How to Promote Quality Perception in Wine Markets: Brand Advertising or Geographic Indication?

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Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Long Beach, California, July 23-26, 2006

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May 30, 2006

Abstract: In the context of the wine industry, we investigate producers' choice between geographic indications and brand advertising to convey information to consumers. Producers also decide whether or not to select an effort level for improving the quality of their products. We show that if this effort is selected, a producer will prefer to rely on brand advertising for promoting its products and set up its own reputation. Despite the sharing of the promotion cost, a geographic indication does not sufficiently reward the effort for improving quality. Finally, the selection of both instruments by producers is examined.

Key words: Geographic indication, GI, brand advertising, effort, wine, quality.

JEL Classification: L15, L66, Q13

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Introduction

Wine promotion has been recently modified with the emergence of “new-world” wine from Australia, California, and Chile. Wineries from these countries mainly use individual brand advertising (BA) to promote quality perception, while more traditional European wineries mainly rely on geographic indications (GI) for signaling the quality of their products. Foreign consumers in Europe are often baffled by the profusion of wine GIs. Reliance on GI to promote food and beverage products is widespread in Europe not only for wine but also for cheese, meat, etc. For instance, nearly seven hundred products are registered under the European designations system, either under the so-called Protected Designation of Origin and Protected Geographical Indication (EC, 2006). These differences raise the issue of the efficiency of the GI system for promoting food products relative to the merit of BA.

We analyze the complex interaction between BA and GI, and rewards to quality improvements. We identify the relative effectiveness of GI and BA to reward producers[1] for improvements in quality of their products, using a stylized framework linking product promotion and quality effort. In a two-period model, GI and BA enhance the quality perception and the willingness to pay of consumers. The BA allows a producer to develop an individual reputation. The GI allows producers to share the promotion cost and to develop a common reputation. Besides the choice of GI or BA, producers choose whether or not to make an effort to improve the overall quality level that affects the consumers’ purchase decision in second period. Both signal and effort strategies influence the producers’ profits.

Wine production is notoriously stochastic with “good” and “bad” years and taste attributes vary. New technologies allow to control the consistency of taste attributes (e.g.,

[1] Producers denote the supply chain (producers, wineries, firms) supplying wine to consumers.

controled fermentation, varietal mix, and use of wood chips). These improvements are what we have in mind when we think of the effort to improve quality. We show that if the effort for improving quality is selected, a producer will prefer to rely on BA for promoting its products and set up its own reputation. Despite the sharing of the promotion cost, a GI does not sufficiently reward the effort for improving quality because of the common reputation. Conversely, when the producer avoids the effort, the GI is selected. Producers take advantage of sharing of the promotion cost under collective reputation.

The present paper is linked to two separate strands of the literature. The first strand includes numerous papers on quality signaling. The latter mainly considers prices (e.g., Mahenc, 2004) or advertising (e.g., Fluet and Garella, 2002) to signal higher quality. The second and more recent strand focuses on GI and collective reputation (e.g., Marette and Crespi, 2003; Zago and Pick, 2004; and Winfree and McCluskey, 2005). In this literature, producers' coordination or even price collusion via a GI may be necessary to improve quality when the fixed costs of certification or quality improvements are large. Our framework differs since we simplify the consumers' belief in higher quality by considering GI and BA as persuasive tools that change consumers' preferences. In addition, our framework contributes to the more recent strand of literature. Here, we abstract from any price collusion linked to the GI and introduce the possibility that producers chose to use brand. Indeed, our paper addresses the question of the relative efficiency of collective reputation compared to that of a private brand.

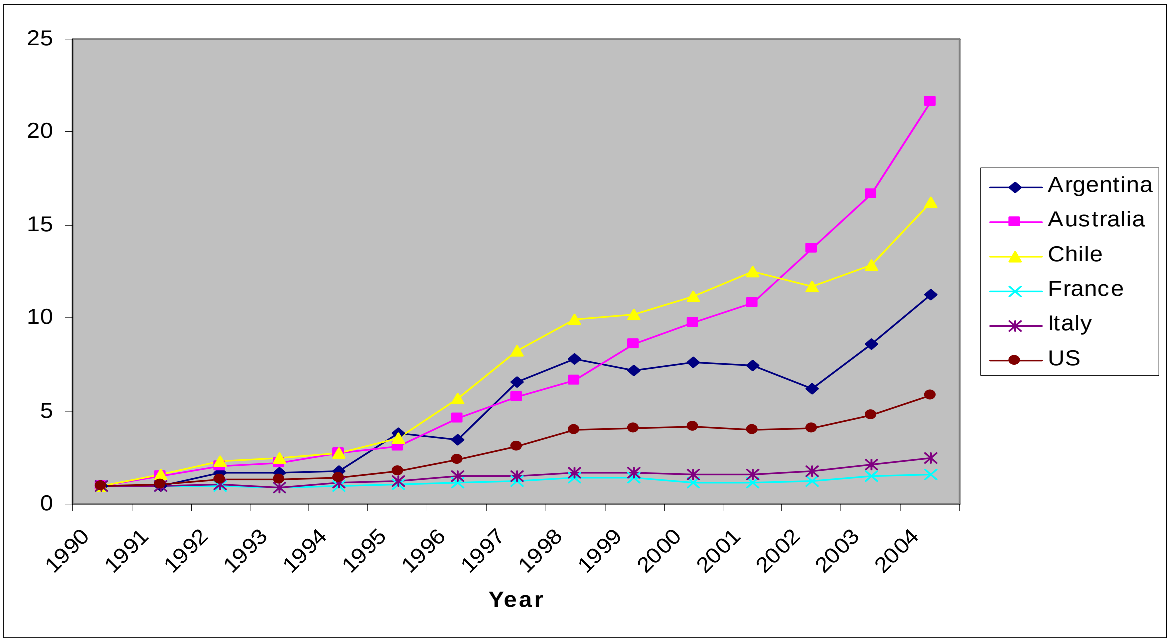
The next section expands on our contention that the emergence of "new-world" wine has relied on BA in contrast to the reliance of European wine on GIs. Then we introduce the model in the third section. The main results are presented in the fourth, while the fifth provides some extensions, and the final section concludes. An appendix provides detailed derivations of results presented in the text.

Promotion Strategies in the Wine Market

In the last 15 years, globalization and trade liberalization have entailed a new context of competition. While world consumption of wine has been increasing (WHO, 2005), wine exports of European countries like France or Italy have leveled off. Conversely, the exports of Australia, Chile, Argentina and the United States have steadily gained grounds as shown in Figure 1, and markedly so in recent years.[2] The European domination is being challenged by these new producers coming from Chile or Australia. This new competition has modified strategies of signaling and promotion in the wine market (BA versus GI), accompanied by differences in cost structure, industry structure, and wine technology. The intellectual challenge is to elucidate the individual effect of these various elements. We focus on the noticeable efforts of these emerging competitors to improve quality through consistency and predictability of taste and the crucial role of their marketing strategies. The following stylized facts allow us to understand the differences between Europe and the emergent countries.[3]

[2] Note that this figure exhibits aggregated volumes that neglect segmentation and quality heterogeneity.
[3] The stylized facts mainly concerned consumption wines that differ from collectible wines reserved to experts (Costanigro, 2005).

Figure 1.Wine Exports Value (Basis 100 in 1990)



Basis Data Source: UN Commodity Trade Statistics Database.

First, several types of information such as the winery, the grape, or the origin are usually mentioned on most bottles. However for a buyer, the most visible information in France is the GI for medium-quality wines, and cumulative GI (appellation, grand cru, etc) combined with winery ("Chateau") for high-quality wines. Conversely, the brand is the most visible information for the Australian wines (e.g., Jacob's Creek, 2005). Wine promotion in Australia, Chile and the United States favors BA, which facilitate the good reputation and the recognition by buyers.

Second, the profusion and proliferation of GIs in Europe lead to some risks of confusion for consumers (Marette and Zago, 2003). Peri and Gaeta (1999) count more than 400 official appellations in the wine sector in Italy, 450 appellations in France, and 1,397 in the wine sector in Europe. Such profusion assures product diversity but certainly increases buyer confusion (*Consumer Reports,* 1997). The recognition of quality labels by French consumers is only 12%

for Appellations d'Origine Contrôlée, the French GI system for high-quality products (Loisel and Couvreur, 2001). Recently, Berthomeau (2002) discusses the difficulty that some French GIs have in entering new export markets because of the absence of any clear specification of the label that distinguishes one appellation from another in consumers' minds.[4] In sharp contrast, Jacob's Creek and Kendall-Jackson wines can be found in most U.S. grocery stores.

Third, many European GIs impose numerous restrictions that often stifle the search for commercial efficiency and innovations in quality that would improve the predictability in taste and its consistency over time. The grape production is regulated, with a maximum yield allowed per unit of land. Excessive regulation for linking origin and quality seems problematic when the international competition is intense (Zago and Pick, 2004; and Ribaut, 2005). Conversely, the main features of regulations in the United States, Chile, and Australia are the lack of detailed rules and the freedom to experiment with new techniques; the production and marketing of wines according to single varieties of grapes, sometimes associated with a relatively large production region; and an intense use of marketing investments.[5]

Fourth, wineries in Australia are much bigger than the ones in Europe, and the industry in the "new world" has been dominated by relatively large producers. The average vineyard size in France is less than 2 hectares compared with 111 hectares in Australia. Four producers dominate the Australian market, namely, Foster, Southcorp, Hardy, and Orlando Wyndham. The combined production share of the four largest producers in New Zealand is 85%, while the combined

[4] The collective reputation of French wines plummeted during the last decade (Conan, 2005; Echikson, 2005; and Ribaut, 2005). Giraud-Heraud et al. (2002) and Ribaut (2005) mentioned the needs of wineries consolidation and/or reforms of French GI system.
[5] In September 2005, the United States and the EU reached a wine-trade agreement which makes some U.S. practices such as adding wood chips to wine barrels legitimate in the EU. U.S. companies will stop using some GIs such as Champagne, Sherry and Port. Some EU lawmakers are not satisfied with this agreement because the Europe wine industry is strictly regulated and emphasizes traditional practices, while the U.S. industry emphasizes new technology that allows better control of taste characteristics and their identification by consumers (Locke, 2005).

production share of the two largest producers in South Africa is 80%. Unlike the industry in Australia, Chile or other new world competitors, the wine industry in Europe is fragmented. Indeed, apart from some notable exceptions, e.g., the Champagne (*Economist*, 2003), the wine industry in Europe is made up of many small producers, which may lack adequate capital for the necessary investments in new technologies and marketing policies. In other words, small wineries are unable to reach the minimum-efficient scale since the quality improvement implies relatively large fixed costs.

Beyond these empirical facts, further effects of the origin and the role of the GI are less easily evaluated. Despite the limits previously mentioned, GI also indicates natural conditions such as the soils and the climate specific to a certain geographic area (Barham, 2003). Origins of product matters for consumers' purchase decisions. Orth et al. (2005) show that the origin of a bottle does affect the U.S. consumers' preference as shown in Table 1.[6]

Table 1. Consumers' Preference for Wine Origin

Origin	Mean rank	Standard Deviation
California	3.03	1.95
France	3.88	2.49
Italy	4.38	2.18
Australia	4.67	2.51
Oregon	4.78	2.55
Chile	5.75	2.32
Spain	5.87	1.98
Washington	6.02	2.42
New Zealand	6.51	1.89

Note: Scale from 1 = most preferred to 9 = least preferred
Source: Table 1 in Orth, Wolf and Dodd (2005).

However, GIs can be an efficient tool to signal collective reputation. The Champagne GI is an example of successful collective reputation in which the combination of famous brands

[6] It should be noted that the origin in table 1 corresponds to countries or U.S. states, as would be the case for GI in France or Italy, associations that often concerned sub-regions or small areas.

(with large vineyard size and enough capital for advertising) and a prestigious GI matters for consumers ready to pay a large premium (Combris et al., 2003). Orth and Krska (2002) show that consumers rank country and region of origin at the top of wine attributes, while producer name is lower. An "efficient" combination of brands and GI also characterizes the Napa Valley appellation, which generates a significant price premium compared to an equivalent-quality bottle with a different appellation (Bombrun and Sumner, 2003). The efficiency of GI compared to that of a private brand is an open question. Some empirical studies of wine have shown consumers' attitude towards GIs and brands. With a parametric hedonic approach, Steiner (2004) shows that the decline of French wine in British market is partly due to the consumers' low valuation of geographical appellation. Riley et al. (1999) show a positive correlation between consumers' attitude (and perception) and relative brand size in the British wine market.

The debate about the strategies of producers and the appropriate regulation will likely gain momentum. This last point leads directly to the focus of our paper. Although the choice among tools for improving quality raises many questions, we focus on the central link between an effort for improving quality and different tools for quality signaling (BA versus GI, a combination of both)). A stylized model is used to isolate the impact of alternative ways to signal quality with and without effort to improve quality.

The Model

We assume purchases occur in two periods ($t=1, 2$) with two producers i and j who may offer products of high-quality or low quality. In the first period, producers i and j choose whether or not to promote their products and/or whether or not to improve the quality of their products. The cost of promotion is A. If the producers choose the GI, each producer incurs the cost $A/2$ since they share the cost. If a producer individually chooses to use BA, it incurs the cost A. The cost of product improvement is *F*. It is assumed that other costs of production are zero. For simplicity, it is also assumed that $A = \gamma F$, with $\gamma \leq 1$.

Each consumer only purchases one unit of the good per period *t* (Mussa and Rosen, 1978). A consumer who buys one unit of the product from producer *i* at a price p_i^t has an expected indirect utility equal to $\theta E(q_i^t) - p_i^t$, where $E(q_i^t)$ is the expected quality. The mass of those consumers is normalized at 1, with a uniformly distributed parameter $\theta \in$ [0, 1]. For simplicity, we assume that consumers only want to get high-quality (denoted q_H) and they get no satisfaction from getting low-quality ($q_\ell = 0$).

Consumers have limited knowledge on the quality. In the first period (*t=1)*, the consumer has a belief about the probability of getting high-quality from producer *i* equal to $\overline{\lambda} + I_i^\alpha \alpha$, with $0 \leq \overline{\lambda} + I_i^\alpha \alpha \leq 1$. $\overline{\lambda}$ is the initial belief about wine quality in the absence of promotion and I_i^α is an indicator linked to the promotion strategy. I_i^α =1 means that the producer *i* invests in promotion (GI or BA) for enhancing the consumer's perception of quality in the first period, while I_i^α =0 means the producer *i* avoids investing in promotion. Parameter *α* is the incremental probability of purchasing wine of high quality.

In the second period (*t=2*), the consumers repeat their purchases by learning the average quality of the products because of an imperfect experience. Consumers can communicate with each other after the first period, so that a common knowledge is formed regarding the average quality of the products among consumers. Cconsumers experience the product even if they know there is a residual uncertainty that limits their knowledge. They learn about the probability of getting high quality by using complementary information (communication among the consumers, newspaper and so on). The probability of getting high quality depends on the producer's decision for improving quality at a cost *F*. The cost *F* implies an improvement of the probability of having high-quality equal to *e*. Under BA, consumers are able to identify each producer's improvement since promotion is individual. If the producer *i* chose BA, the probability of having high-quality products is $\lambda + I_i^e e$ (with $0 < \lambda + I_i^e e \leq 1$), where λ is the real probability to get high-quality in the absence of an effort. I_i^e is an indicator of the probability improvement (I_i^e =1 when *F* is incurred and zero otherwise). If both producers chose GI, consumers are not able to precisely distinguish the quality of both producers since the promotion is collective. As GI leads to a collective reputation, the probability for consumers to get high quality in the absence of distinction between both producers is $(\lambda + I_i^e e)/2 + (\lambda + I_j^e e)/2 = \lambda + (I_i^e + I_j^e)e/2$, with $i \neq j$.

We summarize all the cases faced by producers and consumer in table 2. Recall that the low quality is q_L =0, so that the expected quality for consumers is equal to their belief regarding the probability of getting high quality multiplied by the quality level, q_H.

Table 2. Producers' Strategy and Consumers' Expectation of Producers' quality (q_L =0)

First Period			Second Period
Producer *i*'s Strategy (Producer *j*'s Strategy)	Cost incurred by producer *i* and *j*	Consumer's expected quality of producer *i* and *j*	Consumer's expected quality of producer *i* and *j*
No signal (No signal)*	$I_i^e F$	$\bar{\lambda}\ q_H$	$(\lambda + 0.5(I_i^e + I_j^e)e)\ q_H$
GI (GI)*	$I_i^e F$+0.5*A*	$(\bar{\lambda} + \alpha)\, q_H$	$(\lambda + 0.5(I_i^e + I_j^e)e)\ q_H$
BA (BA)*	$I_i^e F$+*A*	$(\bar{\lambda} + \alpha)\, q_H$	$(\lambda + I_i^e e)\ q_H$
BA (No signal)**	$I_i^e F$+*A* ($I_j^e F$)	$(\bar{\lambda} + \alpha)\, q_H$ ($\bar{\lambda}\ q_H$)	$(\lambda + I_i^e e)\ q_H$ ($(\lambda + I_j^e e)\ q_H$)

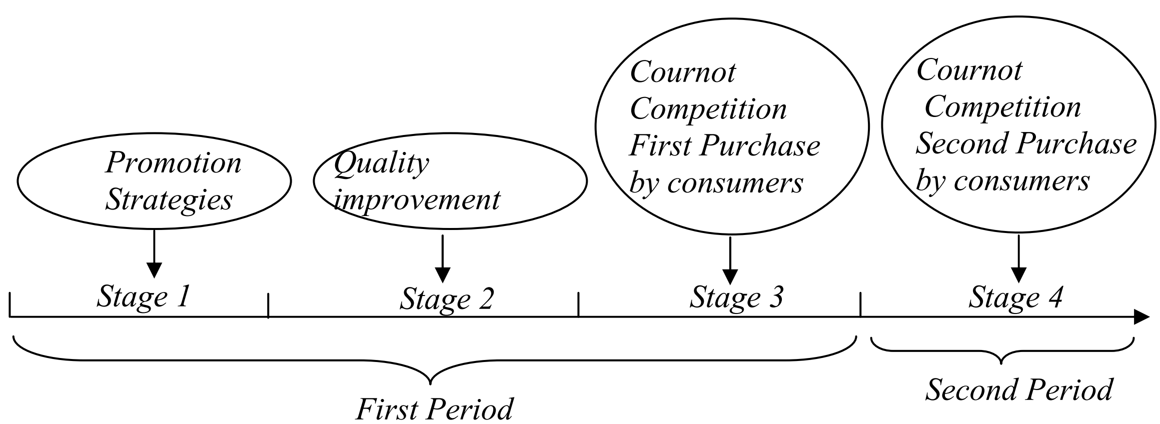
*Identical values for *i* and *j*. **No signal/(BA) is obtained by switching the payoff rows of BA/(No signal).

The game proceeds in three stages in the first period. At the first stage, the producers make their decisions for promoting their products, namely GI, BA or no signal. In the second stage, each producer decides whether or not to make an effort to improve the probability of producing high quality goods. In the third stage of the first period, each producer selects a quantity (Cournot competition), and consumers decides on their consumption levels. They learn partial information via the consumption. The stage 4 corresponds to the second period, where the consumers repeat their purchase and each producer selects a quantity (Cournot competition). The time line of the stages is shown in figure 2. We now turn to the presentation of the producers' choices.

The producers' choices

When the producers choose the information strategy (in stage 1) and the effort strategies (in stage 2) that maximize their profits, they take into account the quantity choices in stages 3 and 4. The subgame perfect equilibrium is detailed in the appendix.

Figure 2. Time Line of the Game



The incentive for a producer to select promotion and/or an effort balances two opposing effects. An information/effort strategy leads to a higher demand for its products by increasing the consumer’s willingness to pay. However, this positive effect may be offset by the fixed cost induced by these strategies or by the strategic interaction with the other producer. The producers’ choices depend on the efficiency of both promotion (represented by parameters $\overline{\lambda}$, α and γ) and effort (represented by the parameter e).

The following propositions 1 to 4 come from the selection of the strategy maximizing the producers’ profits (see the appendix). For sake of simplicity, we characterize the equilibrium strategies for alternative values of γ, namely the relative cost of promotion compared to the cost of quality improvement (recall that $A=\gamma F$). Figures 3 to 4 illustrate the market equilibrium detailed in the propositions, where the X-axis represents the quality level, q_H, and the Y-axis represents the fixed cost, F. The relative values of q_H and F determine the producers' optimal strategy and define the limits of different areas (the frontiers of these regions are detailed in the appendix). Below, we present the propositions and provide an intuitive interpretation, leaving the mathematical proof in the appendix. Let

$$\gamma_1 = \frac{\alpha(4e+3\lambda)^2(36\alpha^2+56\alpha\overline{\lambda}+21\overline{\lambda}^2)}{e(4\alpha+3\overline{\lambda})^2(36e^2+56e\lambda+21\lambda^2)} \qquad (1)$$

Proposition 1: *When the relative cost of signaling is low with $\gamma \leq \gamma_1$, the producers’ strategies are as follows (see Figure 3):*

(a) both producers choose no signal and no producer makes an effort in area 1,

(b) one producer chooses BA and no producer makes an effort in area 2,

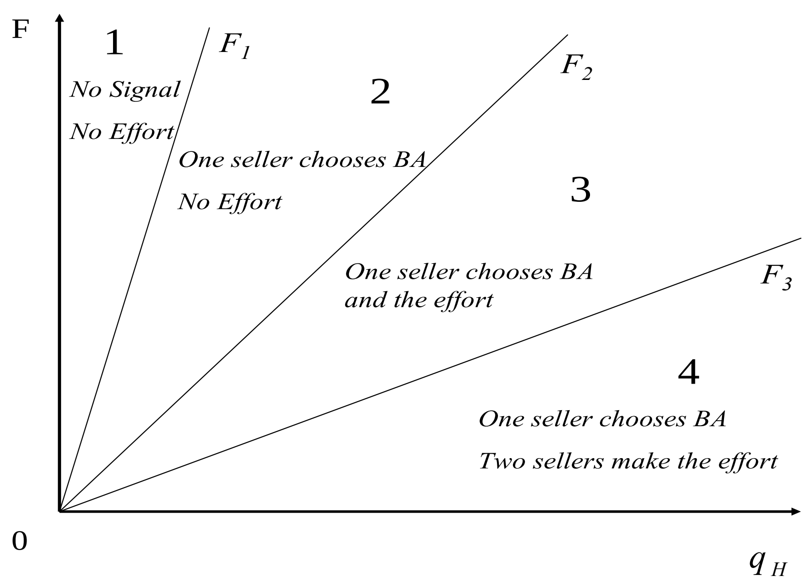
(c) one producer chooses BA and makes an effort in area 3,

(d) one producer chooses BA and both producer make an effort in area 4.

Proof is given in the appendix.

In area 1, making the effort or using a signal is too costly, since the respective costs represented by F (and γF) are relatively large. When F decreases in areas 2, 3 and 4, the different strategies of an effort and signal become affordable for the producer(s). When the cost of signaling is low with $\gamma \leq \gamma_1$, each producer will try to use the BA alone, since it increases the perception differentiation and the profit via the parameter α in the first period and the individual reputation in the second period. This market mechanism leads one producer to choose BA instead of cooperating with the other producer to select a GI since the cost of signaling is relatively small.

Figure 3. The strategies with low relative cost of signaling ($\gamma \leq \gamma_1$ ***)***



In area 2, one producer chooses BA because of the low cost of signaling (small γ), and no producer make an effort because of the relative high cost of the effort compared with the signal cost. When the relative value of F decreases further (area 3), the producer choosing the BA chooses to make an effort. In area 3, the fixed cost is still quite high for the other producer to select a signal or an effort. When F is relatively small (area 4), both producers make an effort.

Only one producer chooses the BA that allows a perceived increased quality differentiation in period 1.

As α, the incremental probability of purchasing wine of high quality coming from promotion, is the same under GI and BA, the market equilibrium with the two producers selecting BA never emerges. Indeed, it is optimal for both sellers to join the GI and to share the cost of promotion.

We now turn to a situation where the cost of promotion increases. Let

$$\gamma_2 = \frac{4\alpha^2(80e^3 + 81\alpha\lambda^2 + 24e\lambda(9\alpha + \lambda) + 4e^2(36\alpha + 25\lambda))}{e(4\alpha + 3\overline{\lambda})^2(16e^2 + 31e\lambda + 15\lambda^2)} + \frac{(8\alpha\overline{\lambda} + 3\overline{\lambda}^2)(60e^3 + 63\alpha\lambda^2 + 6e\lambda(28\alpha + 3\lambda) + e^2(112\alpha + 75\lambda))}{e(4\alpha + 3\overline{\lambda})^2(16e^2 + 31e\lambda + 15\lambda^2)} \quad (2)$$

Proposition 2*: For a medium relative cost of signaling with* $\gamma_1 < \gamma \le \gamma_2$*, the producers' strategies are as follows (see Figure 3):*

(a) both producers choose no signal and no producer makes an effort in area 1,

(b) area 2 in Figure 3 disappears,

(c) one producer choose BA and make an effort in area 3,

(c) one producer chooses BA and both producer make an effort in area 4.

Proof is given in the appendix.

Since signaling is more costly, no producer selects the BA without making the effort. In other words, the BA is valuable only if an effort is made. Indeed compared to proposition 1, the area 2 disappeared when γ increased. We now turn to a situation where the cost of promotion keeps increasing with $\gamma_2 < \gamma_3$[7]. Let

[7] The relative value of γ_2 and γ_3 depends on the relative values of $\lambda, \overline{\lambda}, e$ and α. If $\gamma_2 > \gamma_3$, Proposition 3

$$\gamma_3 = Max\left\{Min\left\{\frac{4\alpha - 2e}{e}, 1\right\}, 0\right\} \qquad (3)$$

$$\alpha_1 = \frac{3\bar{\lambda}}{4} \qquad (4)$$

Proposition 3: *When the relative cost of signaling is of medium level with $\gamma_2 < \gamma \le \gamma_3$, the producers' strategies are as follows (see Figure 4):*

(a) both producers choose no signal and no producer makes an effort in area 1',

(b) both producers choose GI but no producer makes an effort in area 5,

(c) both producers make no signal but make an effort in area 6,

(d) both producers make an effort ; one producer chooses BA if $\alpha > \alpha_1$ and both of them choose GI if $\alpha < \alpha_1$ in area 7.

Proof is given in the appendix.

When the cost of promotion continues to increase, the GI becomes more attractive compared to the BA because the producers share the cost of promotion. The areas 3 and 4 from Figure 3 disappear, since the cost of BA becomes too high for a single producer to afford. In Figure 4, the producers lean towards [choose] GI rather than doing BA individually. Some new equilibria appear in Figure 4.

With respect to the area 4 of Figure 3, here in Figure 4 GI replaces BA for large values of *F.* As the cost of making an effort continues to decrease, producers choose to make an effort instead of signaling in area 6. In reality, this corresponds to a new technology which decreases the fixed cost of making investment in quality improvements. The story in area 7 is the following: if signaling is not persuasive up to a certain level ($\alpha < \alpha_1$), producers would choose to

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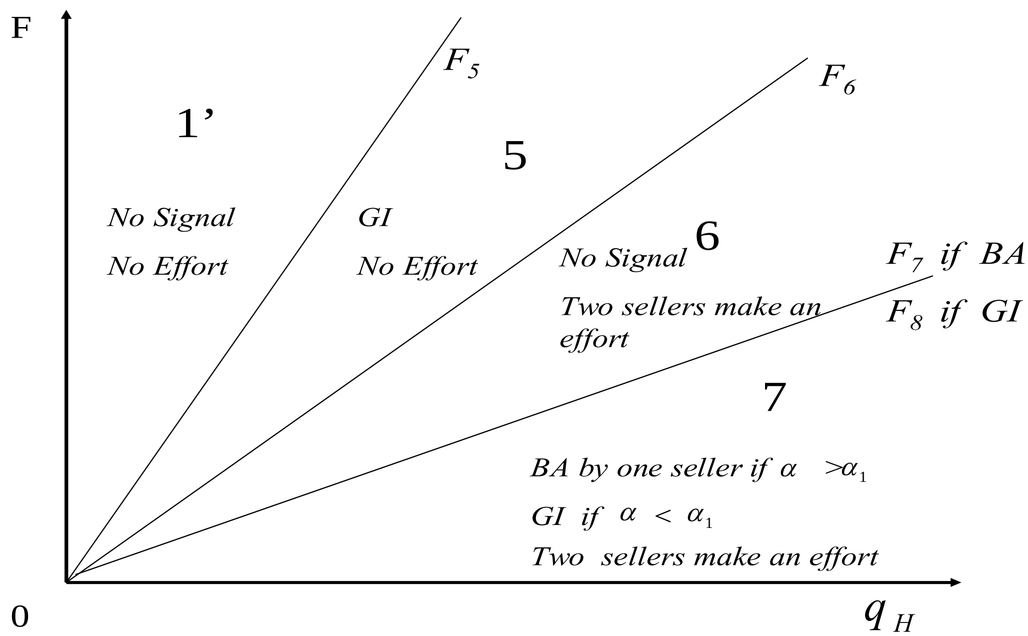
does not exist.

cooperate with each other and do GI to share the fixed cost. However, if signaling is effective and α is greater than some certain level α_1, one producer would do BA to distinguish itself from the other in the first period to gain higher profit.

Figure 4. The strategies with medium relative cost of signaling ($\gamma_2 < \gamma \le \gamma_3$ ***)***



Proposition 4*: When the relative cost of signaling is high (*$\gamma > \max\{\gamma_2, \gamma_3\}$*) the producers' strategies are as follows (see Figure 4):*

(a) no producer chooses any signal strategy and no producer makes an effort in area 1',

(b) area 5 in Figure 4 disappears

(c) both producers make no signal but both producers make an effort in area 6, and

both producers make an effort ; one producer chooses BA if $\alpha > \alpha_1$ *and both of them choose GI if* $\alpha < \alpha_1$ *in area 7.*

Proof is given in the appendix.

Proposition 4 is illustrated in Figure 4. In this case, the cost of signaling is so large that even the effect of cost sharing of GI does not work well. Therefore, the area 5 in Figure 4 disappears. And the producers choose to make an effort instead of signaling in area 6.

From the 4 propositions above we can conclude that the strategies of the producers depend on the relative effectiveness of providing quality improvements and signaling. When signaling is more effective and the fixed cost of providing a quality effort is large, producers tend not to make an effort; when quality improvement is more effective and the fixed cost of signaling is large, producers tend not to signal. We also conclude that BA provides producers with a higher incentive to make an effort than GI does, since GI is a collective reputation. If the effort for improving quality is selected, a producer will prefer to rely on BA for promoting its wine and set up its own reputation. Despite the sharing of the promotion cost, a geographic indication does not sufficiently reward the effort for improving quality due to the common reputation. On the contrary, when the producer avoids making the effort, GI is selected to be the promotion strategy. In this case, producers take advantage of sharing of the promotion cost and collective reputation.

Extensions

In defining the analytical framework, restrictive assumptions were made for simplicity. Some of the results of the model are robust if we consider the following extensions.

(i) In our model we abstract from the combination of GI and BA. One extension could be the incorporation of this combination. The following assumption could be made: In the first period, GI enhances the consumer's expectation by α and costs producers $\frac{A}{2}$, BA enhances the consumer's expectation by α as well but costs producers A, and the combination of the two

enhances the consumer's expectation by $c\alpha$ and costs producers $\frac{3A}{2}$. When the combination of these two are effective (high $c\alpha$ compared with the cost $\frac{3A}{2}$), the producers would choose the combination, if the combination is not effective enough, producers would choose GI or BA individually that goes back to the propositions of this paper. Let

$$c_1 = \min\{1, \frac{32\alpha^4 + 24\alpha^3\overline{\lambda} - 19\alpha^2\overline{\lambda}^2 - 14\alpha\overline{\lambda}^3 - 14\alpha\overline{\lambda}^3}{3(16\alpha^4 + 24\alpha^3\overline{\lambda} + 9\alpha^2\overline{\lambda}^2)}\}$$

and when $c < c_1$, the combination of GI and BA is dominated by GI or BA in equilibrium and it never emerges. (See proof of Lemma (point *viii*)).

(ii) In our model signaling only has an effect in the first period. One extension could be that the introduction of an effect of signaling on the consumers' expectation in the second period. That is, the second period's expectation of consumers is the combination of the expectation of the first period and the real probability. For example, when producers choose GI, the consumers' expectation in the second period is $[\varphi(\lambda + 0.5(I_i^e + I_j^e)e) + (1-\varphi)(\overline{\lambda} + \alpha)]\, q_H$, where $0 \le \varphi \le 1$. The higher the effectiveness of signals in the second period, the closer the consumers' expectation to the real probability. By doing this, we introduce an interaction effect of signaling and making an effort. We expect that producers' incentive of making an effort is lower when the second period effectiveness of signaling is lower.

(iii) Our model abstract from the discount of the second period profit of the consumers. If there is a discount of the second period, the larger the discount, the lower the producers' incentive to make an effort.

(iv) In the model, we abstracted from a context with numerous producers. Since GI has the property of cost sharing one natural question could be: if there are numerous producers, will the

producers prefer GI to BA since they could share the promotion cost by doing GI? To answer this question, we abstract from the strategy of making effort in this extension. Suppose there are n producers. They could choose to do GI together to share the cost of signal in the first period. When the cost of signal is not quite high, the producers have the incentive to deviate to do BA by themselves. Suppose initially all producers do GI and the first producer choose to deviate from GI to BA only if $A < \frac{n(\bar{\lambda}+\alpha)\left(\frac{(n\alpha+\bar{\lambda})^2}{(2n\alpha+(n+1)\bar{\lambda})^2}-\frac{1}{(n+1)^2}\right)}{n-1}$. The results indicate that even though by doing GI a larger number of producers lower the cost of promotion for each producer, the producers still have incentive to deviate to do BA if the promotion cost is not quite high. By doing GI the producers not only share the cost but also the profit[8].

(v) We only considered one region. One extension of our model is the introduction of several regions. Probabilities of producing high quality goods are different across different regions. We expect that producers in a region with high probability have more incentive to do GI.

(vi) We assumed vertical differentiation. An alternative solution is to introduce horizontal differentiation. In this context with m consumers and perfect information, m_1 consumers prefer goods from producer 1 and (m-m_1) consumers prefer goods from producer 2. Using our model we expect that as m_1 increases, producer 1's incentive of signaling and making an effort increases.

(vii) We assumed GI and BA have the same α,which is the incremental probability of purchasing wine of high quality from consumers' subjective point of view. That is, BA enhances consumers' perception in the first period in the same way as GI. This leads to the conclusion that

[8] The proof of the results is available from the authors upon request.

both producers choosing BA as their promotion strategies and both makes effort (or both producer make no effort) is dominated in equilibrium by the strategies that both producer choose GI and both producer make effort (or both producer make no effort). (See Proof of Lemma point (iii) in appendix). One extension of our model is to assume GI and BA have different effects on consumers' perception in the first period. Suppose we assume the incremental probability of purchasing wine of high quality in the first period for BA is α^{BA}, whereas for GI the value is α^{GI}. When $\alpha^{BA} - \alpha^{GI} > \frac{9A}{2}$ ($> \frac{(n+1)^2 A}{n}$ when there are n producers), the strategies that both producers choose BA emerge. That is, producers do BA instead of GI if BA is somewhat more effective in enhancing consumers' perception in the first period than GI.

Conclusions

In the context of the international wine market, we explored producers' choice between promotions strategies (GI and BA) and quality improvement strategies and how these strategic choices affect consumers' wine purchase decisions. Although admittedly stylistic, our model nonetheless highlights the complicated strategies for monitoring uncertain quality.

We show that producers' choice depends on the relative efficiency of promotion strategies compared with that of making an effort to improve quality. Another important result is that if the effort for improving quality is selected, a producer would like to use BA for promoting its wine and set up its own reputation. In spite of its advantage that the producers can share the promotion cost, a GI does not sufficiently reward the effort for improving quality since it promotes a collective reputation. However, when the producer chooses not to make an effort to improve the quality, a GI is selected to be the promotion strategy. In the latter case by using a GI, producers can take advantage of the sharing of the promotion cost and collective reputation.

The previous results can be applied to draw some implications about the diverging fortunes of New-World and European wines. Emergence of wines of New-World led to new contexts of competition that require modifying the signaling strategies. There are more incentives for producers to differentiate themselves by improving quality and revealing more information. Our paper however showed that GI is not necessarily compatible with quality improvement. It means that producers inside a GI should revamp their strategies of promotion, as for instance the development of generic advertising for the world market based on well identified appellation. This may also result in wineries' concentration entailing brands and advertising concentration.

We further explored extensions of our analysis showing it is quite promising for further generalizations. Of course, the diverging fortunes of New-World and European wines hinges on additional factors which we abstracted from to focus on promotion and quality improvement strategies. Beyond, these two aspects, access to capital, regulations, cost structure and size, all play an important role in the evolution of the international wine market.

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APPENDIX

The consumer's demand and producers' profits are presented before detailing the proof of propositions, with the characterization of the sub-game perfect Nash equilibrium of this four-stage game (solved by backward induction).

The consumer utility is $\sum_{t=1}^{2}\theta E(q_i^t) - p_i^t$ by consuming the product by producer i (i=1 or 2). In period t (t=1 or 2), if the two producers choose the same strategy, then $E(q_1^t) = E(q_2^t) = \overline{q}^t$ and $p_1^t = p_1^t = \overline{p}^t$. When $\theta\overline{q}^t - \overline{p}^t = 0$, the consumer is indifferent between buying and not buying a product in period t, implying that her taste parameter $\overline{\theta}^t = \frac{\overline{p}^t}{\overline{q}^t}$. As the distribution of preference is uniform, the demand for the product is $\overline{x}^t = 1 - \frac{\overline{p}^t}{\overline{q}^t}$ and $\overline{p}^t = (1-\overline{x}^t)\overline{q}^t$. In period t, if the two producers choose different strategies, then the expected quality of the products from two producers are different, $E(q_1^t) = \overline{q}_1^t$ and $E(q_2^t) = \overline{q}_2^t$. Suppose $\overline{q}_1^t > \overline{q}_1^t$ (indicating $p_1^t > p_2^t$) the consumer's demand for producer 1's product is $x_1^t = 1 - \frac{p_1^t - p_2^t}{\overline{q}_1^t - \overline{q}_2^t}$. And the demand for producer 2's product is $x_2^t = \frac{p_1^t - p_2^t}{\overline{q}_1^t - \overline{q}_2^t} - \frac{p_2^t}{\overline{q}_2^t}$. By solving the system of equations of $x_1^t = 1 - \frac{p_1^t - p_2^t}{\overline{q}_1^t - \overline{q}_2^t}$ and $x_2^t = \frac{p_1^t - p_2^t}{\overline{q}_1^t - \overline{q}_2^t} - \frac{p_2^t}{\overline{q}_2^t}$ for p_1^t and p_2^t, we get $p_1^t = \overline{q}_1^t(1-x_1^t) - \overline{q}_2^t x_2^t$ and $p_2^t = \overline{q}_2^t(1-x_1^t-x_2^t)$.

In stage 2, each producer chooses a level of quantity, taking into account the quantity of the other producer. For the case that the two producers' strategies are different, the profit for the higher expected quality producer is

$\pi_1 = \sum_{t=1}^{2} p_1^t \bar{q}_1^t - I_1^e F - I_1^\alpha A' = \sum_{t=1}^{2} (\bar{q}_1^t (1 - x_1^t) - \bar{q}_2^t x_2^t) x_1^t - I_1^e F - I_1^\alpha A'$ and the profit for the lower expected quality producer is

$\pi_2 = \sum_{t=1}^{2} p_2^t \bar{q}_2^t - I_2^e F - I_2^\alpha A' = \sum_{t=1}^{2} \bar{q}_2^t (1 - x_1^t - x_2^t) x_2^t - I_2^e F - I_2^\alpha A'$. A' is the fixed cost associated with information strategies: $A' = A$ if BA is chosen and $A' = \frac{A}{2}$ if GI is chosen. The first order conditions for the maximization of π_1 with respect to x_1^t (namely, $\frac{\partial \pi_1}{\partial x_1^t} = 0$) and π_2 with respect to x_2^t (namely $\frac{\partial \pi_2}{\partial x_2^t} = 0$) lead to equilibrium prices x_1^{t*} and x_2^{t*}. The substitution of these equilibrium quantities into π_1 and π_2 leads to the following respective profits for the producer 1 and producer 2:

$$\pi_1^* = \sum_{t=1}^{2} \frac{\bar{q}_1^t (2\bar{q}_1^t - \bar{q}_2^t)^2}{(4\bar{q}_1^t - \bar{q}_2^t)^2} - I_1^e F - I_1^\alpha A' \quad \text{(A1.1)}$$

$$\pi_2^* = \sum_{t=1}^{2} \frac{\bar{q}_2^t \bar{q}_1^{t\,2}}{(4\bar{q}_1^t - \bar{q}_2^t)^2} - I_2^e F - I_2^\alpha A' \quad \text{(A1.2)}$$

A particular case of (A1.1) and (A1.2) is when both producers choose the same strategies in both periods (which leads to $\bar{q}_1^t = \bar{q}_2^t = \bar{q}^t$):

$$\bar{\pi}_i^* = \sum_{t=1}^{2} \frac{\bar{q}^t}{9} - I_i^e F - I_i^\alpha A' \quad i\text{=1 or 2 (A2)}$$

The decision on the choice of strategies in stage 1 depends on these profits, which in turn depends on the expected quality and fixed costs listed in Table 2 of the main text. In stage 1, each producer faces the choices of strategies listed in the first column of Table 2. The decision depends on the comparison among the profits. Table 2 list all the cases of the expected qualities and associated costs by choosing different strategies for the two producers. If the expected qualities for the two producers are the same, substitute them in (A2) and get the profits for the two producers. If the expected qualities for the two producers are different, substitute them in (A1.1) and (A1.2) and get the profits for the two producers. Since there are two periods, the producers' profit would be the first period profit plus a discount parameter δ times the profit of the second period.

We use $\pi^{i}_{strategy1(I_1^e)+strategy2(I_2^e)}$ to denote producer i's profit with producer 1 choosing strategy 1 and producer 2 choosing strategy 2 and an effort making decision ($I_i^e = 1$ means an effort making, $I_i^e = 0$ means avoid making an effort). Among the strategies no signal is denoted by n, GI is denoted by GI and BA is denoted by BA. For example, $\pi^2_{BA(1)+n(1)}$ denotes producer 2's profit when producer 1 chooses BA and making an effort and producer 2 chooses no signal and but makes an effort.

Lemma: The following strategies are dominated:

(i) both producers choose no signal, and one of them chooses to make an effort,

(ii) both producers choose GI, and one of them chooses to make an effort,

(iii) both producers choose BA,

(iv) The strategy that one producer chooses BA and makes no effort and the other producer makes no signal and makes an effort is dominated in equilibrium,

(v) Both producers choose GI and make no effort is dominated by the strategy that one producer choose BA and makes no effort and the other producer choose no signal and no effort if the latter strategy emerges (the emergence of the latter strategy depends on the values of the parameters),

(vi) Both producers choose GI and make an effort is dominated by the strategy that one producer chooses BA and the other producer choose no signal and both producers make an effort when $\alpha > \alpha_1 = \frac{3\overline{\lambda}}{4}$,

(vii) The strategies that both producers choose GI and make an effort, or both producers choose no signal but make an effort are dominated by the strategy that one of them could choose BA and make an effort and the other producer chooses no signal and make no effort if the latter strategy emerges.

(viii) One producer chooses the combination of GI and BA, another producer chooses GI alone; both of the producers choose the combination of GI and BA.

Proof of previous points (i) & (ii):

Both producers choose no signal and producer 1 also chooses to make an effort and producer 2 does not make an effort is not dominated when the following necessary (but not sufficient) conditions are satisfied: producer 1 does not deviate to make no effort and producer 2 does not deviate to make an effort. That is:

$$\pi^1_{n(1)+n(0)} > \pi^1_{n(0)+n(0)} \text{ (A3.1)}$$

$$\pi^2_{n(1)+n(0)} > \pi^2_{n(1)+n(1)} \text{ (A3.2)}$$

(A1.1) is satisfied by $F < \frac{e}{18} q_H$ and A(1.2) is satisfied by $F > \frac{e}{18} q_H$, these two can not be satisfied at the same time, so the equilibrium is dominated. Similar proof applies to *(ii)* of Lemma.

Proof of point (iii):

$\pi^{i}_{BA(1)+BA(1)} = \frac{(\overline{\lambda}+\alpha)+(\lambda+e)}{9} q_H - A - F$ which is always less than

$\pi^{i}_{GI(1)+GI(1)} = \frac{(\overline{\lambda}+\alpha)+(\lambda+e)}{9} q_H - \frac{A}{2} - F$, i=1,2. So the producers would rather choose GI and make an effort to achieve the same profit with a lower cost.

Proof of point (iv):

Producer 1 choosing BA and making no effort and producer 2 making no signal but making an effort is not dominated when the following necessary conditions are satisfied: producer 1 does not deviate to make an effort and producer 2 does not deviate to make no effort. That is:

$$\pi^{1}_{BA(0)+n(1)} > \pi^{1}_{BA(1)+n(1)} \text{ (A4.1)}$$

$$\pi^{2}_{BA(0)+n(1)} > \pi^{2}_{BA(0)+n(0)} \text{ (A4.2)}$$

A(4.1) is satisfied by F> $f_1 = \frac{e(16e^2+31e\lambda+15\lambda^2)}{9(4e+3\lambda)^2} q_H$ and (A4.2) is satisfied by F< $f_2 = \frac{e^2+e\lambda}{4e+3\lambda} q_H$, but $f_1 - f_2 = -\frac{4e(5e^2+8e\lambda+3\lambda^2)}{9(4e+3\lambda)^2} q_H$ <0, so the necessary conditions cannot be satisfied.

Proof of point (v):

Producer 1 choosing GI and making no effort is not dominated when the following necessary conditions are satisfied: producer 1 does not deviate to make no signal and make no effort, and producer 1 doesn't deviate to do BA conditional on producer 2 making no signal and no effort. That is:

$$\pi^{1}_{GI(0)+GI(0)} > \pi^{1}_{n(0)+n(0)} \text{ (A5.1)}$$

$$\pi^{1}_{GI(0)+GI(0)} > \pi^{1}_{BA(0)+n(0)} \text{ (A5.2)}$$

(A5.1) is satisfied by $F < f_3 = \frac{2\alpha}{9\gamma} q_H$, and (A5.2) is satisfied by

F> $f_4 = \frac{2}{\gamma}\left(\frac{(\overline{\lambda}+\alpha)(\overline{\lambda}+2\alpha)^2}{(3\overline{\lambda}+4\alpha)^2} - \frac{\overline{\lambda}+\alpha}{9}\right) q_H$, but $f_3 < f_4$, which can not satisfied.

Proof of point (vi):

Producer 1 choosing BA and making an effort and producer 2 making no signal but making an effort is not dominated when the following necessary conditions are satisfied: producer 1 does not deviate to choose GI and make an effort and producer 2 does not deviate to choose GI make an effort. That is:

$$\pi^1_{BA(1)+n(1)} > \pi^1_{GI(1)+GI(1)} \text{ (A6.1)}$$

$$\pi^2_{BA(1)+n(1)} > \pi^2_{GI(1)+GI(1)} \text{ (A6.2)}$$

(A6.1) is satisfied by $F < f_4 = \frac{2}{\gamma}\left(\frac{(\overline{\lambda}+\alpha)(\overline{\lambda}+2\alpha)^2}{(3\overline{\lambda}+4\alpha)^2} - \frac{\overline{\lambda}+\alpha}{9}\right) q_H$ and (A6.2) is satisfied by

$F > f_5 = \frac{2}{\gamma}\left(\frac{\overline{\lambda}+\alpha}{9} - \frac{\overline{\lambda}(\overline{\lambda}+\alpha)^2}{(3\overline{\lambda}+4\alpha)^2}\right) q_H$. When $f_4 < f_5$ (which indicates $\alpha > \alpha_1 = \frac{3\overline{\lambda}}{4}$),

Producer 1 choosing BA and making an effort and producer 2 making no signal but making an effort is not dominated, but both choosing GI and making an effort is dominated. When $f_4 > f_5$

(which indicates $\alpha < \alpha_1 = \frac{3\overline{\lambda}}{4}$), the equilibrium that producer 1 choosing BA and making an effort and producer 2 making no signal but making an effort is dominated, but both choosing GI and making an effort is not dominated.

Proof of point (vii):

Both producers choose GI and make an effort when the following necessary conditions are satisfied: producers do not deviate to make no effort and one of the producers does not deviate to choose BA and make an effort conditional on the other producer choose no signal and make no effort. That is:

$$\pi^1_{GI(1)+GI(1)} > \pi^1_{BA(1)+n(0)} \quad \text{(A7.1)}$$

$$\pi^1_{GI(1)+GI(1)} > \pi^1_{GI(0)+GI(1)} \quad \text{(A7.2)}$$

(A7.1) is satisfied by

$F > f_6 = \frac{2}{\gamma}\left(\frac{(\overline{\lambda}+\alpha)(\overline{\lambda}+2\alpha)^2}{(3\overline{\lambda}+4\alpha)^2} - \frac{\overline{\lambda}+\alpha}{9} + \frac{(\lambda+e)(\lambda+2e)^2}{(3\lambda+4e)^2} - \frac{\lambda+e}{9}\right)q_H$ and (A7.2) is

satisfied by $F < f_7 = \frac{e}{18}q_H$. But

$f_6 - f_7 = \frac{16e^3(5-\gamma)+45\alpha\lambda^2 + 8e^2(10\alpha+(16-3\gamma)\lambda)+3e\lambda(40\alpha+(16-3\gamma)\lambda)}{18(3\lambda+4e)^2}q_H$ >0. So

the necessary conditions cannot be satisfied. Similar proof could apply to the case that both producers make no signal but make an effort.

Proof of point (viii):

The necessary condition for producer 1 to choose the combination of GI and BA as the marketing strategy if it has no incentive to deviate to do BA alone, which means:

$$\pi^1_{GIBA(0)+GI(0)} > \pi^1_{BA(0)+n(0)} \quad \text{(A8.1)}$$

The condition above leads to the frontier below which the strategies that one producer choose the combination of GI and BA and another producer choose GI alone will emerge in equilibrium.

$$f_8 = \frac{2}{\gamma}\left(\frac{(\overline{\lambda}+c\alpha)((2c-1)\alpha+\overline{\lambda})^2}{((4c-1)\alpha+3\overline{\lambda})^2} - \frac{(\overline{\lambda}+\alpha)(2\alpha+\overline{\lambda})^2}{(4\alpha+3\overline{\lambda})^2}\right)q_H$$

When this frontier is below the horizontal axis in Figure 3 of the main text, the strategy that one producer chooses the combination of GI and BA, the other producer choose GI alone and none of them makes an effort is dominated by the strategy that one producer choose BA, the other producer makes no signal and none of them makes an effort. That is f_8 <0, which generates

c< $c_{11} \approx \frac{32\alpha^4 + 24\alpha^3\overline{\lambda} - 19\alpha^2\overline{\lambda}^2 - 14\alpha\overline{\lambda}^3 - 14\alpha\overline{\lambda}^3}{3(16\alpha^4 + 24\alpha^3\overline{\lambda} + 9\alpha^2\overline{\lambda}^2)}$. The exact value of c_{11} is rather complex, the expression above gives the approximate value by ignoring the smaller order of this value. Similarly, we could prove that the strategy both producers choose the combination of GI and BA is dominated by both of the producer choose GI in equilibrium when c<1.

Therefore, we can get $c_1 = \min\{1, \frac{32\alpha^4 + 24\alpha^3\overline{\lambda} - 19\alpha^2\overline{\lambda}^2 - 14\alpha\overline{\lambda}^3 - 14\alpha\overline{\lambda}^3}{3(16\alpha^4 + 24\alpha^3\overline{\lambda} + 9\alpha^2\overline{\lambda}^2)}\}$.

The frontiers determination and proof of propositions

We now turn to the equilibrium strategies that lead to proposition 1, 2 3,and 4.

The Nash equilibrium is that a producer will choose a strategy that leads to a higher profit than all other available strategies given the other producer's strategy. Due to the page limitation of this paper, we only give an example on how to derive some of the frontiers in proposition 1. The lower limit of area 1 in the proposition 1, which is also the frontier for area 2. If no signal and no effort is Nash equilibrium, applying *Lemma (v)* and *(vii)* the following conditions have to be satisfied:

$\pi^1_{n(0)+n(0)} > \pi^1_{BA(0)+n(0)}$ and $\pi^2_{n(0)+n(0)} > \pi^2_{BA(0)+n(0)}$; (A9.1)

$\pi^1_{n(0)+n(0)} > \pi^1_{BA(1)+n(0)}$ and $\pi^2_{n(0)+n(0)} > \pi^2_{BA(1)+n(0)}$; (A9.2)

$\pi^1_{n(0)+n(0)} > \pi^1_{BA(1)+n(1)}$ and $\pi^2_{n(0)+n(0)} > \pi^2_{BA(1)+n(1)}$; (A9.3)

(A9.1) leads to

$$F > f_9 = \frac{1}{\gamma}\left(\frac{(\overline{\lambda}+\alpha)(\overline{\lambda}+2\alpha)^2}{(3\overline{\lambda}+4\alpha)^2} - \frac{\overline{\lambda}}{9}\right)q_H .$$

(A9.2) leads to

$$F > f_{10} = \frac{1}{\gamma+1}\left(\frac{(\overline{\lambda}+\alpha)(\overline{\lambda}+2\alpha)^2}{(3\overline{\lambda}+4\alpha)^2} + \frac{(\lambda+e)(\lambda+2e)^2}{(3\lambda+4e)^2} - \frac{\overline{\lambda}+\lambda}{9}\right)q_H .$$

(A9.3) Leads to

$$F > f_{11} = \left(\frac{(\overline{\lambda}+\alpha)(\overline{\lambda}+2\alpha)^2}{(3\overline{\lambda}+4\alpha)^2} + \frac{e-\overline{\lambda}}{9}\right)q_H \text{, and}$$

$$F > f_{12} = \left(\frac{\overline{\lambda}(\overline{\lambda}+\alpha)^2}{(3\overline{\lambda}+4\alpha)^2} + \frac{e-\overline{\lambda}}{9}\right)q_H .$$

When $\gamma \le \gamma_1$. $f_9 > f_{10} > f_{11} > f_{12}$, so we have

$$F_1 = \frac{1}{\gamma}\left(\frac{(\overline{\lambda}+\alpha)(\overline{\lambda}+2\alpha)^2}{(3\overline{\lambda}+4\alpha)^2} - \frac{\overline{\lambda}}{9}\right)q_H .$$

If producer 1 choose BA and no effort and the second producer making no signal and no effort is Nash equilibrium, applying *Lemma (iv)* the following conditions have to be satisfied:

$$\pi^1_{BA(0)+n(0)} > \pi^1_{n(0)+n(0)} \quad \text{(A10.1)}$$

$$\pi^1_{BA(0)+n(0)} > \pi^1_{BA(1)+n(0)} \quad \text{(A10.2)}$$

(A10.1) leads to

$$F < F_1 = \frac{1}{\gamma}\left(\frac{(\overline{\lambda}+\alpha)(\overline{\lambda}+2\alpha)^2}{(3\overline{\lambda}+4\alpha)^2} - \frac{\overline{\lambda}}{9}\right)q_H$$

(A10.2) leads to

$$F > f_{13} = \left(\frac{(\lambda+e)(\lambda+2e)^2}{(3\lambda+4e)^2} - \frac{\lambda}{9}\right)q_H .$$

So we get

$$F_2 = \frac{2}{\gamma}\left(\frac{(\overline{\lambda}+\alpha)(\overline{\lambda}+2\alpha)^2}{(3\overline{\lambda}+4\alpha)^2} - \frac{\overline{\lambda}+\alpha}{9}\right)q_H$$

And when $F_2 < F < F_1$, one producer choosing BA and making no effort and the other producer making no signal no effort is an equilibrium.

Similarly, we get other frontiers in the propositions. Let

$$\gamma_4 = \frac{4\alpha^2(4e^2(36\alpha - 7\lambda) + 24e(9\alpha - \lambda)\lambda + 81\alpha\lambda^2)}{e(4\alpha + 3\bar{\lambda})^2(16e^2 + 31e\lambda + 15\lambda^2)} + \frac{(8\alpha\bar{\lambda} + 3\bar{\lambda}^2)(7e^2(16\alpha - 3\lambda) + 6e(28\alpha - 3\lambda)\lambda + 63\alpha\lambda^2)}{e(4\alpha + 3\bar{\lambda})^2(16e^2 + 31e\lambda + 15\lambda^2)}$$

$$\gamma_5 = \frac{2\alpha}{e}$$

Then,

$$F_3 = \begin{cases} \left(\frac{\lambda + e}{9} - \frac{(\lambda + e)^2\lambda}{(3\lambda + 4e)^2}\right)q_H & if \quad \gamma < \gamma_4 \\ \frac{1}{\gamma + 1}\left(\frac{(\bar{\lambda} + \alpha)(\bar{\lambda} + 2\alpha)^2}{(3\bar{\lambda} + 4\alpha)^2} + \frac{e - \bar{\lambda}}{9}\right)q_H & if \quad \gamma > \gamma_4 \end{cases}$$

$$F_4 = \frac{1}{\gamma + 1}\left(\frac{(\bar{\lambda} + \alpha)(\bar{\lambda} + 2\alpha)^2}{(3\bar{\lambda} + 4\alpha)^2} + \frac{(\lambda + e)(\lambda + 2e)^2}{(3\lambda + 4e)^2} - \frac{\bar{\lambda} + \lambda}{9}\right)q_H$$

$$F_5 = \frac{2\alpha}{9\gamma}q_H$$

$$F_6 = \frac{e}{18}q_H$$

$$F_8 = \begin{cases} \frac{2\alpha}{9\gamma}q_H & if \quad \gamma < \gamma_5 \\ \frac{2}{\gamma + 2}\left(\frac{\alpha + e}{9}\right)q_H & if \quad \gamma > \gamma_5 \end{cases}$$