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Information Transparency of Business-to-Business Electronic Markets: A Game-Theoretic Analysis

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The abundance of transaction data available on the Internet tends to make information more transparent in electronic marketplaces. In such a transparent environment, it becomes easier for suppliers to obtain information that may allow them to infer their rivals' costs. Is this good news or bad news? In this study, we focus on the *informational* effects of business-to-business (B2B) exchanges, and explore firms' incentives to join a B2B exchange that provides an online platform for information transmission. We then study the equilibria by developing a game-theoretic model under asymmetric information. We examine whether the incentives to join a B2B exchange would be different under different competition modes (quantity and price), different information structures, and by varying the nature of the products (substitutes and complements). Our results challenge the "information transparency hypothesis" (i.e., open sharing of information in electronic markets is beneficial to all participating firms). In contrast to the popular belief, we show that information transparency could be a double-edged sword. The individual rationality of participation in the online exchange reflects the tradeoff between information transparency and data confidentiality. This may have important implications for the microstructure design (e.g., data access rules) of B2B electronic marketplaces.

Key words: information economics; information transparency; economics of electronic markets; online exchange; asymmetric information; game theory; information transparency hypothesis; B2B
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1. Introduction

Despite the controversies surrounding business-to-business (B2B) online exchanges, the Internet-based digital marketplaces are considered to have the potential to reduce transaction costs, add product and pricing transparency, generate market liquidity, and facilitate bidding by a broad spectrum of potential suppliers in a standardized platform (Zhu 2002).[1] In particular, online B2B exchanges allegedly streamline information flow in supply chains (Lee and Whang 2000). The rebalance of information asymmetry is an important motivation for establishing B2B exchanges (Hansen et al. 2001). Yet, given these multiple benefits, why is it that B2B exchanges have not been widely adopted? Why are suppliers still reluctant to join a high-profile exchange such as Covisint? B2B exchanges, indeed, seem to improve information transparency, but is information transparency a benefit or a threat?

Information technology (IT) has generally improved the flow of information (Kemerer 1998). B2B electronic exchanges in particular provide an online platform in which information is gathered, compiled, displayed, and transmitted among participating companies. In this sense, online B2B exchanges play a role of transmitting or aggregating information within a particular industry (Zhu 2002). Examples include Covisint in the automobile industry, FreeMarkets in the high-tech industry, and Exostar in the aerospace industry. In addition to public exchanges, Internet-based private exchanges have been created by many large corporations by establishing online links with their suppliers and business partners. Examples include Wal-Mart, Cisco, Dell, and Hewlett Packard.

The proliferation of these Internet-based marketplaces creates a vast sea of information about products, prices, transactions, and competitors. Today, a significant flow of information is being exchanged between buyers and sellers, between suppliers and manufacturers, and among competitors. This makes information more transparent in electronic markets than in traditional physical markets. *Information transparency* is defined as the degree of visibility and accessibility of information (Zhu 2002). The subject of information in the context of electronic markets has gained the interest of both academics and practitioners. Bakos (1998) describes the three main functions

[1] We define a B2B marketplace as an online platform that creates a trading community linked by the Internet and provides the mechanism for B2B interactions using industry-wide data standards and computer systems.

of markets: (1) matching buyers and sellers, (2) facilitating the exchange of information, and (3) providing an institutional infrastructure. In this study, we focus on the second role, as the digitization of information combined with the rise of high-speed networks has heightened the role of information in electronic markets. Data are real time, more transparent, and more synchronized; information flows more instantaneously in electronic markets (Grover et al. 1999). In this regard, information transparency becomes one of the key features that distinguish digital exchanges from traditional markets (Zhu 2004).

The Internet increases information transparency in several ways. In general, the Internet not only contains abundant information but also reduces the search cost for that information (Bakos 1997).[2] More specifically, using reverse-auction bidding, extensible markup language (XML) mapping, data mining, and intelligent agent technologies, online exchanges allow participants to see the "price floor" more easily than is possible with traditional markets in which inferring costs has been cumbersome (Sinha 2000).[3] It is often the case that data regarding prices, quantities, and bidding specifications are recorded in a database and made available to participants of the exchanges. For example, on FreeMarkets' reverse-auction platform, suppliers do not have to guess at their competitors' bids as they traditionally do with opaque requests for quotes. They see exactly what the competition is bidding, in real time, and how low they must go to pocket the deal (Tully 2000). Sooner or later, competitors will come to know the price floor—the lowest price for which a company is willing to sell a product or service, which is typically a good proxy for the firm's marginal cost. There are many such real-world examples illustrating that information is more transparent on electronic exchanges than in traditional markets.[4]

In this paper, we leave out the details of the process of price discovery and information transmission. Instead, we focus on the equilibrium effects of such information transmission. Transparent information is typically regarded as a good thing because of possible efficiencies arising from more widespread dissemination of accurate information. Yet, "suppliers are finding that, in a transparent environment where competitors can see each other's bids, the price for goods is being driven down" (Wilson 2000). That there are risks as well as potential gains associated with online marketplaces is reflected in the comment "To have a full collaborative environment is a hard sell for me ... what I am going to lose in terms of visibility and exposing my information to potential competitors is greater than what I would gain on the collaboration side" (Meehan 2001). Hence, cost transparency in B2B exchanges remains a real concern.[5] "For suppliers, the two biggest detractions for exchanges right now are transparency—the fact that every competitor can see what every other competitor is bidding—and lack of liquidity, which means there aren't enough buyers to really generate much bidding" (Wilson 2000).

These issues give rise to a set of critical research questions regarding the informational role of online B2B marketplaces. Research questions of particular interest include the following.

• What incentives will firms have to join the B2B exchange?

• How will these incentives be moderated by cost structures, uncertainty of information, and the nature of competition (price versus quantity)?

• Will firms that expose private cost data to the B2B exchange be able to jointly optimize their output or price decisions to increase their profitability?

[2] The efficiencies of Internet-based searches are especially clear in the context of industrial procurement. In the past, a manufacturer's options were fairly limited. An auto manufacturer that needed steel, for example, either had to rely on its well-worn list of suppliers or hope to hear of new vendors by word of mouth. But B2B exchanges allow a wide range of companies to find one another. The auto maker thus may find 10 suppliers for the type of steel it needs. It can use that information to get a much better sense of what the real costs of the steel are.

[3] Internet searches will become increasingly sophisticated with the spread of XML. XML protocol is replacing the Internet's traditional HTML for B2B procurement. XML makes it possible to describe products, features, and prices with far greater precision. It lets B2B exchanges set more detailed matching criteria, which gives buyers and sellers immediate access to even richer stores of information. Likewise, other technologies such as data mining and intelligent agents are becoming increasingly capable of helping companies make inferences about rivals' costs when past trading patterns are known.

[4] Cost transparency is increasing on all sorts of electronic markets. On Covisint, suppliers can see who is selling brakes and clutches, at what prices, and in what quantities. As posted on its website, "Covisint allows you to quickly share critical information ... and to browse, as well as receive and transmit electronic information." On eBay, data about bidding prices, quantity, winning bids, and seller identity are all visible on its auction website, which started as a business-to-consumer market, but also conducts B2B transactions as small- and medium-sized companies turn to eBay for procurement. As yet another example from our daily life, detailed breakdowns of invoice prices of new cars are now readily available on the Internet; car dealers are no longer able to hide their cost data.

[5] Exchange of cost information was part of the concern in the Covisint investigation conducted by the Federal Trade Commission (FTC). Despite the fact that the FTC gave approval to the auto exchange, concerns remain about the consequences of exchanging private cost information among rivals. Orbitz is another online marketplace that was subject to anticompetitive scrutiny.

Or, will they find that such exposure allows competitors to undermine efforts to optimize their production decisions?

Intuitively, information aggregation tends to have two types of effects: (1) the *direct effect* on the firm and (2) the *cross effect* on its rivals (Zhu 2003). First, receiving more accurate information permits the firms to choose the strategies that are more finely tuned to the actual state of the market, and hence improve the profits, so the increased transparency of information for a firm has a positive effect. On the other hand, transparent information may affect the degree of correlation among the strategies of all other firms. The increased strategy correlation and the increased precision of the rivals have a rather subtle, complicated effect on the behavior of the firms. The equilibrium behavior is not clear without a rigorous model.

Seeking to better understand these issues, we built a game-theoretic model with some abstractions and assumptions, so that we can begin to study the informational effects of B2B marketplaces. We utilized the concept of Fulfilled Rational Expectations Equilibrium with incomplete information.[6] One implication of this equilibrium concept is that the market participants incorporate the information that is contained in the equilibrium price in their decision-making process. This reflects the aggregation and transparency of information in a market mechanism with little friction, such as an Internet-based B2B exchange.

Our model shows that firms' incentives to join a B2B exchange are sensitive to their relative cost positions, the nature of the products, and the competition mode. Firms with heterogeneous costs have different incentives for information exchange. We also find that information transparency benefits some firms but hurts others. For substitute products, profits and market share will be *redistributed* from high- to low-cost firms. Under the assumptions of our model, when uncertainty of information rises, firms would have stronger incentives to participate in the B2B exchange, and the membership size of the exchange would increase.

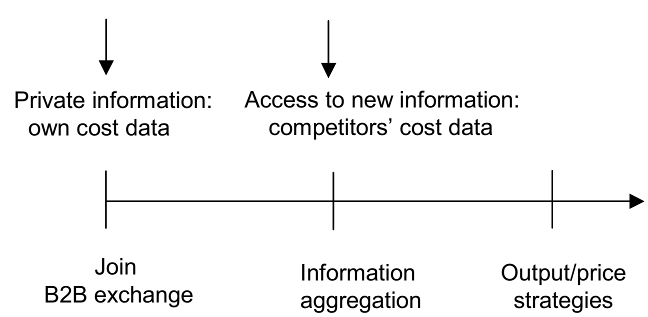
Relationship to Other Studies. Because of the recent emergence of B2B exchange as a recognizable economic phenomenon, prior research aimed directly at the questions posed here has been limited. More general theory, however, has been developed in the context of interorganizational systems—especially electronic data interchange (EDI). Several papers have studied the effects of EDI on buyers and sellers, with issues arising from the intersection of IT and industrial organization (see, among others, Barua and Lee 1997, Riggins et al. 1994, Wang and Seidmann 1995, Zhu 1999, Zhu and Weyant 2003). These studies significantly improved our understanding about strategic behavior in the EDI context. B2B exchanges have some features in common with EDI, but they also exhibit significant differences. In particular, data disclosure and information transparency was less a concern in the proprietary EDI context than in the Internet-based B2B setting. Typically, EDI does not provide market transparency as it is often conducted across proprietary value-added networks and controlled by one large buyer. We build on these studies, particularly the game-theoretic modeling of interorganizational systems, and address additional concerns related to the informational effects arising in the emerging B2B exchange context.

The remainder of this paper proceeds as follows. Section 2 presents the basic setup of the model. Section 3 analyzes firms' incentives to join a B2B exchange under quantity competition. Section 4 extends the model to the setting of price competition. Section 5 concludes the paper. We emphasize the results in the text and relegate the technical proofs to the appendices. For readers' convenience, a list of notations is summarized in the appendix.

2. The Model

We consider a market in which there are a finite number of n suppliers ($n \geq 2$), and each firm's technology is subject to uncertainty. They can trade through either traditional bilateral contracting or a new B2B online exchange. The B2B exchange makes certain transaction data visible on its website. For simplicity, we ignore the cost of joining the B2B exchange. The sequence of events occurs in the following stages: (1) firms decide whether or not to join the B2B exchange with an understanding that the B2B exchange will make signals regarding its cost data visible to other exchange members; (2) with its own cost data endowed initially, each firm may access additional information about other firms' costs on the B2B exchange, depending on its decision from Stage 1; and

Figure 1 The Sequence of Events



[6] For reference, see Grossman (1981), Jordan and Radner (1982), Novshek and Sonnenschein (1982), and Shapiro (1986).

(3) each firm chooses its output or price level, conditional on its information set from Stage 2. This three-stage timing structure is illustrated in Figure 1. Notice that firms do not announce their participation decisions until the game is over (i.e., here we model a one-shot simultaneous game).

We use a simple linear demand function to represent the buying side[7]

$$p = d - \sum_{i=1}^{n} q_i, \tag{1}$$

where p is the price, q_i is the quantity, and d is the demand intercept with slope normalized to 1. We assume there is a continuum of buyers in the market so that their individual decisions do not influence the market outcome. This allows us to focus on the strategic interactions of the suppliers.

The technology is stochastic and exhibits constant returns to scale. In other words, each firm employs a technology with a marginal cost, denoted by c_i for firm i

$$C_i(q_i) = c_i q_i, \quad i = 1, 2, \ldots, n. \tag{2}$$

That is, each firm's marginal cost c_i is a random variable. The cost vector $\mathbf{c} = (c_1, c_2, \ldots, c_n)'$ follows an n-dimensional multivariate normal distribution. Its joint distribution is defined by $\mathbf{c} \sim N(\mu, \Sigma)$ with mean $\mu \in R^n$ and covariance matrix $\Sigma \in R^{n\times n}$, where $\mu_1 = \cdots = \mu_n = \mu > 0$ and

$$\Sigma = \begin{pmatrix} \sigma^2 & \rho\sigma^2 & \cdots & \rho\sigma^2 \\ \rho\sigma^2 & \sigma^2 & \cdots & \rho\sigma^2 \\ \vdots & \vdots & \ddots & \vdots \\ \rho\sigma^2 & \rho\sigma^2 & \cdots & \sigma^2 \end{pmatrix}_{n\times n}, \tag{2'}$$

where ρ is the correlation coefficient between any pair (c_i, c_j), $j \neq i$, with $\rho \in (0, 1)$. The joint normal distribution $N(\mu, \Sigma)$ is common knowledge.[8]

Yet an individual firm's cost is private information. Without the B2B exchange, firm j observes only its own cost, c_j, but not those of the other firms. In contrast, member firms in the B2B exchange may have access to additional information—they observe signals that are correlated to the costs of all k firms trading on the B2B exchange, $(c_1, \ldots, c_k)$, where $1 < k \leq n$.

For multivariate normal distribution, the conditional expectations obey a linear property; namely, the Linear Conditional Expectation (LCE) property.

Lemma 1 (LCE Property). *The conditional expectation of c_j given c_i is*

$$E[c_j \mid c_i] = \mu + \rho(c_i - \mu), \quad i, j = 1, \ldots, n;\ i \neq j. \tag{3}$$

Further, given the cost information, $(c_1, \ldots, c_k)$, of any subset $K \subseteq N$, one can form the conditional expectation for c_j, $j \in N\backslash K$, as

$$E[c_j \mid c_1, \ldots, c_k] = \mu + \frac{\rho}{1+\rho(k-1)} \sum_{i\in K} (c_i - \mu), \quad \text{for } j \in N\backslash K. \tag{4}$$

Proof. See Appendix A.

Notice that for $k = 1$, conditional expectation (4) reduces to (3). The LCE property means that, for a multivariate normal distribution, its regression equations (conditional means) are linear functions of the conditioning variables. The parameters of the regression functions are determined by the covariance structure (i.e., ρ). Given their information sets upon joining the B2B exchange, firms will update their conditional belief about other firms' cost, and the conditional expectations obey a linear function. That is, c_i ($i \in K$) can be used to update posterior expectations on c_j via the mechanism specified by (3) and (4).[9]

We focus on the informational consequences of joining the B2B exchange. After firm i joins the exchange, its trading activities will be recorded in the exchange database, which may reveal its cost, c_i, to other member firms belonging to the exchange. In return, it can observe the costs of other firms that are also trading on the exchange. The set $N = (1, 2, \ldots, n)$ of all n firms is partitioned into two subsets: the set K of $k = |K|$ firms that join the B2B exchange and its complement set $N\backslash K$ of $(n-k)$ firms that trade outside of the B2B exchange (e.g., through traditional bilateral negotiation and contracting). This is shown in Figure 2. Hence, the essential difference between the two sets of firms is their distinct information structures.

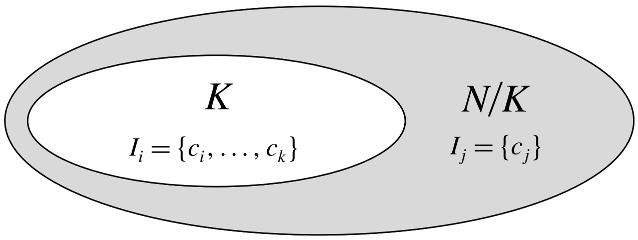
By this construction, the set of firms in K obtains information from their participation in the B2B

[7] Linear demand and Cournot behavior create a linear-quadratic payoff structure that is a second-order approximation to more general problems (Zhu 1999). In particular, the linear demand results tend to be a good approximation to more general demand functions (Shapiro 1986). The linearity assumption is also used in all of the related papers referenced here. In addition, we assume that d is large enough to ensure positive price, capacity is not a concern, and firms are risk neutral.

[8] Normal distributions have several useful properties. First, it is a close approximation to marginal costs in real-world industries. Second, from a modeling perspective, any marginal or conditional distributions of a joint normal distribution are still normal (Tong 1990, pp. 30–35). Additionally, any linear combinations or transformations of normally distributed random variables are also normally distributed (DeGroot and Schervish 2002, p. 272).

[9] In addition to normal distributions, the LCE property is also valid for other types of distributions, such as Gamma-Poisson and Beta-Bernoulli, among others (Malueg and Tsutsui 1998). Hence, results based on the LCE property might be generalizable to other distributions beyond the normal distribution.

Figure 2 Two Subsets



exchange to which no firm in $N\backslash K$ belongs. Their information set is

$$I_i = \{c_1, \ldots, c_i, \ldots, c_k\}, \quad \text{for } i \in K, \tag{5}$$

where I_i denotes the information set available to firm i. Joining the B2B exchange revises firm i's information set from $\{c_i\}$ to $\{c_1, \ldots, c_i, \ldots, c_k\}$. For the $(n-k)$ firms in the set $N\backslash K$ that trade outside of the B2B exchange, each firm's information set is confined to its own cost. That is,

$$I_j = \{c_j\}, \quad \text{for } j \in N\backslash K. \tag{6}$$

To sum up this section, we have made the following assumptions.

Assumption 1. *Demand and cost functions are represented by* (1) *and* (2).

Assumption 2. *Firms use* (3) *and* (4) *to update their conditional belief about rivals' costs.*

Assumption 3. *The B2B exchange facilitates information transparency in the sense that observed transaction data are perfectly correlated with costs* (*i.e.*, *no noise in the signals*).

Assumption 4. *The transmission of information can only be done through the B2B exchange.*[10]

In the following two sections, we will develop the model and examine whether the incentives to join a B2B exchange would be different under different information structures and two types of competition: quantity and price. We will show the results under quantity competition first in §3, as its results are more intuitive and the notions of direct effect and cross-effect can be more easily illustrated. We then consider price competition in §4, and show how the incentives to join the B2B exchange might change.

[10] To isolate the informational role of B2B exchange, we assume that there is no other credible channel for rivals to exchange cost data. For example, unilateral announcement would not be credible, and hence cannot serve as an information exchange mechanism. To avoid further complication, we assume there is only one B2B exchange in this industry, and firms operate in one market only.

3. Incentives to Join a B2B Exchange Under Quantity Competition

Given the above assumptions and the model setup, we proceed to derive the equilibrium quantities and profits under two information structures. Firms maximize their expected profits by choosing output levels noncooperatively for the given information structure, assuming that all other firms behave the same way; namely, they play a Cournot game. Following the standard game-theoretic approach, the equilibrium notion we use is that of a Bayesian-Nash equilibrium, which requires that each firm's strategy be a best response to its conjectures about the behavior of the rivals. By backward induction, we first examine the last stage (optimal quantities), and then work backward to analyze the first stage (whether to join the B2B exchange).

3.1. Optimal Quantities

We derive the optimal strategies corresponding to two different information sets in (5) and (6) associated with B2B exchange members and nonmembers, respectively. A member firm i maximizes its expected profit, conditional on its information set $I_i = \{c_1, \ldots, c_k\}$, $i \in K$

$$\max_{q_i} E[\pi_i \mid I_i] = \left\{ d - q_i - \sum_{\substack{m=1 \\ m \neq i}}^{k} E[q_m \mid I_i] - \sum_{j=k+1}^{n} E[q_j(c_j) \mid I_i] - c_i \right\} q_i. \tag{7}$$

Solving this optimization problem yields the following optimal quantity:

$$q_i^* = \bar{q} + \psi \sum_{m=1}^{k} (c_m - \mu) - \phi(c_i - \mu), \quad i \in K, \tag{8}$$

where

$$\psi = \frac{1}{k+1}\left[1 + \frac{\beta\rho(n-k)}{1+\rho(k-1)}\right], \tag{9}$$

$$\phi = 1, \tag{10}$$

and $\bar{q} = (1/(n+1))(d-\mu)$ is the equilibrium quantity in the absence of cost uncertainty (i.e., if output were all produced at a constant cost, μ). Sensitivity coefficient ϕ represents a "direct" adjustment to the firm's own cost, and ψ represents a "counter" adjustment to rivals' costs. Sensitivity ψ also depends on nonmembers' behavior, β, which is yet to be determined. This means that the direct and counter adjustments by the member firms involve the behavior of the nonmembers.[11] Examining the equilibrium quantities in (8) leads to the following observation.

Lemma 2. *The equilibrium strategy for each firm in the B2B exchange is affine in its private cost, c_i, as well as in the revealed cost data from the exchange, $(c_1, \ldots, c_k)$, with the sensitivity being represented by ϕ and ψ.*

As proved by Basar and Ho (1974) and Basar (1978), affine strategies linear in the signal constitute a Nash equilibrium when objective functions are quadratic in the decision variable (our profit functions are quadratic in q). In equilibrium, given the normality assumption and the linear conditional expectation property, firms' output strategies are a linear function of their costs. Consistent with Shapiro (1986) and Li (1985), we suppose that the nonmember's quantity is expected to be a linear function of its cost, in the affine form $q_j = \alpha - \beta c_j$, where α and β are constants. It must be true $\beta > 0$, because higher cost means lower quantity. As shown in Appendix B, this turns out to be precisely the optimal quantity in equilibrium (see (12)), which is consistent with the notion of fulfilled rational expectations equilibrium.

Now, consider the profit optimization problem of a nonmember firm, $j \in N\backslash K$. Not having access to the information aggregated on the B2B exchange, each firm's information set is confined to its own private cost data, c_j, at the time when it makes its output decisions. Firm j maximizes its expected profit, conditional on its information set, $I_j = \{c_j\}$,

$$\max_{q_j} E[\pi_j \mid I_j] = \left\{ d - q_j - \sum_{i=1}^{k} E[q_i \mid c_j] - \sum_{\substack{m=k+1 \\ m\neq j}}^{n} E[q_m \mid c_j] - c_j \right\} q_j, \quad j \in N\backslash K. \quad (11)$$

Solving this maximization problem in Appendix B yields

$$q_j^* = \bar{q} + \beta(\mu - c_j), \quad (12)$$

where

$$\beta = \frac{(1+k-k\rho)[1+\rho(k-1)]}{(1+k)[1+\rho(k-1)][2+\rho(n-k-1)] - \rho^2 k^2 (n-k)}. \quad (13)$$

The coefficients ϕ, ψ, and β represent the behavior of the member and nonmember firms. Investigating (9), (10), and (13) reveals the following property.

Lemma 3. *Sensitivity coefficients ψ and β are positive and less than* 1.

[11] The members and nonmembers make their decisions simultaneously and *inter*dependently—members' decisions depend on their conjectures about nonmembers' strategies and vice versa. That is why the coefficients of q_i^* also depend on β. Here, we solve q_i^* and q_j^* separately only for the matter of presentation.

3.2. Equilibrium Profits

To analyze the formation of the B2B exchange, it is necessary to derive and compare the equilibrium profits for members $E[\pi_i^*]$ and nonmembers $E[\pi_j^*]$, respectively, for any given exchange membership size, k, where $k = |K|$, $K \subseteq N$. Substituting the optimal strategies, q_i^* in (8) and q_j^* in (12), into the profit functions in (7) and (11), and using the conditional expectations (3) and (4), we derive the following result.

Proposition 1 (Equilibrium Profits). *In equilibrium, for B2B exchange members, expected profit will be*

$$E(\pi_i^*) = [E(q_i^*)]^2 + \psi^2(k-1)[1+(k-2)\rho]\sigma^2, \quad i \in K. \quad (14)$$

For nonmembers, expected profit will be

$$E(\pi_j^*) = [E(q_j^*)]^2, \quad j \in N\backslash K. \quad (15)$$

Proof. See Appendix B.

Here, $\psi^2(k-1)[1+(k-2)\rho]\sigma^2 > 0$, the expected profits of the exchange members increase in the variance of the cost, σ^2. This reflects the convexity of profits as a function of costs. It can be shown

$$\frac{\partial \Delta\pi}{\partial \sigma^2} = \psi^2(k-1)\big[1+(k-2)\rho\big]\sigma^2 > 0,$$

then:

Corollary 1 (Property of Convexity). *Firms would have stronger incentives to join the B2B exchange when they face higher uncertainty, i.e., $\partial\Delta\pi/\partial\sigma^2 > 0$.*

The term $\psi^2(k-1)[1+(k-2)\rho]\sigma^2$ represents the benefits of information aggregation on the B2B exchange. It would be more valuable when the uncertainty, σ^2, is higher. This result is consistent with our conceptualization in the introduction section that B2B exchange serves as an information transmission platform.

3.3. Cost Heterogeneity, Separating Equilibrium, and Differential Incentives

Having derived the optimal outputs and equilibrium profits, we are now prepared to determine whether the firms in the exchange can expect to make higher profits than the nonmembers. Each firm considers information exchange beneficial in the classical Pareto-dominance sense when $E[\pi_i^*] > E[\pi_j^*]$, for any given exchange size, k, $i \in K$ and $j \in N\backslash K$.

To compare the expected profit of joining the exchange versus staying offline, we quantify the expected profit difference, $\Delta\pi = E[\pi_i^*] - E[\pi_j^*]$, from Proposition 1, as

$$\Delta\pi = [E(q_i^*)]^2 - [E(q_j^*)]^2 + \psi^2(k-1)[1+(k-2)\rho]\sigma^2.$$

Defining $\Delta c \equiv c_i - \mu$, and plugging the expectations of (8) and (12), $\Delta\pi$ can be written as a quadratic function of Δc

$$\Delta\pi = (\psi-\phi+\beta)(\psi-\phi-\beta)(\Delta c)^2 + 2(\psi-\phi+\beta)\bar{q}\Delta c + \psi^2(k-1)[1+(k-2)\rho]\sigma^2.$$

By examining its first and second derivatives, we found that $\Delta\pi$ is a convex, U-shaped curve. As shown in Appendix D, solving the equation $\Delta\pi = 0$ yields

$$\hat{c} = \mu + \frac{\bar{q} - \sqrt{\bar{q}^2 - \dfrac{\psi-\phi-\beta}{\psi-\phi+\beta}\psi^2(k-1)[1+(k-2)\rho]\sigma^2}}{\phi+\beta-\psi}, \tag{16}$$

where $\hat{c}$ represents the threshold cost below which $\Delta\pi \geq 0$. That is, when $c_i \leq \hat{c}$, $E[\pi_i^*] \geq E[\pi_j^*]$. This implies that firms with low cost, $c_i \leq \hat{c}$, will have an incentive to join the B2B exchange, as they will derive higher profits than if they stay offline. In contrast, firms with high cost, $c_i > \hat{c}$, will lack the incentive to join the B2B exchange. This is summarized below.

Proposition 2 (Equilibrium Solution—Who Will Join the B2B Exchange). *Cost heterogeneity induces different incentives to join the B2B exchange. In equilibrium, low-cost firms will find it optimal to join the online exchange, while high-cost firms will not. That is,*

$$\Delta\pi = \begin{cases} \geq 0, & \text{if } c \leq \hat{c} \\ < 0, & \text{if } c > \hat{c} \end{cases},$$

where threshold cost $\hat{c}$ is defined in (16).

Proof. See Appendix B.

The basic tradeoff that drives the incentives for a firm to trade on the B2B exchange is the increased precision of information, decomposed in the effect on the firm itself and on its rivals, and the correlation induced in the strategies of the firms. By making cost data more transparent and by "advertising" their relatively aggressive reaction curves, the low-cost firms induce the rivals to shrink their outputs. This leads to a more efficient allocation of output (and market share) than would arise in the absence of information transparency. Without the transparent information facilitated by the B2B exchange, all firms would estimate their rivals' costs based on their limited private information, which tends to make their estimates around the mean of the cost, μ. With the B2B exchange, the fog clears out and the firms can see through each other's costs better than before. In the new information-transparent equilibrium, more efficient firms produce more. Hence, the mix of output (and market share) is shifted from high- to low-cost firms. This would result in entirely different incentives toward information transparency on the B2B exchange: in equilibrium we will find that low-cost firms will prefer to trade on the transparent online exchange, while high-cost firms will have incentives to trade in an opaque environment where they can hide their "uncompetitive" costs.

With the result in Proposition 2, we can now make the notion of "low cost" and "high cost" more precise. Low-cost firms are those firms whose costs are below the critical level, i.e., $c_i < \hat{c}$. High-cost firms are those whose costs are above the critical level, i.e., $c_i > \hat{c}$. That is, $c_H = \{c_i, \forall c_i > \hat{c}\}$ and $c_L = \{c_i, \forall c_i \leq \hat{c}\}$. This cost heterogeneity permits the possibility of a separating equilibrium as follows.

Corollary 2 (Separating Equilibrium). *In equilibrium, those firms trading through the B2B exchange are expected to be the more efficient (with lower costs or better technology) firms, while those less-efficient (higher-cost) firms continue to trade through the traditional markets such as bilateral contracts or negotiation.*

Given the separating equilibrium nature induced by information transparency, the mere existence of the online exchange makes it more difficult for high-cost firms to hide their cost data. Besides information revealed from online transaction data, the action to join or not to join the B2B exchange itself may single out the high-cost firms. For example, if firm j chooses to stay away from the B2B exchange, then other firms could infer that firm j is likely to be a high-cost firm (although they still do not know firm j's exact cost). Therefore, we have the following result.

Corollary 3 (Adverse Effect on High-Cost Firms). *Even though they choose not to participate in the online marketplace, high-cost firms are made worse off by the mere existence of the B2B exchange in the industry.*

Proof. See Appendix D.

Finally, as shown at the end of Appendix B, $\partial\hat{c}/\partial\sigma^2 > 0$, meaning if $\sigma^2 \uparrow$, then $\hat{c} \uparrow$, so more firms will find it profitable to join the exchange. Consequently, the exchange's membership size and critical mass will increase. Hence, uncertainty works to the advantage of the B2B exchange and its members.

Comparison with the Literature. To close this section, it is worth noting the differences between our results and the literature. The closest studies to our model might be Shapiro (1986) and Li (1985). They studied two extreme information-sharing scenarios: either industry-wide complete information pooling or no information sharing at all. They found that *all* firms in the industry always preferred perfect revelation of their private information to rivals. These all-or-none options for information sharing can be considered as two special cases of our model, corresponding to $k = n$ and $k = 1$, respectively. Further, our model shows an entirely different result; namely, not all the firms in the industry would prefer to join the exchange. As shown above, firms with heterogeneous costs have different incentives for information exchange. Uncertainty of information also plays a role in the participation. Generally speaking, it would not be the case that all firms join the exchange. This result is a significant extension to the literature. Finally, price competition was not considered in Shapiro (1986) or Li (1985).

4. Price Competition

We have shown above how information transparency affects firms' incentives to participate in B2B electronic markets under quantity competition. In many real situations, firms compete on prices instead of quantities. Depending on the specific price-discovery mechanisms used by the B2B exchanges, price competition might be more appropriate in some situations. In this section, we extend our model to the setting of price competition and show that our methodology still holds under this alternative competition mode, though some part of the results may change. Following a similar structure to the previous section, we first derive optimal pricing strategies p_i^* and p_j^*, for member firms and nonmember firms, then compare the expected equilibrium profits of joining the B2B exchange versus staying offline. We present the results below, with more detailed proof provided in Appendix D.

4.1. Optimal Pricing Decisions

Assume that the demand function is still linear, but with differentiated products

$$q_i = d - p_i + \theta \sum_{m \neq i} p_m, \tag{17}$$

where p_i, q_i, and d are price, quantity, and demand intercept. $\theta \in [-1, 1]$ denotes the degree of product differentiation, and $\theta > 0$, $= 0$, < 0 represents substitute, independent, and complement products, respectively. The cost function and the LCE property remain the same as defined in §2.

For member firms of the B2B exchange, conditional on the information set, $I_i = \{c_1, \ldots, c_k\}$, firm i maximizes its expected profit by deciding on price

$$\max_{p_i} E(\pi_i \mid I_i) = (p_i - c_i)\left[d - p_i + \theta\left(\sum_{m\neq i} p_m \,\Big|\, I_i\right)\right], \quad i \in K. \tag{18}$$

In Bertrand competition, firms choose prices based on their marginal costs and the conjectures of other firms' strategies. Basar and Ho (1974) showed that the equilibrium strategy is affine in the information set on costs. Consistent with their results, we show that

$$\begin{aligned} p_i^* &= \bar{p} + y \sum_{m=1}^{k} (c_m - \mu) + \frac{1}{2+\theta}(c_i - \mu) \\ &= \bar{p} + y \sum_{m=1}^{k} \Delta c_m + \frac{1}{2+\theta}\Delta c_i, \end{aligned} \tag{19}$$

where

$$y = \frac{\theta}{(2+\theta-k\theta)}\left[\frac{1}{2+\theta} + \frac{(n-k)\beta\rho}{1+\rho(k-1)}\right], \tag{20}$$

$$\bar{p} = \frac{d+\mu}{2+\theta-n\theta}, \tag{21}$$

where $\bar{p}$ represents the equilibrium price in the absence of cost uncertainty. Notice that y is a function of known parameters, θ, ρ, n, k, as well as unknown parameters, β. This means that members' pricing strategies also depend on their conjectures about nonmembers' pricing decisions. As justified earlier, a nonmember pricing strategy is expected to be a linear function of its cost. Solving the nonmember firm's decision, conditional on $I_j = \{c_j\}$,

$$\max_{p_j} E(\pi_j \mid I_j) = (p_j - c_j)\left[d - p_j + \theta\left(\sum_{m\neq j} p_m \,\Big|\, I_j\right)\right], \quad j \in N\backslash K, \tag{22}$$

yields the optimal pricing strategies for nonmembers

$$p_j^* = \bar{p} + \beta \Delta c_j, \tag{23}$$

where

$$\beta = \frac{[2+\theta-k\theta+\rho\theta k][1+\rho(k-1)]}{[2-\rho\theta(n-k-1)][2+\theta-k\theta][1+\rho(k-1)] - \rho^2\theta^2k^2(n-k)}. \tag{24}$$

This shows that β can be computed from known parameters θ, ρ, n, k, μ, and d.

4.2. Equilibrium Profits

Having derived the optimal pricing strategies, p_i^* and p_j^*, we then substitute them into the profit functions of (18) and (22) to compute the equilibrium profits, π_i^* and π_j^*, corresponding to the cases that a firm joins the exchange versus trades offline, respectively. We have obtained the following result.

PROPOSITION 3 (EQUILIBRIUM PROFITS UNDER PRICE COMPETITION). *The equilibrium profit of a member firm is expected to be*

$$E[\pi_i^*] = [E(p_i^*) - c_i]^2 + y^2(k-1)[1+(k-2)\rho]\sigma^2, \quad i \in K. \tag{25}$$

For nonmembers, the equilibrium profit is expected to be

$$E[\pi_j^*] = [E(p_j^*) - c_j]^2, \quad j \in N\backslash K. \tag{26}$$

PROOF. See Appendix D.

4.3. Comparing Expected Profits: Online vs. Offline

To compare the expected profits of joining the B2B exchange versus staying offline, we compute the difference, $\Delta\pi = E[\pi_i^*] - E[\pi_j^*]$, as

$$\Delta\pi = \underbrace{y^2(k-1)[1+(k-2)\rho]}_{\text{Term1}}\sigma^2 + \underbrace{[E(p_i^*)-c_i]^2 - [E(p_j^*)-c_j]^2}_{\text{Term2}}.$$

Term 1 represents the benefit of information aggregation through the B2B exchange. Because

$$y^2(k-1)[1+(k-2)\rho] \geq 0, \quad \forall k \geq 2,\ \rho > 0,$$
$$\frac{\partial \Delta\pi}{\partial \sigma^2} = y^2(k-1)[1+(k-2)\rho] \geq 0. \tag{27}$$

This means that the B2B exchange would be more valuable when firms face higher uncertainty, σ^2, thus, firms would have stronger incentives to join the B2B exchange. This result is similar to Corollary 1 under quantity competition. Further, examining the sign of $\Delta\pi$ leads to the following result.

Proposition 4 (Equilibrium Solution—Who Will Trade on the Exchange). *Whether B2B exchange members make higher expected profits depends on the nature of the products and the firm's cost position. Specifically,*

$$\text{when } \theta > 0 \text{ and } c_i \leq \hat{c}, \quad E(\pi_i^*) \geq E(\pi_j^*),$$
$$\text{when } \theta < 0 \text{ and } c_i \geq \hat{c}, \quad E(\pi_i^*) \geq E(\pi_j^*),$$

where

$$\hat{c} = \mu + \frac{1}{2-y-\beta} \cdot \left[\bar{p} - \mu - \sqrt{(\bar{p}-\mu)^2 + \frac{2-y-\beta}{y-\beta} y^2(k-1)[1+(k-2)\rho]\sigma^2}\right]. \tag{28}$$

Proof. See Appendix D.

Intuitively, the firms engage in strategic interactions of competition and cooperation. The combined forces of technological and stochastic interactions measure the degree of intermixture of competition and cooperation among firms. There also exists a balance of a coalition property and a zero-sum property among exchange members (Tirole 1988). Which effect dominates depends on cost heterogeneity and product differentiation.

When products are substitutes (i.e., $\theta > 0$), information exchange leads to a finer information structure about costs, which increases pricing efficiency among exchange members. Also, information exchange affects the nature of market competition, making it more "competitive" between online and offline markets, yet more "collusive" among exchange members. The low-cost firms would attempt to lead and dominate the market by forming an implicit coalition among exchange members. By revealing their low, hence more competitive costs, they credibly deter the nonmembers from engaging in price war with them. This would enable them to maintain higher prices than what they would charge without the B2B exchange. This benefits the low-cost firms.

On the other hand, when products are complements (i.e., $\theta < 0$), the firms would have incentives to increase the whole "pie" of market demand. To encourage additional buyers to buy their complementary products, a firm would like to see other firms lower prices, while still maintaining a higher price itself. Thus, a high-cost firm has every incentive to reveal its cost to soften other firms' pricing behavior. To understand why, suppose that firm j believes that firm i's cost is high. Then, firm j believes that firm i will charge a high price, reducing the demand facing firm j. Firm j is then led to reduce its price, which raises firm i's demand. *With complement products, charging a low price is like supplying a public good; each firm claims that it will not supply the public good to force other firms to do so.* A credible way to achieve this is to join the B2B exchange and prove that it has a high cost so as to force other firms to charge a lower price.

Corollary 4 (Separating Equilibrium). *In equilibrium, those firms that are expected to trade online are the low-cost firms if products are substitutes, and high-cost firms if products are complements. Other firms continue to trade offline.*

Moreover, from (28), because $2-y-\beta > 0$, $y^2(k-1)\cdot[1+(k-2)\rho]\sigma^2 \geq 0$, then,

$$\frac{\partial \hat{c}}{\partial \sigma^2} = \begin{cases} > 0, & \text{if } \theta > 0 \text{ (or, } y-\beta < 0) \\ < 0, & \text{if } \theta < 0 \text{ (or, } y-\beta > 0) \end{cases}, \tag{29}$$

which leads to the following result.

Corollary 5 (Effect of Uncertainty). *Higher level of uncertainty increases the participation incentives of the firms and the membership size of the exchange.*

The literature shows that no firms would like to reveal cost information under price competition (Vives 1984, Gal-Or 1986; both are duopoly models involving two firms only). Our result is different: The incentives to make cost data transparent depend on cost heterogeneity, product differentiation, and the degree of uncertainty. In most situations, some firms trade online and some others trade offline. It is more complicated than the all-or-none situation in the literature.

5. Concluding Remarks

What have we learned about the informational role of B2B electronic marketplaces? We have found that firms' incentives to join a B2B exchange are sensitive to their relative cost positions, the nature of the products, the types of competition, and the degree of uncertainty. Certain types of companies (e.g., high-cost suppliers of substitute products) will lack the incentives to join the exchange as information transparency hurts more than helps them. In contrast to the widely held belief about its benefits (the so-called *information transparency hypothesis*, Zhu 2004), information transparency is indeed a double-edged sword.

Thus, this paper provides a theoretical interpretation about one aspect of the informational effects of B2B exchanges. In this framework, B2B exchanges add value as information transmission mechanisms, especially if the exchanges are designed in such a way that the tradeoff between information transparency and data confidentiality is appropriately balanced. On the other hand, our results suggest that the assumptions underlying the creation of large, industry-wide, public B2B exchanges are too simplistic to engender adoption by critical numbers of buyers and sellers. Early B2B proponents claimed multiple benefits of B2B exchanges. But our model reveals that the actual experience will be rather complicated—not all exchange effects are positive. A transparent environment is not necessarily a good thing for all participants. This may partially explain the difficulty of most public B2B exchanges in signing up suppliers, and the recent phenomenon that many firms switch from public exchanges to private exchanges (Harris 2001).

Given that firms' incentives are sensitive to the information structures of the B2B exchange, the balance between access and control of information must be carefully maintained through appropriate microstructure design of B2B marketplaces. The kind of data that a B2B exchange collects—and the conditions under which the data are made available—can make the difference between benefits and risks to participants. B2B exchange owners should keep an appropriate balance between information transparency and data confidentiality to minimize the competitive risks, while safeguarding the collaborative benefits of information transparency. Data created through transactions within a B2B marketplace should be guarded or strategically channeled to avoid the "transparency trap," though this may seem to be in direct opposition to the concept that the Internet will give birth to informationally transparent electronic markets.

On the other hand, one has to be careful when linking these results to real-world B2B exchanges. There are many reasons for firms to join a B2B exchange (e.g., to reduce procurement costs, or to gain access to a new distribution channel). The informational effects are just one, albeit an important one, of these many factors. And even these informational effects are multidimensional. Our model focuses on just one aspect of the informational effects induced by the B2B exchange—information transparency about costs. So the propositions and conclusions about joining incentives and outcomes must be conditioned on this partial equilibrium setting and the standard ceteris peribus assumptions under which they have been derived. Nonetheless, we have attempted to show, by using alternative information structures and different competition modes (quantity and price), that the results obtained in this paper are quite robust to the assumptions.

This paper leaves many issues open for further study. First, as indicated by the earlier analysis, the dynamics of information transmission are rather subtle and complex (Zhu 2002). In particular, what happens if a firm joins the B2B exchange but does not transact? The firm would get the benefit of the pooled information from the exchange but still keep its own information private. Such kind of information capture without trading remains a challenging issue for exchange operators. Second, our simultaneous game model can be extended to a more sophisticated dynamic model with multiperiods to allow firms to update their belief structure after they observe the first-period equilibrium (Zhu 1999). This is another fertile area for further research. We hope that the initial work presented in this paper will motivate other researchers to build more sophisticated models and further examine these open issues associated with the informational effects of electronic markets.

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Appendix A. Proof of the Linear Conditional Expectation Property (Lemma 1)

An n-variate random vector, $X \sim N_n(\mu, \Sigma)$, can be partitioned as

$$X = \begin{pmatrix} X_1 \\ X_2 \end{pmatrix}, \qquad \mu = \begin{pmatrix} \mu_1 \\ \mu_2 \end{pmatrix}, \qquad \Sigma = \begin{pmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{pmatrix}.$$

To get a linear transformation, let

$$P = \begin{pmatrix} I_k & -B \\ 0 & I_{n-k} \end{pmatrix}.$$

Then,

$$Y = PX = \begin{pmatrix} X_1 - BX_2 \\ X_2 \end{pmatrix} = \begin{pmatrix} Y_1 \\ Y_2 \end{pmatrix},$$

where $Y_1 = X_1 - BX_2$ and $Y_2 = X_2$. Then, $Y \sim N_n(\mu_Y, \Sigma_Y)$, where

$$\mu_Y = \begin{pmatrix} \mu_1 - B\mu_2 \\ \mu_2 \end{pmatrix},$$

and

$$\Sigma_Y = P\Sigma P' = \begin{pmatrix} \Sigma_{11} - B\Sigma_{21} & \Sigma_{12} - B\Sigma_{22} \\ (\Sigma_{12} - B\Sigma_{22})' & \Sigma_{22} \end{pmatrix}.$$

Thus, if we choose B to satisfy $\Sigma_{12} - B\Sigma_{22} = 0$; that is, $B = \Sigma_{12}\Sigma_{22}^{-1}$, then,

$$\Sigma_Y = \begin{pmatrix} \Sigma_{11} - \Sigma_{12}\Sigma_{22}^{-1}\Sigma_{21} & 0 \\ 0 & \Sigma_{22} \end{pmatrix},$$

which means that Y_1 and Y_2 are uncorrelated. Consequently, we have

$$E[Y_1] = E[X_1 - \Sigma_{12}\Sigma_{22}^{-1}X_2] = \mu_1 - \Sigma_{12}\Sigma_{22}^{-1}\mu_2.$$

Since $Y_2 = X_2$, then Y_1 is independent of X_2 as well. But, $X_1 \mid X_2 = Y_1 + \Sigma_{12}\Sigma_{22}^{-1}X_2$, thus the conditional mean of X_1, given $X_2 = x_2$, is

$$E[X_1 \mid X_2 = x_2] = \mu_1 + \Sigma_{12}\Sigma_{22}^{-1}(x_2 - \mu_2). \tag{A1}$$

Next, we apply this general result to the cost vector $\mathbf{c} = (c_j, c_1, c_2, \ldots, c_k)' \sim N_{k+1}(\mu, \Sigma)$, where μ and Σ are defined in §2. Like X above, $\mathbf{c}$ can be partitioned as $\mathbf{c} = (c_j, c_1, c_2, \ldots, c_k)' = (c_j, c_{(k)})'$, $\Sigma_{11} = \sigma^2$, $\Sigma_{12} = \rho\sigma^2 \cdot (1\ 1\ \cdots\ 1)_{1\times k}$, and

$$\Sigma_{22} = \sigma^2 \cdot \begin{pmatrix} 1 & \rho & \cdots & \rho \\ \rho & 1 & \cdots & \rho \\ \vdots & \vdots & \ddots & \vdots \\ \rho & \rho & \cdots & 1 \end{pmatrix}_{k\times k}.$$

Then, it can be shown

$$\begin{aligned}\Sigma_{12}\Sigma_{22}^{-1} &= \rho\frac{(k-1)\rho - (k-2)\rho - 1}{(k-1)\rho^2 - (k-2)\rho - 1} \cdot e_{1\times k} \\ &= \rho\frac{\rho - 1}{[(k-1)\rho + 1](\rho - 1)} \cdot e_{1\times k} \\ &= \frac{\rho}{(k-1)\rho + 1} \cdot e_{1\times k}.\end{aligned}$$

Further,

$$\begin{aligned}\Sigma_{12}\Sigma_{22}^{-1}(c_{(k)} - \mu_{(k)}) &= \frac{\rho}{(k-1)\rho + 1} \cdot e_{1\times k} \cdot (c_{(k)} - \mu_{(k)}) \\ &= \frac{\rho}{(k-1)\rho + 1}\sum_{r=1}^{k}(c_r - \mu).\end{aligned}$$

Based on (A1),

$$E[c_j \mid c_1, \ldots, c_k] = \mu + \frac{\rho}{1 + \rho(k-1)}\sum_{r=1}^{k}(c_r - \mu), \tag{A2}$$

which proves Lemma 1. This result can be extended to any partition of $\mathbf{c} = (c_1, c_2, \ldots, c_n)'$, because any of its marginal distributions will still be normal. □

Appendix B. Cournot Competition

(1) B2B Exchange Members: Optimal Quantities q_i^*. Conditional on the information set, $I_i = \{c_1, \ldots, c_k\}$, a B2B exchange member i, $i \in K$, faces a decision

$$\max_{q_i} E[\pi_i \mid I_i] = \left\{d - q_i - \sum_{\substack{m=1\\ m\neq i}}^{k} E[q_m \mid I_i] - \sum_{j=k+1}^{n} E[q_j(c_j) \mid I_i] - c_i\right\}q_i. \tag{B1}$$

First-order condition leads to[12]

$$q_i = d - c_i - Q_k - \sum_{j=k+1}^{n} E[q_j(c_j) \mid I_i], \quad i \in K, \tag{B2}$$

where $Q_k = \sum_{m=1}^{k} q_m$ can be computed as

$$Q_k = \frac{1}{1+k}\left\{kd - \sum_{i=1}^{k} c_i - k\sum_{j=k+1}^{n} E[q_j(c_j) \mid I_i]\right\}. \tag{B3}$$

In equilibrium, given the normality assumption and the LCE property, firms' output strategies are a linear function of their costs (Basar and Ho 1974, Basar 1978). Consistent with Shapiro (1986), we suppose that nonmember's strategies are expected to be of the form $q_j = \alpha - \beta c_j$, where α and β are constants, to be determined. Firm i conjectures that nonmembers' total output is

$$\sum_{j=k+1}^{n} E[q_j(c_j) \mid c_1, \ldots, c_k] = \sum_{j=k+1}^{n} \bar{q} + \beta\sum_{j=k+1}^{n}\big(\mu - E[c_j \mid c_1, \ldots, c_k]\big).$$

Inserting (4) gives

$$\sum_{j=k+1}^{n} E[q_j(c_j) \mid c_1, \ldots, c_k] = \sum_{j=k+1}^{n} \bar{q} - \frac{\rho\beta}{1+\rho(k-1)}\sum_{j=k+1}^{n}\sum_{i\in K}(c_i - \mu). \tag{B4}$$

Then, by plugging (B4) and (B3) into (B2) and using $E[c_j \mid c_i] = \mu + \rho(c_i - \mu)$, we obtain

$$q_i^* = \bar{q} + \psi\sum_{m=1}^{k}(c_m - \mu) - \phi(c_i - \mu), \quad i \in K, \tag{B5}$$

[12] It is trivial to show $\partial^2\pi/\partial q^2 < 0$. The second-order condition is satisfied for all remaining maximization problems.

where $\bar{q}$ is the equilibrium quantity in the absence of uncertainty, and

$$\psi = \frac{1}{k+1}\left[1+\frac{\beta\rho(n-k)}{1+\rho(k-1)}\right], \qquad \phi = 1, \tag{B6}$$

$$\bar{q} = \frac{d-\mu}{n+1}. \tag{B7}$$

With (B5), we can now compute the aggregate quantity Q_k in (B3) as follows:

$$Q_k = \bar{Q}_k + \gamma(k\mu - S_K), \tag{B8}$$

where

$$S_K = \sum_{i=1}^{k} c_i, \quad \bar{Q}_k = \sum_{m=1}^{k} \bar{q} = \frac{k}{n+1}(d-\mu), \quad \text{and}$$

$$\gamma = \frac{1}{1+k}\left[1-\beta k\frac{\rho(n-k)}{1+\rho(k-1)}\right].$$

(2) Nonmember Firms: Optimal Quantities q_j^*. Conditional on its information set, $I_j = \{c_j\}$, given that the members are expected to obey (B5) and (B8), a nonmember, firm j, maximizes its profit as follows:

$$\max_{q_j} E[\pi_j \mid I_j] = \left\{d - q_j - \sum_{i=1}^{k} E[q_i \mid c_j] - \sum_{\substack{m=k+1\\ m\neq j}}^{n} E[q_m \mid c_j] - c_j\right\} q_j, \quad j \in N\backslash K. \tag{B9}$$

From firm j's viewpoint, it plays a Cournot game with its own cost c_j and rivals' costs $E[c_i \mid c_j] = \mu + \rho(c_j - \mu)$. First-order condition leads to

$$q_j = \tfrac{1}{2}\{d - c_j - E[Q_k \mid c_j] - E[Q_{-j} \mid c_j]\}, \tag{B10}$$

where $Q_{-j} = \sum_{m=k+1, m\neq j}^{n} q_m$. To solve this, we use the result of (B8) to compute the conditional quantity

$$E[Q_k \mid c_j] = E[\bar{Q}_k + \gamma(k\mu - S_K) \mid c_j] = \bar{Q}_k - \gamma k\rho(c_j - \mu). \tag{B11}$$

Similarly, we can show

$$E[Q_{-j} \mid c_j] = \bar{Q}_{-j} - \beta\rho(n-k-1)(c_j - \mu), \tag{B12}$$

Inserting (B11) and (B12) into (B10) yields

$$q_j^* = \bar{q} + \beta(\mu - c_j), \quad j \in N\backslash K, \tag{B13}$$

where

$$\beta = \frac{(1+k-k\rho)[1+\rho(k-1)]}{(1+k)[1+\rho(k-1)][2+\rho(n-k-1)] - \rho^2 k^2(n-k)}. \tag{B14}$$

(3) Equilibrium Profits. Substituting the optimal outputs, q_i^* in (B5) and q_j^* in (B13), into the profit functions in (B1) and (B9), and using the conditional expectations (3) and (4), we can compute the equilibrium profits as follows. For B2B exchange members, $i \in K$, the expected profit can be computed as

$$E(\pi_i^* \mid c_i) = E(q_i^{*2}) = \underbrace{E(q_i^{*2}) - [E(q_i^*)]^2}_{\text{Var}(q_i^*)} + [E(q_i^*)]^2$$
$$= [E(q_i^*)]^2 + \psi^2(k-1)[1+(k-2)\rho]\sigma^2. \tag{B15}$$

Similarly, for nonmember firms, $j \in N\backslash K$, the expected profit is

$$E(\pi_j^* \mid c_j) = [E(q_j^*)]^2 + \text{Var}(q_j^*)$$
$$= [E(q_j^*)]^2 + \text{Var}(\bar{q} + \beta\Delta c_j) = [E(q_j^*)]^2. \tag{B16}$$

(4) Compare Equilibrium Profits $E[\pi_i^*]$ vs. $E[\pi_j^*]$. To compare the expected profit of joining the B2B exchange versus staying offline, quantify the expected profit difference, $\Delta\pi = E[\pi_i^*] - E[\pi_j^*]$, based on (B15) and (B16)

$$\Delta\pi = [E(q_i^*)]^2 - [E(q_j^*)]^2 + \psi^2(k-1)[1+(k-2)\rho]\sigma^2. \tag{B17}$$

The second term, $\psi^2(k-1)[1+(k-2)\rho]\sigma^2 > 0$, represents the benefit from information aggregation facilitated by the B2B exchange. Taking expectations of (B5) and (B13) yields

$$E(q_i^* \mid c_i) = E\left[\bar{q} + \psi\sum_{m=1}^{k}(c_m - \mu) - \phi(c_i - \mu)\right]$$
$$= \bar{q} - (\phi - \psi)\Delta c_i, \quad i \in K,$$
$$E(q_j^* \mid c_j) = E[\bar{q} + \beta(\mu - c_j)] = \bar{q} - \beta\Delta c_j, \quad j \in N\backslash K.$$

where $\Delta c_i = c_i - \mu$. Then, $[E(q_i^*) - E(q_j^*)] = (\psi - \phi + \beta)\Delta c$ and $[E(q_i^*) + E(q_j^*)] = 2\bar{q} + (\psi - \phi - \beta)\Delta c$. It can be shown that $\psi - \phi - \beta < 0$ and $\psi - \phi + \beta < 0$, $\forall \rho \in (0, 1)$. Plugging them into (B17) yields

$$\Delta\pi = (\psi - \phi + \beta)(\psi - \phi - \beta)(\Delta c)^2 + 2(\psi - \phi + \beta)\bar{q}\Delta c$$
$$+ \psi^2(k-1)[1+(k-2)\rho]\sigma^2. \tag{B18}$$

This shows that $\Delta\pi$ is a quadratic function of Δc. By examining its first and second derivatives, we found that $\Delta\pi$ is a convex, U-shaped curve. Solving $\Delta\pi = 0$ yields two roots. Excluding the root that was found infeasible, we get

$$\hat{c} = \mu + \frac{\bar{q} - \sqrt{\bar{q}^2 - \dfrac{\psi - \phi - \beta}{\psi - \phi + \beta}\psi^2(k-1)[1+(k-2)\rho]\sigma^2}}{\phi + \beta - \psi}. \tag{B19}$$

Then, we found

$$\Delta\pi = \begin{cases} \geq 0, & \text{if } c \leq \hat{c} \\ < 0, & \text{if } c > \hat{c} \end{cases}, \tag{B20}$$

which shows that, when $c \leq \hat{c}$, $\Delta\pi = E[\pi_i^*] - E[\pi_j^*]$ is positive. In addition, because $(\psi - \phi - \beta)/(\psi - \phi + \beta) > 0$ and $\psi^2(k-1)[1+(k-2)\rho]\sigma^2 > 0$, then,

$$\Delta = \bar{q} - \sqrt{\bar{q}^2 - \frac{\psi - \phi - \beta}{\psi - \phi + \beta}\psi^2(k-1)[1+(k-2)\rho]\sigma^2} > 0.$$

Hence,

$$\hat{c} \geq \mu \quad \text{and} \quad \frac{\partial\hat{c}}{\partial\sigma^2} > 0. \quad \square \tag{B21}$$

Appendix C. Profits with and Without the B2B Exchange

(1) Comparing Nonmember Firms' Profits with and Without the B2B Exchange. If there is no B2B exchange, the demand function is $p = d - \sum_{r=1}^{n} q_r$, as defined in (1). A firm, say firm j, maximizes its expected profit by

$$\max_{q_j} E[\pi_j \mid I_j] = \left[d - \sum_{r=1}^{n} E(q_r \mid I_j) - c_j\right] \cdot q_j, \quad j = 1, \ldots, n, \qquad \text{(C1)}$$

where $I_j = \{c_j\}$ is the information set, along with common knowledge of industry parameters, $\{n, k, \rho, F(c)\}$. Then, the first-order condition is

$$q_j^* = d - \sum_{r=1}^{n} E[q_r^* \mid I_j] - c_j. \qquad \text{(C2)}$$

To compute $E[q_r^* \mid I_j]$, we assume that $E[q_r^* \mid I_j]$ follows the linear conditional expectation property as proved earlier, i.e.,

$$E[q_r^* \mid I_j] \triangleq \bar{q} + \beta \cdot E[\Delta c_r \mid I_j], \quad \text{where } \Delta c_r = c_r - \mu. \qquad \text{(C3)}$$

For normal distribution, we have $E[\Delta c_r \mid I_j] = E[\Delta c_r \mid \Delta c_j] = \rho \Delta c_j$. Substituting this into (C3) yields $E[q_r^* \mid I_j] = \bar{q} + \beta\rho\Delta c_j$. Plugging this back to (C2), we have

$$\bar{q} + \beta \cdot \Delta c_j = d - \mu - \{n\bar{q} + \beta[\rho(n-1)+1]\Delta c_j\} - \Delta c_j.$$

As before, solving this equation yields the equilibrium quantity

$$q_j^* = \bar{q} - \beta\Delta c_j = \frac{d-\mu}{n+1} - \frac{1}{2+(n-1)\rho}\Delta c_j, \quad j = 1, \ldots, n, \qquad \text{(C4)}$$

where

$$\bar{q} = \frac{d-\mu}{n+1}, \qquad \beta = -\frac{1}{2+(n-1)\rho}.$$

Accordingly, the expected equilibrium profit is

$$E(\pi_j^* \mid I_j)^{NB2B} = [E(q_j^*)]^2. \qquad \text{(C5)}$$

With the B2B exchange, a nonmember firm's equilibrium quantity has been derived in (B13), and expected profit in (B16) as

$$E(\pi_j^* \mid I_j)^{B2B} = [E(q_j^*)]^2. \qquad \text{(C6)}$$

With the results in (C4)–(C6), we are ready to compare the nonmember's profit without the B2B exchange and the profit with the B2B exchange as follows:

$$\begin{aligned}\Delta E(\pi)_{\text{nonmember}} &= E(\pi_j^{NB2B} \mid I_j) - E(\pi_j^{B2B} \mid I_j) = (q_j^{NB2B})^2 - (q_j^{B2B})^2 \\ &= [(q_j^{NB2B}) - (q_j^{B2B})][(q_j^{NB2B}) + (q_j^{B2B})].\end{aligned}$$

Since $(q_j^{NB2B}) + (q_j^{B2B}) > 0$, we only need to focus on $(q_j^{NB2B}) - (q_j^{B2B})$

$$\begin{aligned}&(q_j^{NB2B}) - (q_j^{B2B}) \\ &= \left(\frac{(1+k-k\rho)[1+\rho(k-1)]}{(1+k)[1+\rho(k-1)][2+\rho(n-k-1)] - \rho^2 k^2 (n-k)} - \frac{1}{2+(n-1)\rho}\right) \cdot \Delta c_j \\ &= \frac{\rho k(k-1)(1-\rho)[1+(n-1)\rho]}{[2+(n-1)\rho]D_1} \cdot \Delta c_j, \qquad \text{(C7)}\end{aligned}$$

where $D_1 = k[2 + (n-1)\rho] + (1-\rho)(2-\rho) + \rho(1-\rho) \cdot [n + k(k-1)] > 0$. It can be shown that

$$\frac{\rho k(k-1)(1-\rho)[1+(n-1)\rho]}{[2+(n-1)\rho]D_1} > 0.$$

Thus, if $\Delta c_j \geq 0$, then $(q_j^{NB2B}) - (q_j^{B2B}) \geq 0$.

Proposition 2 indicates that high-cost firms with $c > \hat{c}$ stay outside as nonmembers. Following the result in (B21), we have $\Delta\hat{c} = \hat{c} - \mu \geq 0$. Therefore, for nonmembers, $\Delta c_j > \Delta\hat{c} \geq 0$, which, in turn, leads to $(q_j^{NB2B}) \geq (q_j^{B2B})$, and, hence,

$$E(\pi_j^{NB2B} \mid I_j) \geq E(\pi_j^{B2B} \mid I_j). \qquad \text{(C8)}$$

(2) Comparing Member Firms' Profits with and Without the B2B Exchange. For member firms, the equilibrium quantity and expected profit have been derived in (B5) and (B15), respectively. Using a similar approach as above, we can compare a member firm's expected profits with and without the B2B exchange. Based on (C5) and (B15), we have

$$\begin{aligned}\Delta E(\pi)_{\text{member}} &= E(\pi_i^{B2B} \mid I_i) - E(\pi_j^{NB2B} \mid I_j) \\ &= [E(q_i^{B2B})]^2 + \psi^2(k-1)[1+(k-2)\rho]\sigma^2 \\ &\quad - [E(q_j^{NB2B})]^2 \\ &= [q_i^{B2B} + q_j^{NB2B}][q_i^{B2B} - q_j^{NB2B}] \\ &\quad + \psi^2(k-1)[1+(k-2)\rho]\sigma^2. \qquad \text{(C9)}\end{aligned}$$

Since $[q_i^{B2B} + q_j^{NB2B}] > 0$ and $\psi^2(k-1)[1+(k-2)\rho] > 0$, we only need to focus on $[q_i^{B2B} - q_j^{NB2B}]$

$$\begin{aligned}[q_i^{B2B} - q_j^{NB2B}] &= \psi[(k-1)\rho + 1]\Delta c - \Delta c + \frac{\Delta c}{2+(n-1)\rho} \\ &= \frac{(k-1)(1-\rho)[1+(n-1)\rho]D_2}{[2+(n-1)\rho]D_1}(-\Delta c),\end{aligned}$$

where $D_2 = k\rho + (1-\rho)[2+(n-1)\rho] > 0$, hence the coefficient is positive. Thus, if $\Delta c < 0$, then, $q_i^{B2B} > q_j^{NB2B}$, meaning that member firms produce more when there is an exchange than when there is no exchange. Correspondingly, they make higher profits. From Proposition 2, $c \leq \hat{c}$ or $\Delta c < \Delta\hat{c}$ for member firms. The above conclusion will hold if $c \leq \mu$ or $\Delta c \leq 0$; that is,

$$E(\pi_i^{B2B} \mid I_i) \geq E(\pi_j^{NB2B} \mid I_j). \qquad \text{(C10)}$$

Otherwise, if $\mu \leq c < \hat{c}$, the first term in (C9) will be negative. Yet, if σ is big enough, then, (C10) will still hold. □

Appendix D. Bertrand Competition

We first derive equilibrium pricing strategies p_i^* and p_j^*, for member firms and nonmember firms, then, compare the expected equilibrium profits of joining the B2B exchange versus staying offline, i.e., $\Delta\pi = E(\pi_i^*) - E(\pi_j^*)$. We will show under what conditions the member firms would expect to make higher profits than the nonmembers.

(1) Equilibrium Pricing Decisions p_i^* and p_j^*. Demand function is defined in (17). A member firm i, conditional on its information set, $I_i = \{c_1, \ldots, c_k\}$, maximizes its expected profit by deciding on price

$$\max_{p_i} E(\pi_i \mid I_i) = p_i q_i - c_i q_i = (p_i - c_i) q_i$$
$$= (p_i - c_i)\left[d - p_i + \theta\left(\sum_{m\neq i} p_m \,\Big|\, I_i\right)\right], \quad i \in K$$

$$\frac{\partial \pi_i}{\partial p_i} = 0$$
$$\Rightarrow \quad p_i = \frac{1}{2}\left(d + c_i + \theta \sum_{m\neq i} p_m \,\Big|\, I_i\right)$$
$$= \frac{1}{2}\left[d + c_i + \theta \sum_{\substack{m=1\\ m\neq i}}^{k} p_m \,\Big|\, I_i + \theta \sum_{m=k+1}^{n} p_m \,\Big|\, I_i\right]. \quad \text{(D1)}$$

Similarly, conditional on its information set, $I_j = \{c_j\}$, a nonmember firm j faces a decision

$$\max_{p_j} E(\pi_j \mid I_j) = (p_j - c_j) q_j$$
$$= (p_j - c_j)\left[d - p_j + \theta\left(\sum_{m\neq j} p_m \,\Big|\, I_j\right)\right], \quad j \in N\backslash K$$

$$\frac{\partial \pi_j}{\partial p_j} = 0$$
$$\Rightarrow \quad p_j = \frac{1}{2}\left(d + c_j + \theta \sum_{m\neq j} p_m \,\Big|\, I_j\right)$$
$$= \frac{1}{2}\left\{d + c_j + \theta E\left[\sum_{m=1}^{k} p_m \,\Big|\, I_j\right] + \theta \sum_{\substack{m=k+1\\ m\neq j}}^{n} E[p_m \mid I_j]\right\}. \quad \text{(D2)}$$

In Bertrand competition, firms choose prices based on their marginal costs and the conjectures of other firms' equilibrium strategies. Basar and Ho (1974) showed that the equilibrium strategy is affine in the information set on costs. Consistent with their results, by solving the optimal price, p_i^*, for member firms, we found that

$$p_i^* = \bar{p} + y \sum_{m=1}^{k} (c_m - \mu) + \frac{1}{2+\theta}(c_i - \mu)$$
$$= \bar{p} + y \sum_{m=1}^{k} \Delta c_m + \frac{1}{2+\theta} \Delta c_i, \quad \text{(D3)}$$

where $\Delta c_i = c_i - \mu$,

$$y = \frac{\theta}{(2+\theta-k\theta)}\left[\frac{1}{2+\theta} + \frac{(n-k)\beta\rho}{1+\rho(k-1)}\right], \quad \text{(D4)}$$
$$\bar{p} = \frac{d+\mu}{2+\theta-n\theta},$$

where $\bar{p}$ represents the equilibrium price in the absence of cost uncertainty.

Solving the optimal price, p_j^*, for nonmember firms, $j \in N\backslash K$, yields

$$p_j^* = \bar{p} + \beta \Delta c_j, \quad \text{(D5)}$$

where

$$\beta = \frac{[2+\theta-k\theta+\rho\theta k][1+\rho(k-1)]}{[2-\rho\theta(n-k-1)][2+\theta-k\theta][1+\rho(k-1)] - \rho^2\theta^2 k^2 (n-k)}. \quad \text{(D6)}$$

(2) Equilibrium Profits π_i^* and π_j^*. Having derived the optimal pricing strategies, p_i^* and p_j^*, we then substitute (D3) and (D5) into the profit functions in (D1) and (D2) to compute the equilibrium profits, π_i^* and π_j^*. For B2B exchange members, $i \in K$, the expected profit can be computed as

$$E(\pi_i^* \mid c_i) = E[(p_i^* - c_i)^2]$$
$$= \underbrace{E[(p_i^* - c_i)^2] - [E(p_i^* - c_i)]^2}_{\mathrm{Var}(p_i^* - c_i)} + [E(p_i^* - c_i)]^2$$
$$= \mathrm{Var}(p_i^*) + [E(p_i^*) - c_i]^2, \quad \text{(D7)}$$

where c_i is known to firm i. From (D3), we can compute

$$\mathrm{Var}(p_i^*) = \mathrm{Var}\left(\bar{p} + y \sum_{m=1}^{k} \Delta c_m + z \Delta c_i\right) = y^2 (k-1)[1 + (k-2)\rho]\sigma^2.$$

Substituting it into (D7) yields

$$E(\pi_i^* \mid c_i) = \mathrm{Var}(p_i^*) + [E(p_i^*) - c_i]^2$$
$$= y^2 (k-1)[1 + (k-2)\rho]\sigma^2 + [E(p_i^*) - c_i]^2. \quad \text{(D8)}$$

Using the same approach, the expected profit for nonmembers, $j \in N\backslash K$, can be computed as

$$E(\pi_j^* \mid c_j) = E[(p_j^* - c_j)^2] = \mathrm{Var}(p_j^*) + [E(p_j^*) - c_j]^2$$
$$= [E(p_j^*) - c_j]^2. \quad \text{(D9)}$$

(3) Compare Equilibrium Profits $E(\pi_i^*)$ vs. $E(\pi_j^*)$. To compare the expected profit of joining the B2B exchange versus staying offline, we need to compare the difference, $\Delta\pi = E(\pi_i^*) - E(\pi_j^*)$, by using the results of (D8) and (D9)

$$\Delta\pi = E(\pi_i^*) - E(\pi_j^*) = \underbrace{y^2 (k-1)[1 + (k-2)\rho]}_{\text{Term 1}} \sigma^2$$
$$+ \underbrace{[E(p_i^*) - c_i]^2 - [E(p_j^*) - c_j]^2}_{\text{Term 2}}. \quad \text{(D10)}$$

Term 1 represents the benefit of information aggregation through the B2B exchange. Because

$$(k-1)[1 + (k-2)\rho] y^2 \geq 0, \quad \forall k \geq 2, \ \rho > 0,$$
$$\frac{\partial \Delta\pi}{\partial \sigma^2} = (k-1)[1 + (k-2)\rho] y^2 \geq 0. \quad \text{(D11)}$$

Equation (D11) means that the B2B exchange would be more valuable when the uncertainty, σ^2, is higher.

We now examine Term 2, assuming $c_i = c_j$ so as to compare the two alternatives that the same firm faces—join or not join the B2B exchange. Taking expectation of (D3) and (D5) yields

$$\begin{cases} E[p_i^* \mid c_i] = \bar{p} + \big(y + 1/(2+\theta)\big)\Delta c_i = \bar{p} + y \Delta c_i \\ E[p_j^* \mid c_j] = \bar{p} + \beta \Delta c_j \end{cases}. \quad \text{(D12)}$$

Substituting (D12) into (D10), we have

$$\Delta\pi = y^2(k-1)[1+(k-2)\rho]\sigma^2 + [E(p_i^*)+E(p_j^*)-2c_i][E(p_i^*)-E(p_j^*)], \quad (\because c_i = c_j) \quad \text{or}$$

$$\Delta\pi = (y-\beta)(y+\beta-2)(\Delta c)^2 + 2(\bar{p}-\mu)(y-\beta)\Delta c + y^2(k-1)[1+(k-2)\rho]\sigma^2. \tag{D13}$$

This shows that $\Delta\pi$ is a quadratic function of Δc. By examining its first and second derivatives, we found that $\Delta\pi$ is a U-shaped curve, for $\theta > 0$, and a reversed U-shaped curve if $\theta < 0$. It can be shown $\text{Sign}(\beta - y) = \text{Sign}(\theta)$. Solving $\Delta\pi = 0$ yields two roots. Excluding the root that was found infeasible, we get

$$\hat{c} = \mu + \frac{1}{2-y-\beta} \cdot \left[\bar{p}-\mu-\sqrt{(\bar{p}-\mu)^2+\frac{2-y-\beta}{y-\beta}y^2(k-1)[1+(k-2)\rho]\sigma^2}\,\right] \tag{D14}$$

Further, because $2-y-\beta > 0$, $y^2(k-1)[1+(k-2)\rho]\sigma^2 \geq 0$, then,

$$\Delta = (\bar{p}-\mu) - \sqrt{(\bar{p}-\mu)^2 + \frac{2-y-\beta}{y-\beta}y^2(k-1)[1+(k-2)\rho]\sigma^2} = \begin{cases} \leq 0, & \text{if } (y-\beta) > 0 \\ > 0, & \text{if } (y-\beta) < 0 \end{cases}.$$

Substituting it into (D14) leads to

$$\hat{c} = \mu + \frac{\Delta}{2-y-\beta} = \begin{cases} <\mu, & \text{if } (y-\beta) > 0 \\ =\mu, & \text{if } \sigma^2 = 0 \\ >\mu, & \text{if } (y-\beta) < 0 \end{cases}.$$

To sum up, the conditions that $\Delta\pi \geq 0$ can be specified as follows:

(1) if $\theta > 0$,

$$\Delta\pi = \begin{cases} \geq 0, & \text{if } c \leq \hat{c} \\ < 0, & \text{if } c > \hat{c} \end{cases} \quad \text{and} \quad \hat{c} > \mu; \tag{D15}$$

(2) if $\theta < 0$,

$$\Delta\pi = \begin{cases} \geq 0, & \text{if } c \geq \hat{c} \\ < 0, & \text{if } c < \hat{c} \end{cases} \quad \text{and} \quad \hat{c} < \mu. \quad \square \tag{D16}$$

Notations

α, β	Constants
c_i, c_j	Marginal cost for firm i, j (a stochastic variable, where $c \sim N(\mu, \sigma^2)$)
Δc	Cost differential from the mean, defined as $\Delta c \equiv c_i - \mu$
$\hat{c}$	Threshold cost
d	Demand intercept, constant
I_i	Information set available to member firm i, $i \in K$
I_j	Information set available to nonmember firm j, $j \in N\backslash K$
k	Number of members in the set of K, $k = \|K\|$
K	Set of k firms that belong to the B2B exchange, $\|K\| = k$ and $K \subseteq N$
N	Set of the total firms in the industry, where $N = (1, 2, \ldots, n)$ and $\|N\| = n$
$N\backslash K$	The complement set of $(n-k)$ firms that trade outside of the B2B exchange
p_i	Price of the product
p_i^*	Optimal price at equilibrium
$\bar{p}$	Price in the absence of uncertainty (i.e., the optimal price if all firms' cost were μ)
q_i	Quantity of the product supplied by firm i
q_i^*	Optimal quantity at equilibrium
$\bar{q}$	Output in the absence of uncertainty (i.e., if output was all produced at a constant cost, μ)
Q_k	Sum of output from all firms belonging to the B2B exchange
Q_{-j}	Sum of output from all firms outside of the B2B exchange, excluding firm j
μ	Mean of cost vector, $\mu \equiv E[c]$
σ^2	Variance of marginal cost
ρ	Correlation coefficient between any pair (c_i, c_j), $j \neq i$
Σ	Covariance matrix of cost vector $\mathbf{c} = (c_1, c_2, \ldots, c_n)'$
π_i, π_j	Profit of firms i, j
$\bar{\pi}$	Profits that would arise if output were all produced at a constant cost, μ
$\Delta\pi$	The difference of profit between a member firm and a nonmember firm
θ	Degree of product differentiation, where $\theta > 0$, $\theta = 0$ and $\theta < 0$ represent substitute, independent, and complement products, respectively
ϕ, ψ, β, y	Sensitivity coefficients in equilibrium profits as functions of ρ, θ, k, n
S_k	Sum of the costs of k firms, $S_K = \sum_{i=1}^{k} c_i$.

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