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Buyer's strategic demand information sharing with an upstream echelon for entry promotion

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ABSTRACT

Nowadays, because of the prevalence of information technology, the question of whether or not a firm should share various information vertically with outside firms constituting a supply chain has become a critical issue. Given this environmental change, this paper investigates the information sharing problem of whether a buyer purchasing products from a supplier should disclose its demand information in a noncooperative game setting. To date, a number of game-theoretic studies have shown that the optimal strategy for the buyer pursuing only its own profit is to disclose no demand information, because information disclosure causes a portion of the profit to be drained vertically from the buyer to the supplier. Contrary to this conventional insight in the literature, we demonstrate that the buyer can increase its own profit by fully disclosing information when there exists not only an incumbent supplier currently operating, but also a potential alternative supplier who waits for the chance to enter the upstream market. This finding means that the well-known result in the information sharing game in a supply chain can be reversed when there is an entry threat at the upstream supplier level. This result provides the practical implication that a buyer in a supply chain can strategically reveal demand information, which is seemingly disadvantageous to the buyer, to improve its profit through promoting the entry of another supplier as an alternative source of products. Consequently, we gain managerial insights that differ significantly from existing ones, which is the unique contribution of this study.

1. Introduction

Today, information sharing among firms constituting complex supply chains has been a critical issue in the field of operations and supply chain management from both academic and practical perspectives. Traditionally, the notorious "bullwhip effect", in which upstream firms in a supply chain face greater demand uncertainty caused by order variations from downstream firms, has often been observed in various industries. Previous research suggests that information sharing among supply chain members operates as an effective remedy to overcome the bullwhip effect and enhance supply chain performance (e.g. Lee et al., 1997; Cachon and Fisher, 2000). Accordingly, firms make substantial investments in information systems and technologies to collect and share information on product sales with their suppliers (Anand and Goyal, 2009).[1] The rapid growth of information and communication technologies (ICT) also facilitates firms' abilities to collect and share demand information at low cost.

In general, firms downstream of a supply chain tend to accumulate richer demand information because they are closer to end consumers and thus have more opportunities to interact with consumers than firms that are upstream. For example, if a buyer downstream is a manufacturer who purchases parts for a finished product from an upstream supplier, the manufacturer is likely to have more demand information, because the manufacturer producing finished products is closer to end consumers than the supplier. Moreover, several prominent manufacturers such as Dell, Hewlett-Packard (HP), Adidas, Nike, Timbuk, and Harley-Davidson, adopt the mass customization of products based on make-to-order (MTO) or build-to-order (BTO) systems. Manufacturers that adopt mass customization are especially likely to accumulate more precise demand information regarding which parts and varieties of products are in higher demand and hence more needed by customers. These radical changes of the production and distribution systems assisted by the growth of ICT also make the decision of whether private information should be disclosed by a buyer procuring products to suppliers an increasingly important practical issue.

Given the growing importance of demand information sharing among supply chain members, this paper investigates the information sharing problem of whether a buyer purchasing products from a supplier

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[1] See Callioni and Billington (2001) for the real-life case of information sharing through partnerships between Hewlett-Packard (HP) and its suppliers.

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should disclose its demand information in a noncooperative game setting. To date, previous substantial game-theoretic studies have shown that the optimal strategy for the buyer pursuing only its own profit is to disclose no demand information, because information disclosure causes a portion of the profit to drain vertically from the buyer to the supplier (e.g., Li, 2002; Zhang, 2002). Contrary to the conventional insight gained in the literature, this paper demonstrates that the buyer can increase its own profit by fully disclosing information when there exists not only an incumbent supplier currently operating, but also a potential alternative supplier who waits for the opportunity to enter the upstream market. This finding means that the well-known result in the information sharing game in a supply chain can be reversed when there is an entry threat at the upstream supplier level. This result provides the practical implication that a buyer in a supply chain can strategically reveal demand information, which is seemingly disadvantageous to the buyer, to improve its profit through promoting the entry of another supplier as an alternative source of products.

The logic behind this counterintuitive result is as follows. If the buyer discloses demand information, the risk for a potential supplier of entering the market decreases, because the supplier can make a more precise demand forecast by receiving the information from the buyer. The risk reduction increases the expected profit of the potential supplier when it actually enters the market, and thus helps it to enter the market. This entry of the potential supplier intensifies the degree of competition in the upstream market, which in turn enables the downstream buyer to purchase a product at a lower price from suppliers, leading to a higher profit for the buyer. As a consequence of these causal relationships, a buyer's disclosure can increase its own profit.

In this study, we consider the following two firms as specific real-life cases described by our information sharing model. The first case is Apple Inc. Apple now orders and purchases key components of iPhones from various suppliers, including Japan Display Inc., LG Display Co., and Sharp Corp.[2] In particular, Apple's current management has a clear policy of inducing potential suppliers to enter into contract with Apple and to make them compete with incumbent suppliers in order to extract favorable purchase terms (Spence, 2018).[3] To support suppliers' decisions, Apple shares its demand forecast information with suppliers through Statista.com, a third-party data service provider, enabling potential suppliers to obtain demand information about Apple's products (Wu et al., 2019). Therefore, this case corresponds to strategic disclosure to lure potential suppliers, which will compete with incumbent suppliers, into contracts with the buyer. The second case of information sharing is Haier, which is a giant manufacturing company of white goods in China. To facilitate communications with spare parts suppliers, Haier employs a procurement plan sharing mechanism, known as a *business-to-business procurement* (*BBP*) *system*.[4] When customers place orders, the sales department in Haier collects the order information and transfers it to the BBP system. Then, Haier shares its procurement plan with upstream parts suppliers such as Hitachi, Matsushita, and Mitsubishi Electric. When sending the procurement plan, Haier has several options for information sharing in order to purchase parts at the lowest possible price. For example, Haier can send its procurement plan to only a single supplier, or to multiple suppliers simultaneously. After receiving a plan via the BBP system, suppliers offer prices for their parts. Therefore, potential suppliers are able to decide whether or not to enter into a supply contract with Haier after reviewing the information obtained through the system. This case also corresponds to a real-life case described by the information sharing model in this paper.

The present paper makes contributions to two areas of the academic literature: the literature on information sharing and the literature on competition with consideration of entry threat, both of which have been extensively examined issues in the operations and supply chain management field. First, as mentioned earlier, conventional wisdom proposed in previous game-theoretic studies suggests that a downstream firm should not disclose demand information to an upstream supplier if the buyer pursues only its own profit. Contrary to this previous result, we draw the counterintuitive implication that a buyer's information disclosure can increase its own profit. This finding is strikingly different from the conventional result in existing research and hence contributes to the literature relating to strategic information sharing. Second, while there are many papers that analyze competition in the presence of entry threat, as will be overviewed in the next section, most of the existing models demonstrate that strategic "deterrence" of the entry of a potential rival firm helps an incumbent firm achieve a higher profit. Contrary to previous research that suggests entry "deterrence" as an effective competitive strategy, we gain a new theoretical perspective that entry "promotion" or "encouragement" improves the profit of an incumbent firm, which is a contrasting result to that of existing models. More specifically, whereas an incumbent firm should generally "deter" the entry of another firm in a horizontal relationship at the same echelon level in order to reduce the number of competitors, the firm should "promote" the entry of another firm in a vertical relationship at a different echelon level in order to draw advantageous transaction terms by providing competitive pressure at the different level. We present this new strategic perspective, thereby contributing to the existing literature on competition under entry threat.

The results and implications of our study are valuable from both academic and practical viewpoints. As discussed earlier, because a supply chain member closer to end consumers accumulates more precise demand information, the disclosure and sharing of information have become a crucially important issue, particularly for downstream firms. Our result provides a practical insight that can be used as decision support by a downstream buyer, so that the buyer can secure an alternative source of products from another supplier through information disclosure, thereby enhancing its profit.

The remainder of the paper is structured as follows. Section 2 reviews the literature on information sharing as well as the literature on competition in the presence of entry threat. In Section 3, we present the assumptions and supply chain structure upon which we theoretically analyze optimal information sharing strategies. Section 4 derives the equilibrium results and discusses their implications. In Section 5, we extend the basic model by considering the existence of multiple stages to draw equilibrium results for the longer term. The conclusions are presented in Section 6.

2. Literature review

To date, a considerable number of operations and supply chain management studies investigate the issue of information sharing among supply chains members by applying game theory (e.g., Li, 2002; Zhang, 2002; Chu and Lee, 2006; Yue and Liu, 2006; Li and Zhang, 2008; Wu and Cheng, 2008; Yao et al., 2008; Anand and Goyal, 2009; Mukhopadhyay et al., 2011; Zhu et al., 2011; Shamir, 2012; Zhang and Chen, 2013; Bian et al., 2014; Bian et al., 2016; Huang and Wang, 2017; Matsui, 2019; Wu et al., 2019; Zhang et al., 2019; Zhou et al., 2019; Lei et al., 2020; Wang and Zhuo, 2020; Zhang and Zhang, 2020; Hu et al., 2021). Li (2002) investigates the incentives for firms to reveal information vertically in a two-echelon supply chain that is composed of an upstream firm and multiple downstream firms. The downstream firms are endowed with some private information. He points out that vertical information sharing engenders two effects: a "direct effect" because of

[2] Wu et al. (2019) describe the case of Apple's information sharing with suppliers. The list of suppliers is available from the following website. https://images.apple.com/supplier-responsibility/pdf/Apple-Supplier-List.pdf.

[3] Spence (2018) reports: "Apple is reportedly looking to extend its partnership with Wistron this year to assemble its new iPhones. That should allow Tim Cook to squeeze more value out of the supply chain by pitting Wistron against incumbent Foxconn".

[4] Lei et al. (2020) elaborate on the process of how Haier shares its demand information with potential suppliers through the BBP system.

the changes in strategies by the firms involved in sharing information and an "indirect effect" because of the changes in strategies by other competing firms. He shows that while both changes affect the incentive of the buyer to disclose information, the direct effect always prevents the buyer from disclosing information. The existence of the two effects is also discussed by Zhang (2002). As explained earlier, whereas Li (2002) and Zhang (2002) suggest that the direct effect always has a negative impact on the incentive of a buyer to disclose information, we will prove that this negative effect is reversed when there is an entry threat in the upstream market. Chu and Lee (2006) consider a newsboy problem in a supply chain consisting of a downstream retailer and an upstream vendor. The retailer obtains a signal about demand before actual demand is realized and must determine whether to disclose the information to the vendor before the vendor commences production. They describe the situation as a model of a Bayesian game, finding that the equilibrium disclosure strategy is influenced by the cost of disclosing the information and the type of the market demand signal. They show that if the cost of sharing the information is sufficiently large, the retailer withholds the information irrespective of the type of signal. By contrast, if the cost of sharing the information is small, the retailer reveals the information if a high demand is signaled, but withholds it from the vendor if a low demand is signaled. Zhu et al. (2011) consider a supply chain consisting of a manufacturer and a retailer, which independently obtain information on market demand. They consider the three different scenarios: (1) no information sharing, (2) information sharing, and (3) only the retailer possesses information. They derive the optimal price and forecast accuracy in the three cases, showing conditions under which the two firms share their information in equilibrium. Zhang and Chen (2013) investigate an information sharing problem in a supply chain that consists of a supplier and a retailer, both of which possess partial demand information. They find that the decision of a firm on information disclosure depends on the variance and the correlation of the firms' information and the other firm's disclosure decision under the single wholesale price contract. They also show that when only one of the two firms has complete information on demand, the firm with information conceals information while another reveals information. Lastly, they conclude that a revenue sharing contract enables the two firms to share their information completely. Wang and Zhuo (2020) investigate whether a retailer should share its demand information with a supplier considering whether to sell products directly through an online channel in a two-echelon supply chain consisting of a supplier and a retailer. Hence, they consider the possibility that the supplier disintermediates the retailer, which is called supplier encroachment. They investigate ex post information sharing after the information content has been realized, showing that the retailer's incentive for information sharing depends only on the retailer's information acquisition capability and the demand distribution, but not on the possibility of supplier encroachment. Hu et al. (2021) study a supply chain that consists of a software house developing an online game and a distributor. They investigate how demand information sharing by the distributor influences the game-quality investment and the marketing investment, showing that information sharing does not always improve marketing investment, while it always affects the developer's decision on product quality.[5]

As discussed in the introduction section, there is another stream of research that is closely related to the present paper; that is, the literature on competition with consideration of entry threat into a market (e.g., Dixit, 1979; Xiao and Qi, 2010; Matsui, 2012; Karaer and Erhun, 2015; Zhou et al., 2015; Gao et al., 2017; Hartl and Kort, 2017; Chen et al., 2018; Cui, 2019; He et al., 2019; Liu et al., 2020). The idea that the entry deterrence of a rival firm can work as an effective strategy for an incumbent firm dates back to at least industrial economic research by Dixit (1979), who points out that a firm can deter entry of a rival by supplying a larger amount of products than the amount that would be optimal in competition with the rival. Xiao and Qi (2010) investigate the problem of entry deterrence in the context of multi-level supply chain management. They develop an adverse selection model involving a supply chain with one supplier, one retailer, and a potential entrant supplier who makes and sells a substitutable product. The authors study how the incumbent supplier in a two-echelon supply chain reacts to the potential entry of another supplier by strategically controlling the wholesale price. They first construct the main model, in which both suppliers will commonly use the retailer to sell their products, and then they compare the main model with three alternative models with different channel structures. Through a comparison between the models, they show that the common use of the downstream retailer increases the incentive of the incumbent supplier overall to deter the entry of the entrant supplier. Assuming that an incumbent firm can control the quality of its product, Karaer and Erhun (2015) identify conditions under which the incumbent overinvests in quality to deter the entry of a rival firm. They also identify the conditions under which the incumbent firm intentionally decreases its quality investment to accommodate entry. They conclude that the decision of overinvestment for deterrence or underinvestment for accommodation depends on the market potential under duopoly and cost and market characteristics. Zhou et al. (2015) consider a two-echelon supply chain consisting of a dominant retailer, an incumbent supplier, and an "incursive" vendor, in which the incumbent supplier and the incursive vendor supply substitutable products to the dominant retailer. They investigate whether the retailer should sell products supplied by the incursive vendor and, if it does, how the retailer strategically determines the alliance structure with the supplier or the vendor. Their results show that the existence of the vendor always benefits the retailer and often benefits the incumbent suppler. Moreover, if the price competition between the supplier and the vendor is sufficiently intense, the retailer should ally with the upstream member who has a relatively stronger competitive ability. If the competition is moderate, the dominant retailer should ally with both the incumbent supplier and the incursive vendor. Liu et al. (2020) examine the influence of technology upgrade on entry behavior of a buyer into a supply chain, in which an incumbent buyer can upgrade production technology through its direct investment. They find that the entry of a buyer can encourage the incumbent buyer to upgrade the production technology. As a result, the entry enables the incumbent buyer to increase its own profit, contrary to the conventional result that the entry reduces the profit of an existing firm.

Because we consider the existence of a potential entrant into an upstream market in a two-echelon supply chain, Xiao and Qi (2010) and Zhou et al. (2015) are especially closely associated with this paper. As overviewed, however, the result that entry "deterrence" increases the profit of an incumbent firm under various economic environments has been shown in a number of game-theoretic studies. Differing from the previous studies above, the present paper shows that not only entry "deterrence" but also entry "promotion" can increase the profit of the incumbent pursuing its own profit.[6] Moreover, even though a number of existing operations management studies investigate the issue of strategic information sharing in supply chains, no study points out that a supply

[5] In addition to the supply chain management literature, we also consider the economic literature as a stream of research that has addressed the issue of information sharing extensively; the latter literature focuses on horizontal competitive relationships among firms rather than on vertical relationships such as supply chains (e.g., Vives, 1984; Gal-Or, 1985; Raith, 1996).

[6] Corstjens et al. (1989) is an exceptional theoretical study showing that entry encouragement improves the profit of an incumbent firm. Their model considers an existing market and a new market in which a product requiring new technology is sold, showing that an incumbent firm encourages entry in order to induce the entrant to research the profitability of the new market. Differing from their paper, our stochastic model focuses on information sharing and involves only one product market.

chain member can increase its profit by strategically revealing its information to attract entry and thereby providing competitive pressure at a different echelon level. Therefore, it is worth highlighting that the present paper is the first to provide a new practical view that not entry deterrence but entry promotion in a different echelon level is desirable for an incumbent firm, thereby contributing to the supply chain management literature.

3. Model description

In this section, we present the assumptions and settings of our model. Table 1 lists the variables used in the model. As described in Fig. 1, we consider a two-echelon supply chain composed of upstream and downstream levels. We assume that there is one incumbent supplier (Firm I) currently operating and there is one potential entrant supplier (Firm P) considering whether to enter the market at the upstream echelon level. In the downstream echelon level, there is only one buyer (Firm B). Henceforth, Firms B, I, and P denote the buyer, the incumbent supplier, and the potential entrant supplier, respectively. A supplier can produce a product at marginal cost c, which is positive, and wholesales the product to Firm B. Firm B then resells the product to customers. While Firm I is currently operating and selling products, Firm P needs to pay F to enter the upstream market if producing and selling products. Hence, F represents the entry cost for Firm P.

In line with previous information sharing models, we assume the following linear stochastic inverse demand function:

$$p = a + e - bQ, \tag{1}$$

where p is price, Q is demand from customers, and a and b are positive constants. a and e are the deterministic part and the stochastic part of the intercept of the inverse demand function, respectively. Let V (>0) denote the variance of e. As V increases, the difficulty of forecasting the market demand increases. Therefore, V can be interpreted as the market volatility. Although e is unknown to all firms, Firm B, which is closer to customers than Firms I and P, forecasts the value using information-gathering technology. Specifically, Firm B obtains a noisy signal denoted by f, which consists of e plus some noise:

$$f = e + \varepsilon, \tag{2}$$

where ε is the noise of the observed signal, independent of e, with mean 0 and variance σ (>0). The signal f provides more precise information about e as σ decreases. Stated differently, the accuracy of the demand forecast by Firm B increases as σ decreases, and vice versa.

We also assume the following linearity of the expectation of demand conditional on the information, as commonly assumed in previous game-theoretic information sharing models (e.g., Li, 2002; Zhang, 2002):

$$\mathrm{E}(e|f) = \alpha + \beta f, \tag{3}$$

where α and β are constants.[7] This assumption leads to the following lemma that shows the conditional expectation of e. (all proofs are provided in the Appendix.)

Lemma 1. *The following equation holds.*

$$E(e|f) = \frac{Vf}{\sigma + V}$$

We assume that all parameters in the model, except for information, are common knowledge for all firms.

Next, the profits of Firms B and I defined as π_B and π_I are:

$$\pi_B = (p - w)Q \tag{4}$$

$$\pi_I = (w - c)q_I, \tag{5}$$

where w denotes the wholesale price, and q_I denotes the quantity supplied by Firm I. The profit of Firm P (π_P) depends on whether the firm enters the market as follows:

$$\pi_P = \begin{cases} (w - c)q_P - F, & \text{(if Firm P enters the market)} \\ 0, & \text{(if Firm P does not enter the market)} \end{cases} \tag{6}$$

where q_P denotes the quantity supplied by Firm P.

Fig. 2 illustrates the timeline of events. At Date 1, Firm B makes a precommitment to its disclosure strategy on whether to disclose demand information at Date 3. Specifically, Firm B chooses either strategy D (disclosure) or ND (no disclosure).[8] At Date 2, Firm P determines whether to enter the market by paying the entry cost, F. Namely, Firm P chooses either strategy E (entry) or strategy NE (no entry). At Date 3, Firm B obtains demand signal, f, and discloses (or does not disclose) the signal based on the disclosure strategy predetermined at Date 1. At Date 4, Firms I and P choose their respective supply quantities if Firm P enters the market, while only Firm I chooses its supply quantity if Firm P does not enter. Lastly, Firm B sets its selling quantity at Date 5.

This timeline of events suggests that the entire game consists of four subgames classified by the disclosure strategy (strategy D or ND) chosen by Firm B and the entry strategy (strategy E or NE) chosen by Firm P. Hereafter, the combinations of possible strategies are denoted as: (D, E), (D, NE), (ND, E), and (ND, NE).

4. Results and implications

Based on the settings described in the previous section, we derive equilibrium strategies and expected profits. The following lemma summarizes the equilibrium results by the combinations of strategies.

Table 1
Notation.

p	retail price
w	wholesale price
Q	total demand quantity
q_I	supply from the incumbent supplier
q_P	supply from the potential entrant supplier
F	entry cost of the potential entrant supplier
c	marginal cost
a	deterministic part of the intercept in the inverse demand function
e	stochastic part of the intercept in the inverse demand function
b	slope of the inverse demand function
f	signal of market demand obtained by the buyer
ε	noise of the signal of market demand
V	variance of e
σ	variance of ε
δ	discount factor ($0 < \delta \le 1$)
π_B	profit of the buyer
π_I	profit of the incumbent supplier
π_P	profit of the potential entrant supplier
B	symbol that denotes the buyer
I	symbol that denotes the incumbent supplier
P	symbol that denotes the potential entrant supplier
D	strategy for the buyer to disclose demand information
ND	strategy for the buyer to disclose no demand information
E	strategy for the potential entrant supplier to enter the market
NE	strategy for the potential entrant supplier not to enter the market

[7] Equation (3) means that the conditional expectation is linear in the signal, which is satisfied by various pairs of prior-posterior distribution including normal-normal, gamma-Poisson, and beta-binomial. DeGroot (1970) lists such conjugate families of distributions satisfying the assumption.

[8] Previous game-theoretic models examining information sharing strategies in a supply chain commonly assume that a supply chain member makes a precommitment to a particular disclosure policy before obtaining demand information, because a change in the information sharing strategy usually requires substantial investment into information systems that a firm cannot complete instantly and hence the disclosure policy choice is a long-term decision (e.g., Li, 2002; Zhang, 2002; Yue and Liu, 2006).

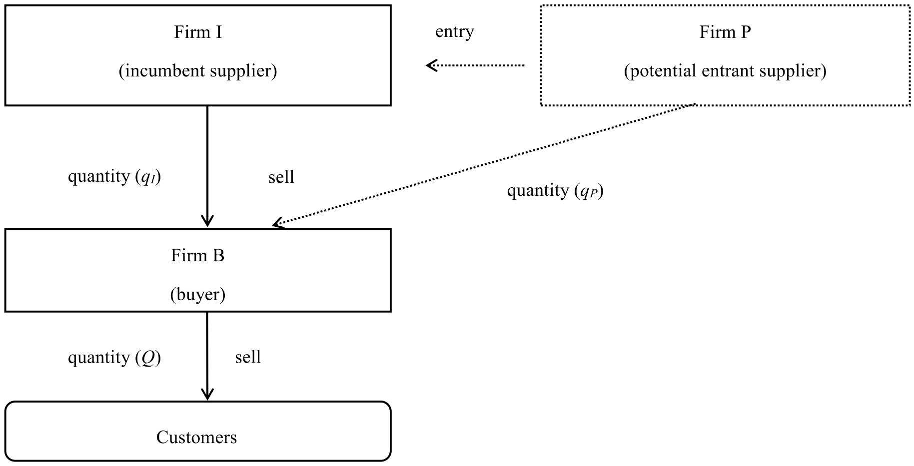

Fig. 1. Supply chain structure.

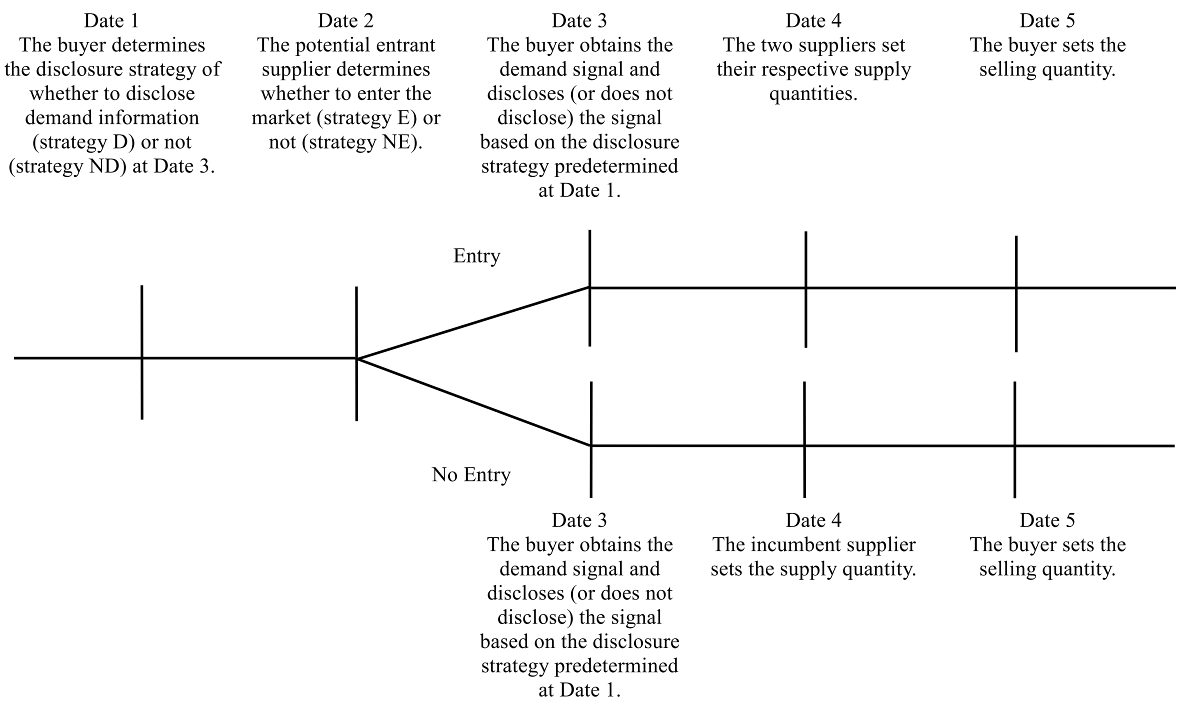

Fig. 2. Timeline of events.

Lemma 2. *Equilibrium expected profits of Firms B, I, and P classified by the combinations of strategies are summarized in the following four cases.*

Case (I): *strategy (D, E)*:

$$E\left(\pi_B^{D,E}\right) = \frac{1}{9b}\left((a-c)^2 + \frac{V^2}{V+\sigma}\right),$$

$$E\left(\pi_I^{D,E}\right) = \frac{1}{18b}\left((a-c)^2 + \frac{V^2}{V+\sigma}\right),$$

$$E\left(\pi_P^{D,E}\right) = \frac{1}{18b}\left((a-c)^2 + \frac{V^2}{V+\sigma}\right) - F.$$

Case (II): strategy (D, NE):

$$E\left(\pi_B^{D,NE}\right) = \frac{1}{16b}\left((a-c)^2 + \frac{V^2}{V+\sigma}\right),$$

$$E\left(\pi_I^{D,NE}\right) = \frac{1}{8b}\left((a-c)^2 + \frac{V^2}{V+\sigma}\right),$$

$$E\left(\pi_P{}^{D,NE}\right) = 0.$$

Case (III): strategy (ND, E):

$$E\left(\pi_B^{ND,E}\right) = \frac{1}{b}\left(\frac{(a-c)^2}{9} + \frac{V^2}{4(V+\sigma)}\right),$$

$$E\left(\pi_I^{ND,E}\right) = \frac{1}{18b}(a-c)^2,$$

$$E\left(\pi_P^{ND,E}\right) = \frac{1}{18b}(a-c)^2 - F.$$

Case (IV): strategy (ND, NE):

$$E\left(\pi_B^{ND,NE}\right) = \frac{1}{16b}\left((a-c)^2 + \frac{4V^2}{V+\sigma}\right),$$

$$E\left(\pi_I^{ND,NE}\right) = \frac{1}{8b}(a-c)^2,$$

$$E\left(\pi_P^{ND,NE}\right) = 0.$$

Superscripts D and ND attached to π_B, π_I, and π_P represent equilibrium profits when Firm B discloses information and when Firm B does not disclose information, respectively. Superscripts E and NE represent equilibrium profits when Firm P enters the market and when Firm P does not enter the market, respectively.

To obtain a more vivid picture of the results in Lemma 2, the equilibrium expected profits classified by the combinations of strategies are also summarized in Table 2. The first, second, and third values in parentheses in the table represent the equilibrium profits of Firm B, Firm I, and Firm P, respectively. A comparison of the equilibrium expected profits enables us to determine which of the strategies is optimal for Firm B at Date 1 and Firm P at Date 2.

Prior to the main analysis in the presence of an entry threat, we temporarily assume that Firm P does not exist in the game to give the benchmark result when there is no possibility of entry.

Proposition 1. *If Firm P does not exist in the game, then Firm B always generates a higher profit by choosing strategy ND than strategy D, indicating that Firm B never discloses demand information.*

Proposition 1 is the well-known result shown in a number of previous game-theoretic models investigating information sharing in a supply chain (*e.g.*, Li, 2002; Zhang, 2002). For example, Zhang (2002, *p*. 532) and its Appendix analytically show that given the typical two-echelon supply chain consisting of one supplier and one buyer, no disclosure is always the optimal strategy for the buyer because information disclosure would shift some profits from the buyer to the supplier. This effect of vertical profit shift from the buyer to the supplier through information disclosure is called the "direct effect" of the disclosure in a supply chain. Due to the direct effect, without an entry threat at the upstream echelon level, it is always optimal for the downstream buyer to not disclose any demand information to prevent the drain of a portion of its profit to the supplier.

Let us resume addressing the original problem in the paper by assuming that Firm P exists in the game again. If the upstream supplier faces an entry threat, the conventional result shown in Proposition 1 can be reversed as follows.

Proposition 2. *Assume that the exogenous parameters satisfy the following inequalities*:

$$\frac{1}{18b}(a-c)^2 \le F \le \frac{1}{18b}\left((a-c)^2 + \frac{V^2}{V+\sigma}\right), \tag{P1}$$

$$(a-c)^2 \ge \frac{20V^2}{7(V+\sigma)}. \tag{P2}$$

Then, whereas Firm P does not enter the market if Firm B chooses strategy ND, Firm P enters the market if Firm B chooses strategy D. Moreover, Firm B achieves a higher profit by choosing strategy D, which induces Firm P to enter the upstream market, than strategy ND. Consequently, strategy (D, E) constitutes the equilibrium.

Proposition 2 is the most central result in this paper and thus deserves attention. While Proposition 1 shows that strategy ND is more favorable for Firm B if there exists no potential entrant, Proposition 2 demonstrates that, when there is a potential entrant in the upstream market, strategy D is more favorable than strategy ND for Firm B as long as the exogenous parameters satisfy Inequalities (P1) and (P2). Namely, the result that we derive is the opposite of the conventional one found in the previous literature. In this respect, Proposition 2 suggests that the buyer chooses a seemingly disadvantageous strategy. At first impression, strategy D is less desirable for the buyer because Proposition 1 suggests that strategy ND is the dominant strategy if there exists no potential entrant supplier. However, this inference is no longer the case when the entry threat is present in the upstream market. If Firm B chooses strategy ND at Date 1, which seems favorable for Firm B, then Firm P does not enter the market as its optimal response at Date 2. In this case, Firm I monopolizes the upstream market, leading to a lower profit for Firm B because of the upstream monopoly. To avoid this undesirable equilibrium, instead, Firm B should adopt strategy D at Date 1, which enables Firm P to earn sufficient revenue to offset the entry cost, *F*. Consequently, Firm P enters the market in equilibrium, which leads to a duopoly in the upstream market. In summary, disclosure of demand information by the buyer enables the potential entrant to enter the upstream market, which increases competitiveness upstream. This intensified competition upstream in turn enables the buyer to purchase a

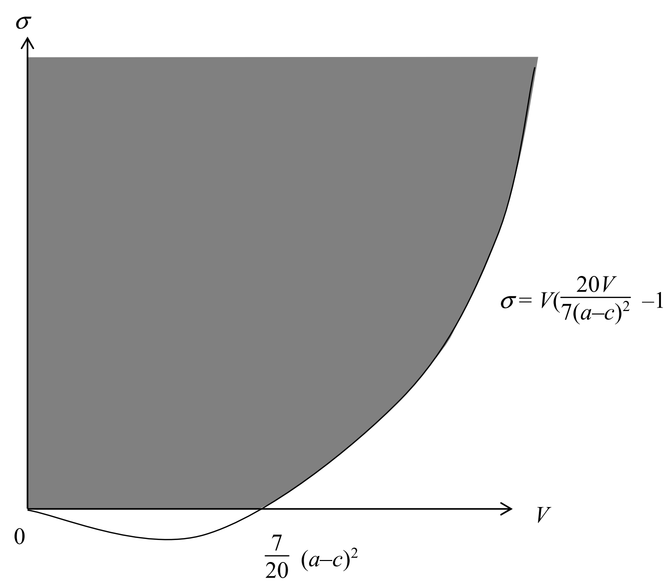

Fig. 3. Parameter region yielding disclosure and entry in equilibrium.
Note: If V and σ fall into the region colored in gray, the equilibrium in which Firm B discloses demand information and Firm P enters the market can arise. In addition, the possibility of reaching the equilibrium increases as the combination of the two parameters approaches the curve described by the quadratic function.

Table 2
Payoff matrix.

		Firm P (potential entrant supplier)	
	Strategy	NE (no entry)	E (entry)
Firm B (buyer)	D (disclosure)	$(\frac{1}{16b}\left((a-c)^2+\frac{V^2}{V+\sigma}\right), \frac{1}{8b}\left((a-c)^2+\frac{V^2}{V+\sigma}\right), 0)$	$(\frac{1}{9b}\left((a-c)^2+\frac{V^2}{V+\sigma}\right), \frac{1}{18b}\left((a-c)^2+\frac{V^2}{V+\sigma}\right), \frac{1}{18b}\left((a-c)^2+\frac{V^2}{V+\sigma}\right)-F)$
	ND (no disclosure)	$(\frac{1}{16b}\left((a-c)^2+\frac{4V^2}{V+\sigma}\right), \frac{1}{8b}(a-c)^2, 0)$	$(\frac{1}{b}\left(\frac{(a-c)^2}{9}+\frac{V^2}{4(V+\sigma)}\right), \frac{1}{18b}(a-c)^2, \frac{1}{18b}(a-c)^2-F)$

Note: The first, second, and third values in parentheses are the equilibrium profits of Firm B, Firm I, and Firm P, respectively.

product at a lower price and to achieve a higher profit.

Next, we examine which values of the exogenous parameters are likely to satisfy Inequalities (P1) and (P2). First, subtracting the left-hand side from the right-hand side of Inequality (P1) gives $((a-c)^2 + V^2/(V+\sigma))/(18b)$–$(a-c)^2/(18b) = V^2/(18b(V+\sigma))$, which is increasing in V and decreasing in σ. Therefore, the range of F satisfying Inequality (P1) widens as V increases or σ decreases. Second, because the right-hand side of Inequality (P2), $20V^2/(7(V+\sigma))$, is increasing in V and decreasing in σ, the range of a–c that satisfies Inequality (P2) widens as V decreases and σ increases. The region of such combinations of V and σ satisfying Inequality (P2) is drawn in Fig. 3. As long as V and σ fall into the region colored in gray in the figure, the equilibrium in which Firm B discloses demand information and Firm P enters the market can arise. In addition, given Inequality (P1), the possibility of strategy (D, E) constituting the equilibrium increases as V increases and σ decreases as long as V and σ are within the gray region in Fig. 3. In other words, Inequality (P1) is more likely to be satisfied as the combination of the two parameters approaches the curve described as the quadratic function of $\sigma = V(20V/(7(a–c)^2)–1)$. However, if the set of the parameter values go beyond the curve to the right of the gray region, Inequality (P2) is no longer satisfied, meaning that the buyer loses its incentive to disclose demand information. In this case, strategy (D, E) never occurs on the equilibrium path.

Lastly, we overview other possible equilibria when either Inequality (P1) or (P2) is not satisfied. We first consider Inequality (P1). If $F > ((a-c)^2 + V^2/(V+\sigma))/(18b)$, then Firm P does not enter the market irrespective of whether Firm B chooses strategy D or ND, since an excessively high entry cost, F, prevents Firm P from earning a positive profit even if Firm P receives demand information from Firm B. Hence, Firm B prefers strategy ND as shown in Proposition 1, because Firm B needs to purchase products only from Firm I as the monopolist irrespective of its disclosure strategy. As a result, the combination of strategies (ND, NE) constitutes the equilibrium. At the other extreme, if $F < (a-c)^2/(18b)$, then Firm P enters the market irrespective of whether Firm B chooses strategy D or strategy ND, because the low entry cost of F allows Firm P to obtain a positive profit even if Firm P receives no demand information. Thus, strategy ND remains the optimal strategy for Firm B and strategy (ND, E) is the equilibrium in this case. As a consequence, Firm B has the incentive to disclose information only if $(a-c)^2/(18b) \le F \le ((a-c)^2 + V^2/(V+\sigma))/(18b)$.

Second, we shift our focus to Inequality (P2). Because the right-hand side of this inequality is increasing in V and decreasing in σ, this inequality is less likely to be met if V is higher and σ is lower, meaning that the value of the buyer's demand information is higher. In this case, because the value of the demand information is significantly high for Firm B, it should keep its demand information secret rather than revealing it, even though no information disclosure causes the monopoly to persist in the upstream market. Stated differently, the value of not disclosing the information, which preserves the upstream monopoly, outweighs the value of the low purchase price, which results from the duopoly caused by disclosure. Consequently, strategy ND is better than strategy D for Firm B in this case.

To sum up our results, disclosure of information (strategy D) and entry (strategy E) constitute the equilibrium if and only if entry cost, F, takes a moderate value and the relative value of demand information is not too high, as suggested in Proposition 2. When this condition is satisfied, the buyer should disclose demand information contrary to the conventional insight suggested by previous game-theoretic studies on information sharing, which is the central implication drawn from our analysis.

5. Extension: Multiple stages

In the basic model developed in the previous section, we considered a situation where the series of events illustrated in Fig. 2 arise only once. However, firms may choose different strategies if the game shown in Fig. 2 is repeated multiple times, because then Firm P can continue to operate without incurring fixed costs over multiple games as long as Firm P has paid F once to enter the market. Because Firm P enjoys this advantage in the case of such a repeated game, Firm B's incentive for information sharing may change substantially in response to Firm P's advantage over the longer term. Given this additional question, it is more desirable to investigate whether the main message of this paper continues to hold even in the setting in which the game is repeated multiple times. Hence, in this section, we extend the basic model by considering a dynamic game consisting of two stages.

We lay out the assumptions behind the extended model. First, we assume that all the events described in Fig. 2 are repeated twice over two stages, which are denoted by Stage 1 and Stage 2. In addition, let δ denote the time discount factor that satisfies $0 < \delta \le 1$, meaning that one unit of profit generated in Stage 2 is equivalent to δ units evaluated in Stage 1. Given these basic assumptions, there arises one critical difference between the extended model and the basic model. That is, if Firm P has already entered in Stage 1, it can stay in the market and continue to operate in Stage 2 without incurring the entry cost F as described above. Accordingly, the decisions made by Firms B and P in the extended model are described as follows. In Stage 1, Firm B chooses strategy D or ND and Firm P chooses strategy E or NE, respectively, as in the basic model. Subsequently, Firm B chooses strategy D or ND in Stage 2. Meanwhile, the strategy that Firm P chooses in Stage 2 depends on whether the firm has chosen strategy E or NE in Stage 1. On the one hand, if Firm P has already entered the market by choosing strategy E in Stage 1, then in Stage 2, the firm has two options: to stay in and operate (strategy Stay) or to stop operating and exit (strategy Exit). On the other hand, if Firm P has chosen strategy NE in Stage 1, it chooses strategy E or NE in Stage 2, similar to the choice in Stage 1. As a consequence, there are $2^4 = 16$ combinations of feasible strategies in the dynamic game described by the extended model.

Based on the assumptions above, we derive the equilibrium in the extended model, summarizing the strategies chosen on the equilibrium path in the following lemma.

Lemma 3. *The following three combinations of strategies chosen by firms can arise on the equilibrium path. The first and second symbols in each set of parentheses below represent Firm B's strategy and Firm P's strategy in each stage, respectively.*

- *strategies (D, E) in Stage 1 and strategies (ND, Stay) in Stage 2*
- *strategies (ND, E) in Stage 1 and strategies (ND, Stay) in Stage 2*
- *strategies (ND, NE) in Stage 1 and strategies (ND, NE) in Stage 2*

Lemma 3 indicates that if the first combination of strategies (D, E) in Stage 1 and strategies (ND, Stay) in Stage 2 arises, in the extended model, Firm B also chooses strategy D to share demand information with the aim of entry promotion. The next proposition shows that this combination of strategies indeed arises on the equilibrium path if the exogenous parameters fall into a specific region, which is the central result of the extended model.

Proposition 3. *Assume that the exogenous parameters satisfy the following inequalities:*

$$\frac{1+\delta}{18b}(a-c)^2 \le F \le \frac{1}{18b}\left((1+\delta)(a-c)^2 + \frac{V^2}{V+\sigma}\right), \tag{P3}$$

$$(a-c)^2 \ge \frac{20V^2}{7(1+\delta)(V+\sigma)}. \tag{P4}$$

Then, whereas Firm P does not enter the market if Firm B chooses strategy ND in Stage 1, Firm P enters the market if Firm B chooses strategy D in Stage 1. Moreover, Firm B achieves a higher profit by choosing strategy D instead of strategy ND in Stage 1, which induces Firm P to enter the upstream market. Consequently, the combination of strategy (D, E) in Stage 1 and strategy (ND, Stay) in Stage 2 constitutes the equilibrium.

Proposition 3 shows that the central result of this paper also holds in the extended model; that is, Firm B strategically discloses information with the aim of promoting Firm P's entry.

Comparing Propositions 2 and 3, we observe that the quantitative results are slightly different between the basic and the extended model. First, Inequality (P3) is the condition that Firm P can earn a higher profit by entering the market when information is available, and by not entering the market when information is not available. Comparing Inequalities (P1) and (P3), we find that the upper and lower bounds of Inequality (P3) in Proposition 3 respectively exceed the counterparts of Inequality (P1) in Proposition 2 as the following two inequalities hold because of the assumption $0 < \delta \leq 1$.

$$\frac{1}{18b}\left((1+\delta)(a-c)^2+\frac{V^2}{V+\sigma}\right) > \frac{1}{18b}\left((a-c)^2+\frac{V^2}{V+\sigma}\right) \tag{7}$$

$$\frac{1+\delta}{18b}(a-c)^2 > \frac{1}{18b}(a-c)^2 \tag{8}$$

Inequalities (7) and (8) indicate that the range of F leading to the strategic disclosure equilibrium is shifted upward in the extended model that considers multiple stages, compared with the basic model that considers only a single stage. This is because even if entry cost F is relatively high, Firm P can earn enough revenue over the two stages to offset the high F. Accordingly, in the extended model, Firm P chooses to enter even when F is relatively high.

Next, Inequality (P4) is the condition that Firm B achieves a higher profit by disclosing and sharing information in the extended model because the disclosure induces Firm P to enter the market. Comparing Inequalities (P2) and (P4), we find that the region of parameter values satisfying Inequality (P4) is wider than the region of parameters satisfying Inequality (P2), because the right-hand side of Inequality (P4) is obviously lower than that of Inequality (P2) because of the assumption $0 < \delta \leq 1$. Namely, Proposition 3 indicates that Firm B has an incentive to disclose information to promote entry of Firm P in a wider range of environments in the extended model. This is because if there are more stages, the buyer has more opportunities to purchase a product at a lower wholesale price by inducing the potential entrant supplier to enter the market and thereby making the upstream market more competitive. As a result, disclosure of demand information for the purpose of entry promotion arises over a wider range of parameter values. Therefore, even if F is relatively high, Firm B chooses strategy D to disclose its information in order to induce Firm P to enter in the extended model.

Finally, because the discount factor δ also affects the range of Inequalities (P3) and (P4), we examine the impact of δ on the equilibrium. As both the left-hand side and the right-hand side of Inequality (P3) in Proposition 3 are obviously increasing in δ, the range of F satisfying Inequality (P3) shifts downward as the discount factor δ decreases. When δ converges to 0, Inequality (P3) becomes identical to Inequality (P1) in Proposition 2. This is because as δ decreases and approaches 0, the net value of the profit of Firm P when operating in Stage 2 decreases and thus the result of the extended model approaches the result of the basic model.

6. Conclusion

This paper investigates the problem of whether a downstream buyer who purchases products from an upstream supplier should disclose demand information when the supplier faces an entry threat. Overall, previous game-theoretic supply chain management studies have reached the consensus that no disclosure of demand information is the dominant strategy for a downstream buyer in a noncooperative game situation. Contrary to this, our paper demonstrates that full disclosure of demand information can earn a buyer a higher profit when there is not only an incumbent supplier but also a potential entrant supplier upstream. Namely, the familiar result from game-theoretic information sharing models is reversed when we consider an entry threat. The rationale for this outcome is that the buyer can promote the entry of a potential supplier and increase competitiveness in the upstream market by disclosing demand information. This intensified competition at the upstream level in turn enables the buyer to obtain a lower purchase price of a product, thereby increasing its own profit. Therefore, our model provides the practical implication that a general supply chain member can improve its own profit by promoting the entry of a firm and providing competitive pressure in a different echelon level of the supply chain. This is the main message of this paper, which provides a new perspective for supply chain management.

Our model suggests that no information disclosure is not necessarily a favorable strategy for a downstream buyer, even though conventional wisdom suggests that no disclosure precludes the drain of a portion of profit from the downstream buyer to the upstream supplier. Therefore, a buyer should note that the seemingly advantageous strategy of no information disclosure may actually be disadvantageous because it may preserve a noncompetitive environment in the upstream market, which drives up the purchase price of a product for the buyer. As revealed in Section 4, the relative value of the demand information of the buyer is an important factor in determining its disclosure policy. If the value of information is too high, the buyer should keep its demand information secret. By contrast, if the value is too low, the buyer need not disclose information because the entrant enters the market and the upstream market becomes competitive no matter whether suppliers receive the information with little value or not. This result indicates that a supply chain member should carefully examine the value of its information before choosing its disclosure policy.

Finally, it should be noted that our model describes a general vertical relationship between supply chain members. Specifically, the implication from our model can apply not only to the relationship between an upstream supplier and a downstream manufacturer, which has been considered in the first section, but also to the relationship between an upstream manufacturer and a downstream retailer. Indeed, several giant retailers such as Walmart, Carrefour, and Tesco, are now in a relatively stronger competitive position than upstream manufacturers because retailers collect information from consumers at low cost through various information systems (Ertek and Griffin, 2002). In general, entry deterrence of a rival firm at the same echelon level is an advantageous competitive strategy for a supply chain member because it reduces the number of competitors in a horizontal relationship. By contrast, our model suggests that entry promotion of a potential firm in a vertical relationship at a different echelon level can be an advantageous strategy for a supply chain member. As information disclosure can be used as an effective tool for entry promotion, if the downstream buyer is a retailer, who is closer to end consumers than a manufacturer, the retailer may also strategically disclose information to put itself in an advantageous position by providing competitive pressure to the upstream market at the manufacturing level. Likewise, our model can apply to a general vertical relationship between firms constituting a supply chain.

Before closing, we explore possible future research directions. First, while we considered quantity as the decision variable at the wholesale level, there is a possible alternative setting in which the wholesale price is the decision variable and is determined by the supplier(s). However, as long as the products supplied are differentiated among suppliers, the most important message of the paper still holds even in the setting of price competition because the product differentiation guarantees that suppliers earn positive profits under duopoly, and hence the same logic elaborated in this paper still applies to such an alternative model. Another possible extension is the consideration of a multi-echelon supply chain, in which there is a potential supplier who waits for the chance to enter the market at each echelon. Because this extension would require a substantial reconstruction of the current model, this topic is reserved for future research.

Author contribution

Kenji Matsui: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition.

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Appendix

Proof of Lemma 1. Given Equation (3) and the properties of e and f, we obtain Equations (A1) and (A2) using the law of iterated expectations.

$$\mathrm{E}(e) = \mathrm{E}(\mathrm{E}(e|f)) = \mathrm{E}(\alpha + \beta f) = \alpha \tag{A1}$$

$$\mathrm{E}(ef) = \mathrm{E}(\mathrm{E}(ef|f)) = \mathrm{E}(f\mathrm{E}(e|f)) = \mathrm{E}(f(\alpha + \beta f)) = \mathrm{E}(\alpha f + \beta f^2) = \beta \mathrm{E}(f^2) = \beta(V+\sigma) \tag{A2}$$

Substituting $\mathrm{E}(e) = 0$ and $\mathrm{E}(ef) = \mathrm{E}(e(e+\varepsilon)) = \mathrm{E}(e^2) = V$ into Equations (A1) and (A2) yields $\alpha = 0$ and $\beta(V+\sigma) = V$. Solving $\beta(V+\sigma) = V$ yields $\beta = V/(V+\sigma)$. Finally, substituting $\alpha = 0$ and $\beta = V/(V+\sigma)$ into Equation (3) yields the equation shown in this lemma. □

Proof of Lemma 2. We derive equilibrium strategies and expected profits in four cases classified by the strategies chosen by Firms B and P.

Case (I): strategy (D, E):

Using backward induction, we first derive the optimal strategy adopted by Firm B. Firm B chooses Q to maximize its expected profit of Equation (4) conditional on available information, f. The first-order condition with respect to Q yields the reaction function:

$$Q = (a - w + (V/(V + \sigma))f)/(2b). \tag{A3}$$

Equation (A3) is restated as:

$$w = a - 2bQ + Vf/(V+\sigma). \tag{A4}$$

Note that $Q = q_I + q_P$ holds when Firm P enters the market. Because Firm P enters the market, both Firms I and P maximize their respective expected profits using this reaction function. Because the suppliers know the value of f in the information sharing case, the conditional expected profits of Firms I and P are:

$$\mathrm{E}(\pi_I|f) = (w - c)q_I = (a - c + Vf/(V+\sigma) - 2b(q_I + q_P))q_I, \tag{A5}$$

$$\mathrm{E}(\pi_P|f) = (w - c)q_P - F = (a - c + Vf/(V+\sigma) - 2b(q_P + q_I))q_P - F. \tag{A6}$$

Maximizing Equation (A5) with respect to q_I and Equation (A6) with respect to q_P yields the reaction function:

$$q_i = \left(a - c - 2bq_j + Vf / (V + \sigma)\right) / (4b). \quad (i,j) = (I,P), \quad (P,I) \tag{A7}$$

Solving the reaction functions of Equation (A7) for quantities yields:

$$q_i = (a - c + Vf / (V + \sigma)) / (6b). \quad (i = I, P) \tag{A8}$$

Finally, we substitute Equation (A8) and $f = e + \varepsilon$ into Equations (4)–(6) to yield the unconditional expected payoffs at Date 1. Using $\mathrm{var}(e) = V$, $\mathrm{var}(\varepsilon) = \sigma$, and $\mathrm{E}(e) = \mathrm{E}(\varepsilon) = 0$, we derive $\mathrm{E}({\pi_B}^{D,E})$, $\mathrm{E}({\pi_I}^{D,E})$, and $\mathrm{E}({\pi_P}^{D,E})$ as shown in this lemma.

Case (II): strategy (D, NE):

Firm B chooses Q to maximize its expected profit of Equation (4) conditional on available information, f, yielding the reaction function of Equation (A3). Using this reaction function, Firm I maximizes its expected profit. Note that $Q = q_I$ holds when Firm P does not enter the market and Firm I thus monopolizes the market. As Firm I knows the value of f in the information sharing case, the conditional expected profit is stated as:

$$\mathrm{E}(\pi_I|f) = (w - c)q_I = (a - 2bq_I + Vf/(V+\sigma) - c)q_I. \tag{A9}$$

Maximization of Equation (A9) with respect to q_I yields the reaction function:

$$q_I = (a - c + Vf/(V+\sigma))/(4b). \tag{A10}$$

Finally, we substitute Equation (A10) and $f = e + \varepsilon$ into Equations (4) and (5) to yield the unconditional expected payoffs at Date 1. Using $\mathrm{var}(e) = V$, $\mathrm{var}(\varepsilon) = \sigma$, and $\mathrm{E}(e) = \mathrm{E}(\varepsilon) = 0$, we derive $\mathrm{E}({\pi_B}^{D,NE})$ and $\mathrm{E}({\pi_I}^{D,NE})$ as shown in this lemma. Because Firm P does not enter the market, $\mathrm{E}({\pi_P}^{D,NE}) = 0$.

Case (III): strategy (ND, E):

Firm B chooses Q to maximize its expected profit of Equation (4) conditional on available information, f, yielding the reaction function of Equation (A3). Using this reaction function, Firms I and P maximize their respective expected profits. Equation (A3) is restated as:

$$w = a - 2bQ + Vf/(V+\sigma). \tag{A11}$$

Note that $Q = q_I + q_P$ holds when Firm P enters the market. Because the suppliers do not know the value of f in the no disclosure case, the expected profits of Firms I and P are:

$$\mathrm{E}(\pi_I) = (w - c)q_I = (a - c - 2b(q_I + q_P))q_I, \tag{A12}$$

$$\mathrm{E}(\pi_P) = (w - c)q_P - F = (a - c - 2b(q_P + q_I))q_P - F. \tag{A13}$$

Maximizing Equation (A12) with respect to q_I and Equation (A13) with respect to q_P yields the reaction function:

$$q_i = \left(a - c - 2bq_j\right) / (4b). \quad (i,j) = (I,P), \ \ (P,I) \tag{A14}$$

Solving the reaction functions of Equation (A14) for quantities yields:

$$q_i = (a - c) / (6b). \quad (i = I, P) \tag{A15}$$

Finally, we substitute Equation (A15) and $f = e + \varepsilon$ into Equations (4)–(6) to yield the unconditional expected payoffs at Date 1. Using var(e) = V, var(ε) = σ, and E(e) = E(ε) = 0, we derive $\mathrm{E}(\pi_B{}^{ND,E})$, $\mathrm{E}(\pi_I{}^{ND,E})$, and $\mathrm{E}(\pi_P{}^{ND,E})$ as shown in this lemma.

Case (IV): strategy (ND, NE):

Firm B chooses Q to maximize its expected profit of Equation (4) conditional on available information, f, yielding the reaction function of Equation (A3). Using this reaction function, Firm I maximizes its expected profit. Note that $Q = q_I$ holds when Firm P does not enter the market and Firm I thus monopolizes the market. Because Firm I does not know the value of f in the no disclosure case, the expected profit is:

$$\mathrm{E}(\pi_I) = (w - c)q_I = (a - 2bq_I - c)q_I. \tag{A16}$$

Maximization of Equation (A16) with respect to q_I yields the reaction function:

$$q_I = (a - c)/(4b). \tag{A17}$$

Finally, we substitute Equation (A17) and $f = e + \varepsilon$ into Equations (4) and (5) to yield the unconditional expected payoffs at Date 1. Using var(e) = V, var(ε) = σ, and E(e) = E(ε) = 0, we derive $\mathrm{E}(\pi_B{}^{ND,NE})$ and $\mathrm{E}(\pi_I{}^{ND,NE})$ as shown in this lemma. Because Firm P does not enter the market, $\mathrm{E}(\pi_P{}^{ND,NE}) = 0$. □

Proof of Proposition 1. If there is no potential entrant supplier, there are two possible realized profits for Firm B: $E(\pi_B^{D,NE}) = ((a-c)^2 + V^2/(V+\sigma))/(16b)$ or $E(\pi_B^{ND,NE}) = ((a-c)^2 + 4V^2/(V+\sigma))/(16b)$, as suggested by Lemma 2. Because $E(\pi_B^{ND,NE}) - E(\pi_B^{D,NE}) = ((a-c)^2 + 4V^2/(V+\sigma))/(16b) - ((a-c)^2 + V^2/(V+\sigma))/(16b) = 3V^2/(16b(V+\sigma)) > 0$ holds, the profit of the buyer is always higher under strategy ND than under strategy D. □

Proof of Proposition 2. Initially, suppose that Firm B chooses strategy ND at Date 1. When Firm P subsequently chooses strategy E at Date 2, Lemma 2 suggests that its expected profit is:

$$E\left(\pi_P^{ND,E}\right) = \frac{1}{18b}(a-c)^2 - F. \tag{A18}$$

If Equation (A18) is nonpositive, that is, $F \geq (a-c)^2/(18b)$, Firm P will not enter the market due to a negative profit realized under duopoly by Firms P and I.

Second, suppose that Firm B chooses strategy D at Date 1. If Firm P chooses strategy E at Date 2, its expected profit is:

$$E\left(\pi_P^{D,E}\right) = \frac{1}{18b}\left((a-c)^2 + \frac{V^2}{V+\sigma}\right) - F. \tag{A19}$$

As long as Equation (A19) is nonnegative, Firm P will enter the market in this case, that is, $F \leq ((a-c)^2 + V^2/(V+\sigma))/(18b)$. As a result, if Inequality (P1) holds, Firm P enters the market if Firm B chooses strategy D, but Firm P does not enter if Firm B chooses strategy ND.

Next, we compare the expected profits of Firm B between strategies (D, E) and (ND, NE). Based on the results in Lemma 2, $E(\pi_B^{D,E}) \geq E(\pi_B^{ND,NE})$ is restated as $(a-c)^2 \geq 20V^2/(7(V+\sigma))$. If this inequality holds, Firm B has a higher profit when strategy (D, E) is chosen than when strategy (ND, NE) is chosen. As a consequence, strategy (D, E) is the unique equilibrium if Inequalities (P1) and (P2) hold. □

Proof of Lemma 3. Because each of Firms B and P chooses one of two strategies in each of the two stages, there are $2^4 = 16$ possible strategies, which are listed as follows. The first and second symbols in each set of parentheses below represent Firm B's strategy and Firm P's strategy in each stage, respectively.

(i) strategies (D, E) in Stage 1 and strategies (D, Stay) in Stage 2
(ii) strategies (D, E) in Stage 1 and strategies (D, Exit) in Stage 2
(iii) strategies (D, E) in Stage 1 and strategies (ND, Stay) in Stage 2
(iv) strategies (D, E) in Stage 1 and strategies (ND, Exit) in Stage 2
(v) strategies (D, NE) in Stage 1 and strategies (D, E) in Stage 2
(vi) strategies (D, NE) in Stage 1 and strategies (D, NE) in Stage 2
(vii) strategies (D, NE) in Stage 1 and strategies (ND, E) in Stage 2

(viii) strategies (D, NE) in Stage 1 and strategies (ND, NE) in Stage 2
(ix) strategies (ND, E) in Stage 1 and strategies (D, Stay) in Stage 2
(x) strategies (ND, E) in Stage 1 and strategies (D, Exit) in Stage 2
(xi) strategies (ND, E) in Stage 1 and strategies (ND, Stay) in Stage 2
(xii) strategies (ND, E) in Stage 1 and strategies (ND, Exit) in Stage 2
(xiii) strategies (ND, NE) in Stage 1 and strategies (D, E) in Stage 2
(xiv) strategies (ND, NE) in Stage 1 and strategies (D, NE) in Stage 2
(xv) strategies (ND, NE) in Stage 1 and strategies (ND, E) in Stage 2
(xvi) strategies (ND, NE) in Stage 1 and strategies (ND, NE) in Stage 2

We examine whether a strategy included in each of the 16 cases is dominated by another strategy. That is, if a strategy included in one case is dominated by another strategy, i.e., if a strategy earns less profit for the firm than another strategy, the case is off the equilibrium path because the firm can increase its own profit by changing its strategy. By checking this dominance relationship, we exclude the cases that cannot arise on the equilibrium path below.

First, if Firm P chooses strategy E and enters the market in Stage 1, the firm obviously does not exit in Stage 2 because the firm earns a positive profit without incurring any further entry costs in the latter stage. Therefore, (ii), (iv), (x), and (xii), which include this dominated strategy (i.e., Exit), are all excluded from the combinations of strategies that arise on the equilibrium path.

Second, if Firm P chooses strategy E in Stage 1 and enters the market, strategy ND dominates strategy D for Firm B in Stage 2. This is because Firm P continues to operate regardless of whether Firm B takes strategy D or ND in Stage 2, meaning that Firm B would lower its own profit by choosing strategy D rather than strategy ND in Stage 2. Therefore, (i) and (ix), which include these strategies, are excluded from the combinations of strategies that arise on the equilibrium path.

Third, if Firm P chooses strategy NE in Stage 1 and does not enter, the firm continues to choose strategy NE in Stage 2 for the following reason. If Firm P enters with strategy E in Stage 2, despite having taken strategy NE in Stage 1, then the firm would obtain revenue for only one term in Stage 2. However, if Firm P chooses strategy E in Stage 1, the firm obtains revenue for two terms in both Stages 1 and 2, which is obviously more profitable for Firm P. For this reason, (v), (vii), and (xv), which include the combination of strategy NE in Stage 1 and strategy E in Stage 2, are excluded from the combinations of strategies that arise on the equilibrium path.

Fourth, if Firm P always chooses strategy NE and hence never enters the market in both Stages 1 and 2 even when Firm B chooses strategy D and discloses information, then Firm B can increase its own profit by changing its strategy from D to ND. For this reason, (vi), (viii), and (xiv), in which Firm P's strategy is always NE even though Firm B chooses strategy D, are excluded.

Fifth, (xiii) is dominated by (iii) for the following reason. Firm B discloses information for the first time in Stage 2 to induce Firm P to enter the market in (xiii), but in this case, Firm B obtains incremental revenue for only one term in Stage 2 because of the upstream competition. Meanwhile, if Firm B chooses (iii), in which Firm B chooses D and Firm P enters in Stage 1, it gains incremental revenue for two terms in both Stages 1 and 2 because of the upstream competition. For this reason, (xiii) is dominated by (iii) and thus excluded.

Consequently, the three cases (iii), (xi), and (xvi) remain as the combinations of strategies that can arise on the equilibrium path, which are shown in this lemma. □

Proof of Proposition 3. We consider the first case in Lemma 3 of strategies (D, E) in Stage 1 and strategies (ND, Stay) in Stage 2. Using the profit per one term shown in Lemma 2 and noting that each profit in Stage 2 is multiplied by the discount factor, δ, we calculate the expected profits of Firm B and Firm P in this case as follows.

$$E(\pi_P) = \frac{1}{18b}\left((1+\delta)(a-c)^2 + \frac{V^2}{V+\sigma}\right) - F \tag{A20}$$

$$E(\pi_B) = \frac{1}{9b}\left((1+\delta)(a-c)^2 + \frac{(4+9\delta)V^2}{4(V+\sigma)}\right) \tag{A21}$$

Next, we consider the second case in Lemma 3 of strategies (ND, E) in Stage 1 and strategies (ND, Stay) in Stage 2. Using the profit shown in Lemma 2, we calculate the expected profits of Firm B and Firm P in this case as follows.

$$E(\pi_P) = \frac{1}{18b}(1+\delta)(a-c)^2 - F \tag{A22}$$

$$E(\pi_B) = \frac{1+\delta}{b}\left(\frac{(a-c)^2}{9} + \frac{V^2}{4(V+\sigma)}\right) \tag{A23}$$

Finally, we consider the third case in Lemma 3 of strategies (ND, NE) in Stage 1 and strategies (ND, NE) in Stage 2. Using the result of Lemma 2, we calculate expected profits as follows.

$$E(\pi_P) = 0 \tag{A24}$$

$$E(\pi_B) = \frac{1+\delta}{16b}\left((a-c)^2 + \frac{4V^2}{V+\sigma}\right) \tag{A25}$$

Based on the profits in these three cases, we next consider the incentives for firms regarding which strategies they choose. The condition that Firm P enters when Firm B chooses strategy D in Stage 1 is that Equation (A20) is greater than or equal to Equation (A24), which is expressed as:

$$\frac{1}{18b}\left((1+\delta)(a-c)^2 + \frac{V^2}{V+\sigma}\right) - F \geq 0. \tag{A26}$$

Meanwhile, the condition that Firm P does not enter when Firm B chooses strategy ND in Stage 1 is that Equation (A22) is less than or equal to Equation (A24) as follows.

$$\frac{1}{18b}(1+\delta)(a-c)^2 - F \leq 0 \tag{A27}$$

Combining Inequalities (A26) and (A27) yields Inequality (P3) in this proposition.

Next, the condition under which Firm B prefers strategy D to strategy ND in Stage 1 is that Equation (A21) is greater than or equal to Equation (A25), which is expressed as:

$$\frac{1}{9b}\left((1+\delta)(a-c)^2 + \frac{(4+9\delta)V^2}{4(V+\sigma)}\right) \geq \frac{1+\delta}{16b}\left((a-c)^2 + \frac{4V^2}{V+\sigma}\right) \tag{A28}$$

By transforming Inequality (A28) so that $(a–c)^2$ is summarized on the left-hand side, we obtain Inequality (P4). □

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