Sharing Knowledge to an Entrant for Production Investment
Confronting COVID-19: Incentive Alignment and Lose–Lose Dilemma

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Facing the urgent demand of medical devices for COVID-19 treatment, many automakers have recently begun manufacturing ventilators, even though they are inefficient in production and uninformed of demand variability. To help them, some incumbent ventilator manufacturers have chosen to share knowledge, such as production techniques and demand information. Clearly, the incumbent ventilator manufacturers are fulfilling social responsibility, but is their knowledge sharing rewarding, especially when the automakers are entrant rivals? If possible, are win–win situations in the sense of social responsibility and firms’ profitability identifiable? In this work, we develop a game-theoretic model in which an incumbent and an entrant ventilator manufacturer engage in two-dimensional competition in production investment and sales volume. We examine the incumbent manufacturer’s profitability with and without knowledge sharing by formulating the tradeoffs among supply expansion, intensified competition, and the entrant’s production efficiency improvement and demand variance reduction. We identify both “win-win” and “lose-lose” situations for the two competing manufacturers. Specifically, we find that free knowledge could be harmful for the entrant manufacturer, but the incumbent manufacturer benefits from knowledge sharing when market competition is intense, or when market competition is mild but the production investment efficiency varies.

KEY WORDS: Competition and cooperation; incentive analysis; knowledge sharing; production investment

1. INTRODUCTION

The COVID-19 pandemic has caused an urgent demand for critical medical devices and materials (Berlinger, 2020; Salter, 2021; World Health Organization, 2020), among which the ventilator is almost the unique lifesaving device that helps patients before the miracle drugs are available (Resnick, 2020). Therefore, to expand the supply, many countries have actively encouraged automakers to manufacture ventilators, and they have been effective. General Motors, Tesla, Ford, Toyota, and Rolls-Royce have all temporarily shut down factories and entered the unfamiliar ventilator market for both profitability and social responsibility reasons (Buyck, 2020; Wattles, 2020).

It has not been easy for automakers to switch quickly from car manufacturing to ventilator manufacturing. In practice, these automakers, as entrant ventilator manufacturers, are experiencing low production investment efficiency, high demand variability, and heavy investment cost burden because they lack the critical knowledge in ventilator manufacturing that serves as the cornerstone of production investment (Wattles, 2020). An interesting question naturally arises: Driven by the government’s
initiative and social responsibility, is it possible for the incumbent ventilator manufacturers to share their knowledge voluntarily with the entrants?

Interestingly, entrant ventilator manufacturers have in fact obtained the knowledge from the incumbent ventilator manufacturers. For example, General Motors has spoken with Ventec Life Systems (General Motors, 2020), and Tesla is reported to have collaborated with the ventilator maker Medtronic and has obtained demand information, production processes, and effective methods for production control. This acquisition helps to improve Tesla’s production investment efficiency and to eliminate the demand variability (Alvarez, 2020; Klender, 2020).

Intuitively, critical knowledge must be kept private, especially when the knowledge holder faces rivals (Liebeskind, 1996; Lippman & Rumelt, 1982). Although the decision to share knowledge might seem contrary to conventional wisdom, there are external forces to consider. First, according to the literature on horizontal knowledge (e.g., information) sharing (Li, 1985, 2002), exchanging knowledge with rivals actually forms alliances and changes relationships from competition to co-opetition (Jiang & Hao, 2016). This development softens market competition by aligning operational decisions such as sales volumes, retail prices, and production investments. Second, knowledge sharing improves the entrant ventilator manufacturers’ production investment efficiency and reduces the demand variability. As a result, production investments are stimulated and the total ventilator supply potential can expand. When the incumbent ventilator manufacturers have production investment advantage, the benefit from the entrant ventilator manufacturers’ supply potential expansion could spill over under a co-opetition relationship.

Our research questions are as follows:

1. Under what conditions are incumbent ventilator manufacturers more profitable when they share knowledge with entrant ventilator manufacturers?
2. As the competitors, will the entrant ventilator manufacturers really benefit from knowledge sharing?
3. Are there “win-win” or “lose-lose” situations for the incumbent and entrant ventilator manufacturers?

To answer the aforementioned research questions, we built a game-theoretic model composed of an incumbent ventilator manufacturer and an entrant ventilator manufacturer. Hereafter, for the ease of reference, we denote the incumbent ventilator manufacturer and the entrant ventilator manufacturer as incumbent and entrant, respectively. They produce and sell substitutable ventilators, and their decision variables include sales volumes and the production investment levels. The incumbent has accumulated knowledge, whereas the entrant has a disadvantage because of its sudden change of market. It is optional for the incumbent to share the knowledge with the entrant. If so, the entrant’s production investment efficiency will improve, and its demand variability will be eliminated. We consider two scenarios: (1) Scenario N, in which the incumbent keeps the knowledge private; (2) Scenario S, in which the incumbent shares the knowledge, so that the entrant has the identical demand information and production investment efficiency with the incumbent. The main results are summarized as follows.

We first compared the equilibrium of sales volume and the production investment levels in two scenarios. We found that, interestingly, the incumbent’s sales volume and production investment level were both higher in Scenario S, whereas the opposite is true for the entrant. Conventional wisdom suggests that knowledge sharing helps the entrant to improve production investment efficiency, resulting in increased incentive for production investment. In turn, the incumbent will be motivated to invest more because they traditionally have an efficiency advantage in production investment. As a result, the total ventilator supply potential—that is, \((a + e_1^I) + (a + e_1^E)\)—is expanded (Lus & Muriel, 2009). This expansion indicates that knowledge sharing induces the ventilator manufacturers’ production investment competition. For the entrant, with knowledge sharing, the production investment efficiency and demand information become identical to the incumbent’s. As a result, their decisions are similar, and competition intensifies. To avoid the possible profit loss, the entrant is motivated to invest less in production and become a free rider of the expanded supply potential because of the incumbent’s increased production investment. This also reduces the investment burden and further benefits the entrant.

We find that the incumbent’s profit can be divided into two parts: (1) the deterministic value from product sales and (2) the information value from the elimination of demand variability. In equilibrium, the incumbent obtains a higher deterministic value in Scenario S, whereas the entrant’s deterministic value is lower. In terms of information value, we show that
the incumbent obtains a higher information value when product substitutability is high, or when product substitutability is low but the production investment is extremely efficient.

Consequently, given a high product substitutability, incumbents are more profitable when they share knowledge with entrants, regardless of the production investment efficiency. Given a low product substitutability and a high production investment efficiency, incumbents can also be more profitable when they share knowledge with entrants.

Next, we investigated whether entrants truly benefit from knowledge sharing and found that the weight of information value in its overall profit is the key. We further identify the “win-win zone” and the “lose-lose dilemma” when there is knowledge sharing for the two manufacturers in Scenario S, which mainly depends on the production investment efficiency. Specifically, if the production investment efficiency is high, both the incumbent and the entrant benefit from knowledge sharing because of the significant benefit from supply potential expansion and the affordable investment cost; this leads to a win-win situation. On the contrary, if the production investment efficiency is low, the investment competition induced by knowledge sharing will become extremely costly, resulting in a small supply expansion whose benefit could not offset the investment cost; this eventually leads to a lose-lose dilemma.

Knowledge and information sharing is believed to be an important and interesting research topic (Choi, Govindan, Li, & Li, 2017; Shen, Choi, & Minner, 2018). Previous studies have extensively examined the interactions between knowledge and information sharing and other elements such as quality-improvement efforts (Chen, Zhao, Lewis, & Squire, 2016; Zhu, Zhang, & Tsung, 2007), risk management (Niu & Zou, 2017), production timing decisions (Niu, Chen, Fang, Yue, & Wang, 2019a), and product innovation (Hu, Mai, & Pekeč, 2020; Shen, Li, Dong, & Quan, 2016). Zhu et al. (2007) and Chen et al. (2016) are the most related publications with a common interest in improving production efficiency; however, they omit the roles of horizontal competition and cooperation. Our work fills this research gap by building a cooperative model comprising an incumbent and an entrant, in which they compete in selling product and sharing horizontal knowledge. We have studied the incumbents’ incentives to share knowledge with rivals, where the knowledge helps entrants to improve production investment efficiency and to eliminate demand variability. In addition, we provide focus on how firms engage in supply expansion effectively when unprecedented emergencies occur (e.g., COVID-19 epidemic). We will show that knowledge sharing is an effective way to increase total supply of key medical material and devices (e.g., ventilators) in the context of emergencies. This insight could be helpful for governments confronting similar crises.

In Section 2, we review the related literature. In Section 3, we discuss the model setting and assumptions. We investigate whether incumbents are more profitable when they share knowledge with rivals, and we identify the two manufacturers’ incentive alignment opportunities in Section 4. In Section 5, we provide several extensions of our model where we consider factors such as the entrant’s risk aversion, the component supply capacity constraint, and the entrant’s partial improvement of production investment efficiency, the effects of government subsidies, and the social welfare performance. Finally, Section 6 discusses future directions for research. The proofs and thresholds used in this discussion are presented in Supporting Information S1 and S2.

2. LITERATURE REVIEW

Our work is related to the literature on production and innovation investment. Zhu et al. (2007) study how a buyer and its supplier jointly invest in quality-improvement efforts by considering the minimization of nonconforming units. Bhaskaran and Krishnan (2009) examine the effects of investment cost-sharing and revenue-sharing schemes on the participating firms’ benefits from investment collaboration. Wang and Shin (2015) compare the suppliers’ production investment levels and supply chain profits under wholesale price, quality-dependent, and revenue-sharing contracts. Yoon (2016) reports on an encroached manufacturer’s cost-reducing investment and its spillover to the reseller, which mitigates the double marginalization effect. Shen et al. (2016) investigates how contract types between a competing original equipment manufacturer (OEM) and an original design manufacturer (ODM) can affect supply chain performance when there is product design investment outsourcing. Dong, Liu, and Shen (2019) develop a two-period model to study which supply chain party’s investments (i.e., the manufacturer or the retailer) in green product development are optimal for the whole supply chain. Findlater, Satterfiel, and Kandlikar (2019) study farmers’ capacity decisions considering limited information related to weather and climate risk. Niu et al.
We consider two scenarios. See Fig. 1 for an illustration.
Table I. Notations and Definitions

| Notations | Descriptions |
|------------|--------------|
| $q_j$      | Incumbent’s sales volume in Scenario N/S, where $j \in \{N, S\}$. |
| $q_E$      | Entrant’s sales volume in Scenario N/S. |
| $p_j$      | Incumbent’s retail price in Scenario N/S. |
| $p_E$      | Entrant’s retail price in Scenario N/S. |
| $e_j$      | Incumbent’s production investment level in Scenario N/S. |
| $e_E$      | Entrant’s production investment level in Scenario N/S. |
| $k$        | Production investment efficiency of the incumbent. |
| $\lambda$ | Production investment efficiency of the entrant, where $\lambda > 1$ represents the efficiency disadvantage of the entrant. |
| $\pi_j$   | Incumbent’s profit in Scenario N/S. |
| $\pi_E$   | Entrant’s profit in Scenario N/S. |

Fig 1. Structures in two scenarios.

(1) No knowledge sharing (Scenario N). The incumbent maintains its knowledge and does not share it with the entrant. Hence, the entrant determines sales volume $q_E^N$ and production investment level $e_E^N$ on the basis of expectations.

(2) Knowledge sharing (Scenario S). The incumbent shares its knowledge with the entrant. Therefore, the entrant determines sales volume $q_E^S$ and production investment level $e_E^S$ on the basis of accurate demand information and improved production investment efficiency.

Facing the urgent demand of ventilators for COVID-19 treatment, both the incumbent and the entrant invest in production to expand the total supply potential. Since the incumbent’s knowledge sharing can not only eliminate the entrant’s demand variability but also improve the entrant’s production investment efficiency, we identify the effects of knowledge sharing on supply expansion and the entrant’s investment cost reduction as follows.

(1) Effect of supply expansion: We use the following inverse demand functions, which are widely used in economics and operations management (Christen, Boulding, & Staelin, 2009; Hu et al., 2020; Niu et al., 2019a; Singh & Vives, 1984; Swinney, Cachon, & Netessine, 2011; Vives, 2000):

\[
p_E^j = a + e_E^j + d^j \epsilon - q_E^j - bq_E^j,
\]

\[
p_j^j = a + e_j^j + \epsilon - q_j^j - bq_j^j,
\]

where $j \in \{N, S\}$, $a$ represents the basic supply potential, $\epsilon$ is the demand variability with the mean zero and variance $\sigma^2$, and $b$ stands for product substitutability. The parameter $d^N > 1$ indicates that the entrant faces a higher demand variability in Scenario N because of lacking knowledge, while $d^S = 1$
(2) Effect of investment cost reduction: Define the production investment cost as 
\[ C(e_i) = \frac{1}{2} k_i e_i^2, \]
where \( k_i \) is manufacturer \( i \)'s production investment efficiency \((i \in \{E, I\})\). A large (or small) \( k_i \) stands for manufacturer \( i \)'s low (or high) production investment efficiency, which is widely assumed in the literature (e.g., Bhaskaran & Krishnan, 2009; Crama, Reyck, & Taneri, 2017; Ge, Hu, & Xia, 2014; Wang & Shin, 2015). Without loss of generality, we let the incumbent’s production investment efficiency be \( k_E = k \) in both Scenarios N and S. For the entrant, the knowledge-sharing decision depends on the incumbent’s knowledge-sharing decisions. In Scenario N, the entrant has a low investment efficiency compared with the incumbent; therefore, we have \( k_E = \lambda k \) and \( \lambda > 1 \). In Scenario S, with the entrant benefitting from the incumbent’s knowledge sharing, both have identical production investment efficiencies (i.e., \( k_E = k_I = k \)). Note that the entrant’s production investment efficiency might not be perfectly improved in Scenario S because of learning ability or confidentiality issues; therefore, we relax this assumption by studying a case in which the entrant’s production investment efficiency is partially improved (see Section 5.3).

We first assume that both the incumbent and the entrant are risk-neutral, and we then relax this assumption in an extension (see Section 5.1). The decisionmakers’ profit functions in two scenarios are as follows, respectively:

- In Scenario N, 
  \[
  \begin{align*}
  \max_{\{q^N_E, q^N_I\}} & \quad E [\pi^N_E] = E \left[p^N_E q^N_E - \frac{1}{2} \lambda k e^2_N\right] \\
  \max_{\{q^N_I, e^N_I\}} & \quad \pi^N_I = p^N_I q^N_I - \frac{1}{2} k e^2_N
  \end{align*}
  \]

- and in Scenario S,
  \[
  \begin{align*}
  \max_{\{q^S_E, e^S_E\}} & \quad p^S_E q^S_E - \frac{1}{2} k e^2_N \\
  \max_{\{q^S_I, e^S_I\}} & \quad p^S_I q^S_I - \frac{1}{2} k e^2_N
  \end{align*}
  \]

Fig. 2 illustrates the sequence of events. At stage 1, the incumbent decides whether to share the knowledge with the entrant. In Scenario N, at stage 2, the incumbent determines the production investment level \( e^N_1(e) \), and the entrant determines the expected production investment level \( E[e^N_1] \). At stage 3, the incumbent determines the sales volume \( q^N_E \), and the entrant determines the expected sales volume \( E[q^N_E] \). In Scenario S, at stage 2, the incumbent determines the production investment level \( e^S_1(e) \), and the entrant determines \( e^S_2(e) \) on the basis of accurate demand information. At stage 3, the incumbent determines the sales volume \( q^S_E \), and the entrant determines \( q^S_E \) on the basis of accurate demand information.

We assume \( k \) and \( \lambda \) are in the region \( \Omega = \{(k, \lambda)|k(b) < k < \tilde{k}(b), 1 < \lambda < \tilde{k}(b)/k\} \) to guarantee all the equilibrium outcomes are positive, where \( k(b) = \frac{b + \lambda b^2}{(4 - b)^2} \), \( \tilde{k}(b) = \frac{4}{(2 - b)(2 + b)} \), and \( \tilde{k}(b)/k \). Note that, region \( \Omega \) indicates that the incumbent and the entrant have a relatively high production investment efficiency, which ensures that both of them have production investment incentives. We use backward induction to solve the games. The equilibrium outcomes and the supply chain parties’ expected profits are presented in Table II.

4. ANALYSIS

We first investigate the incumbent and the entrant’s equilibrium production investment levels in two scenarios. The main findings are in Lemma 1 and Corollary 1.

**Lemma 1.**

(a) The incumbent’s (or entrant’s) expected production investment level in Scenario S is higher (or lower) than that in Scenario N (i.e., \( E[e^S_1] > E[e^S_2] \) and \( E[e^N_1] < E[e^N_2] \)).

(b) The difference between the incumbent’s (or entrant’s) expected production investment levels in Scenario S (or N) and that in Scenario N (or S) is increasing in \( \lambda \) and \( k \), respectively (i.e., we have \( \frac{\partial (E[e^S_1] - E[e^S_2])}{\partial \lambda} > 0 \), \( \frac{\partial (E[e^S_1] - E[e^S_2])}{\partial k} > 0 \), \( \frac{\partial (E[e^N_1] - E[e^N_2])}{\partial \lambda} > 0 \), and \( \frac{\partial (E[e^N_1] - E[e^N_2])}{\partial k} > 0 \)).
Fig 2. Sequence of events

Table II. The Expected Equilibrium Outcomes in Each Scenario

| Scenario N | Scenario S |
|------------|-----------|
| **Production investment levels** | **Production investment levels** |
| $E[e_d^N]$ = $\frac{4a[(b^-)^2(2+b)(k-4)]}{16+a(4-b^2)k^2-8a(4-b^2)(1+\alpha)}$ | $E[e_d^S]$ = $\frac{4a}{(2-b)(2+b)^2k-4}$ |
| $E[e_f^N]$ = $\frac{4a[(2-b)^2(2+b)(4-k)]}{16+a(4-b^2)k^2-8a(4-b^2)(1+\alpha)}$ | $E[e_f^S]$ = $\frac{4a}{(2-b)(2+b)^2k-4}$ |
| **Sales volumes** | **Sales volumes** |
| $E[q_d^N]$ = $\frac{a(4-b^2)(2-b)(2+b)(4-k)}{16+a(4-b^2)k^2-8a(4-b^2)(1+\alpha)}$ | $E[q_d^S]$ = $\frac{a(2-b)(2+b)k}{(2-b)(2+b)^2k-4}$ |
| $E[q_f^N]$ = $\frac{a(4-b^2)(2-b)(2+b)(4-k)}{16+a(4-b^2)k^2-8a(4-b^2)(1+\alpha)}$ | $E[q_f^S]$ = $\frac{a(2-b)(2+b)k}{(2-b)(2+b)^2k-4}$ |
| **Expected profits** | **Expected profits** |
| $E[\pi_d^N]$ = $\frac{2a[(2-b)^2(2+b)(4-k)]}{16+a(4-b^2)k^2-8a(4-b^2)(1+\alpha)}$ | $E[\pi_d^S]$ = $\frac{4[(4-b^2)^2k-8](a^2+r^2)}{4[(2-b)(2+b)^2k-4]}$ |
| $E[\pi_f^N]$ = $\frac{(4-b^2)^2k^2[6a+8b^2(4-b^2)^2(1+2k)-8a^2]}{4[(4-b^2)^2k^2]}$ | $E[\pi_f^S]$ = $\frac{k[(4-b^2)^2k-8](a^2+r^2)}{4[(2-b)(2+b)^2k-4]}$ |
| $E[\pi_f^N]$ = $\frac{2a[(2-b)^2(2+b)(4-k)]}{16+a(4-b^2)k^2-8a(4-b^2)(1+\alpha)}$ | |
| (i.e., $|E[e_d^N] - E[e_d^S]| > |E[e_f^N] - E[e_f^S]|$). A rational entrant tends to be differentiated from the incumbent in production investment to avoid tense competition, because their profit functions become identical in Scenario S. Noting that the entrant’s reduction of supply potential is smaller than the incumbent’s increase, we find that the total supply potential in Scenario S is still expanded compared with Scenario N. Consequently, the entrant has the opportunity to become a free rider of the incumbent’s production investment in Scenario S; this also saves the entrant’s production investment cost $\frac{1}{2}k[e_d^N]$. |

Lemma 1(a) indicates that the incumbent determines a higher production investment level, while the entrant determines a lower production investment level in Scenario S. A possible reason for the incumbent’s decision is that knowledge sharing intuitively stimulates the entrant’s production investment, thus inducing production investment competition. Since the incumbent traditionally has efficiency advantage in production investment, it is motivated to invest more to expand its supply potential $a + e_f$. However, being aware of this, the entrant interestingly determines a lower production investment level in Scenario S (i.e., $E[e_d^S] < E[e_d^N]$). For this counterintuitive result, we have the following explanations. Comparing the production investment levels between Scenario S and Scenario N, we find that the increase of the incumbent’s production investment level is more significant (i.e., $|E[e_d^S] - E[e_d^N]| > |E[e_f^S] - E[e_f^N]|$). A rational entrant tends to be differentiated from the incumbent in production investment to avoid tense competition, because their profit functions become identical in Scenario S. Noting that the entrant’s reduction of supply potential is smaller than the incumbent’s increase, we find that the total supply potential in Scenario S is still expanded compared with Scenario N. Consequently, the entrant has the opportunity to become a free rider of the incumbent’s production investment in Scenario S; this also saves the entrant’s production investment cost $\frac{1}{2}k[e_d^N]$.

Lemma 1(b) shows the sensitive analysis of the incumbent’s (entrant’s) production investment level difference with respect to $\lambda$ and $k$. Note that $\lambda$ represents the entrant’s efficiency disadvantage. Therefore, it can be straightforward to see that a large $\lambda$ is conducive to the incumbent but harmful to the
entrant. This explains why the incumbent (entrant) has a stronger (weaker) incentive to determine a higher (lower) production investment level as the entrant’s efficiency disadvantage becomes significant.

**Corollary 1.** The total investment cost saving with knowledge sharing is achieved if one of the following conditions occurs, i.e., $E(\sum_{i=1}^{E} k_i e_{i}^{N}) < E(\sum_{i=1}^{E} \frac{1}{2} k_i e_{i}^{S})$:

\[
\begin{aligned}
\text{(ai)} & \quad 0 < b < b_1, \quad \begin{cases} k < k_1 \text{ and } \sigma > \sigma_1, \\
& k > k_1, \quad \begin{cases} \lambda < \lambda_1 \text{ and } \sigma > \sigma_1, \\
& \lambda > \lambda_1 \end{cases}
\end{cases} \\
\text{or,} & \\
\text{(aii)} & \quad b_1 < b < 1, \quad \begin{cases} \lambda < \lambda_1 \text{ and } \sigma > \sigma_1.
\end{cases}
\end{aligned}
\]

**Corollary 1** shows that, the incumbent’s knowledge sharing has the opportunities to save total investment cost, depending on the product substitutability $b$, the production investment efficiency $k/\lambda$, and the information value $\sigma$. The entrant’s disadvantage in production investment (i.e., $\lambda > \lambda_1$) drives a significantly large total investment cost in Scenario N, which highlights the value of knowledge sharing in total investment cost saving, especially for the entrant. However, when the entrant’s disadvantage in production investment is negligible in Scenario N (i.e., $\lambda < \lambda_1$), we find that a sufficiently large information value (i.e., $\sigma > \sigma_1$) can exert great effect and create opportunities for total investment cost saving with knowledge sharing. The reason is that knowledge sharing helps to coordinate the incumbent and the entrant’s production investment decisions, forming an information alliance. We then compare the equilibrium sales volumes and obtain Lemma 2 and Corollary 2.

**Lemma 2.**

(a) The incumbent’s (entrant’s) expected sales volume in Scenario S is larger (smaller) than that in Scenario N (i.e., $E[q_1^S] > E[q_1^N]$ and $E[q_1^N] < E[q_1^S]$).

(b) The difference between incumbent’s (entrant’s) expected sales volume in Scenario S (N) and that in Scenario N (S) is increasing in $\lambda$ and $k$, respectively (i.e., we have $\frac{\partial (E[q_1^S] - E[q_1^N])}{\partial \lambda} > 0$, $\frac{\partial (E[q_1^S] - E[q_1^N])}{\partial k} > 0$, and $\frac{\partial (E[q_1^S] - E[q_1^N])}{\partial \lambda} \frac{\partial (E[q_1^S] - E[q_1^N])}{\partial k} > 0$).

**Lemma 2(b)** shows the sensitive analysis of the incumbent’s (entrant’s) expected sales volume difference with respect to $\lambda$. We observe that $E[q_1^S] - E[q_1^N] (E[q_1^N] - E[q_1^S])$ increases in $\lambda$ and $k$, which means that the incumbent’s (entrant’s) demand advantage (disadvantage) becomes more significant as the entrant’s production investment efficiency disadvantage $\lambda$ and $k$ increase. In other words, the incumbent is more willing to share knowledge when they acquire a significant advantage in sales volume competition.

**Corollary 2.** The total sales volume in Scenario S is higher than that in Scenario N (i.e., $E[q_1^S] + E[q_2^S] > E[q_1^N] + E[q_2^N]$).

Before we examine the profits of the incumbent and the entrant, we note that their profits comprise two parts: (1) the deterministic value from product sales (denoted as $DV_i^j$, $i \in \{E, I\}$ and $j \in \{N, S\}$), which is associated with the basic supply potential $a$, production investment efficiency $k$ and $\lambda$; and (2) the information value from demand variability elimination via knowledge sharing (denoted as $IV_i^j$, $i \in \{E, I\}$ and $j \in \{N, S\}$), which is mainly related to demand variance $\sigma^2$. We have the following propositions by comparing the deterministic values and information values in two scenarios.

**Proposition 1.** The incumbent’s deterministic value in Scenario S is higher than that in Scenario N (i.e., $DV_i^S > DV_i^N$), and the deterministic value difference is increasing in $k$ and $\lambda$, respectively, i.e., $\frac{\partial (DV_i^S - DV_i^N)}{\partial k} > 0$ and $\frac{\partial (DV_i^S - DV_i^N)}{\partial \lambda} > 0$.

**Proposition 1** can be straightforward. The incumbent will determine a higher production investment level and obtain a larger production or sales volume in Scenario S (see Lemma 1 and Lemma 2); this enables the incumbent to obtain a higher deterministic value. If the entrant’s disadvantage in production investment efficiency becomes more significant (i.e., $\lambda$ and $k$ are increasing), we find that the incumbent’s deterministic value will become even higher in Scenario S. It confirms our intuition, because according to Lemmas 1 and 2, we know that the incumbent can acquire a more significant advantage in the two-dimensional competition in sales volume and production investment as the entrant’s disadvantage in production investment efficiency is becoming more significant (i.e., $\lambda$ and $k$ increase). Next, we examine the entrant’s deterministic value and obtain Proposition 2.

**Proposition 2:** The entrant’s deterministic value in Scenario S is lower than that in Scenario N (i.e.,
$DV^I_S < DV^N_E$, and the deterministic value difference is increasing in $\lambda$ and $k$, i.e., $\frac{d(DV^I_S - DV^N_E)}{d\lambda} > 0$ and $\frac{d(DV^I_S - DV^N_E)}{dk} > 0$.

In contrast to the incumbent, the entrant will determine a lower production investment level and a smaller sales volume in Scenario $S$ to save its investment cost, although the production investment efficiency is improved. This results in a smaller sales volume and a lower deterministic value for the entrant, although his information value because of the incumbent’s knowledge sharing is undoubtedly increased.

We compare the incumbent’s information values in two scenarios and obtain Proposition 3 as follows.

**Proposition 3**: The incumbent’s information value in Scenario $S$ is higher than that in Scenario $N$ if one of the following conditions occurs (i.e., $IV^I_S > IV^N_E$):

(a) $0 < b < b_2$ and $k < k_2$,

(b) $b_2 < b < 1$.

Proposition 3 shows that the incumbent has opportunities to obtain a higher information value in Scenario $S$, depending on the product substitutability $b$ and the production investment efficiency $k$. We find that a low product substitutability (i.e., $b < b_2$) and a high production investment efficiency (i.e., $k < k_2$) jointly help the incumbent to obtain a higher information value in Scenario $S$. We also find that the incumbent can obtain a higher information value in Scenario $S$, even though there is fierce sales volume competition (i.e., $b > b_2$). We interpret this finding as follows. Note that knowledge sharing requires the incumbent and the entrant to form an information alliance, which changes their relationship from competition to co-operation (Li, 1985, 2002). This significantly enlarges the total supply potential, softens the sales volume competition, and avoids the loss of system efficiency. We indeed find that knowledge sharing helps to enlarge the total information value, especially when market competition is fierce (i.e., $IV^I_{total} > IV^N_{total}$ if $b > b_2$). We also find that the incumbent obtains a larger share of total information value in Scenario $S$ when $b$ is large or $k$ is small. Therefore, if $b < b_2$, although the total information value in Scenario $S$ is relatively small, $k < k_2$ enables the incumbent to take a large share; if $b > b_2$, then the total information value in Scenario $S$ becomes sufficiently large. As a result, regardless of $k$, the incumbent obtains a higher information value in Scenario $S$ as the compensation for knowledge sharing (i.e., $IV^I_S > IV^N_E$ if $b > b_2$).

Considering the above analysis, we investigate the conditions under which the incumbent and the entrant benefit from knowledge sharing. The main findings are summarized in Propositions 4 and 5.

**Proposition 4**: The incumbent is more profitable when sharing knowledge with the entrant if one of the following conditions occurs i.e., $E[\pi^I_f] > E[\pi^I_i]$:

(a) $0 < b < b_2$, \(k > k_2\) and $0 < \sigma < \sigma_2$,

or

(b) $b_2 < b < 1$.

Proposition 4 shows that, three factors—(1) product substitutability $b$, (2) production investment efficiency $k$, and (3) information value $\sigma$—hold the key that makes the incumbent profitable in the Scenario $S$. Proposition 4 (a) shows that, given a low product substitutability (i.e., $b < b_2$) and a high production investment efficiency (i.e., $k < k_2$), the incumbent is more profitable when she shares knowledge with the entrant. This result directly follows Proposition 1 and Proposition 3(ai), where the incumbent obtains the higher deterministic value and information value in Scenario $S$ if $0 < b < b_2$ and $k < k_2$.

Recall Proposition 3. We know that the incumbent’s information value will be lower in Scenario $S$ when $k > k_2$ (i.e., $IV^I_S < IV^N_E$ if $k > k_2$), implying that the incumbent might have no incentive to share knowledge with the entrant. Interestingly, given $k > k_2$, we find that the incumbent still has opportunities to benefit from knowledge sharing, if demand variance is small (i.e., $\sigma < \sigma_2$). The reason is that the incumbent always obtains a higher deterministic value in Scenario $S$, and this benefit increases in the production investment efficiency $k$ (see Proposition 1). As a result, the limited loss in information value (i.e., $\sigma < \sigma_2$) is effectively offset by the increase of deterministic value in Scenario $S$.

Proposition 4(aii) shows another interesting result—that is, the incumbent can be more profitable with knowledge sharing even if the product substitutability is high (i.e., $b > b_2$), because the incumbent acquires a higher deterministic value and a higher information value when the product substitutability is high. A knowledge alliance effectively offsets the system efficiency loss because of a large $b$, and a large share of the increased information value goes to the knowledge holder—the incumbent (see Propositions...
We investigate the entrant’s preference for knowledge sharing and have Proposition 5.

Proposition 5: The entrant benefits from the incumbent’s knowledge sharing when information value takes a large weight in his overall profit (i.e.,\( E[\pi^S]\) > \(E[\pi^N]\) if \(\frac{\sigma}{a} > \sigma_3\)).

Note that the deterministic value is associated with the basic supply potential \(a\), and the information value is a function of \(\sigma\). Hence, \(\frac{\sigma}{a}\) represents the weight of the information value over the deterministic value in the entrant’s overall profit (Huang, Guan, & Chen, 2018). Clearly, the larger coefficient is, the larger weight the information value occupies. Proposition 5 shows that the entrant’s preference over knowledge sharing depends on the coefficient \(\frac{\sigma}{a}\).

According to the analysis for Proposition 2, the entrant obtains a lower deterministic value but a higher information value in Scenario S. In other words, the information value holds the key in the entrant’s preference over knowledge sharing. As a result, it is natural to find that only when the information value occupies a larger weight in overall profit will the entrant benefit from knowledge sharing.

We then investigate whether there exist incentive alignment opportunities for the incumbent and the entrant toward knowledge sharing. It is challenging to obtain analytical results; therefore, we conduct extensive numerical studies and have the following observations. Combined with Propositions 4 and 5, we find that the incumbent will benefit from knowledge sharing when \(0 < b < b_2\) and \(k < k_2\), or \(b_2 < b < 1\) regardless of information value \(\sigma\), i.e.,\(E[\pi^N] > E[\pi^S]\) iff \(0 < b < b_2\) and \(k < k_2\). We also find that whether the entrant will benefit from knowledge sharing depends solely on the information value \(\sigma\) (i.e., \(E[\pi^S]\) > \(E[\pi^N]\) iff \(\sigma > \sigma_3\)). In other words, given \(0 < b < b_2\) and \(k < k_2\), or \(b_2 < b < 1\), the incumbent and the entrant will achieve “win-win” (“win-lose”) if \(\sigma > \sigma_3\) \((\sigma < \sigma_3)\), while the “lose-lose” zone will not arise. Therefore, a “win-win” zone or a “lose-lose” zone can be obtained only when \(0 < b < b_2\) and \(k > k_2\), depending on the information value \(\sigma\). We then investigate whether there exist incentive alignment opportunities for the incumbent and the entrant towards knowledge sharing. It is challenging to obtain analytical results, so we conduct extensive numerical studies by testing around 169,200 combinations of the parameter values including production substitutability \(b\) and production investment efficiency \(\lambda/k\) (see Table III for the detailed parameter values). We derive the following two observations and illustrate the typical curves in Fig. 3.

Observation 1: There coexists a “win-win” zone (i.e., both the incumbent and the entrant are more profitable in Scenario S) or a “lose-lose” zone (i.e., both the incumbent and the entrant are less profitable in Scenario S), depending on the production investment efficiency \(k\).

Observation 2: The “win-win” zone shrinks as the production investment efficiency \(k\) increases, while the opposite is true for the “lose-lose” zone.

In terms of Observation 1, we find that, given a relatively small \(k\), the “win-win” zone holds, while given a relatively large \(k\), the “lose-lose” dilemma arises. Note that production investment has two sides regarding the revenue and cost. Therefore, we define a net investment effect to help explain the observations.

Definition of net investment effect: The incumbent’s and entrant’s expected profits when they do not invest in production investment are \(E[\pi^I]\) and \(E[\pi^J]\) (\(j \in \{N, S\}\)), respectively.\(^1\) The net investment effect of the incumbent and entrant are formulated as

\[ E[\pi^N] = E[\pi^S] = \frac{\sigma^2}{(2+\delta)^2} + \frac{\sigma^2}{(2+\delta)^2}, \quad E[\pi^S] = \frac{\sigma^2}{(2+\delta)^2} + \frac{\sigma^2}{(2+\delta)^2} \]

\(^1\)Note that, \(E[\pi^N] = E[\pi^S] = \frac{\sigma^2}{(2+\delta)^2} + \frac{\sigma^2}{(2+\delta)^2}, \quad E[\pi^S] = \frac{\sigma^2}{(2+\delta)^2} + \frac{\sigma^2}{(2+\delta)^2} \). They are all independent of \(k\).
Proposition 6. Both the incumbent and the entrant benefit from net investment effect (i.e., \( E[\pi_j^i] > E[\pi_j^E] \), \( i \in \{I, E\} \) and \( j \in \{N, S\} \)), but the incumbent (entrant) benefits less (more) in Scenario S (i.e., \( E[\pi_j^S] - E[\pi_j^I] < E[\pi_j^N] - E[\pi_j^I] \) and \( E[\pi_j^S] - E[\pi_j^E] > E[\pi_j^N] - E[\pi_j^E] \)).

Proposition 6 indicates that production investment undoubtedly benefits the incumbent and the entrant. However, the benefit from the net investment effect shows opposite results for the incumbent and the entrant in Scenario S (see Fig. 4). Clearly, knowledge sharing lowers the incumbent’s benefit from the net investment effect but increases the entrant’s; this eventually results in the “win-win” or the “lose-lose” zone.

Specifically, given a high production investment efficiency (i.e., a small \( k \)), it is intuitive to observe that both incumbent and entrant are profitable in Scenario S, because the production investment cost is affordable and the horizontal alliance because of knowledge sharing benefits the total system. Thus, a “win-win” zone holds (Fig. 3(a)). However, we find that the “win-win” zone will shrink as \( k \) increases.
(from Fig. 3(a) to Fig. 3(b)), which is a result of the incumbent’s incentive for migration. There are two reasons contributing to this finding. First, according to Lemma 1 and Proposition 1, we note that the entrant enjoys the benefit of enlarged total supply potential as a free rider in Scenario S, which might reduce the incumbent’s incentive to share knowledge. Second, the incumbent (entrant) benefits less (more) from the net investment effect in Scenario S (see Region 1 in Fig. 4). Hence, production investment with knowledge sharing actually benefits the entrant more but benefits the incumbent less, which induces the entrant to favor scenario S, while the incumbent has a strong incentive to move from Scenario S to N. Eventually, the “win-win” zone shrinks.

Interestingly, given a relatively low production investment efficiency (i.e., a relatively large $k$), we find that both the incumbent and the entrant are less profitable in Scenario S, which indicates that the “lose-lose” dilemma arises. We explain this finding as follows. Intuitively, the incumbent conjectures that the entrant has a strong incentive to increase his production investment in Scenario S because of knowledge sharing, so the incumbent will be stimulated to increase its production investment given the traditional efficiency advantage in production investment. However, the entrant actually determines a lower production investment level and acts as a free rider, which goes against the incumbent’s expectation. For the entrant, acting as a free rider not only shares the gains but also the pains. According to Lemma 1, the total supply potential in Scenario S is still expanded, but the benefit from total supply expansion could not compensate for the costly production investment, given a low production investment efficiency. As a result, the “lose-lose” dilemma arises.

Following the same logic, we find that the “lose-lose” zone will expand as the production investment efficiency becomes lower (i.e., a larger $k$; see Figs. 3(c) and (d)). There are two reasons. First, a low production investment efficiency indicates that production investment is incredibly costly for the incumbent and the entrant, resulting in a small supply expansion and a profit that cannot offset the high cost. Second, as Region 3 in Fig. 4 shows, a large $k$ weakens the entrant’s advantage in the net investment effect, which induces the entrant to shift from Scenario S to N. This eventually expands the “lose-lose” zone.

5. EXTENSIONS

5.1. Risk-Averse Entrant

In our basic model, we investigate whether the incumbent will be profitable because of knowledge sharing (Scenario S) by assuming the entrant is risk-neutral. In practice, the entrant (i.e., an automaker) could face pronounced demand variability when it enters the unfamiliar ventilator manufacturing field, especially when it could not access the incumbent’s knowledge. Therefore, the entrant can be risk-averse in Scenario N. Being aware of this, we are interested in how the entrant’s risk aversion affects the incumbent’s profitability and whether knowledge sharing is possible. We use a mean–variance framework that has been well studied by Lau (1980), Choi and Chiu (2012), MacKenzie (2014), Chiu and Choi (2016), and Chiu et al. (2018) to capture the risk-averse entrant’s decisions. The objective functions in Scenario N are as follows, respectively:

In Scenario N:

$$\max_{\{q^N_1, q^N_2\}} \left\{ U^N = E\left[\pi^N\right] - \rho \sqrt{\text{Var}\left[\pi^N\right]} \right\}$$

$$= \max_{\{q^N_1, q^N_2\}} \left[ (a + e^N_k - q^N_k - bq^N_k) q^N_k - \frac{1}{2} \lambda k e^N_k^2 - \rho \left( \sigma q^N_k \right) \right].$$

$$\max_{\{q^N_1, q^N_2\}} \pi^N_1 = p^N_1 q^N_1 - \frac{1}{2} k e^N_1^2,$$

where $\rho > 0$ is the entrant’s risk aversion degree where a more risk-averse entrant has a larger $\rho$. $\text{Var}[\pi^N]$ is the variance of entrant’s profit, and $U^N$ is the entrant’s utility. The equilibrium outcomes in Scenario N are presented in Table IV. We assume the feasible region on

$$\Omega = \left\{ (k, \lambda, \rho, \sigma) | k(b) < k < \bar{k}(b), 1 < \lambda < \bar{k}(b)/k, \rho > 0, \right.$$  
$$0 < \sigma < \frac{a(4 - (2 - b)^2(2 + b)k\lambda)}{b(4 - b^2)kk\rho} \right\}$$

to guarantee all the equilibrium outcomes are positive.

It is challenging to obtain the closed-form condition. Therefore, we conduct extensive numerical studies to investigate the incumbent’s knowledge-sharing decisions. First, given a large or small $b$ in the feasible region $\Omega$, we investigate the incumbent’s knowledge-sharing decisions when $k$ is large and small, respectively. Then, in each combination of $b$
and $k$, we further take multiple values of $\rho$ to examine how $\rho$ affects the incumbent’s knowledge-sharing decisions. The detailed parameter values and the simulation step lengths for each parameter are summarized in Table V.

We have Observations 3 and 4, which are illustrated in Fig. 5.

Observation 3: Given a large $b$, or a small $b$ but a large $k$, the incumbent will be more profitable in Scenario S (Figs. 5(a) and (b)). Given a small $b$ and a small $k$, the incumbent will be more profitable in Scenario S when $\rho$ is small and $\sigma$ is below a threshold (Fig. 5(ci)). Otherwise, the incumbent will be more profitable in Scenario S regardless of the value of $\sigma$ (Fig. 5(cii)).

Observation 4: When $b$, $k$, and $\rho$ are small, the incumbent has a stronger incentive to share knowledge as $\rho$ decreases (Fig. 5(cii)).

Compared with Proposition 4, Observation 3 shows the conditions in which the incumbent’s benefits from knowledge sharing are qualitatively unchanged, especially when $b$ is large, or when $b$ is small but $k$ is large. In particular, the incumbent will be more profitable in Scenario S when the information value is not so significant (i.e., $\sigma$ is small) and the entrant is not so risk-averse (i.e., $\rho$ is small). Observation 4 further demonstrates that the incumbent’s incentives of knowledge sharing increase as the entrant’s risk-aversion degree decreases. We explain these observations as follows.

Investigating the incumbent’s production investment levels and sales volumes in Scenarios N and S, we find that the incumbent will determine a higher production investment level and sales volume when it shares knowledge with the entrant (i.e., $E[e^N] > E[e^S]$ and $E[q^N] > E[q^S]$). However, we find that the incumbent will benefit less from the higher production investment level and sales volume in Scenario S when the entrant becomes more risk-averse, i.e., $\iota(E[e^N] - E[e^S]) < 0$ and $\iota(E[q^N] - E[q^S]) < 0$. This finding is intuitive because we also find that the entrant’s production investment level and sales volume in Scenario N are both decreasing in $\rho$, i.e., $\iota(E[e^N]) < 0$ and $\iota(E[q^N]) < 0$. As a result, the incumbent significantly benefits in production investment level and sales

### Table IV. The Expected Equilibrium Outcomes in Scenario N

| Scenario N |
|------------------|------------------|
| Production Investment Levels |
| $E[e^N] = \frac{a\left(2 - b\right)^2(2 + b)k - 4}{16 + (4 - b^2)k^2 - 8(4 - b^2)k(1 + \lambda)}$ |
| $E[q^N] = \frac{\lambda\left(2 - b\right)^2(2 + b)k\lambda - 4}{16 + (4 - b^2)k^2 - 8(4 - b^2)k(1 + \lambda)}$ |
| $E[\pi^N] = \frac{k\lambda\left(2 - b\right)^2(2 + b)k\lambda - 4}{16 + (4 - b^2)k^2 - 8(4 - b^2)k(1 + \lambda)}$ |

### Table V. Summary of Parameters

| Parameters                  | Parameter Values |
|-----------------------------|------------------|
| Basic supply potential $a$  | $a = 1$          |
| Product substitutability $b$| $b = 0.1, 0.5, 0.9$ |
| Production investment efficiency $k$ | $k \in (k(b), \hat{k}(b))$, step length = 0.01 |
| Efficiency disadvantage of the entrant $\lambda$ | $\lambda \in (1, \hat{k}(b)/k)$, step length = 0.01 |
| Entrant’s risk-aversion degree $\rho$ | $\rho \in (0, +\infty)$, step length = 0.01 |
volume in Scenario N, i.e., $\frac{\partial E[\pi_N]}{\partial \rho} > 0$ and $\frac{\partial E[q_N]}{\partial \rho} > 0$. We indeed find that the incumbent’s deterministic value becomes higher as $\rho$ increases in Scenario N, i.e., $\frac{\partial DV_N}{\partial \rho} > 0$. On the contrary, in Scenario S, we find that the incumbent’s production investment level, sales volume, and deterministic value are independent of $\rho$. As $\rho$ increases, the incumbent’s disadvantage in production investment level and sales volume in Scenario N will be mitigated, thus we have $\frac{\partial (DV^2_N-DV^1_N)}{\partial \rho} < 0$. In other words, knowledge sharing (Scenario S) will be less attractive for the incumbent as $\rho$ increases (see Fig. 5(a)).

Next, we investigate whether the entrant can benefit from knowledge sharing when it is risk-averse. Fortunately, we obtain the closed-form conditions in Proposition 7.

**Proposition 7.** When the entrant is risk-averse, there exist two thresholds $\rho_1$ and $\sigma_3$ such that the entrant benefits from the incumbent’s knowledge sharing if $\rho < \rho_1$ and $\sigma > \sigma_3$ (i.e., $E[\pi_E^N] > U_N^E$ if $\rho(\rho_1)$ and $\sigma(\sigma_3)$).

Compared to Proposition 5 in our basic model, Proposition 7 demonstrates that the entrant still has the opportunity to benefit from knowledge sharing as long as it is not extremely risk-averse (i.e., $\rho < \rho_1$). Furthermore, it is interesting to find that the entrant’s opportunities to benefit from knowledge sharing become limited as $\rho$ increases (Fig. 6(a)). We explain this result by discussing the interactions among the entrant’s deterministic value, risk loss, and information value. Note that the entrant’s expected profit in Scenario S comprises two parts: deterministic value ($DV^S_E$) and information value ($IV^S_E$).
The entrant’s expected profit in Scenario N also comprises two parts: the deterministic value $DV^N_E$, which is independent of $\rho$ and $\sigma$, and the risk loss $RL^N_E$ that is dependent on $\rho$ and $\sigma$. Please see the following expression.

$$U^N_E = \frac{a^2k\lambda[(2-b)^2(2+b)k-4]^2[(4-b^2)k\lambda-8]}{[16+(4-b^2)^3k^2\lambda-8(4-b^2)k(1+\lambda)]^2}$$

It can be verified that the entrant determines a lower production investment level and sales volume in Scenario S, i.e., $E[e^N_E] < E[e^S_E]$ and $E[q^N_E] < E[q^S_E]$. Therefore, the entrant will obtain a lower deterministic value in Scenario S regardless of $\rho$ (i.e., $DV^S_E < DV^N_E$). On the other hand, we find that the entrant will be hurt less in Scenario S in the sense of deterministic value, because the disadvantage in production investment level and sales volume are mitigated as $\rho$ increases (i.e., $\frac{\partial(E[e^S_E]-E[e^N_E])}{\partial\rho} < 0$, $\frac{\partial(E[q^S_E]-E[q^N_E])}{\partial\rho} < 0$ and $\frac{\partial(E[DV^S_E]-E[DV^N_E])}{\partial\rho} < 0$). The result is that, given a small $\rho$ (i.e., $\rho < \rho_1$), the entrant has a significant disadvantage in deterministic value (i.e., $DV^N_E - DV^S_E$ is large); therefore, the entrant can benefit from knowledge sharing only when the information value is sufficiently large (i.e., $\sigma > \sigma_0$) that can offset the loss of deterministic value and the risk loss (see Fig. 6(a)).

Following the same logic, the entrant has a negligible disadvantage in deterministic value when $\rho$ is large (i.e., $DV^N_E - DV^S_E$ is very small). In this case, one might think the entrant has more opportunities to benefit from knowledge sharing (Scenario S); however, we find the opposite is true from Fig. 6(b). The reason is that, although the disadvantage in deterministic value is ignorable, the role of entrant’s information value (in Scenario S) in compensating for his risk loss (in Scenario N) is weakened as $\rho$ increases, i.e., $IV^S_E > RL^N_E$ if $\rho < \rho_1$ and $\frac{\partial(IV^S_E-RL^N_E)}{\partial\rho} < 0$, and the risk loss cannot be offset when $\rho$ is sufficiently large (i.e., $IV^S_E < RL^N_E$ if $\rho > \rho_1$). Therefore, the entrant’s opportunity to benefit from knowledge sharing will shrink as $\rho$ increases, especially when $\rho$ is sufficiently large.

5.2. Component Supply Capacity Constraint

In this subsection, we consider a scenario in which the incumbent and the entrant face component supply capacity constraint. It is reported that a ventilator needs key components such as extracorporeal membrane oxygenation (ECMO), chips, and so on, which easily experience supply disruption confronting COVID-19 (Aspan & Elegant, 2020; Ma, 2020). In this case, the incumbent and the
entrant’s capacities are limited to $Q$ (i.e., $q_i^j + q_k^j \leq Q, j \in \{N, S\}$). Their profit functions are as follows:

In Scenario N:

$$\begin{align*}
\max \ E \left[ \pi^N_E \right] &= E \left[ p^N_E q^N_E - \frac{1}{2} \lambda k e^N_E \right] \\
\max \ \pi^N_I &= p^N_I q^N_I - \frac{1}{2} k e^N_I \\
q^N_E + q^N_I &\leq Q \\
q^N_E &\geq 0 \\
q^N_I &\geq 0
\end{align*}$$

s.t.

In Scenario S:

$$\begin{align*}
\max \ \pi^S_E &= p^S_E q^S_E - \frac{1}{2} k e^S_E \\
\max \ \pi^S_I &= p^S_I q^S_I - \frac{1}{2} k e^S_I \\
q^S_E + q^S_I &\leq Q \\
q^S_E &\geq 0 \\
q^S_I &\geq 0
\end{align*}$$

To guarantee that all the equilibrium outcomes are positive, we assume the feasible region

$$\Omega = \left\{ (Q, k, \lambda, \sigma) \mid a(4 + 3b - b^2) - 2 \sqrt{4a^2(1-b)} \leq Q < a, \frac{4 - b}{8 - 8b + 2b^2} < k < \frac{5 - 2b}{8 - 8b + 2b^2}, 1 < \lambda < \frac{2a(2 - b)k + [4 - 8k + b(4k - 1)]Q}{2(2 - b)k[a + 2(2 - b)(1 - (2 - b)k)Q]} \right\}$$

Then we obtain the equilibrium outcomes that are presented in Supporting Information S2. It is too complicated to derive analytical comparison results. We thus conduct extensive numerical studies to investigate how capacity constraint $Q$ affects the incumbent’s preference for knowledge sharing. Typical curves are in Fig. 7.

Fig. 7 shows that, the incumbent will not share knowledge when both manufacturers are capacity constrained, which is different from the results in our main model. When there is no capacity constraint, the incumbent determines a higher production investment level to obtain a larger sales volume and a higher deterministic value in Scenario S. However, if the incumbent and the entrant’s capacities are constrained, the entrant will determine a higher production investment level to obtain a larger sales volume, i.e., $E[e^T_E] > E[e^N_E]$ and $E[q^T_E] > E[q^N_E]$, and the incumbent will behave oppositely, i.e., $E[e^T_I] < E[e^N_I]$ and $E[q^T_I] < E[q^N_I]$. As a result, the incumbent obtains a lower deterministic value (i.e., $DV^S_I < DV^N_I$). The underlying reason is that, when the incumbent and the entrant have component supply capacity constraint, both of them would compete for limited capacity. Being aware of this, the incumbent could occupy a larger capacity in Scenario N because of an efficiency advantage in production investment. This advantage will disappear if the incumbent shares knowledge with the entrant. In Scenario S, the entrant will make use of improved production investment efficiency and will determine a large production quantity. This result can be significant
when the capacity constraint \( Q \) becomes smaller, i.e., \( \frac{\partial \pi^N}{\partial Q} > 0 \). Therefore, the incumbent has no incentive to share knowledge with the entrant.

### 5.3. Entrant’s Partial Improvement in Production Investment Efficiency

In this subsection, we investigate a case in which the entrant’s production investment efficiency is partially improved in Scenario S. We use \( \delta \) to capture the improvement degree, which indicates that the entrant’s production investment efficiency is \( (\lambda - \delta)k \). Note that, our basic model holds when \( \delta = \lambda - 1 \).

The incumbent and the entrant’s equilibrium outcomes are unchanged in Scenario N, while their expected profits in Scenario S are

\[
\max_{(q^N_E, q^N_I)} E [\pi^N_E] = E \left[ p^N_E q^N_E - \frac{1}{2} \lambda k e_{E^N}^2 \right];
\]

\[
\max_{(q^N_I)} \pi^N_I = p^N_I q^N_I - \frac{1}{2} \lambda e_{I^N}^2.
\]

Using backward induction, the expected equilibrium outcomes in Scenario S are derived in Table VI. We assume the feasible region on

\[
\Omega = \{ (k, \lambda, \delta) | k(b) < k < \tilde{k}(b), 1 < \lambda < \tilde{k}(b)/k, 0 < \delta < \lambda - 1 \}
\]

to guarantee all the equilibrium outcomes are positive.

It is challenging to obtain the closed-form conditions under which the incumbent is more profitable with knowledge sharing. Therefore, we conduct extensive numerical studies to investigate how \( \delta \) affects an incumbent’s knowledge-sharing decisions. Parameters are summarized in Table VII.

![Table VI. The Expected Equilibrium Outcomes in Scenario S](image)

| Scenario S |  |
|---|---|
| Production investment levels | \( E [q^N_E] = \frac{a k (a + b) (a + b k - 4)}{16 - 8 b (a - b) k (a + b k - 4) (4 - b)^2 (a - b)^2} \) |
| Sales volumes | \( E [q^N_I] = \frac{a k (a + b) (a + b k - 4)}{16 - 8 b (a - b) k (a + b k - 4) (4 - b)^2 (a - b)^2} \) |
| Expected profits | \( E [\pi^N_E] = \frac{a k (a + b) (a + b k - 4)}{16 - 8 b (a - b) k (a + b k - 4) (4 - b)^2 (a - b)^2} \) |

![Table VII. Summary of Parameters](image)

| Parameters | Parameter Values |
|---|---|
| Basic supply potential \( a \) | \( a = 1 \) |
| Product substitutability \( b \) | \( b = 0.1, 0.5, 0.9 \) |
| Production investment efficiency \( k \) | \( k \in (\tilde{k}(b), \tilde{k}(b)^*) \), step length = 0.01 |
| Efficiency disadvantage of the entrant \( \lambda \) | \( \lambda \in (1, \tilde{k}(b)/k^*) \), step length = 0.01 |
| Efficiency improvement degree \( \delta \) | \( \delta \in (0, \lambda - 1) \), step length = 0.005 |
reasons are as follows. Note that, the incumbent determines a higher production investment level and a larger sales volume when the entrant has knowledge, which increases the incumbent’s deterministic value. In this subsection, these findings still hold, i.e., $E[q^x_S] > E[q^x_N]$ and $E[q^y_S] > E[q^y_N]$. Moreover, we find the incumbent’s production investment level and sales volume in Scenario S are higher as $\delta$ is increas-
ing, i.e., $\frac{\partial (E[e^N_i] - E[e^S_i])}{\partial \eta} > 0$ and $\frac{\partial (E[q^N_i] - E[q^S_i])}{\partial \eta} > 0$, indicating that the entrant actually determines a smaller sales volume (Lemma 1). This result benefits the incumbent.

5.4. Effects of Government Subsidies

Confronting COVID-19, many governments provide subsidies to compensate for the firms’ production capacity investments. In this subsection, we consider two cases to study the incumbent’s knowledge-sharing decisions in the presence of a government subsidy.

In Case I, only the entrant’s production investment cost is partially compensated by the government, and the subsidy ratio is $\eta$. Therefore, the entrant’s production investment costs are $(1 - \eta)(\frac{1}{2}ke_E^2)$ in Scenario N, and $(1 - \eta)(\frac{1}{2}ke_E^2)$ in Scenario S, respectively.

In Case II, if the incumbent shares knowledge with the entrant (in Scenario S), both of them will obtain a government subsidy. The subsidy ratio is identical because many governments have made a unified incentive policy confronting COVID-19 (e.g., China). See The State Council of the PRC (2020a, b) for the details. In this case, the incumbent’s and the entrant’s production investment costs are $(1 - \eta)(\frac{1}{2}ke_E^2)$ and $(1 - \eta)(\frac{1}{2}ke_E^2)$ in Scenario S, respectively.

We first investigate Case I. The profit functions of the incumbent and the entrant are

In Scenario N:

$$\max_{\{q^N_i, q^N_i\}} E[\pi^N_i] = E\left[p^N_i q^N_i - (1 - \eta)\left(\frac{1}{2}ke_E^2\right)\right].$$

In Scenario S:

$$\max_{\{q^S_i, q^S_i\}} E[\pi^S_i] = p^S_i q^S_i - \left(1 - \eta\right)\left(\frac{1}{2}ke_E^2\right).$$

We obtain the equilibrium outcomes presented in Supporting Information S2. Assume the feasible region on $\Omega = \{(k, \lambda, \eta, \sigma)|k(b) < k < \tilde{k}(b), 1 < \lambda < \tilde{k}(b)/k, 0 < \eta < \frac{(4 - \beta^2)\gamma - 8}{(4 - \beta^2)\gamma k}, \sigma > 0\}$ to guarantee that all the equilibrium outcomes are positive. It is challenging to obtain the closed-form conditions; therefore, we conduct numeric studies to investigate how the subsidy ratio $\eta$ affects the incumbent’s knowledge-sharing decisions and the entrant’s profits. Parameters are summarized in Table VIII.

We first show the incumbent’s knowledge-sharing decisions in Observations 7 and 8 (Fig. 9).

Observation 7: In Case I, given a small $\eta$, the incumbent will be more profitable in Scenario S when $\sigma$ is below a threshold (Fig. 9(a)). Otherwise, the incumbent will be more profitable in Scenario S regardless of the value of $\sigma$ (Fig. 9(b)).

Observation 8: In Case I, given a small $\eta$, the incumbent has a stronger incentive to share knowledge as $\eta$ increases (Fig. 9(a)).

Observation 7 shows that the incumbent’s knowledge sharing follows a similar structure to that in the base model, as long as the subsidy ratio $\eta$ is not large. Otherwise, driven by a sufficiently large subsidy, the incumbent prefers knowledge sharing unconditionally.

Interestingly, Observation 8 reveals that if the government compensates the entrant with a large subsidy ratio $\eta$, the incumbent will be more willing to share knowledge. We explain it as follows. First, we find that the incumbent will determine a higher production investment level and supply volume in Scenario S, i.e., $E[e^N_i] > E[e^S_i]$ and $E[q^N_i] > E[q^S_i]$. Second, for the incumbent, the benefits from the higher production investment level and supply volume in Scenario S become more significant as $\eta$ increases, i.e., $\frac{\partial (E[e^N_i] - E[e^S_i])}{\partial \eta} > 0$ and $\frac{\partial (E[q^N_i] - E[q^S_i])}{\partial \eta} > 0$. Recall Proposition 1, where a larger supply volume and a higher production investment level enable the incumbent to obtain a higher deterministic value (i.e., $DV^S - DV^N > 0$). If the incumbent shares knowledge, then the largest proportion of the increased information value will be taken by the incumbent (Propositions 1 and 3). Therefore, the incumbent can effectively benefit from the complementary force of government subsidy and knowledge sharing, which helps to satisfy more demand without intensifying the competition with the entrant too much (see Fig. 9).

Next, we investigate whether an entrant can benefit from knowledge sharing when it obtains a government subsidy. We fortunately obtain the closed-form conditions shown in Proposition 8.

Proposition 8: The entrant benefits from the incumbent’s knowledge sharing if $\sigma > \sigma_2$ (i.e., $E[\pi^S_i] > E[\pi^N_i]$ if $\sigma > \sigma_2$). Furthermore, the threshold $\sigma_2$ is increasing in $\eta$ (i.e., $\partial \sigma_2 / \partial \eta > 0$).

Proposition 8 demonstrates that the entrant will benefit from the incumbent’s knowledge sharing when $\sigma > \sigma_2$, which is in line with the result in our
Table VIII. Summary of Parameters

| Parameters                                                                 | Parameter Values |
|---------------------------------------------------------------------------|------------------|
| Basic supply potential \(a\)                                              | \(a = 1\)       |
| Product substitutability \(b\)                                            | \(b = 0.1, 0.5, 0.9\) |
| Production investment efficiency \(k\)                                     | \(k \in (k(b), \bar{k}(b))\), step length = 0.01 |
| Efficiency disadvantage of the entrant \(\lambda\)                       | \(\lambda \in (1, \bar{k}(b)/k)\), step length = 0.01 |
| Government’s subsidy ratio of production investment cost \(\eta\)          | \(\eta \in (0, (4-b^2)^2k^{-8}), \text{step length} = 0.001\) |

Fig 9. The effects of government subsidies on the incumbent’s knowledge-sharing decision in Case I \((a = 1, b = 0.5, k = 0.65, \text{and } \lambda = 1.01)\).

Fig 10. The effect of a government subsidy on the entrant’s preference for knowledge sharing in Case I \((a = 1, b = 0.5, k = 0.65, \text{and } \lambda = 1.01)\).
In Scenario S:

\[
\begin{align*}
\max_{\{q^S_E, e^S_E\}} \pi^S_E &= p^S_E q^S_E - (1 - \eta) \left( \frac{1}{2} k e^S_E^2 \right), \\
\max_{\{q^S_I, e^S_I\}} \pi^S_I &= p^S_I q^S_I - (1 - \eta) \left( \frac{1}{2} k e^S_I^2 \right).
\end{align*}
\]

The equilibrium outcomes are presented in Supporting Information S2, and we have the feasible region on \( \Omega = \{(k, \lambda, \eta, \sigma) | k(b) < k < \tilde{k}(b), 1 < \lambda < \bar{\lambda}, 0 < \eta < \frac{(4-b^2)^2 k - 8}{(4-b^2)^2 k}, \sigma > 0 \} \) to guarantee that all the outcomes are positive. Similar to Case I, we conduct numeric studies to investigate how the subsidy ratio \( \eta \) affects the incumbent’s knowledge-sharing decisions. We have Observations 9 and 10, which are illustrated in Fig. 11.

Observation 9: In Case II, given a large \( b \) and a large \( \eta \), the incumbent will be more profitable in Scenario S when \( \sigma \) exceeds a threshold (Fig. 11(a)).

Observation 10: In Case II, given a small \( b \), whether the incumbent will be more profitable in Scenario S depends on \( \eta \) and \( \sigma \). Given a small \( \eta \), the incumbent will be more profitable in Scenario S when \( \sigma \) is below a threshold. Otherwise, the incumbent will be more profitable in Scenario N regardless of the value of \( \sigma \) (Fig. 11(b)).

When the incumbent can also obtain a government subsidy, Observation 10 reveals that the conditions in which the incumbent benefits from knowledge sharing are qualitatively unchanged when the subsidy ratio \( \eta \) is small and the competition between the incumbent and the entrant is mild (i.e., \( b \) is small). The underlying reasons are similar to that for Proposition 4, so we omit the details here.
The interesting observation is that the incumbent might be worse off in Scenario $S$ given a large $b$, as Observation 9 shows. This scenario occurs because when the incumbent also receives a government subsidy, the overall supply volume increases too quickly. Given a high product substitutability (i.e., a large $b$), there will arise fierce competition between the incumbent and the entrant, which hurts profits.

Next, we investigate whether the entrant can benefit from knowledge sharing in Case II.

Observation 11: In Case II, given a small or large $\eta$, the entrant will be more profitable in Scenario $S$ when $\sigma$ exceeds a threshold (Figs. 12(a) and (c)). Otherwise, the entrant will be more profitable in Scenario $S$ regardless of the value of $\sigma$ (Fig. 12(b)).

Observation 11 and Fig. 12 show that the entrant might be first better-off in Scenario $N$, then better-off in Scenario $S$, and back to better-off in Scenario $N$, as the subsidy ratio $\eta$ increases. To explain this observation, we investigate the entrant’s deterministic values (DV) in Scenario $N$ and $S$ and find that the entrant might obtain a higher deterministic value in Scenario $S$ (or $N$) when $\eta$ is moderate (either small or large). In other words, the entrant might enjoy a deterministic value advantage (disadvantage) in Scenario $S$ when $\eta$ is moderate (either small or large). Furthermore, when $\eta$ is either small or large and given a large (small) $\sigma$, we find that the entrant’s information value (IV) advantage is more (or less) significant than its deterministic value disadvantage in Scenario $S$, which makes the entrant more profitable in Scenario $S$ (or $N$). Therefore, when $\eta$ is moderate, the entrant could enjoy both the deterministic value advantage and information value advantage in Scenario $S$, making the entrant more profitable (see Figs. 13(a) and (b)).

5.5. Social Welfare Analysis and Implications

In this subsection, social welfare (SW) is defined as the sum of consumer surplus (CS), and firms’ (i.e., the incumbent and the entrant) profits ($\pi_I$ and $\pi_E$). CS in the two scenarios is characterized as follows (Singh & Vives, 1984):

$$CS^i(q^i_I, q^i_E) = (a^i_I + e^i_I)q^i_I + (a^i_E + e^i_E)q^i_E - \frac{1}{2}(q^i_I + 2bq^i_Iq^i_E + q^i_E^2) - (p^i_Iq^i_I + p^i_EQ^i_E)$$

$$= (a^i_I + e^i_I)q^i_I + (a^i_E + e^i_E)$$

$$q^i_E - \frac{1}{7}(q^i_I + 2bq^i_Iq^i_E + q^i_E^2)$$

$$-[(a^i_I + e^i_I - bq^i_I)q^i_I + (a^i_E + e^i_E - bq^i_E)q^i_E]$$

$$= \frac{1}{7}(q^i_I + 2bq^i_Iq^i_E + q^i_E^2)$$

where $a^i_I = a + \epsilon$ and $a^i_E = a + d^i' \epsilon$, $i \in \{N, S\}$.

Then, the social welfare is:

$$SW^i = CS^i + \pi^i_I + \pi^i_E, \quad i \in \{N, S\}.$$ 

The Table IX summarizes the outcomes.

It is challenging to obtain the closed-form conditions under which the social welfare is higher. Therefore, we conduct numeric studies and conclude the main findings in Observation 12, which are illustrated by Fig. 14.

Observation 12. Whether the incumbent’s knowledge sharing could improve social welfare depends on the interactions between $b$, $k$, $\lambda$, and $\sigma$:

(a) Given a small $b$ and $\sigma$, the social welfare in Scenario $S$ outperforms that in Scenario $N$ when $k$ is small (Fig. 14(ai)), or, $k$ is large but $\lambda$ is small (Figs. 14(aji) and (a(ii))).
Table IX. The Expected Outcomes in Each Scenario

| Scenario N                                                                 | Scenario S                                                                 |
|--------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Consumer surplus                                                         | Consumer surplus                                                          |
| \( E[CS^N] = \frac{\alpha^2k(2-b)^{\gamma}(2+b)k-4k^2 \lambda^2 + \left[ (2-b)^3(2+b)k\lambda - 4 \right]}{4 \left( 4-b^2 \right)^2 \lambda^2} \) | \( E[CS^S] = \frac{(\alpha^2+\sigma^2)(1+\beta)(4-b^2)^2 k^2}{4(4-b)^2(2+b)^2 k^2} \) |
| \( + 2b \alpha \left[ (2-b)^3(2+b)k\lambda - 4 \right] \)                  |                                                                           |
| \( \frac{2 \left( 1+\beta \right) k^2 - 8k(4-b^2)(1+\lambda)}{8(4-b^2)^2 \lambda^2} \) |                                                                           |
| Total supply chain profit                                                 | Total supply chain profit                                                 |
| \( E[\pi^N] = \frac{\alpha^2k(2-b)^{\gamma}(2+b)k-4k^2 \lambda^2 + \left[ (2-b)^3(2+b)k\lambda - 4 \right]}{4 \left( 4-b^2 \right)^2 \lambda^2} \) | \( E[\pi^S] = \frac{2 \left( 1+\beta \right) k^2 - 8(\alpha^2+\sigma^2)}{4(4-b)^2(2+b)^2 k^2} \) |
| \( \frac{2 \left( 1+\beta \right) k^2 - 8k(4-b^2)(1+\lambda)}{8(4-b^2)^2 \lambda^2} \) |                                                                           |
| Social welfare                                                           | Social welfare                                                            |
| \( E[SW^N] = \frac{\frac{1}{k} k^2 \left[ 8 \alpha^2k(2-b)^{\gamma}(2+b)k-4k^2 \lambda^2 + \left[ (2-b)^3(2+b)k\lambda - 4 \right] \right]}{4 \left( 4-b^2 \right)^2 \lambda^2} \) | \( E[SW^S] = \frac{2 \left( 1+\beta \right) k^2 - 8(\alpha^2+\sigma^2)}{4(4-b)^2(2+b)^2 k^2} \) |
| \( \frac{2 \left( 1+\beta \right) k^2 - 8k(4-b^2)(1+\lambda)}{8(4-b^2)^2 \lambda^2} \) |                                                                           |
Fig 13. The effects of government subsidy on the entrant’s deterministic and information values in Case II \((a = 1, b = 0.5, k = 0.65, \text{ and } \lambda = 1.01)\).

(b) Given a large \(b\) and a small \(\sigma\), the social welfare in Scenario S outperforms that in Scenario N when \(\lambda\) is small regardless of the value of \(k\) (Figs. 14(b) and (c)).

Intuitively, social welfare is more likely to be larger in Scenario S because knowledge sharing can increase the two manufacturers’ total outputs and thus increase the consumer surplus. However, Observation 12 shows that knowledge sharing might not always result in improved social welfare. Note that, the social welfare consists of two parts—that is, the consumer surplus and the total supply chain profit, where the former is positively related to the two manufacturers’ total outputs, and the latter is affected by their profitability. We first analyze whether knowledge sharing can improve consumer surplus. Recall that the motivation of the incumbent and the entrant’s production investments is to increase the outputs. Production investment not only boosts their supply potential expansion \(i.e., e_i^j, i \in \{E, I\}, j \in \{N, S\}\) but results in investment costs, \(i.e., C(e_i^j) = \frac{1}{2} k_i^j e_i^{1/2}, i \in \{E, I\}, j \in \{N, S\}\). For ease of exposition and discussion, we use the supply expansion effect and investment cost effect to characterize the positive and negative forces, respectively. We have Proposition 9 as follows.
Fig 14. The comparison of social welfare.
Proposition 9.

(a) The aggregated supply expansion effect in Scenarios N and S is more significant than the aggregated investment cost effect, i.e., \( \sum_{i=1}^{e} e_i^j q_i^j - \sum_{i=1}^{e} e_i^j q_i^j = 0, j \in \{N, S\} \).

(b) The dominant role of aggregated supply expansion effect in Scenario S is more significant than that in Scenario N if one of the following conditions occurs, i.e., \( \sum_{i=1}^{e} e_i^N q_i^N - \sum_{i=1}^{e} e_i^N q_i^N = 0, j \in \{N, S\} \).

\[
(b) \quad 0 < b < b_1, \begin{cases} k < k_1, \\ k > k_1 \text{ and } \lambda < \lambda_1, \end{cases} \quad 0 < \sigma < \sigma_1
\]
or

\[
(b) \quad b_1 < b < 1, \lambda < \lambda_1 \text{ and } 0 < \sigma < \sigma_1.
\]

Proposition 9(a) demonstrates that the negative effect of production investment (i.e., the aggregated investment cost effect) can be dominated by the positive effect (i.e., aggregated supply expansion effect) despite whether there is knowledge sharing, which means that both the incumbent and the entrant have incentives to invest in production and the total outputs are therefore enlarged. Proposition 9(b) shows that, when \( \sigma \) is small (i.e., \( \sigma < \sigma_1 \)), knowledge sharing does not always play a positive role in output enlargement, which depends on the interactions between product substitutability \( b \), the production investment efficiency \( k \), and the efficiency disadvantage of the entrant \( \lambda \). If the conditions in Proposition 9(bi) and (bii) are satisfied, the advantage of aggregated supply expansion effect in Scenario S will be stronger, indicating that knowledge sharing stimulates the incumbent and the entrant to increase their outputs significantly. Regarding consumer surplus, it can be verified that the larger output results in the larger consumer surplus, implying that the consumer surplus in Scenario S is larger when the conditions in Proposition 9(b) hold.

Possible reasons are as follows. Note that, a small \( b \) and a small \( k \) (i.e., \( b < b_1 \) and \( k < k_1 \)) imply the competition between the two manufacturers is not fierce and the production investment is efficient. These two positive forces highlight the aggregated supply expansion effect; therefore, total output and the consumer surplus in Scenario S are larger. Given a small \( b \) and a large \( k \) (i.e., \( b < b_1 \) and \( k > k_1 \)), although a large \( k \) implies that the aggregated supply expansion effect might be diminished while the aggregated investment cost effect might be highlighted by the inefficient production investment (i.e., \( k > k_1 \)), the significant efficiency improvement (i.e., \( \lambda < \lambda_1 \)) will weaken the aggregated investment cost effect, making the aggregated supply expansion effect dominant. Hence, the total output and the consumer surplus outperform in Scenario S. If \( b \) is large, the aggregated supply expansion effect could still dominate because of the buffering effect of significant efficiency improvement (i.e., \( \lambda < \lambda_1 \)), resulting in a larger total output and consumer surplus in Scenario S.

6. CONCLUSIONS

6.1. Main Conclusions

Motivated by social responsibility, some automakers have moved from car manufacturing to ventilator manufacturing to increase the supply of ventilators to confront COVID-19. However, the automakers are generally inefficient in production and uninformed of demand variability because they lack knowledge of ventilator manufacturing. In practice, we have observed that some incumbent ventilator manufacturers (e.g., Medtronic) are helping the automakers (e.g., Tesla) manufacture ventilators by sharing the related knowledge for free. We therefore are interested whether the incumbent manufacturers’ knowledge sharing is rewarding or not.

We consider two competing ventilator manufacturers including an incumbent with knowledge of ventilator manufacturing, and an entrant who is uninformed. Knowledge sharing can help the entrant benefit from the elimination of demand variability, the expansion of total supply, and the improvement of production investment efficiency. However, this situation may also intensify their competition in both production investment and sales volume. We undertake two scenarios to investigate whether the incumbent and the entrant could be more profitable with the former’s knowledge sharing, namely: (1) Scenario N, where the entrant could not access to the incumbent’s knowledge, so that they experience lower production investment efficiency and higher demand variability; (2) Scenario S, where the incumbent shares knowledge with the entrant, resulting in the same production investment efficiency and demand information. We compare their profits in Scenarios S and N and identify their incentive alignment opportunities toward knowledge sharing.
We first analyze the equilibrium production investment levels and sales volumes and find that the incumbent determines a higher production investment level and thus obtains a larger sales volume in Scenario S. This enables the incumbent to obtain a higher deterministic value in Scenario S. In contrast, the entrant can benefit from the incumbent’s enlarged supply potential as a free rider, so he tends to determine a lower production investment level to avoid tense competition.

We find that, given a low product substitutability and a low production investment efficiency, the incumbent is more profitable in Scenario S when the information value is low. The reason for this finding is that the incumbent obtains a low information value but a high deterministic value, which can offset the loss in information value. On the other hand, given a high product substitutability, the incumbent obtains a sufficiently large information value in Scenario S, which induces them to be more profitable regardless of the production investment efficiency. Regarding the entrant, we find that only when the information value occupies a large weight in his overall profits can he benefit from knowledge sharing. We also investigate the incumbent and the entrant’s incentive alignment opportunities and identify a “win-win” zone and a “lose-lose” zone. We find that the “win-win” zone arises when the production investment efficiency is high. Interestingly, given a lower production investment efficiency, a “lose-lose” dilemma could arise because the production investment competition induced by knowledge sharing becomes extremely costly when production investment efficiency is low, resulting in small supply expansion whose benefit could not offset the investment cost.

6.2. Managerial Insights

Our work provides useful managerial insights for the incumbents when they decide whether to share knowledge with the competing entrants. These insights are summarized as follows.

(1) Entrants benefit from the improved production investment efficiency with knowledge sharing, and they can invest more to expand the supply potential. However, we show that when knowledge sharing exists, an entrant could act as a free rider of the increased supply potential contributed by the incumbent, and thus determines a smaller supply volume. This action coordinates the manufacturers’ decisions regarding production investment and supply volume, thus softening their competition.

(2) Proposition 4 suggests that the incumbent can be better-off by sharing knowledge with the entrant although their product competition is fierce. This suggestion indicates that knowledge sharing can effectively offset the system loss because of tense competition by expanding the total supply potential.

(3) Knowledge sharing makes both manufacturers better-off when the production investment efficiency is high and helps to achieve a “win-win” situation. However, a “lose-lose” zone can also arise where the manufacturers’ production investment becomes inefficient. This possibility should serve to remind manufacturers that knowledge sharing can be a double-edged sword, depending on the production investment efficiency, and knowledge sharing is suggested when the production investment efficiency is high.

6.3. Future Research Directions

We discuss two future research directions. First, entrants could still face high demand variability because they might not fully learn the shared knowledge. In this case, an incumbent might have a stronger or weaker incentive to share knowledge with the entrant because the latter’s information disadvantage could benefit or hurt the system’s total information value, depending on the entrant’s learning ability. Second, considering a case in which both the incumbent and the entrant purchase a key component from a common supplier, we have a one-to-two supply chain rather than the duopoly model we have studied here. In this case, the pricing decisions of the upstream supplier might alter the two manufacturer’s alliance decisions via knowledge sharing and, hence, the downstream market competition. Their incentive alignment opportunities will be altered, too.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1: Proofs

Appendix S2: Outcomes