select what θ signals), I follows his signal.
- 2) If $q > q^*$ (if I believes that U is more likely to select what θ signals), $\exists p^*$ s.t. if $p \in (\frac{1}{2}, p^*)$, I deviates from his signal and if $p \in (p^*, 1)$, I follows his signal.
- 3) If $q = q^*$, I is indifferent between following and deviating from θ .

For the given belief, we derive U's best response and check whether the given belief is consistent or not. Here, for each given belief, *what U expects is whether I will follow θ or not. U cannot expect whether I will go to north or south because θ is private information.* That is, U's belief should be about both true state and θ . In following, $E\pi_U(a_U = N)$ ($E\pi_U(a_U = S)$) is U's expected payoff when he selects N(S).

- 1) If $q < q^*$ (if U is less likely to select what θ signals), I follows θ . Then

$$E\pi_U(a_U = N) = \sum_{w \in \{N, S\}} \sum_{\theta \in \{N, S\}} \Pr(w, \theta) \pi_U(a_I = \theta, a_U = N, w) = \frac{p}{2}\alpha y + \frac{1-p}{2}y + \frac{1-p}{2}\alpha x + \frac{p}{2}x$$

$$E\pi_U(a_U = S) = \sum_{w \in \{N, S\}} \sum_{\theta \in \{N, S\}} \Pr(w, \theta) \pi_U(a_I = \theta, a_U = S, w) = \frac{p}{2}x + \frac{1-p}{2}\alpha x + \frac{1-p}{2}y + \frac{p}{2}\alpha y$$

Hence, $E\pi_U(a_U = N) = E\pi_U(a_U = S)$, which implies that U is indifferent between selecting N and S. Then $q < q^*$ is a consistent belief.

- 2) If $q > q^*$ (if U is more likely to select θ says), the information quality matters. First, if $p \in (\frac{1}{2}, p^*)$, I deviates from his signal θ . Then, $E\pi_U(a_U = N) = E\pi_U(a_U = S)$ because

$$E\pi_U(a_U = N) = \sum_{w \in \{N, S\}} \sum_{\theta \in \{N, S\}} \Pr(w, \theta) \pi_U(a_I \neq \theta, a_U = N, w) = \frac{p}{2}y + \frac{1-p}{2}\alpha y + \frac{1-p}{2}x + \frac{p}{2}\alpha x$$

$$E\pi_U(a_U = S) = \sum_{w \in \{N, S\}} \sum_{\theta \in \{N, S\}} \Pr(w, \theta) \pi_U(a_I \neq \theta, a_U = S, w) = \frac{p}{2}\alpha x + \frac{1-p}{2}x + \frac{1-p}{2}\alpha y + \frac{p}{2}y$$

Second, if $p \in (p^*, 1)$, I follows his signal. We have already checked in 1) that, in this case, $E\pi_U(a_U = N) = E\pi_U(a_U = S)$. So I's belief that $q > q^*$ is consistent.

- 3) If $q = q^*$, I is indifferent between following or deviating from θ . Let's assume that h is the probability that I follows θ when I is indifferent between following or deviating from θ , i.e.,

$h = \Pr(a_I = \theta)$. Then

$$\begin{aligned}
E\pi_U(a_U = N) &= h \left(\sum_{w \in \{N, S\}} \sum_{\theta \in \{N, S\}} \Pr(w, \theta) \pi_U(a_I = \theta, a_U = N, w) \right) \\
&\quad + (1-h) \left(\sum_{w \in \{N, S\}} \sum_{\theta \in \{N, S\}} \Pr(w, \theta) \pi_U(a_I \neq \theta, a_U = N, w) \right) \\
&= h \left(\frac{p}{2} \alpha y + \frac{1-p}{2} y + \frac{1-p}{2} \alpha x + \frac{p}{2} x \right) + (1-h) \left(\frac{p}{2} y + \frac{1-p}{2} \alpha y + \frac{1-p}{2} x + \frac{p}{2} \alpha x \right) \\
E\pi_U(a_U = S) &= h \left(\sum_{w \in \{N, S\}} \sum_{\theta \in \{N, S\}} \Pr(w, \theta) \pi_U(a_I = \theta, a_U = S, w) \right) \\
&\quad + (1-h) \left(\sum_{w \in \{N, S\}} \sum_{\theta \in \{N, S\}} \Pr(w, \theta) \pi_U(a_I \neq \theta, a_U = S, w) \right) \\
&= h \left(\frac{p}{2} x + \frac{1-p}{2} \alpha x + \frac{1-p}{2} y + \frac{p}{2} \alpha y \right) + (1-h) \left(\frac{p}{2} \alpha x + \frac{1-p}{2} x + \frac{1-p}{2} \alpha y + \frac{p}{2} y \right)
\end{aligned}$$

For all $h \in [0, 1]$, $E\pi_U(a_U = N) = E\pi_U(a_U = S)$, which implies that the belief $q = q^*$ is consistent.

Finally, it can be checked that, I's belief $q \in [0, 1]$ is a consistent belief. \square

8.2 Proof of Proposition 1

First, consider the case where the entry is simultaneous. In this case, U chooses randomly between N and S because he has only prior belief. Now, as for the best response of I, without loss of generality, assume that $\theta = N$. Then,

$$\begin{aligned}
E\pi_I(a_I = \theta, a_U, w) &= \sum_{w \in \{N, S\}} \Pr(w | \theta = N) [.5\pi_I(\cdot, a_U = N) + .5\pi_I(\cdot, a_U = S)] \quad (A1) \\
&= \frac{1}{2} (x - px + py) (\alpha + 1)
\end{aligned}$$

$$\begin{aligned}
E\pi_I(a_I \neq \theta, a_U, w) &= \sum_{w \in \{N, S\}} \Pr(w | \theta = N) [.5\pi_I(\cdot, a_U = N) + .5\pi_I(\cdot, a_U = S)] \quad (A2) \\
&= \frac{1}{2} (y + px - py) (\alpha + 1)
\end{aligned}$$

where (A1) is the expected payoff when informed player uses his signal and (A2) is the one when he deviates from it. Then:

$$E\pi_I[a_I = N, a_U, w] - E\pi_I[a_I = S, a_U, w] = \frac{1}{2} (y - x) (2p - 1) (\alpha + 1) > 0 \quad (A3)$$

So, I's best response is $a_I = N$. This implies that if $\theta = S$, it should be that $a_I = S$. Hence, I's best response is to use his signal.

Second, consider the case where the entry is sequential.

1) What if U moves first? There are two cases depending on whether I's signal equals U's action or not: $\theta = a_U$ and $\theta \neq a_U$.

Case i: $\theta = a_U$. Without loss of generality, assume that $\theta = a_U = N$. Then, under the posterior beliefs $\Pr(w = N|\theta = N) = p$ and $\Pr(w = S|\theta = N) = 1 - p$,

$$E\pi_I(a_I = \theta, a_U, w) = \sum_{w \in \{N, S\}} \Pr(w|\theta = N)\pi_I(a_I = \theta, a_U, w) = p(\alpha y) + (1 - p)(\alpha x) \quad (A4)$$

$$E\pi_I(a_I \neq \theta, a_U, w) = \sum_{w \in \{N, S\}} \Pr(w|\theta = N)\pi_I(a_I \neq \theta, a_U, w) = p(x) + (1 - p)(y) \quad (A5)$$

Then, $p \gtrless \frac{(x\alpha - y)}{(\alpha + 1)(x - y)} = \bar{p} \implies (A4) \gtrless (A5)$ where $\bar{p} \in (\frac{1}{2}, 1)$.

Case ii: $\theta \neq a_U$. Without loss of generality, assume that $\theta = N$ and $a_U = S$. Then, under the posterior beliefs $\Pr(w = N|\theta = N) = p$ and $\Pr(w = S|\theta = N) = 1 - p$,

$$E\pi_I(a_I = \theta, a_U, w) = \sum_{w \in \{N, S\}} \Pr(w|\theta = N)\pi_U(a_I = \theta, a_U, w) = py + (1 - p)x \quad (A6)$$

$$E\pi_I(a_I \neq \theta, a_U, w) = \sum_{w \in \{N, S\}} \Pr(w|\theta = N)\pi_U(a_I \neq \theta, a_U, w) = p(\alpha x) + (1 - p)(\alpha y) \quad (A7)$$

Then for all $p \in (\frac{1}{2}, 1)$, $(A6) > (A7)$.

Therefore, I's best response is as follows: If $p > \frac{(x\alpha - y)}{(\alpha + 1)(x - y)} = \bar{p}$, regardless of U's choice in round 1, I uses his signal. On the other hand, when $p < \bar{p}$, if $\theta = a_U$, he deviates from his signal and if $\theta \neq a_U$, he uses his signal.

2) What if I moves first? This is the harder case, because what U observes is a_I , not θ . As θ is private information, U does not know whether I follows his signal or not in deciding a location. Here, note that whether $\theta = N$ or $\theta = S$, both cases are ex-ante symmetric. Hence, intuitively a pooling strategy or semi-separating strategy cannot constitute equilibrium. The following analysis shows that the separating strategy which constitutes equilibrium is the one which implies that I follows his signal in selecting location.

U must assign belief λ for that $a_I = \theta$. In a pure strategy equilibrium, this belief is $\lambda \in \{0, 1\}$. As a first step in looking at beliefs, suppose that U's belief λ does equal zero or one. Suppose U believes $a_I = \theta$, i.e., $\lambda = 1$. Without loss of generality, let $a_I = N$. U's posterior beliefs are $\Pr(w = N|\theta = N) = p$ and $\Pr(w = S|\theta = N) = 1 - p$, so

$$E\pi_U(a_I = \theta, a_U, w) = \sum_{w \in \{N, S\}} \Pr(w|\theta = N)\pi_U(a_I = a_U, w) = p(\alpha y) + (1 - p)(\alpha x) \quad (A8)$$

$$E\pi_U(a_I \neq \theta, a_U, w) = \sum_{w \in \{N, S\}} \Pr(w|\theta = N)\pi_U(a_U \neq a_I, w) = p(x) + (1 - p)(y) \quad (A9)$$

Next, suppose U believes that $a_I \neq \theta$, i.e., $\lambda = 0$. Then, U's posterior beliefs are $\Pr(w = N|\theta =$

$S) = 1 - p$ and $\Pr(w = S | \theta = S) = p$, so

$$E\pi_U(a_I = \theta, a_U, w) = \sum_{w \in \{N, S\}} \Pr(w | \theta = S) \pi_U(a_I = a_U, w) = (1 - p)(\alpha y) + p(\alpha x) \quad (\text{A10})$$

$$E\pi_U(a_I \neq \theta, a_U, w) = \sum_{w \in \{N, S\}} \Pr(w | \theta = S) \pi_U(a_I \neq a_U, w) = (1 - p)(x) + p(y) \quad (\text{A11})$$

More generally, I might mix, so U's belief that $a_I = \theta$ would be $\lambda \in [0, 1]$. Then

$$E\pi_U(a_I = \theta, a_U, w) \quad (\text{A12})$$

$$= \lambda \left(\sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_U(a_I = a_U, w) \right) + (1 - \lambda) \left(\sum_{w \in \{N, S\}} \Pr(w | \theta = S) \pi_U(a_I = a_U, w) \right)$$

$$E\pi_U(a_I \neq \theta, a_U, w) \quad (\text{A13})$$

$$= \lambda \left(\sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_U(a_U \neq a_I, w) \right) + (1 - \lambda) \left(\sum_{w \in \{N, S\}} \Pr(w | \theta = S) \pi_U(a_U \neq a_I, w) \right)$$

Consequently,

$$\lambda \gtrless \lambda^* \implies E\pi_U(a_U = a_I, w) \gtrless E\pi_U(a_U \neq a_I, w) \quad (\text{A14})$$

where $\lambda^* = \frac{(x - px + py - y\alpha - px\alpha + py\alpha)}{(y - x)(2p - 1)(\alpha + 1)}$. We will state and prove Lemma A.1, included only here in the Appendix to help prove Proposition 1.

Lemma A.1. *Suppose that I chose a location as the leader.*

a) *Suppose that $p \in (\frac{1}{2}, \bar{p})$. Then, for all $\lambda \in [0, 1]$, U diverges from I's choice.*

b) *Suppose that $p \in (\bar{p}, 1)$. Then, there exists $\lambda^* \in (0, 1)$ such that if $\lambda \in (\lambda^*, 1]$, U imitates I's choice, if $\lambda \in [0, \lambda^*)$, U diverges from I's choice, and if $\lambda = \lambda^*$, U is indifferent between imitating and diverging.*

Proof of Lemma A.1. We start by checking whether $\lambda^* \in (0, 1)$ or not. First, for λ^* , if $p \gtrless \frac{y\alpha - x}{(y - x)(\alpha + 1)}$, $\lambda^* \gtrless 0$. However, $\frac{y\alpha - x}{(y - x)(\alpha + 1)} - \frac{1}{2} = \frac{(\alpha - 1)(x + y)}{2(\alpha + 1)(y - x)} < 0$. So, for $p \in (\frac{1}{2}, 1)$, $\lambda^* > 0$. Also, from $\lambda^* - 1 = \frac{(y + px - py - x\alpha + px\alpha - py\alpha)}{(\alpha + 1)(2p - 1)(y - x)}$, if $p \gtrless \frac{y - \alpha x}{(y - x)(\alpha + 1)}$, $\lambda^* \gtrless 1$ where $\frac{y - \alpha x}{(y - x)(\alpha + 1)} \in (\frac{1}{2}, 1)$. Therefore, we can summarize as follows: a) If $p \in (\frac{1}{2}, \frac{y - \alpha x}{(y - x)(\alpha + 1)})$ then for all $\lambda \in [0, 1]$, $E\pi_U(a_U = a_I) < E\pi_U(a_U \neq a_I)$. b) If $p \in (\frac{y - \alpha x}{(y - x)(\alpha + 1)}, 1)$ then if $\lambda \gtrless \lambda^*$, $E\pi_U(a_U = a_I) \gtrless E\pi_U(a_U \neq a_I)$. \square

Let us now return to I's best response, which we can derive using Lemma A.1. In following, we denote $\frac{y - \alpha x}{(y - x)(\alpha + 1)} \equiv \bar{p}$. Without loss of generality, assume $\theta = N$. Then, I's posterior beliefs are $\Pr(w = N | \theta = N) = p$ and $\Pr(w = S | \theta = N) = 1 - p$.

First, assume that $p \in (\frac{1}{2}, \bar{p})$. In this case, U chooses a location different from I's choice for all $\lambda \in [0, 1]$. Then

$$E\pi_I(a_I = \theta, a_U, w) = \sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_U(a_I = \theta \neq a_U, w) = p(y) + (1 - p)(x) \quad (\text{A15})$$

$$E\pi_I(a_I \neq \theta, a_U, w) = \sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_U(a_I \neq \theta = a_U, w) = p(x) + (1 - p)(y) \quad (\text{A16})$$

and

$$E\pi_I(a_I = \theta, a_U, w) - E\pi_I(a_I \neq \theta, a_U, w) = (y - x)(2p - 1) > 0 \quad (\text{A17})$$

Thus, I's best response is to choose the location following his signal, which is consistent to U's belief that $\lambda \in [0, 1]$.

Next, let $p \in (\bar{p}, 1)$. First, suppose $\lambda > \lambda^*$, so U imitates I. Then:

$$E\pi_I(a_I = \theta, a_U, w) = \sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_U(a_I = \theta = a_U, w) = p(\alpha y) + (1 - p)(\alpha x) \quad (\text{A18})$$

$$E\pi_I(a_I \neq \theta, a_U, w) = \sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_U(a_I = a_U \neq \theta, w) = p(\alpha x) + (1 - p)(\alpha y) \quad (\text{A19})$$

and:

$$E\pi_I(a_I = \theta, a_U, w) - E\pi_I(a_I \neq \theta, a_U, w) = \alpha(y - x)(2p - 1) > 0 \quad (\text{A20})$$

Hence, I's best response is to choose a location following the signal, which is consistent to U's belief that $\lambda > \lambda^*$.

Second, suppose $\lambda < \lambda^*$, so U diverges from I's choice. Then, from (A15) - (A16), I chooses a location following the signal. However, this is inconsistent to U's belief that $\lambda < \lambda^*$. Hence, this case is excluded.

Third, suppose $\lambda = \lambda^*$, so , U is indifferent between imitating and diverging from a_I . Suppose σ_U is the probability that U imitates I's choice. Then:

$$\begin{aligned} & E\pi_I(a_I = \theta, a_U, w) - E\pi_I(a_I \neq \theta, a_U, w) \quad (\text{A21}) \\ = & \sigma \left(\sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_U(a_I = a_U, w) \right) + (1 - \sigma) \left(\sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_U(a_I \neq a_U, w) \right) \\ & - \left(\sigma \left(\sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_U(a_I = a_U, w) \right) + (1 - \sigma) \left(\sum_{w \in \{N, S\}} \Pr(w | \theta = N) \pi_U(a_I \neq a_U, w) \right) \right) \\ = & (y - x)(2p - 1)(\alpha\sigma - \sigma + 1) \end{aligned}$$

It can be checked that $E\pi_I(a_I = \theta, a_U, w) = E\pi_I(a_I \neq \theta, a_U, w)$ only at $\sigma = \frac{1}{1-\alpha}$. But $\frac{1}{1-\alpha} \notin [0, 1]$ for $0 < \alpha < 1$. Hence, there exists no $\sigma \in [0, 1]$ which yields $E\pi_I(a_I = \theta, a_U, w) = E\pi_I(a_I \neq \theta, a_U, w)$.

Finally, I's best response in round 1 is to act so as to reveal his signal perfectly. Since U's belief must be correct in equilibrium, it must be $\lambda = 1$ and his strategy must be to diverge from a_I if $p < \bar{p}$ and to imitate a_I if $p > \bar{p}$, as stated in Proposition 1. \square

8.3 Proof of Proposition 2

Denote $z = \Pr(t_U = t_1)$ and $w = \Pr(t_I = t_1)$. Also, let $E_i(t_i = t_k)$ denote i 's expected payoff when he acts at round k , where $i \in \{I, U\}$ and $k \in \{1, 2\}$.

(1) Consider the case in which $\frac{1}{2} < p < \bar{p}$. From Table 2:

$$E_U [t_U = t_1] = w \left(-\frac{(p(y-x)(1-\alpha) - y - x\alpha)}{2} \right) + (1-w) \left(\frac{1}{2}(x+y) \right) \quad (\text{A22})$$

$$E_U [t_U = t_2] = w(y + px - py) + (1-w) \left(-\frac{(p(y-x)(1-\alpha) - y - x\alpha)}{2} \right) \quad (\text{A23})$$

Thus:

$$E_U [t_U = t_1] - E_U [t_U = t_2] = w \left(x\alpha - \frac{1}{2}y - \frac{1}{2}x - px\alpha + py\alpha \right) + \left(\frac{1}{2} \right) (x - px + py) (1 - \alpha) \quad (\text{A24})$$

For $p \in (\frac{1}{2}, \bar{p})$, $x\alpha - \frac{1}{2}y - \frac{1}{2}x - px\alpha + py\alpha < 0$. Hence U's best response for given w is:

$$w < w^* \implies z = 1, w = w^* \implies z \in [0, 1], w > w^* \implies z = 0 \quad (\text{A25})$$

where $w^* = \frac{(x-px+py)(\alpha-1)}{(2x\alpha-y-x-2px\alpha+2py\alpha)} \in (0, 1)$. Returning to Table 2 for I 's payoffs:

$$E_I [t_I = t_1] = z \left(\frac{1}{2}(x - px + py) (\alpha + 1) \right) + (1-z) (x - px + py) \quad (\text{A26})$$

$$E_I [t_I = t_2] = z \left(\frac{1}{2}(x + y) \right) + (1-z) \left(\frac{1}{2}(x - px + py) (\alpha + 1) \right) \quad (\text{A27})$$

Thus:

$$E_I [t_I = t_1] - E_I [t_I = t_2] = z \left(x\alpha - \frac{1}{2}y - \frac{1}{2}x - px\alpha + py\alpha \right) + \frac{1}{2} (x - px + py) (1 - \alpha) \quad (\text{A28})$$

Equation (A28) is identical to (A24). Hence, I 's best response for z is the same as U's one for w :

$$z < z^* \implies w = 1, z = z^* \implies w \in [0, 1], z > z^* \implies w = 0 \quad (\text{A29})$$

Finally, the intersection of the players' best response functions (A25) and (A29) yields that $(z, w) = (0, 1), (1, 0)$ and (z^*, w^*) – there exist two pure strategy equilibria $(t_U, t_I) = (t_2, t_1), (t_1, t_2)$ and one mixed strategy equilibrium $(z, w) = \left(\frac{(x-px+py)(\alpha-1)}{(2x\alpha-y-x-2px\alpha+2py\alpha)}, \frac{(x-px+py)(\alpha-1)}{(2x\alpha-y-x-2px\alpha+2py\alpha)} \right)$.

(2) Consider the case in which $\bar{p} \leq p < 1$. Table 3 gives U 's payoffs as:

$$E_U [t_U = t_1] = -\frac{(p(y-x)(1-\alpha) - y - x\alpha)}{2} \quad (\text{A30})$$

$$E_U [t_U = t_2] = w(\alpha(x - px + py)) + (1-w) \left(-\frac{(p(y-x)(1-\alpha) - y - x\alpha)}{2} \right) \quad (\text{A31})$$

Thus:

$$E_U [t_U = t_1] - E_U [t_U = t_2] = \frac{1}{2}w(p(-(y-x)(\alpha+1)) + y - x\alpha) \quad (\text{A32})$$

Note that for $\bar{p} \leq p < 1$, $p(-(y-x)(\alpha+1)) + y - x\alpha < 0$. So U's best response for w is:

$$w < 0 \implies z = 1, w = 0 \implies z \in [0, 1], w > 0 \implies z = 0 \quad (\text{A33})$$

Next, Table 3 gives I 's payoffs as:

$$E_I [t_I = t_1] = z \left(\frac{1}{2}(x - px + py) (\alpha + 1) \right) + (1-z) (\alpha(x - px + py)) \quad (\text{A34})$$

$$E_I [t_I = t_2] = \frac{1}{2}(x - px + py) (\alpha + 1) \quad (\text{A35})$$

Thus:

$$E_I [t_I = t_1] - E_I [t_I = t_2] = z \left(\frac{1}{2} (x - px + py) (1 - \alpha) \right) + \frac{1}{2} (x - px + py) (\alpha - 1) \quad (\text{A36})$$

Hence, I 's best response to the uninformed player is:

$$z > 1 \implies w = 1, \quad z = 1 \implies w \in [0, 1], \quad z < 1 \implies w = 0 \quad (\text{A37})$$

The intersections of both players' best response functions (A33) and (A37) yield that $z \in [0, 1]$ and $w = 0$. \square

8.4 Proof of Proposition 3

Case 1: When $\bar{p} \leq p < 1$: In equilibrium, $t_I = t_2$ and $z \in [0, 1]$ where $z = \Pr(t_U = t_1)$. From Table 3:

$$\sum_{i \in \{U, I\}} \pi_i(t_1, t_1) = \sum_{i \in \{U, I\}} \pi_i(t_1, t_2) = \sum_{i \in \{U, I\}} \pi_i(t_2, t_2) = \frac{1}{2} (x + y + 2x\alpha - 2px\alpha + 2py\alpha) \quad (\text{A38})$$

$$\sum_{i \in \{U, I\}} \pi_i(t_2, t_1) = 2\alpha (x - px + py) \quad (\text{A39})$$

The computation of (A38) and (A39) yields the following result: A) Suppose that $\frac{x+y}{2y} < \alpha < 1$. Then, if $\bar{p} < p < \frac{y+x-2x\alpha}{2\alpha(y-x)}$, (A38) $>$ (A39) but if $\frac{y+x-2x\alpha}{2\alpha(y-x)} < p < 1$, (A38) $<$ (A39). B) Suppose that $\frac{x}{y} < \alpha < \frac{x+y}{2y}$. Then, for all $p \in (\bar{p}, 1)$ (A38) $>$ (A39). First, assume that $\frac{x+y}{2y} < \alpha < 1$. If $\bar{p} < p < \frac{y+x-2x\alpha}{2\alpha(y-x)}$, the ex-ante efficient case is $(t_U, t_I) = (t_1, t_1)$, (t_1, t_2) or (t_2, t_2) . If U uses a pure strategy, i.e., $z \in \{0, 1\}$, the outcome is (t_1, t_2) or (t_2, t_2) , which is ex-ante efficient. If U uses a mixed strategy, i.e., $z \in (0, 1)$, then $E\pi_U = -\frac{(p(y-x)(1-\alpha)-y-x\alpha)}{2}$ and $E\pi_I = \frac{(x-px+py)(\alpha+1)}{2}$. So $E\pi_U + E\pi_I = \frac{1}{2} (x + y + 2x\alpha - 2px\alpha + 2py\alpha)$, which is also ex-ante efficient. Therefore, all equilibria are ex-ante efficient. On the other hand, if $\frac{y+x-2x\alpha}{2\alpha(y-x)} < p < 1$, the ex-ante efficient case is the one where $(t_U, t_I) = (t_2, t_1)$. Since $t_I = t_2$ in equilibrium, the equilibrium is not ex-ante efficient. Second, assume that $\frac{x}{y} < \alpha < \frac{x+y}{2y}$. Then, for all $p \in (\frac{1}{2}, 1)$, the ex-ante efficient case is $(t_U, t_I) = (t_1, t_1)$, (t_1, t_2) or (t_2, t_2) . From the analysis for the case where $\frac{x+y}{2y} < \alpha < 1$ and $\bar{p} < p < \frac{y+x-2x\alpha}{2\alpha(y-x)}$, all equilibria are ex-ante efficient.

Case 2: When $\frac{1}{2} < p < \bar{p}$: Recall that if $\frac{1}{2} < p < \bar{p}$, the equilibrium is $(t_U, t_I) = (t_1, t_2)$, (t_2, t_1) and the mixed strategy equilibrium (z^*, w^*) where $z = \Pr(t_U = t_1)$ and $w = \Pr(t_I = t_1)$. From Table 2,

$$\sum_{i \in \{U, I\}} \pi_i(t_1, t_1) = \sum_{i \in \{U, I\}} \pi_i(t_2, t_2) = \frac{1}{2} (x + y + 2x\alpha - 2px\alpha + 2py\alpha) \quad (\text{A40})$$

$$\sum_{i \in \{U, I\}} \pi_i(t_1, t_2) = \sum_{i \in \{U, I\}} \pi_i(t_2, t_1) = x + y \quad (\text{A41})$$

Comparison of (A40) and (A41) yields that for all $p \in (\frac{1}{2}, \bar{p})$, (A40) $<$ (A41). Therefore, for the ex-ante efficiency, the players must enter sequentially. Hence the pure-strategy equilibria $(t_U, t_I) =$

$(t_2, t_1), (t_1, t_2)$ are ex-ante efficient. As for the mixed strategy equilibrium, the computation yields that:

$$(E\pi_U + E\pi_I) - (x + y) \tag{A42}$$

$$= \frac{p^2 \left(2(y-x)^2 (\alpha^2 + 1) \right) + p \left(2(y-x) (x - y - x\alpha - y\alpha + 2x\alpha^2) \right) + (x^2 - 2xy\alpha + y^2 - 2x^2\alpha + 2x^2\alpha^2)}{2(2x\alpha - y - x - 2px\alpha + 2py\alpha)}$$

For $p \in \left(\frac{1}{2}, \bar{p}\right)$, the denominator is negative. The numerator is a convex function of p and it attains the minimum of $\frac{(x+y)^2(\alpha-1)^2}{2(\alpha^2+1)} > 0$. Therefore, for all $p \in \left(\frac{1}{2}, \bar{p}\right)$, $E\pi_U + E\pi_I < x + y$, which means that the mixed strategy equilibrium is ex-ante inefficient.

Then the above analysis can be summarized as follows:

Result:

- 1) Suppose that duopoly profit is low relative to monopoly profit, so $\frac{x}{y} < \alpha < \frac{x+y}{2y}$.
 - 1-1) If $p < \bar{p}$, both pure strategy equilibria are efficient and the mixed strategy equilibrium is not. (A1 in Figure 1)
 - 1-2) If $\bar{p} < p$, all equilibria are efficient. (A2 in Figure 1)
- 2) Suppose that duopoly profit is high relative to monopoly profit, so $\frac{x+y}{2y} < \alpha$.
 - 2-1) If $p < \bar{p}$, both pure strategy equilibria are efficient but the mixed strategy equilibrium is not. (A5 in Figure 1)
 - 2-2) If $\bar{p} < p < \frac{y+x-2x\alpha}{2\alpha(y-x)}$, all equilibria are efficient. (A4 in Figure 1)
 - 2-3) If $\frac{y+x-2x\alpha}{2\alpha(y-x)} < p$, all equilibria are inefficient. (A3 in Figure 1)

So we proved Proposition 3. \square

8.5 Proof of Lemma 2

Player U gains from a delay by being able to observe I's choice. Hence, $d_U = \pi_u^F - \pi_u^L = \pi_u^F - \pi_u^S$. Player I's gain from a delay is from preventing U from observing his choice. Hence, $d_I = \pi_I^F - \pi_I^L = \pi_I^S - \pi_I^L$. Then,

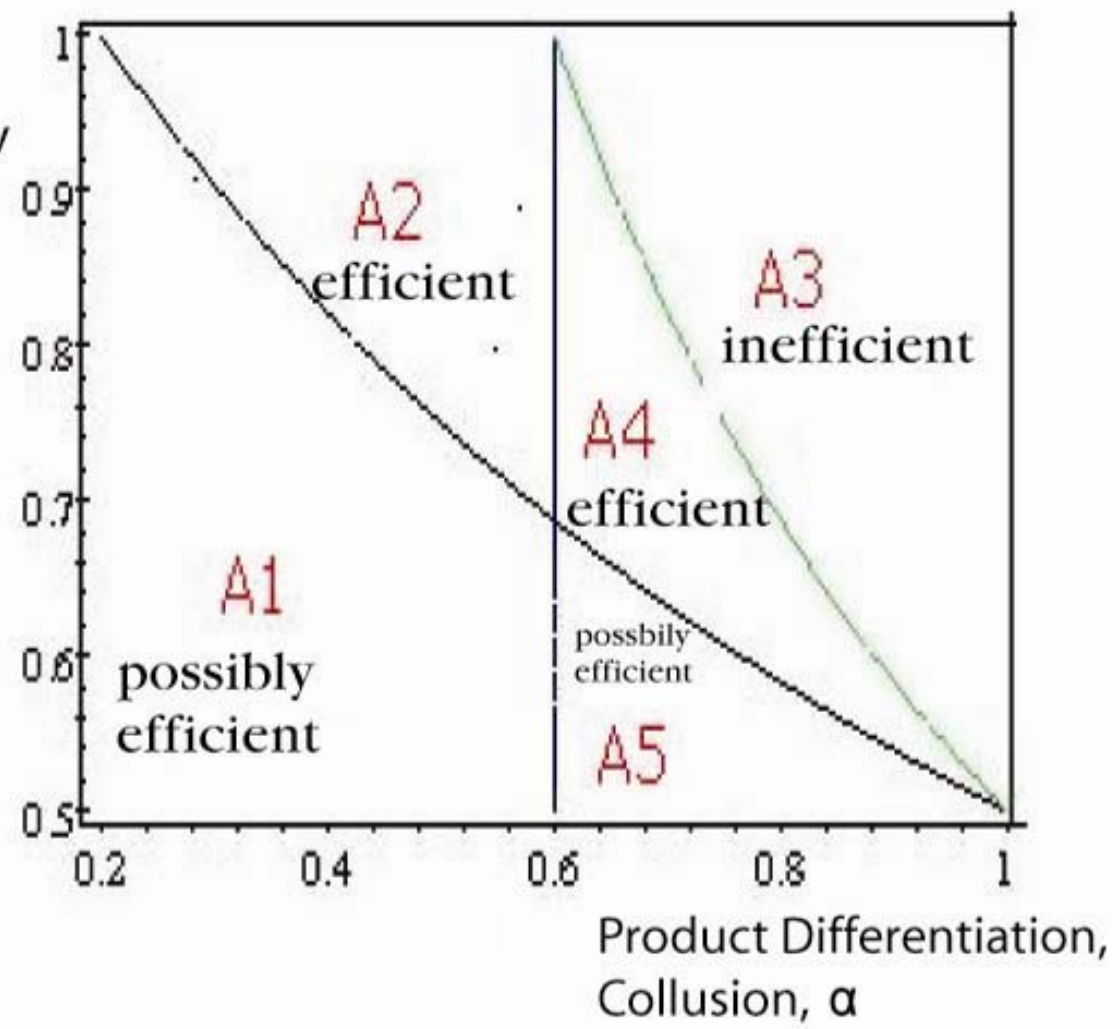
$$d_U - d_I = p(y\alpha - x\alpha) + x\alpha - \frac{1}{2}y - \frac{1}{2}x \tag{A46}$$

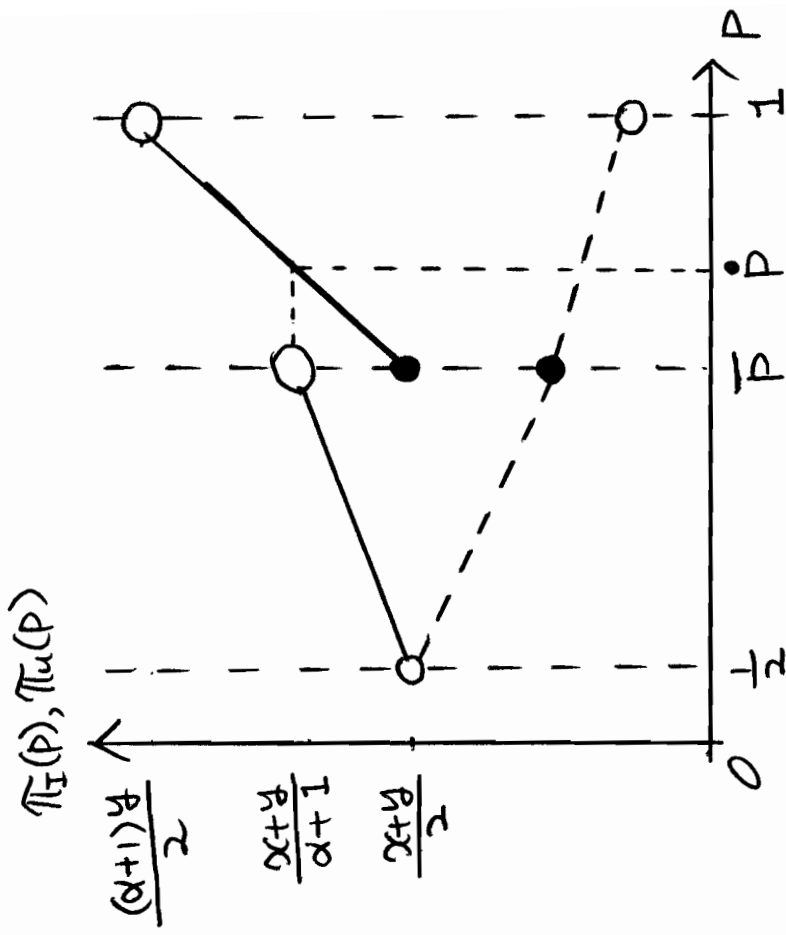
So, $p \geq \frac{(x+y-2x\alpha)}{2(y-x)\alpha} \implies d_U \geq d_I$. It is easily verified that: $\frac{(x+y-2x\alpha)}{2(y-x)\alpha} > \frac{1}{2}$ and $\frac{(x+y-2x\alpha)}{2(y-x)\alpha} > \bar{p} \equiv \frac{y-x\alpha}{(y-x)(\alpha+1)}$. However, $\frac{(x+y-2x\alpha)}{2(y-x)\alpha} - 1 = -\frac{(2y\alpha-y-x)}{2(y-x)\alpha}$. Here, $2y\alpha - y - x$ is an increasing function of α . Also, from the condition that $\alpha y > x$, we know $\frac{x}{y} < \alpha$. Then, $2y\alpha - y - x|_{\alpha=\frac{x}{y}} < 0$ and $2y\alpha - y - x|_{\alpha=1} > 0$. Hence, there exists $\alpha^* = \frac{x+y}{2y} \in \left(\frac{x}{y}, 1\right)$ such that if $\alpha \in \left(\frac{x}{y}, \alpha^*\right)$, $\frac{(x+y-2x\alpha)}{2(y-x)\alpha} > 1$ and if $\alpha \in (\alpha^*, 1)$, $\frac{(x+y-2x\alpha)}{2(y-x)\alpha} < 1$. Finally, if $\alpha \in \left(\frac{x}{y}, \alpha^*\right)$, $d_U < d_I$ for all $p \in (\bar{p}, 1)$. On the other hand, if $\alpha \in (\alpha^*, 1)$, for $p \in \left(\bar{p}, \frac{(x+y-2x\alpha)}{2(y-x)\alpha}\right)$, $d_U < d_I$ and if $p \in \left(\frac{(x+y-2x\alpha)}{2(y-x)\alpha}, 1\right)$, $d_U > d_I$. \square

8.6 Proof of Proposition 4

Note that $\pi_I(t_U = t_2, t_I = t_1)|_{p < \bar{p}} = (x - px + py)$ and $\pi_I(p)|_{p > \bar{p}} = \frac{(x - px + py)(\alpha + 1)}{2}$. Then, a) Both $\pi_I(t_U = t_2, t_I = t_1)|_{p < \bar{p}}$ and $\pi_I(p)|_{p > \bar{p}}$ are monotone increasing functions, b) $\pi_I(t_U = t_2, t_I = t_1)|_{p = \frac{1}{2}} = \frac{1}{2}(x + y)$, c) $\pi_I(t_U = t_2, t_I = t_1)|_{p = \bar{p}} = \frac{(x + y)}{(\alpha + 1)}$, d) $\pi_I(p)|_{p = \frac{y - x\alpha}{(y - x)(\alpha + 1)}} = \frac{1}{2}(x + y)$, e) $\pi_I(p)|_{p = 1} = \frac{1}{2}(\alpha + 1)y$, f) $\pi_I(t_U = t_2, t_I = t_1)|_{p = \bar{p}} > \pi_I(p)|_{p = \bar{p}}$, and g) $\pi_I(t_U = t_2, t_I = t_1)|_{p = \bar{p}} - \pi_I(p)|_{p = 1} = -\frac{(2y\alpha - y - 2x + y\alpha^2)}{2(\alpha + 1)}$. In g), if we let $A(\alpha) \equiv 2y\alpha - y - 2x + y\alpha^2$, it is a convex function and attains the Min value at $\alpha = -1$ where $A(\alpha = -1) < 0$. Also $A(\alpha = 0) < 0$ and $A(\alpha = 1) > 0$. Hence there exists $\bar{\alpha}$ such that if $0 < \alpha < \bar{\alpha}$, $\pi_I(t_U = t_2, t_I = t_1)|_{p = \bar{p}} > \pi_I(p)|_{p = 1}$ and if $\bar{\alpha} < \alpha < 1$, $\pi_I(t_U = t_2, t_I = t_1)|_{p = \bar{p}} < \pi_I(p)|_{p = 1}$. Therefore, if $0 < \alpha < \bar{\alpha}$, he pick $p = \bar{p} - \epsilon$ and if $\bar{\alpha} < \alpha < 1$, he picks $p = 1 - \epsilon$. Here, $\bar{\alpha} = \frac{1}{y} \left(\sqrt{2} \sqrt{xy + y^2} - y \right)$. Figure 2 represents this result. \square

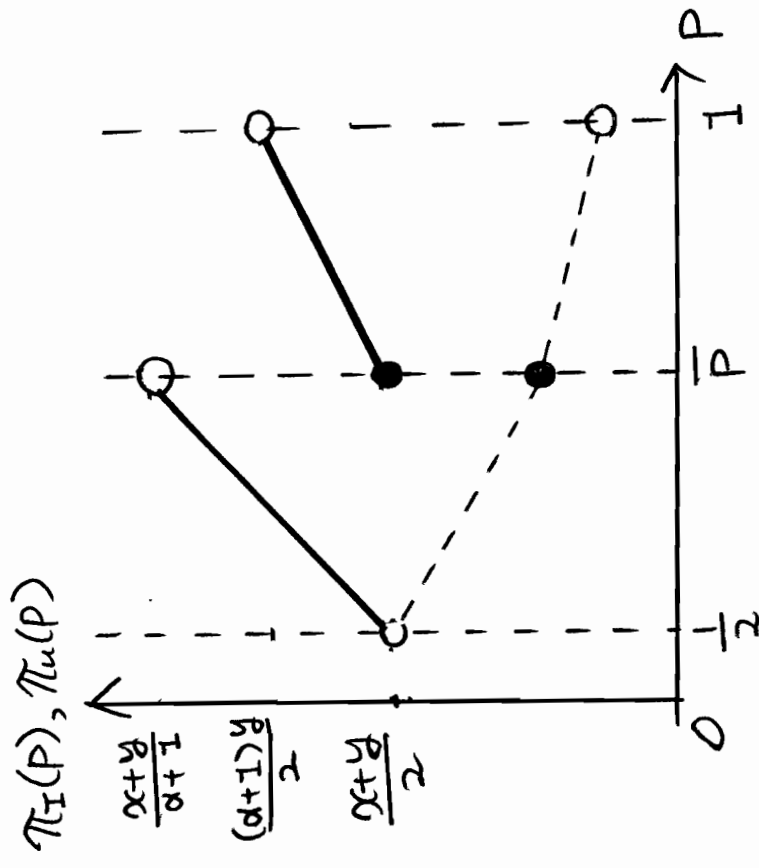
Information quality
 p





{ — ; $\pi_I(P)$
 { - - - ; $\pi_u(P)$

When $\alpha^* < \alpha < 1$

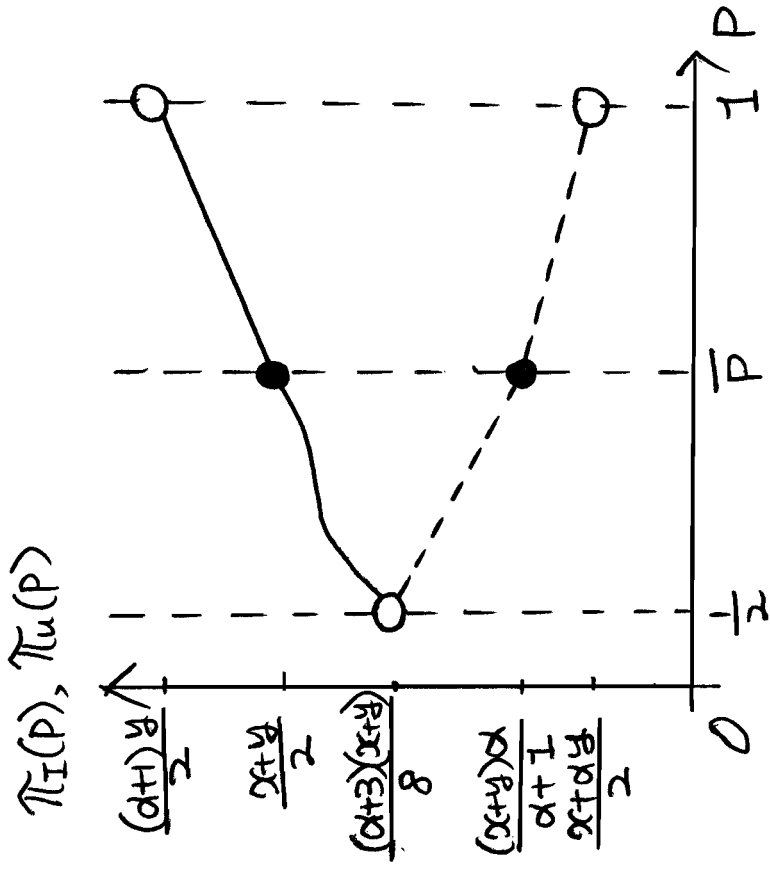


{ — ; $\pi_I(P)$
 { - - - ; $\pi_u(P)$

When $0 < \alpha < \alpha^*$

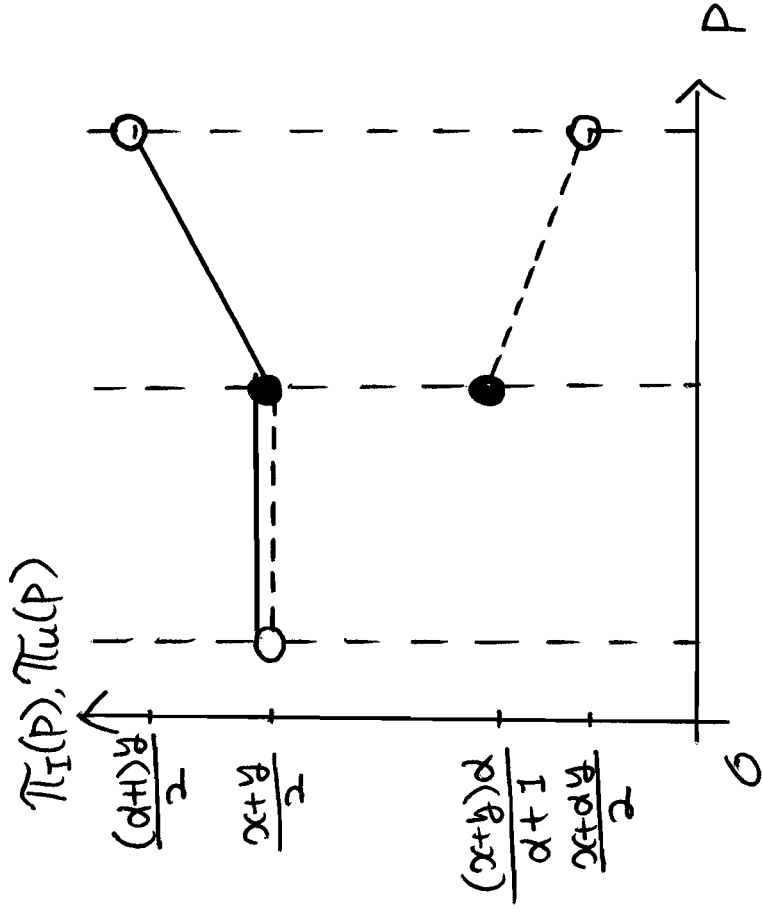
$(t_u, t_I) = (t_2, t_1)$ when $P < \bar{P}$

< Figure 2 >



$\begin{cases} \text{---} & ; \pi_I(P) \\ \text{- - -} & ; \pi_U(P) \end{cases}$

Mixed Eq when $P < \bar{P}$



$\begin{cases} \text{---} & ; \pi_I(P) \\ \text{- - -} & ; \pi_U(P) \end{cases}$

$(t_u, t_I) = (t_1, t_2)$ when $P < \bar{P}$

< Figure 3 >

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