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

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Abstract

Is it better to move first, or second— to innovate, or to imitate? Suppose two players, one with superior information about market quality, consider entering one of two new markets immediately or waiting until the last possible date. We show that the more accurate the informed player's information, the more he wants to delay to keep his information private. The less-informed player also wants to delay, but in order to learn. The less accurate the informed player's information, the more both players want to move first to foreclose the market. More accurate information can thus lead to inefficiency by increasing the players' incentive to delay.

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1 Introduction

Some companies are better than others at introducing new products or entering new markets. One kind of advantage is technological– some companies can serve customers at lower cost. Another kind of advantage is informational– some companies are better at predicting which new products or markets will be profitable. If this advantage is known, though, it brings with it the peril of attracting imitation. If Burger King knows that McDonald's is better at marketing research, it might follow McDonald's entry into a new town, free riding on its information. If Airbus knows that Boeing has an advantage in gauging the strength of demand (or the cost of development) for a new superjumbo class of jets, Airbus may imitate Boeing's entry into that market. Entering first, however, can result in preemption, a concern very much in the minds of Airbus and Boeing when they actually did consider entering that market in the 1990's (see Esty & Ghemawat (2002)). A firm with information that a new market will be profitable must choose its entry time and announcement date 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 in game theory, the subject of an extensive literature that we will later discuss. discuss below. The choice of when to move has most commonly been seen as a question of whether it is better to commit or to outbid– of whether actions are strategic substitutes or strategic complements.

Uncertainty is another reason to delay. There are two dimensions to uncertainty: when it is resolved, and whether information is asymmetric. 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, the less-informed player wants to delay so as to observe the better-informed player's move and learn from it. The better- informed player wants to delay to keep his information private. We will look at the conflict between these two motivations.

In our model, 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 a 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 big market. Instead, they might both end up in the small 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, the greater precision of information can lead to inefficiency. More precise information increases the informed player's incentive to conceal through delay.

Industry profits fall because this prevents both players from being in the market most likely to be large.

2 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. In the first period they choose simultaneously to enter North, enter South, or wait. If only one player waits, he cannot observe profits, which are received only at the end of the game. 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.

		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 $0 < \alpha < 1$)

If 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 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.

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 (though perhaps not if he were unsure).

The common prior is that both markets are equally likely to be the big market. Before the first period, the informed player observes the signal $\theta \in \Theta = \{N, S\}$ which correct identifies the big market with probability $p \geq \frac{1}{2}$. 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

$$s_I = (t_I(\theta), a_I(\theta|t_I = t_1), a_I(\theta|t_I = t_U = t_2), a_I(\theta|t_U = t_1, t_I = t_2)) \tag{1}$$

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

$$s_U = (t_U, a_U|(t_U = t_1), a_U|(t_I = t_U = t_2), a_U(a_I|t_I = t_1, t_U = t_2)) \tag{2}$$

since he observes no signal. We also 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.

One particular value of p is critical for determining the equilibrium, so let us define:

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

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

We have not yet specified the timing of moves. In Section 3 which firm enters first is exogenous; in Section 4 it will be endogenous.

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.[1]

The possible exogenous-timing games are (1) the players move simultaneously, (2) the uninformed player moves first, and (3) the informed player moves first. Proposition 1 says what happens in the equilibrium of each game.

[1] xxx I think if there's poor information and the players enter simultaneously, then if the Uninformed player always entered Market North instead of randomizing the players would have higher payoffs than if he randomizes, because they can discoordinate.

When the uninformed player does not move after the informed player, he has no information at all and is indifferent about which market he enters. Different equilibria will result, however, depending on whether his strategy is then to flip a coin or instead is to always enter a particular market. Let us denote the probability that the uninformed player chooses $North$ when he has no information by q. Without loss of generality assume that $q \geq .5$.

Proposition 1.
1) Consider the perfect bayesian equilibria of the entry game when timing is exogenous.
1) Suppose entry is simultaneous. If $q \leq q^* = xxx$, the informed player uses his signal and the informed player is indifferent about which market he chooses.
2) Suppose entry is sequential.
2-1) If the uninformed player chooses first and $q < q^*$, he is indifferent about which market he chooses. The informed player uses the signal if $p > \overline{p}$, chooses the opposite of the uninformed player if $p < \overline{p}$, and is indifferent if $\overline{p} = p$.
2-2) If the informed player chooses first, he uses the signal. The uninformed player imitates him if if $p > \overline{p}$, chooses the opposite of the informed player if $p < \overline{p}$, and is indifferent if $\overline{p} = p$.

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., $p < \overline{p}$, 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., $p \in (\overline{p}, 1)$, 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 other player's information quality is low, the uninformed player thinks mainly of avoiding competition and diverges in his choice of market.

From (5), it can be checked that

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

As the large market size y increases, the parameter set for which $p \in (\overline{p}, 1)$ 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 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 $p \in (\overline{p}, 1)$ 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, 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 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, (7) or (8), depending on whether the uninformed player will have a chance to observe him 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:

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

If, however, the uninformed player has no chance to infer the informed player's signal, he chooses a_U only using his prior, and we have assumed he randomizes 50-50. Hence, the informed player's expected payoff is:

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

These two equations cover the four possible combinations of timing. Payoff (7) is for $(t_U, t_I) = (t_2, t_1)$ and payoff (8) 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:

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

Here, note that 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_U	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_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 Depending on the Period of Entry When the Signal Is Imprecise: $\frac{1}{2} < p < \overline{p}$

		t_I	
		t_1	t_2
t_U	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_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 Depending on the Period of Entry when the Signal Is Precise: $\overline{p} < p < 1$

We will use Tables 2 and 3 to find the equilibrium when firms choose their times of entry endogenously.

4 Endogenous Timing of Entry

4.1 First-Mover and Second-Mover Advantage

Now we will find the conditions under which a player wishes to enter first. 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.

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

$$\pi_U^S < \pi_U^F < \pi_U^L \text{ and } \pi_I^S < \pi_I^F < \pi_I^L \tag{8}$$

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 ($\alpha > x/y$). As the follower, he can operate as a monopolist in one market by diverging from the leader. This follower behavior is why equation (10) 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 other 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 he believes is likely to be small. Though if he chooses the signalled market the most likely outcome is duopoly in the big market, which is better than duopoly in the small market, it might 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 payoff from sharing the market is lower than 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 weak 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 $p > \overline{p}$, Table 3 tells us that:

$$\pi_U^S = \pi_U^L < \pi_U^F \text{ and } \pi_I^L < \pi_I^S = \pi_I^F \tag{9}$$

Expression (11) 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 value. Hence, his expected profits are the same in both cases.

Thus, if information precision is relatively low, there is a first- mover advantage; but if information precision is high, there is a second- mover advantage. If $p < \overline{p}$, 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 $p > \bar{p}$, 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. *When entry timing is endogenous, then:*
1) If information is precise enough, i.e., $p > \bar{p}$, there is a second-mover advantage. In equilibrium, 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., $p \leq \bar{p}$, there is a first-mover advantage. There are two pure-strategy equilibria, one for each of two players entering first, and a mixed strategy equilibrium in which the informed player enters without delay with probability z and the uninformed player enters without delay with probability w:

$$(z, w) = \left(\frac{(x - px + py)(\alpha - 1)}{(2x\alpha - y - x - 2px\alpha + 2py\alpha)}, \frac{(x - px + py)(\alpha - 1)}{(2x\alpha - y - x - 2px\alpha + 2py\alpha)} \right) \tag{10}$$

Proof: *In the appendix.*

The signal's precision is high if $p > \bar{p}$. 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 $p \leq \bar{p}$. 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 $p \leq \bar{p}$ 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), and 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:

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

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

$$\frac{\partial z}{\partial y} = \frac{\partial w}{\partial y} = \frac{(1-\alpha)(2p-1)\,x}{(2x\alpha - y - x - 2px\alpha + 2py\alpha)^2} > 0 \tag{13}$$

Inequality (13) 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 (14) and (15) 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 ($p > \overline{p}$). 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 the 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: [2]

$$\alpha \geq \frac{x+y}{2[py+(1-p)x]} \quad \text{or} \quad p \geq \frac{y+x-2x\alpha}{2\alpha(y-x)} \tag{14}$$

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 now too, as shown in equation (16). Proposition 4 characterizes ex-ante efficiency using both α and p.

Proposition 4. *Ex-ante efficiency depends on the ratio of duopoly profit to monopoly profit* (α) *and the quality of information* (p) *as follows.*
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.*
1-1) If $p < \overline{p}$, *both pure strategy equilibria are efficient and the mixed strategy equilibrium is not. (A1 in Figure 1)*
1-2) If $\overline{p} < p$, *all equilibria are efficient. (A2 in Figure 1)*
2) Suppose that duopoly profit is high relative to monopoly profit, so $\frac{x+y}{2y} < \alpha$. *Then improved information can lead to the inefficient equilibria.*
2-1) If $p < \overline{p}$, *both pure strategy equilibria are efficient but the mixed strategy equilibrium is not. (A5 in Figure 1)*

[2] When 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 $2\alpha(py+(1-p)x) \geq x+y$.

2-2) If $\overline{p} < p < \frac{y+x-2x\alpha}{2\alpha(y-x)}$*, 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)*

Proof: *In the appendix.*

Figure 1: Information Quality, Market Size, and Efficiency for $x = 1$ and $y = 5$
(*see end of paper*)

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 $p = \overline{p}$ 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 greater information precision. 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 The Literature

The Stackelberg model is an early model of first-mover advantage, a sequential-move quantity game in which the first mover, by committing to a large quantity, gains a profit advantage over the second mover compared to in the simultaneous-move Cournot model. Eric van Damme & S. Hurskens (1999, 2004) are examples of two recent articles on this kind of question: whether a player would prefer to move first or second in various games in which both players are already in the market and the choice variables are price or quantity. They show that in the risk-dominant equilibrium, the high-cost player will choose to wait and the low-cost player will emerge as the endogenous Stackelberg leader. In this class of model, however, informational externalities play no role.

Another 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 (2004) on clock games). Bouis, Huisman & Kort (2006) adds 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 step is for entry to reveal information. Gal-Or (1987) shows that a player with superior information on demand may prefer ex ante to have to move simultaneously rather than first, to avoid revealing his knowledge that demand is strong by choosing c high output (though George 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). Hans-Theo Normann (1997, 2002) also looks at what happens when one duopolist is better informed when he makes his quantity decision. Levin & Peck (2003) looks 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. Here, our two major concerns have been (1) what happens when the well-informed player turns out to be wrong after all (since he has imperfect information), and (2) whether entry in two markets is more efficient than entry in one.

In other models, players are symmetric but the first player's move creates new information. In Rafael Rob (1991), entry has an informational and payoff externality, but the players are not asymmetrically informed, and the market is competitive. The timing of actions is given exogenously, and the focus is on the second mover's advantage from seeing what happens to the first mover. Rob does not analyze the possible advantage to moving second to prevent the other player from learning. Patrick Bolton & Chris Harris, Midori Hirokawa & Dan Sasaki (2001) and Heidrun Hoppe (2000) also look at what happens when the first mover's move reveals something about the state of the world, as opposed to something about the first mover's information. 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.

Appelbaum and Lim (1985), Spencer and Brander (1992), and Somma (1999) also deal with the topic of market preemption and delay. Their focus is the tradeoff 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 these models, the uncertainty is not resolved till both firms make their choices. so delay doesn't help.

Another setting has players asymmetrically informed, but without any payoff externality, e. g. Christopher Chamley and Douglas Gale (1994) and Jianbo Zhang (1997), which discuss strategic delay and the endogenous timing of action when there are informational externalities but no payoff externalities from one player choosing the same action as another. In Chamley and Gale (1994), a player has an incentive to delay his action to observe other players' decisions 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. He acts as the leader, and other players mimic him immediately. In these models, although the action timing is endogenous, there are not payoff externalities from actions. Each player's main concern is whether the cost of delay is worth learning other players' information.

Two papers look at the combination of assumptions in the present paper: both informational and payoff externalities:Yoon (2006) and Frisell (2003).

Yoon (2006) has worse-informed player who delays to learn and a better-informed player who delays to prevent learning in a war of attrition. Although both players benefit from being the follower, the gain from learning is greater than from preventing learning, so the leader is the better-informed player. The payoff functions are different from the present paper's. Although the best outcome is to be correct alone (as here), the worst outcome is to be incorrect alone, not to be incorrect in company with the other player. 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. It also is why the relative magnitude of the gain from learning and the gain from preventing learning will depend on the business environment in the present model.

Frisell (2003) asks whether a less informed will enter first in a war of attrition. He finds that the informed player enters first. If duopoly profit is enough lower, however, the informed player waits longer. What matters is the ratio of duopoly to monopoly profits, not the degree of information superiority. Delay costs are crucial, but delay can be infinitely long.

In our paper, on the other hand, players must decide to enter either early, or late; one player cannot simply outwait the other. If he waits, the result will be simultaneous choices. As a result, i a player who moves late must be concerned about ending up in the same market as his rival by accident, even if he has prevented purposeful imitation. A deadline models either the closing of the entry opportunity or the necessity of choosing which market to enter without having observed the other player's decision. 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.

6 Concluding Remarks

Often, a player must make a choice knowing that the 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 his 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 strategy 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.

7 Appendix

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

7.1 Proof of Proposition 1

First, consider the case where the entry is simultaneous. In this case, it is obvious that U chooses randomly between N and S because no additional information is observable except his prior belief that $\Pr(w = N) = \Pr(w = S) = .5$. Now, as for the best response of I, without loss of generality, assume that $\theta = N$. Then,

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

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

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

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

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

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

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

where $(A4)$ is I's expected payoff when he uses his signal and $(A5)$ is the one when he deviates from his signal. Then, if $p \gtreqless \frac{(x\alpha - y)}{(\alpha+1)(x-y)} = \overline{p}$, $E\pi_I(a_I = \theta, a_U, w) \gtreqless E\pi_I(a_I \neq \theta, a_U, w)$ where $\overline{p} \in \left(\frac{1}{2}, 1\right)$.

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

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

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

Thus, if $p > \frac{(y\alpha - x)}{(\alpha+1)(y-x)}$, $(A6) > (A7)$ and if $p < \frac{(y\alpha - x)}{(\alpha+1)(y-x)}$, $(A6) < (A7)$. However, $\frac{(y\alpha - x)}{(\alpha+1)(y-x)} - \frac{1}{2} = \frac{(\alpha-1)(x+y)}{2(\alpha+1)(y-x)} < 0$. Hence, for all $p \in \left(\frac{1}{2}, 1\right)$, $(A6) > (A7)$.
Therefore, I's best response is as follows: If $p > \frac{(x\alpha - y)}{(\alpha+1)(x-y)} = \overline{p}$, regardless of U's choice in round 1, I uses his signal. On the other hand, when $p < \overline{p}$, 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 some 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

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

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

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

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

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

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

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

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

$$E\pi_U\left(a_I \neq \theta, a_U, w\right)$$

$$= \lambda \left(\sum_{w \in \{N,S\}} \Pr(w|\,\theta = N)\pi_U\left(a_U \neq a_I, w\right) \right) + (1-\lambda) \left(\sum_{w \in \{N,S\}} \Pr(w|\,\theta = S)\pi_U\left(a_I \neq a_U, w\right) \right) \quad \text{(A13)}$$

Consequently,

$$\lambda \gtreqqless \lambda^* \Longrightarrow E\pi_U\left(a_U = a_I, w\right) \gtreqqless E\pi_U\left(a_U \neq a_I, w\right) \quad \text{(A14)}$$

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 $p \in \left(\frac{1}{2}, \overline{p}\right)$ *. Then, for all* $\lambda \in [0,1]$*, U diverges from I's choice.*
b) Suppose that $p \in (\overline{p}, 1)$*. 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 $p > \frac{y\alpha - x}{(y-x)(\alpha+1)}$, $\lambda^* > 0$ and if $p < \frac{y\alpha - x}{(y-x)(\alpha+1)}$, $\lambda^* < 0$. 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 $p \in \left(\frac{1}{2}, 1\right)$, $\lambda^* > 0$. Also, from $\lambda^* - 1 = \frac{(y + px - py - x\alpha + px\alpha - py\alpha)}{(\alpha+1)(2p-1)(y-x)}$, if $p > \frac{y - \alpha x}{(y-x)(\alpha+1)}$, $\lambda^* > 1$ and if $p < \frac{y - \alpha x}{(y-x)(\alpha+1)}$, $\lambda^* < 1$ where $\frac{y - \alpha x}{(y-x)(\alpha+1)} \in \left(\frac{1}{2}, 1\right)$. Therefore, we can summarize as follows: a) If $p \in \left(\frac{1}{2}, \frac{y - \alpha x}{(y-x)(\alpha+1)}\right)$ then for all $\lambda \in [0,1]$, $E\pi_U(a_U = a_I) < E\pi_U(a_U \neq a_I)$. b) If $p \in \left(\frac{y - \alpha x}{(y-x)(\alpha+1)}, 1\right)$ then if $\lambda > \lambda^*$, $E\pi_U(a_U = a_I) > E\pi_U(a_U \neq a_I)$, if $\lambda < \lambda^*$, $E\pi_U(a_U = a_I) < E\pi_U(a_U \neq a_I)$, and if $\lambda = \lambda^*$, $E\pi_U(a_U = a_I) = E\pi_U(a_U \neq a_I)$. □

Let us now return to the informed player'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 $p \in \left(\frac{1}{2}, \overline{p}\right)$. In this case, U chooses a location different from I's choice for all $\lambda \in [0,1]$. Then

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

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

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 $p \in (\overline{p}, 1)$. 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:

$$E\pi_I(a_I = \theta, a_U, w) - E\pi_I(a_I \neq \theta, a_U, w) \quad \text{(A21)}$$

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

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

$$= (y - x)(2p - 1)(\alpha\sigma - \sigma + 1)$$

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 $p < \overline{p}$ and to imitate a_I if $p > \overline{p}$, as stated in Proposition 1. □

7.2 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 $\frac{1}{2} < p < \overline{p}$. From Table 2:

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

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

Thus:

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

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

$$w < w^* \implies z = 1,\ w = w^* \implies z \in [0,1],\ w > w^* \implies z = 0 \tag{A25}$$

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:

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

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

Thus:

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

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

$$z < z^* \implies w = 1,\ z = z^* \implies w \in [0,1],\ z > z^* \implies w = 0 \tag{A29}$$

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 $\overline{p} < p < 1$. Table 3 gives U's payoffs as:

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

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

Thus:

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

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

$$w < 0 \implies z = 1, w = 0 \implies z \in [0,1], w > 0 \implies z = 0 \tag{A33}$$

Next, Table 3 gives I's payoffs as:

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

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

Thus:

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

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

$$z > 1 \Longrightarrow w = 1,\ z = 1 \Longrightarrow w \in [0,1],\ z < 1 \Longrightarrow w = 0 \tag{A37}$$

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

7.3 Proof of Proposition 4

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

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

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

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 $E\pi_U + E\pi_I = \frac{1}{2}\left(x + y + 2x\alpha - 2px\alpha + 2py\alpha\right)$, 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 $p \in \left(\frac{1}{2}, 1\right)$, 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 $\frac{1}{2} < p < \overline{p}$, 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 $w = \Pr(t_I = t_1)$.[3] From Table 2,

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

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

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

Comparison of (A40) and (A41) yields that for all $p \in \left(\frac{1}{2}, \overline{p}\right)$, $(A40) < (A41)$. 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:

$$\begin{aligned} &(E\pi_U + E\pi_I) - (x+y) &\text{(A42)} \\ &= \frac{p^2\left(2(y-x)^2\left(\alpha^2+1\right)\right) + p\left(2(y-x)\left(x - y - x\alpha - y\alpha + 2x\alpha^2\right)\right) + \left(x^2 - 2xy\alpha + y^2 - 2x^2\alpha + 2x^2\alpha^2\right)}{2\left(2x\alpha - y - x - 2px\alpha + 2py\alpha\right)} \end{aligned}$$

For $p \in \left(\frac{1}{2}, \overline{p}\right)$, 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 $p \in \left(\frac{1}{2}, \overline{p}\right)$, $E\pi_U + E\pi_I < x + y$, which means that the mixed strategy equilibrium is ex-ante inefficient. □

7.4 Proof of Proposition 5

Denote $z = \Pr(t_U = t_1)$ and $w = \Pr(t_I = t_1)$. Also, denote $E_i(t_i = t_k)$ as i's expected payoff when he acts at round k where $i \in \{U, I\}$ and $k \in \{1, 2\}$. From Table 2 and (A24):

$$E_U\left[t_U = t_1\right] - E_U\left[t_U = t_2\right] = w\left(x\alpha - \frac{1}{2}y - \frac{1}{2}x - px\alpha + py\alpha\right) + \left(\frac{1}{2}\right)(x - px + py)(1-\alpha) + c \quad \text{(A43)}$$

As $x\alpha - \frac{1}{2}y - \frac{1}{2}x - px\alpha + py\alpha < 0$ for $p \in \left(\frac{1}{2}, \frac{y - x\alpha}{(y-x)(\alpha+1)}\right)$,

$$w < w_1^* \Longrightarrow z = 1, w = w_1^* \Longrightarrow z \in [0,1], w > w_1^* \Longrightarrow z = 0 \quad \text{(A44)}$$

where $w_1^* = \frac{(x-px+py)(\alpha-1)-2c}{(2x\alpha-y-x-2px\alpha+2py\alpha)}$. It can be checked that the numerator is also negative, so $w^* > 0$. Also, $w_1^* - 1 = -\frac{(2c-y-px+py+x\alpha-px\alpha+py\alpha)}{(2x\alpha-y-x-2px\alpha+2py\alpha)}$ which has a negative denominator. Then, if $c > c^*$, the numerator is positive and if $c < c^*$, it is negative where $c^* = \frac{1}{2}(y + px - py - x\alpha + px\alpha - py\alpha)$. Hence, for $p \in \left(\frac{1}{2}, \frac{y-x\alpha}{(y-x)(\alpha+1)}\right)$, if $c > c^*$, $w_1^* > 1$ and if $0 < c < c^*$, $w_1^* < 1$. Thus, U's best response function is: a) If $c > c^*$, $z = 1$. b) If $c < c^*$, it is (A44). Using an analogous procedure, it can be checked that I's best response function is as follows: a) If $c > c^*$, $w = 1$. b) If $c < c^*$,

$$z < z_1^* \Longrightarrow w = 1, z = z_1^* \Longrightarrow w \in [0,1], z > z_1^* \Longrightarrow w = 0 \quad \text{(A45)}$$

Then the equilibrium is: a) If $c > c^*$, $(z, w) = (1, 1)$, b) If $c < c^*$, $(z, w) = (0, 1), (1, 0)$ and (z, w) where $z = w = \frac{(px-x-2c-py+x\alpha-px\alpha+py\alpha)}{(2x\alpha-y-x-2px\alpha+2py\alpha)}$. □

7.5 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,

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

So, if $p > \frac{(x+y-2x\alpha)}{2(y-x)\alpha}$, $d_U > d_I$ and if $p < \frac{(x+y-2x\alpha)}{2(y-x)\alpha}$, $d_U < d_I$. 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 $p \in \left(\frac{(x+y-2x\alpha)}{2(y-x)\alpha}, 1\right)$, $d_U > d_I$. $\square$

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