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Abstract: Motivated by Google's technology specifications on Android devices, we consider firms' decisions on production timing in a co-opetitive supply chain comprising a manufacturer and an original equipment manufacturer (OEM), where the manufacturer acts as the OEM's upstream contract manufacturer and downstream competitor. We consider the market acceptance uncertainty of key product designs. If a firm decides to implement ex post production strategy (PS), it can delay the production until the market acceptance uncertainty of its product is resolved. Otherwise, ex-ante production strategy (AS) is implemented. We find that, due to the co-opetition, PS does not always benefit either the manufacturer or the OEM, because the value of delayed production is diminished as the competitor may commit a production quantity earlier under AS. Further, firms' decisions on production timing are dependent on the degree of market acceptance uncertainty of their products and competition intensity. We find that both firms choose PS when uncertainty is high, while only one of them chooses PS when uncertainty is moderate or low. Interestingly, when the competition is intense, the manufacturer tends to choose PS, which can benefit from both the resolved market acceptance uncertainty and OEM's early commitment of production quantity.

Keywords: Co-opetition, Market acceptance, Production timing, Technology specifications

1 Introduction

In recent years, many cell phone companies have outsourced their production to other manufacturers that also sell self-branded phones. For example, Google outsourced the production of its phone, Pixel, to HTC (Wired 2016). Meanwhile, HTC produced its self-branded phone and competed with Google in the consumer market. In this case, the manufacturer becomes both Google's *upstream partner* and *downstream competitor*. This "*co-opetition*" relationship (Brandenburger and Nalebuff 1996) has been observed among Google and Google's other upstream manufacturers.

The competition and cooperation among original equipment manufacturers (OEMs)[1] and their competitive manufacturers have received attention in the operations management field. Previous studies have examined the supply chain parties' strategic decisions and their incentives (e.g., selling or not selling self-branded products) in different industries. For example, Lim and Tan (2010) and Wang et al. (2013) study electronics products. Chen et al. (2012) focus on the computer industry. Hsu et al. (2017) is motivated by the examples in retailing and logistics industries. In this study, we focus on the cell phone industry, particularly those phones with the Android operating system.

Since Android is open source, if firms customize their Android phones arbitrarily, it may expose Android to the risk of fragmented user experience. Therefore, Google tries to control hardware and software specifications to avoid such a risk by providing Android's Compatibility Definition Document (CDD).[2] For example, the CDD requires the aspect ratio of a phone screen to be between 4:3 and 16:9. With these specifications, Google is able to ensure the "reliability and consistency" of the user experience on Android phones (Wired 2016). Furthermore, this CDD plays a significant role in the supply chain structure and manufacturers' operational decisions.

Although Google provides the CDD, it is up to cell phone firms to decide whether they will follow the CDD. If a manufacturer decides not to follow the CDD, the firm may suffer from significant uncertainty in market acceptance because Android's CDD is designed according to mainstream preference and is well known among enthusiastic Android fans. For example, in 2014 Amazon launched its Fire Phone running on a heavily customized Android operating system. This system is against many CDD specifications (e.g., it introduced a 3D display that is not part of the CDD). Two months after its release, Amazon was reported to have $83 million worth of unsold Fire Phones in its inventory (Time 2014). Having said that, not following the CDD is not necessarily a bad thing, because possible innovations could bring significant profits. For example, in 2016 Xiaomi launched Mix, an Android-based phone with a bezel-less and fillet-cutting design as well as a screen aspect ratio of 17:9, which are all against the CDD specifications. This phone made "full screen" a hot trend in 2017 (Wired 2017). Therefore, it is a manufacturer's strategic decision on whether or not to follow the CDD, especially in a co-opetitive setting. In the example of HTC, Pixel was made exactly according to Google's specifications (Wired 2016), whereas HTC saw non-compliance in designing its self-branded phone, e.g., HTC U11+ with a full screen (Gsmarena 2017).

Further, manufacturers' decisions on whether to follow the CDD can also affect their production timing, which is closely related to market acceptance uncertainty. Companies can make their production quantity decisions either before or after they learn the market acceptance of a certain product design. Some companies choose to postpone the production decisions until they are fully aware of the uncertainty of market acceptance, which is referred to in this study as *ex post* production strategy (PS). For example, HTC released its "full screen" phone U11+ in late 2017 after "full screen" became a trend (Gsmarena 2017). Similar strategies were observed in Huawei's launch of its first "full screen" phone,

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[1] OEMs in this study are referred to as firms that specialize in their core competencies such as product design, development,and marketing, but outsource production to contract manufacturers. This definition is widely adopted in literature. See Plambeck and Taylor (2005), Ulku et al. (2007), Chen et al. (2012), Kayis et al. (2013), Wang et al. (2013), Hu and Qi (2018) for more references. In our study, e.g., Google is an OEM that relies on HTC for contract manufacturing.

[2] See https://source.android.com/compatibility/cdd

Maimang 6 (China Daily 2017), and in its development of the related technology in 2018 (LetsGoDigital 2018). By contrast, some companies, such as LG and Xiaomi, choose to produce early and face the market acceptance uncertainty (BBC 2017, Wired 2017), which is referred to in this study as *ex-ante* production strategy (AS). Table 1 displays the main features from the motivating examples.

Table 1. Main Features from Practice

Features	**Corresponding motivating cases**
Co-opetition relationship	Google relies on upstream competitors (that sell self-branded phones) for manufacturing, e.g., HTC (Pixel), Huawei (Nexus 6P), LG (Nexus 5X)
Technology specifications	Specifications in Android's CDD: developed by Google to control phone design and ensure user experience
Market acceptance uncertainty	Uncertainty in consumers' acceptance of Android-based phone design
Specifications (non-)compliance	Amazon Fire Phone and Xiaomi Mix: justify the upside- and downside-effects of significant uncertainty due to non-compliance; HTC U11+: shows non-compliance practice in Google's supply chain
Production timing	HTC U11+ (PS), Huawei Maimang 6 (PS), Xiaomi Mix (AS), LG (AS)

With a co-opetitive supply chain comprising an OEM and a manufacturer, we investigate: (i) how the difference in market acceptance uncertainty affects co-opetition between the OEM and manufacturer as well as their production timing decisions; and (ii) the manufacturer's incentive to follow the OEM's specifications in the co-opetitive setting and the resulting effect.

We find that, both market acceptance uncertainty and competition intensity play critical roles in firms' strategic choices between AS and PS. In the presence of competition, adopting PS does not always benefit a firm. This is because the firm that makes production decision first enjoys the first-mover advantage (referred to as "commitment value" in the literature (Cvsa and Gilbert 2002, Roller and Tombak 1993, Spencer and Brander 1992, Wang et al. 2014a)). Intuitively, when a firm faces low market acceptance uncertainty, the commitment value may offset the value of information from PS (referred to as "information value"). However, with the co-opetition between the OEM and manufacturer, we further find the following:

1. When both firms face low uncertainty, one firm chooses AS and the other chooses PS in equilibrium (i.e., a sequential equilibrium). The underlying reason is that both firms' early commitment values disappear if they choose AS simultaneously (i.e., a simultaneous equilibrium), and their differences in market acceptance uncertainty and source of profits result in a sequential equilibrium. In contrast, both firms choose PS when they face high uncertainty. This implies that market acceptance uncertainty determines the nature of competition and cooperation between the OEM and the

manufacturer. In a simultaneous equilibrium, the manufacturer and the OEM choose the same strategy, and thus competition is intensified. Alternately, in a sequential equilibrium in which one firm chooses AS to seize early commitment value and the other firm chooses PS to obtain information value, the competition between two firms is softened. Overall, low uncertainty results in less competition in a sequential equilibrium.

2. When uncertainty of the two firms is moderate, their preference over AS/PS is determined by competition intensity. Intuitively, the OEM is more likely to choose AS due to its lower uncertainty (i.e., lower information value under PS). Consistent with this intuition, we find that the OEM chooses AS when competition is sufficiently intense. Interestingly, although firms' information values from PS is significantly reduced by intense competition, the manufacturer still chooses PS in this case. This is because, in the co-opetitive relationship, the manufacturer benefits from the *spillover value* of the OEM's early commitment. When competition is not very intense, however, the opposite holds true (i.e., the OEM chooses PS and the manufacturer chooses AS). This occurs also due to the co-opetitive relationship. The OEM's commitment value, from AS in this case, is significantly reduced by a high wholesale price paid to the manufacturer for contract manufacturing. Conversely, for the manufacturer, adopting AS leads to significant commitment value because high profit is achieved through both contract manufacturing and selling self-branded products.

With regard to the manufacturer's incentives to follow the OEM's CDD, we obtain the following findings. First, the manufacturer has no incentives to follow the OEM's CDD when they both have high market acceptance uncertainty and the competition is not very intense. The manufacturer's market acceptance uncertainty is decreased by following the CDD, and this can result in a sequential equilibrium in which the manufacturer chooses AS and the OEM chooses PS. However, when the market acceptance uncertainty is high, the early commitment value from AS cannot offset the loss of information value from PS for the manufacturer. Second, the manufacturer may have incentives to follow the OEM's CDD when the OEM's uncertainty is moderate, the manufacturer's uncertainty is high, and the competition is sufficiently intense. In this case, by following the CDD, the OEM chooses AS, and the manufacturer may benefit from high information value in a sequential equilibrium as well as the *spillover value* from the OEM's early commitment.

The remainder of this study is organized as follows. We briefly review the related literature in section 2. In section 3, we describe the model setup. In section 4, we analyze firms' strategic choices between AS and PS for the case in which the manufacturer does not follow the CDD, and in section 5, we analyze the case in which the manufacturer follows the CDD. The manufacturer's decision on the CDD is investigated in section 6. Sections 7 and 8provide extensions and conclusions.

2 Literature Review

Our work is related to the research that studies the value of waiting under demand uncertainty. Cachon (2004) investigates how order/production timing influences the allocation of inventory risk and hence supply chain efficiency. In his model, an early (a late) order is allowed before (after) demand is observed under a push (pull) contract, and inventory risk is born by the retailer (supplier). He also designs an advance-purchase discount contract that better allocates the value of waiting under demand uncertainty, wherein the inventory risk is shared by the retailer and supplier. Similarly, Dong and Zhu (2007) study the impact of pull, push and advance-purchase discount contracts on supply chain performance and identity Pareto improvement opportunities for the supply chain parties. Swinney et al. (2011) formulate the competition between an established firm and a start-up by assuming the former is concerned with profit gains while the latter is concerned with the probability of survival. If firms produce late until demand uncertainty is resolved, they can benefit from the value of information. They identify equilibrium where the start-up produces early while the established firm produces late. Chen and Xiao (2012) investigate the value of forecasting accuracy improvement in a three-tier supply chain, and they find that the reseller's improved accuracy is beneficial to both the manufacturer and the reseller under a wholesale price contract. Wang et al. (2014a) study two identical quantity competitors and their efficient-responsive choices. An efficient firm produces early while a responsive firm produces late. Wang et al. (2014b) analyze firms' decisions on timing of order (before or after demand is realized) in a three-tier supply chain comprising an OEM, a contract manufacturer, and a supplier, by using two procurement outsourcing structures: control and delegation. Choi (2018) considers a fashion supply chain comprising an upstream make-to-order manufacturer and a downstream risk-averse retailer. By comparing the slow-response (early production) case with the quick-response (late but responsive production) case, he investigates the impact of risk aversion on the quick-response system and finds that the retailer benefits from later production due to a better demand forecast. Choi et al. (2018) and Choi (2017) further explore the value of quick-response by considering a stochastically risk sensitive retailer (i.e., the retailer's risk preference may vary from time to time) and a boundedly rational retailer, respectively. The forgoing works are mainly based on newsvendor-typed models, which emphasize production quantity decisions under demand uncertainty, but lack the supply chain parties' cross interactions when they make decisions. The only exception is Wang et al. (2014a), where symmetric competition models and the value of production timing are investigated. Our work is therefore mostly close to Wang et al. (2014a), but we consider a co-opetition structure between the OEM and the manufacturer as well as their differences in market acceptance. We find that the firms' AS/PS choices are fundamentally determined by their co-opetitive relationships and market acceptance uncertainty.

Our work is also related to the literature on product design innovation. This stream of literature is comprehensively reviewed in Krishnan and Ulrich (2001). Most of the papers in this stream focus on cost-reduction effect of production process innovation within a single firm. There has been recent growth in the literature considering the vertical interactions among supply chain parties. For example, by focusing on new product development, Bhattacharya et al. (1998) study firms' product definition timing decisions (i.e., early definition to take advantage of low costs, or delayed definition to ensure a better fit to consumer preferences) in highly dynamic environments. Gilbert and Cvsa (2003) study product innovation interactions between a supplier and a buyer in a supply chain, where the supplier can strategically pre-commit pricing decisions to stimulate downstream innovation, or postpone decisions until demand uncertainty is resolved. Ülkü et al. (2005) investigate firms' optimal timing decisions on technological innovation adoption, which is dependent upon competition intensity, cost structure, and forecast improvement. Wang and Shin (2015) consider a downstream manufacturer and an upstream supplier that invests in innovation, which improves the product quality, thus, increasing the consumers' assessment of the product value. They study the impact of contract types and upstream competition on the supplier's investment in innovation. Wang et al. (2018) explore an upstream technology supplier's licensing decision in two different supply chain structures: (i) the supplier separately licenses its technology to a design firm and a manufacturer firm in a network supply chain, and (ii) the supplier licenses to a firm with both design and manufacturing capacities in a traditional integrated supply chain. Different from these papers' cost considerations, our work focuses on the effect of product innovations on the degree of market acceptance in a co-opetitive setting, and study how it influences firms' production timing decisions.

There is a growing amount of literature on co-opetitive supply chains. Spiegel (1993) shows that outsourcing production to a potential rival can reduce its incentives to develop self-branded business. Arya et al. (2007) study a single-OEM, single-supplier Cournot competition model, demonstrating that supplier encroachment can achieve better performance of both itself and the OEM by reducing wholesale price and increasing downstream competition. Lim and Tan (2010) investigate the interactions between an OEM and its upstream contract manufacturer (CM), finding that the OEM's high degree of brand equity can prevent the CM from entering the market. Chen et al. (2012) examine the OEM's sourcing decisions in the presence of a competing CM. Wang et al. (2013) consider a co-opetitive supply chain comprising an OEM along with a competitive CM acting as the OEM's upstream partner and downstream competitor, and they examine the impact of quantity competition on their preference over leadership and followership. Niu et al. (2015) conduct a similar study under price competition. Compared with the forgoing works, differences of our work exist on both practical and theoretical sides. We note that previous works study problems such as supplier encroachment, entry deterrence methods, and cooperation incentives issues. Our study is motivated by specific observations from the practice in Android phone industries. We characterize the manufacturers' strategies regarding the specifications compliance. This links the study of market acceptance uncertainty and production timing in a natural way. We also note that, previous works on co-opetition focus on the profit comparison with and without co-opetition. Differently, we study the players' incentives toward demand uncertainty, production timing, and operational decisions under an existing co-opetition framework.

3 Model Settings

3.1 The Structures of the Supply Chain and Market

Consider a co-opetitive supply chain comprising an OEM (denoted as *o*, e.g., Google in our motivating example) and a manufacturer (denoted as *m*), who acts as both the OEM's upstream partner and downstream competitor. The OEM outsources its production to the manufacturer who also sells self-branded products. The OEM's products and the manufacturer's products are partially substitutable as we explain below. Let *w* denote the wholesale price (for per unit of product) that the manufacturer charges the OEM.

The OEM and the manufacturer engage in quantity competition with market acceptance uncertainty. The inverse demand function for firm *i* is given by

$$p_i = a + \varepsilon_i - q_i - bq_j,\ i, j = o, m;\ i \neq j, \quad (1)$$

where p_i is firm *i*'s market clearance price, *a* and ε_i are the deterministic and random parts of the market potential, respectively, q_i and q_j are the quantities supplied by the two firms, and $b \in (0, 1)$ denotes the substitutability between the two firms' products. This form of inverse demand function is a standard assumption in the economics and marketing literature (Christen et al. 2009, Singh and Vives 1984, Vives 2000, to name a few).[3] The parameter *b* measures the intensity of market competition: The market becomes more competitive as *b* increases. We assume that the random variable ε_i, which represents the market acceptance uncertainty faced by firm *i*, has zero mean and variance σ_i^2. We further impose the following two assumptions on ε_i.

Assumption 1. ε_o and ε_m are statistically independent of each other, and

Assumption 2. $\sigma_o^2 < \sigma_m^2$.

Assumption 1 states that the OEM and the manufacturer conduct product design *independently* and have *exclusive* access to a market acceptance signal (relaxing this assumption will not change our main intuitions; see section 7.3 for the analysis). Assumption 1 captures the difference in market acceptance uncertainty faced by the OEM and the manufacturer. As explained in the Introduction, the OEM's CDD is based on mainstream preference. Hence, the products designed according to the CDD have low market acceptance uncertainty. This assumption is consistent with industrial practice. For example, International Data Corporation (IDC) reports that, the top two Android-based phone manufacturers in China, Xiaomi

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[3] We assume a linear demand function here, which could be partially justified by empirical studies (Galetovic et al. , Green and Newbery). For example, Green and Newbery () believe linear demand competition widely exists and works well in parameter estimations. Galetovic et al. () assume a linear demand function and use data from the smartphone industry. We admit the limitations of linear demand functions and discuss alternative models as future research directions in section 8.

and Huawei, face significant variations in market share performance (IDC 2017a,b). In contrast, Google's sales growth in Pixel family was steady (VentureBeat 2018).

3.2 Three-Stage Game

We consider that market acceptance uncertainty can be resolved after a certain time spot. Specifically, firms can make quantity decisions either at time 0 (i.e., adopting AS), or at time 1 (i.e., adopting PS). At time 0, the market condition noise ε_i is unknown, whereas at time 1, the realization of ε_i can be observed. The sequence of events is as follows:

1. The OEM and the manufacturer observe their valuation of market acceptance uncertainty. The manufacturer decides whether or not to follow the CDD.
2. The OEM and the manufacturer simultaneously choose whether to implement AS (denoted as *A*) or PS (denoted as *P*); that is, they choose to make quantity decisions at time 0 or time 1.
3. The manufacturer sets the wholesale price *w*.
4. According to their choices on production timing, the OEM and the manufacturer set their quantity levels.

We formulate this problem as a three-stage game. Figure 1 shows the sequence of events.

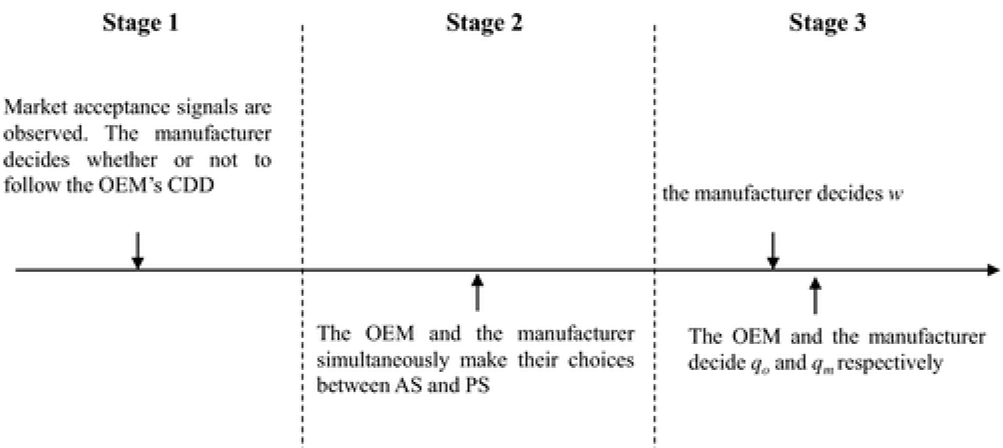

Figure 1 Sequence of Events

If the manufacturer does not follow the CDD, it designs the product and faces high uncertainty. The expected profit functions of the OEM and the manufacturer are, respectively,

$$\Pi_o = E[(a + \varepsilon_o - q_o - bq_m)q_o - wq_o], \quad (2)$$

$$\Pi_m = E[(a + \varepsilon_m - q_m - bq_o)q_m + wq_o]. \quad (3)$$

Here, we normalize the production cost to zero. Using a non-zero production cost will only generate results that differ by a constant (see section 7.4 for details). If the manufacturer follows the CDD, it shares the same uncertainty with the OEM. The expected profit of the manufacturer is

$$\Pi_m = E[(a + \varepsilon_o - q_m - bq_o)q_m + wq_o]. \quad (4)$$

We solve this game backwards. We first solve the third-stage subgame (wholesale price and quantity decisions) for any given production timing choices in stage 2 and decision on the CDD of the manufacturer in stage 1. We then solve the timing decisions, and finally we solve the manufacturer's decision on the CDD. To do so, in section 4, we solve the problems in stages 2 and 3 for the case in which the manufacturer does not follow the CDD, and in section 5, we analyze the case in which the manufacturer follows the CDD. In section 6, we compare the manufacturer's profits in these two cases and obtain the manufacturer's optimal decision on the CDD in equilibrium.

Since the OEM and the manufacturer engage in a simultaneous game if both of them implement AS or PS, and they engage in a sequential game otherwise, there are potentially four Cournot competition subgames in stage 3: a simultaneous game with uncertainty, a simultaneous game without uncertainty, a sequential game with the OEM as the Stackelberg leader, and a sequential game with the manufacturer as the Stackelberg leader. It is worth noting that, in a sequential game where one player enters early and the other waits, the early mover's quantity is public information. For notational convenience, we let $\alpha = (\alpha_o, \alpha_m)$ denote the joint actions between the OEM and the manufacturer, where $\alpha \in \{(A, A), (P, P), (A, P), (P, A)\}$. The notation in this study takes a general form of $X_i^{I\_\alpha}$, where X is the quantity of interest that can be profit(Π), quantity(q) or wholesale price(w). The superscript I_α represents the joint actions (α) between the two players under the status of technology specifications (non-)compliance ($I \in (N, F)$), where $N(F)$ indicates that the manufacturer does not (does, respectively) follow the CDD when it designs the product. The subscript i can be $o(m)$ for the OEM (manufacturer).

4 Not Following the CDD (*N*)

In this section, we analyze our model in the case where the manufacturer does not follow the OEM's CDD. By backward induction, we first focus on Stage 3 and derive firms' operational decisions on the wholesale price and production quantities in the four possible subgames: (*A*, *A*), (*P*, *P*), (*A*, *P*), (*P*, *A*). We then investigate firms' strategic decisions on production timing in stage 2.

4.1 Stage 3: Firms' Decisions on w, q_o, q_m

The equilibrium outcomes of the four subgames are summarized in Table 2. Lemma 1 shows the comparisons of equilibrium decisions among these four scenarios.

Lemma 1. (Comparison of w and q)

1. $w^{N\_AP*} < w^{N\_AA*} = w^{N\_PP*} < w^{N\_PA*}$;
2. $q_o^{N\_AA*} = q_o^{N\_PP*} < q_o^{N\_PA*} < q_o^{N\_AP*}$;
3. $q_m^{N\_PA*} < q_m^{N\_AP*} < q_m^{N\_AA*} = q_m^{N\_PP*}$;

By setting a proper wholesale price, the manufacturer is able to (i) increase its business opportunity (through wq_o); and (ii) suppress the OEM's market share. However, Lemma 1shows that the manufacturer's incentives on wholesale pricing are totally different in the scenarios of (*P*, *A*) and (*A*, *P*). In the case of (*P*, *A*) where the manufacturer is a leader, the manufacturer aggressively sets a high wholesale price (w^{N_PA*} is large), while it shows less aggression in occupying a large market share ($q_m^{N\_PA*}$ is small), to make it a balance between its manufacturing business and its erosion of the OEM's market share ($q_o^{N\_PA*}$ is moderate). In contrast, in the case of (*A*, *P*) where the OEM is a leader, one may conjecture that the manufacturer would set a high wholesale price to weaken the OEM's leadership. However, the manufacturer marks down the wholesale price (w^{N_AP*} is small) to encourage the OEM order more ($q_o^{N\_AP*}$ is large). The manufacturer may benefit from such a low-pricing strategy, since the OEM's extra gains from its early commitment will spill over to the manufacturer through wq_o.

Table 2. The Equilibrium Outcomes of Four Scenarios

	Scenario (A, A)	Scenario (P, P)	Scenario (A, P)	Scenario (P, A)
$w^{N\_\alpha*}$	$\frac{(8-4b^2+b^3)a}{2(8-3b^2)}$	$\frac{(8-4b^2+b^3)a}{2(8-3b^2)}$	$\frac{(8-6b^2+b^3)a}{2(8-5b^2)}$	$\frac{a}{2}$
$q_o^{N\_\alpha*}$	$\frac{2(1-b)a}{8-3b^2}$	$\frac{2(1-b)a}{8-3b^2}$	$\frac{2(1-b)a}{8-5b^2}$	$\frac{(1-b)a}{2(2-b^2)}$
$q_m^{N\_\alpha*}$	$\frac{(2-b)(4+b)a}{2(8-3b^2)}$	$\frac{(2-b)(4+b)a}{2(8-3b^2)}$	$\frac{(8-2b-3b^2)a}{2(8-5b^2)}$	$\frac{(2-b)a}{2(2-b^2)}$
$\Pi_o^{N\_\alpha*}$	$\frac{4(1-b)^2a^2}{(8-3b^2)^2}$	$\frac{4(1-b)^2a^2}{(8-3b^2)^2} + \frac{2(2-b^2)}{(4-b^2)^2}\sigma_o^2$	$\frac{2(1-b)^2(2-b^2)a^2}{(8-5b^2)^2}$	$\frac{(1-b)^2a^2}{4(2-b^2)^2} + \frac{1}{4}\sigma_o^2$
$\Pi_m^{N\_\alpha*}$	$\frac{(2-b)(6-b)a^2}{4(8-3b^2)}$	$\frac{(2-b)(6-b)a^2}{4(8-3b^2)} + \frac{2(2-b^2)}{(4-b^2)^2}\sigma_m^2$	$\frac{(12-8b-b^2)a^2}{4(8-5b^2)} + \frac{1}{4}\sigma_m^2$	$\frac{(3-2b)a^2}{4(2-b^2)}$

Lemma 2. (Impact of b on w, q, and Π)

1. $w^{N\_\alpha*}$ is first decreasing and then increasing in *b*;
2. $q_o^{N\_\alpha*}$ is decreasing in *b*;
3. $q_m^{N\_\alpha*}$ is first decreasing and then increasing in *b*;
4. $\Pi_o^{N\_\alpha*}$ and $\Pi_m^{N\_\alpha*}$ are both decreasing in *b*; where $\alpha \in \{AA, PP, AP, PA\}$.

Lemma 2 shows that the manufacturer's wholesale price is determined by competition intensity. More precisely, the manufacturer sets a high wholesale price when competition intensity is either high or low, whereas it sets a low wholesale price otherwise. We first highlight several essences: (i) as analyzed in Lemma 1, the manufacturer's pricing power might suppress the OEM's market share; and (ii) the interaction between the OEM and the manufacturer is closely related to the product substitutability (i.e., positively correlated). Keeping these in mind, we next elaborate the manufacturer's wholesale price decisions (see Figure 2 for illustrations).

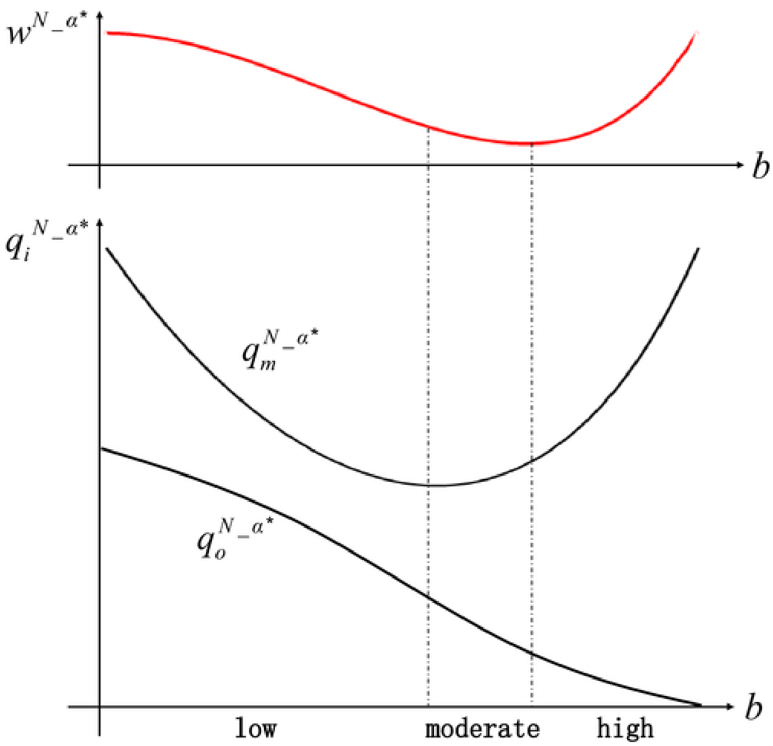

Figure 2 Effect of Wholesale Price on Firms' Quantities

When competition intensity is low, there is little interaction between the two firms' actions because of low product substitutability. The OEM can still determine a high order size in spite of a high wholesale price. In spite of the OEM's large quantity, the manufacturer can still choose a high quantity because it can still occupy a large market share due to the low competition intensity. This motivates the manufacturer to charge a high wholesale price to generate profits in both self-branded business and manufacturing business.

In contrast, when competition is fierce, the interaction between the OEM and the manufacturer is strong, which enhances the manufacturer's pricing power. The manufacturer thus charges a higher wholesale price to suppress the OEM's market share. A high wholesale price and a high market share compensate for the reduced order size in the manufacturing business. In particular, however, when the manufacturer's self-branded products are improved to be perfectly substitutable to the OEM's (i.e., b = 1), the OEM will withdraw the wholesale order and stop manufacturing business. This implies that, it is necessary for the manufacturer to take the OEM's threat into account when developing self-branded business.

When competition intensity is moderate, the manufacturer determines a low wholesale price. Because the OEM's order decreases rapidly as competition intensity increases, a low wholesale price is used to incentivize the OEM to purchase more.

4.2 Stage 2: Firms' Decisions on AS and PS

As Table 2 shows, profits are different in the four scenarios, but the profits have a similar structure in which they are comprised of two parts. The first part is independent of $\sigma_i^2,\ i = o,\ m$, (referred to as riskless profits), while the second part is a function of $\sigma_i^2,\ i = o,\ m$, (referred to as risk profits). We define the commitment value and the information value as follows.

Definition 1. Player *i*'s early commitment value (CV_i) is defined as the difference between the riskless profits of adopting AS and those of adopting PS if player *j* adopts PS; that is, $CV_o^N = \frac{2a^2b^4(1-b)^2(16-9b^2)}{(64-64b^2+15b^4)^2}$, and $CV_m^N = \frac{a^2b^2(1-b)^2}{4(2-b^2)(8-3b^2)}$.

Definition 2. Player *i*'s information value (IV_i) is defined as the difference between the risk profits of adopting PS and those of adopting AS if player *j* adopts either AS or PS; that is, $IV_i^N = \frac{1}{4}\sigma_i^2$ if player *j* adopts AS, and $IV_i^N = \frac{2(2-b^2)}{(4-b^2)^2}\sigma_i^2$ if player *j* adopts PS.

If a firm chooses AS to take advantage of early commitment, it faces operational risk, that is, over- or under-production due to choosing production quantity before market acceptance is realized. Alternately, if it chooses PS, it can postpone the quantity decision until market acceptance uncertainty is resolved to take advantage of information. The choice depends on the trade-off between the commitment value and the information value.

Based on Table 2, the OEM's and manufacturer's preferences over AS and PS can be deduced by comparing their profits. Table 3 shows the profit matrix of the OEM and the manufacturer.

Table 3. Profit Matrix of the OEM and the Manufacturer

OEM \ Manufacturer	AS	PS
AS	$\Pi_o^{N\_AA}, \Pi_m^{N\_AA}$	$\Pi_o^{N\_AP}, \Pi_m^{N\_AP}$
PS	$\Pi_o^{N\_PA}, \Pi_m^{N\_PA}$	$\Pi_o^{N\_PP}, \Pi_m^{N\_PP}$

With the definitions in the profit matrix, we derive the following results.

Lemma 3. For the OEM, there exists a threshold $\sigma_o^N = \frac{a^2b^4(1-b)^2(4-b^2)^2(16-9b^2)}{(2-b^2)(64-64b^2+15b^4)^2}$, such that

1. $\Pi_o^{N\_AA*} < \Pi_o^{N\_PA*}$; and
2. $\Pi_o^{N\_AP*} > \Pi_o^{N\_PP*}$ if and only if $\sigma_o^2 < \sigma_o^N$.

Lemma 3 shows that, if the manufacturer chooses AS, it is better for the OEM to choose PS than AS, because there is no early commitment value when they both choose AS and play a simultaneous game; while there is information value when the OEM chooses PS.

However, if the manufacturer indeed chooses PS, the OEM's preference over AS and PS depends on market acceptance uncertainty. When uncertainty is low, the OEM chooses AS because the early commitment value of AS dominates the information value of PS. In contrast, when uncertainty is high, the OEM chooses PS instead of AS. Although AS brings commitment value, it also puts the OEM in a position with high operational risk due to large uncertainty; that is, the information value from PS dominates the commitment value of AS. Lemma 1 indicates that, to make better production timing decisions, firms should evaluate the market acceptance of their products, and effects of early/delayed commitment. We find that the equilibrium outcomes of the manufacturer are similar to those of the OEM, which are captured in the following lemma.

Lemma 4. For the manufacturer, there exists a threshold $\sigma_m^N = \frac{a^2b^2(1-b)^2(4-b^2)^2}{8(2-b^2)^2(8-3b^2)}$, such that

1. $\Pi_m^{N\_AA*} < \Pi_m^{N\_AP*}$; and
2. $\Pi_m^{N\_PA*} > \Pi_m^{N\_PP*}$ if and only if $\sigma_m^2 < \sigma_m^N$.

Based on Lemmas 3 and 4, we derive a threshold b^* that uniquely solves $\sigma_o^N = \sigma_m^N$, and obtain firms' strategic decisions on production timing in Proposition 1.

Proposition 1. There exists a unique threshold b^*, where we have $\sigma_o^N < \sigma_m^N$ when $b \in (0, b^*)$, and $\sigma_o^N > \sigma_m^N$ when $b \in (b^*, 1)$.

I. $\sigma_o^N < \sigma_m^N$ if $0 < b < b^*$
   1. If $\sigma_o^2 < \sigma_o^N$ and $\sigma_m^2 < \sigma_m^N$, then (*A*, *P*) and (*P*, *A*) are the two NE;
   2. If $\sigma_o^2 < \sigma_o^N$ and $\sigma_m^2 > \sigma_m^N$, then (*A*, *P*) is the unique pure NE;
   3. If $\sigma_o^N < \sigma_o^2 < \sigma_m^N$ and $\sigma_m^2 < \sigma_m^N$, then (*P*, *A*) is the unique pure NE;
   4. If $\sigma_o^2 > \sigma_o^N$ and $\sigma_m^2 > \sigma_m^N$, then (*P*, *P*) is the unique pure NE.

II. $\sigma_o^N > \sigma_m^N$ if $b^* < b < 1$
   1. If $\sigma_o^2 < \sigma_m^N$ and $\sigma_m^2 < \sigma_m^N$, then (*A*, *P*) and (*P*, *A*) are the two NE;
   2. If $\sigma_o^2 < \sigma_m^N$ and $\sigma_m^2 > \sigma_m^N$, then (*A*, *P*) is the unique pure NE;
   3. If $\sigma_m^N < \sigma_o^2 < \sigma_o^N$, then (*A*, *P*) is the unique pure NE;
   4. If $\sigma_o^2 > \sigma_o^N$, then (*P*, *P*) is the unique pure NE.

Figure 3 illustrates firms' strategic choices in equilibrium on the two-dimensional $\sigma_o^2 - \sigma_m^2$ plane. The solid lines partition the upper left region of Figure 3a and b) into four (three) parts that correspond to four (three) outcomes in Proposition 1(I) (Proposition 1(II)).[4] It shows that the market acceptance uncertainty determines the outcome of competition between the OEM and the manufacturer. Intuitively, AS should be a dominant strategy for the firm with low uncertainty because the operational risk under AS is low and the information value from PS is small. Conversely, PS should be a dominant strategy for the firm with high uncertainty. Finally, we note that (*A*, *A*) is not an equilibrium because firms neither receive the commitment value nor the information value.

[4] Because , that is, the manufacturer's market acceptance uncertainty is larger than the OEM's, no equilibrium occurs in the lower right region.

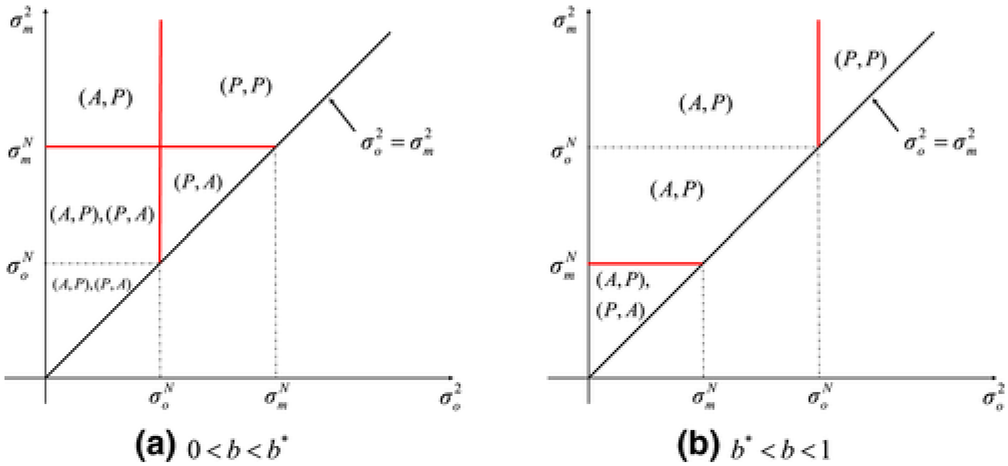

Figure 3 Firms' Production Timing in the Not-Following Case

When both firms face low uncertainty (with small σ_o^2 and σ_m^2), the equilibrium is that one firm chooses AS and the other chooses PS (The lower left region of Figure 3a and b). In this sequential game, they choose different strategies and obtain the early commitment value and information value, respectively. The different strategies result in less competition.

When both firms have high uncertainty (with large σ_o^2 and σ_m^2), a simultaneous game occurs in which both the OEM and the manufacturer choose PS, resulting in more intense competition (the upper right region of Figure 3a and b). This diminishes the information value. The underlying implication is that, a firm is suggested to choose PS when market uncertainty is large. This intuition can be widely applied, in spite of the supply chain structure (competition/co-opetition),[5] and in spite of the specification compliance (following/not following).[6] Evidence is that in the Indian smartphone market with large variability, Huawei launched its smartphone before Xiaomi and Vivo (Financial Times 2012, Forbes 2017). However, according to a recent report by Counterpoint, the latter two's strategic benefits from PS are more significant (Counterpoint 2018).

When the manufacturer's uncertainty is much larger than the OEM's, the equilibrium is that the OEM chooses AS to take advantage of the commitment value, and the manufacturer chooses PS to benefit from the information value (the upper left region of Figure 3a and b).

When market acceptance uncertainty of both firms is moderate, we find that the preferences over AS and PS of the OEM and the manufacturer are determined by the competition intensity (the lower right region of Figure 3a and the middle region of Figure 3b). The OEM chooses AS while the manufacturer chooses PS when the competition is sufficiently intense ($b^* < b < 1$), and the OEM chooses PS while the manufacturer chooses AS when the competition is not intense ($0 < b < b^*$). To explain this result, let us first examine how the information value changes with the competition intensity.

[5] Wang et al. () shows similar intuition in a setting without co-opetition.
[6] As we will show in section 5, this intuition holds when the manufacturer follows the CDD.

Figure 4 illustrates how the information value changes in the competition intensity. One can see that, the information value decreases in *b* and decreases significantly when *b* is large; that is, the information value is significantly reduced when competition is sufficiently intense.[7] Thus, the OEM chooses AS to preempt the initiative and to obtain the early commitment value. However, the manufacturer chooses PS. Although the information value of the manufacturer is also reduced by intense competition, larger uncertainty σ_m^2 makes it worthwhile to wait until uncertainty is resolved. Moreover, PS enables the manufacturer to benefit from the *spillover value* from the OEM's early commitment value. Note that the manufacturer's profits come from two channels: self-branded business by selling its own products and contract manufacturing business by producing for the OEM. By choosing PS, the manufacturer can mitigate the competition between the two firms. It also lowers the wholesale price to stimulate the OEM's order. Thus, the OEM will choose a larger order quantity, resulting in more profits for the manufacturer from his contract manufacturing business. The information value and the *spillover value* from the OEM's early commitment make it attractive for the manufacturer to choose PS. This finding explains the observations in Google's supply chain, e.g., HTC's late product launch in "full screen" phone design. However, Google's late launch might be a blunder (Forbes 2018).

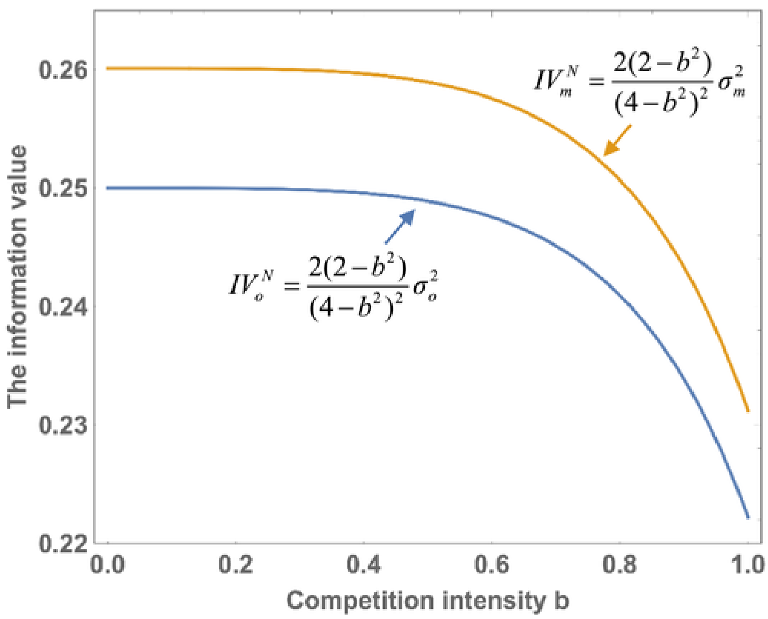

Figure 4 The Effect of *b* on Information Value ($\sigma_o^2 = 1,\ \sigma_m^2 = 1.02$)

Interestingly, in the case with moderate uncertainty and less intense competition (i.e., $0 < b < b^*$), we find that the OEM chooses PS even though OEM's uncertainty is moderate and its information value is not high. The reason is that, if the OEM chooses AS, its early commitment value is reduced by a significant cost increment paid to the manufacturer for the contract manufacturing service. The gain from information value, although not high, still dominates the commitment value; thus, the OEM chooses PS. In anticipation of the OEM's choice, the manufacturer chooses AS with low production quantity and high

[7] This intuition can be practical. For example, Mobile World Congress (MWC) is the world's largest exhibition, attracting many mobile device manufacturers to release their products. According to a most recent report by Gartner, however, these years Samsung and LG have launched new Android smartphones ahead of MWC (Gartner). Anshul Gupta, Research Director at Gartner, attributes this phenomenon to the "unabated competition" (Gartner), suggesting that waiting until the market becomes clear becomes less attractive as competition heats up.

price for its own product. We find that the positive effect of the increase in price compensates for the decrease in quantity, resulting in a higher profit in self-branded business for the manufacturer than when choosing PS. Further, the manufacturer determines a higher wholesale price, resulting in a higher profit in contract manufacturing business. Higher profits in both channels incentivize the manufacturer to choose AS. Figure 5 shows how the manufacturer’s commitment value changes in competition intensity.

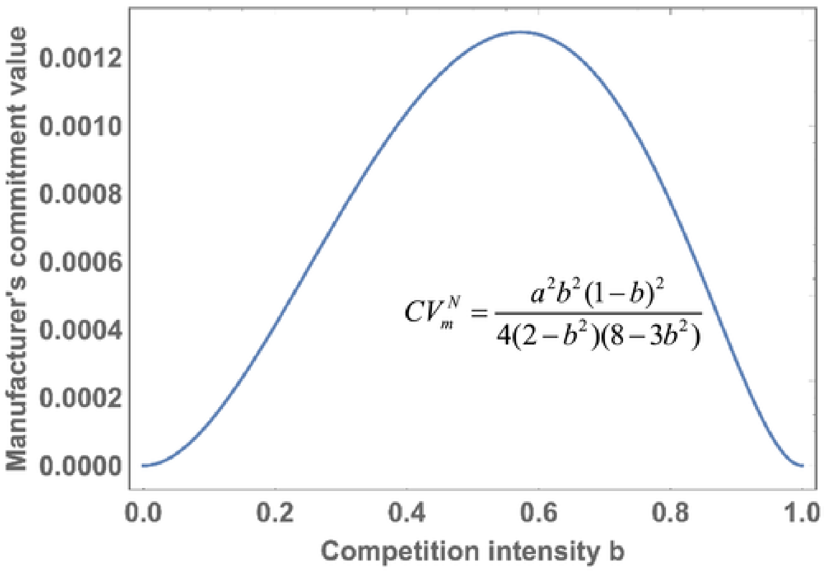

Figure 5 The Effect of *b* on the Manufacturer’s Commitment Value (*a* = 1)

5 Following the CDD (*F*)

Consider that the manufacturer follows the OEM’s CDD to conduct product design. In this case, there is no difference between the two firms’ market acceptance (i.e., they both have uncertainty ε_o). We derive firms’ equilibrium decisions on *w* and *q* in Stage 3 (see Table A1 in Appendix A), as well as their strategic choices between AS and PS in Stage 2. Firms’ commitment value and information value in this case are as follows: $CV_o^F = CV_o^N$, $CV_m^F = CV_m^N$, and $IV_i^F = \frac{1}{4}\sigma_o^2$ ($IV_i^F = \frac{1}{(2+b)^2}\sigma_o^2$, respectively) if firm *j* adopts AS (PS, respectively).

Similar to Lemma 1 and 1, we derive two thresholds $\sigma_o^F = \frac{2a^2b^4(2-b-b^2)^2(16-9b^2)}{(64-64b^2+15b^4)^2}$ and $\sigma_m^F = \frac{a^2b^2(1-b)^2(2+b)^2}{4(2-b^2)(8-3b^2)}$, and we have: (i) for the OEM, $\Pi_o^{F\_AP*} > \Pi_o^{F\_PP*}$ if and only if $\sigma_o^2 < \sigma_o^F$; and (ii) for the manufacturer, $\Pi_m^{F\_PA*} > \Pi_m^{F\_PP*}$ if and only if $\sigma_o^2 < \sigma_m^F$. We find that, however, if the manufacturer follows the CDD, firms’ strategic choices between AS and PS are fundamentally different from those in the case where the manufacturer does not follow the CDD, as shown in Figure 6. By comparing the equilibrium outcomes of these two cases, we derive a threshold b^* (b^{**}) that uniquely solves $\sigma_o^F = \sigma_m^F$ ($\sigma_o^F = \sigma_m^N$), based on which we obtain the following results.

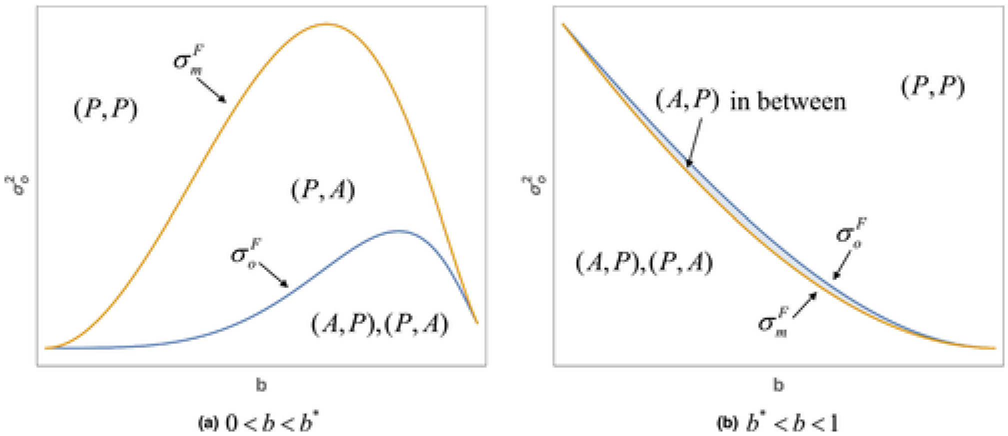

Figure 6 Firms' Production Timing in the Following Case

Proposition 2. (Impact of the Manufacturer Following the CDD)

1. $\sigma_o^N < \sigma_o^F$, $\sigma_m^N < \sigma_m^F$;
2. there exists a unique threshold b^{**} satisfying $0 < b^{**} < b^* < 1$ such that:
   i. $\sigma_o^N < \sigma_o^F < \sigma_m^N < \sigma_m^F$ when $0 < b < b^{**}$,
   ii. $\sigma_o^N < \sigma_m^N < \sigma_o^F < \sigma_m^F$ when $b^{**} < b < b^*$,
   iii. $\sigma_m^N < \sigma_o^N < \sigma_m^F < \sigma_o^F$ when $b^* < b < 1$,

Proposition 2 is derived by comparing the thresholds in the cases where the manufacturer follows and does not follow the CDD. We show that σ_o^F (σ_m^F) is always larger than σ_o^N (σ_m^N), which indicates that, following the CDD expands the region for the equilibrium in which one firm chooses AS and the other chooses PS, and shrinks the region in which both firms choose PS. Therefore, the manufacturer's following the CDD increases the possibility of a sequential equilibrium while it reduces that of a simultaneous equilibrium. This highlights that following the CDD contributes to the mitigation of supply chain competition.

6 Incentives of Following the CDD (Stage 1)

In this section, we compare the manufacturer's profits when following and not following the OEM's CDD and derive its decision in Stage 1. To do so, we first derive two lemmas that investigate the information value and the commitment value in different scenarios.

Recall that firm *i*'s information value, $IV_i^I,\ I \in \{N,\ F\}$, is a function of σ_i^2 (see Table 4). The information value IV_i^I can be written as $\varphi_i^{I\_\alpha}\sigma_i^2$, where $\varphi_i^{I\_\alpha}$ is the coefficient of the information value and *α* = *sim* for simultaneous games and *α* = *seq* for sequential games.

Table 4. Firm *i*'s Information Values

Case \ Firm *j*'s strategy	AS	PS
N	$IV_i^N = \frac{1}{4}\sigma_i^2$	$IV_i^N = \frac{2(2-b^2)}{(4-b^2)^2}\sigma_i^2$
F	$IV_i^F = \frac{1}{4}\sigma_o^2$	$IV_i^F = \frac{1}{(2+b)^2}\sigma_o^2$

Lemma 5. $\varphi_i^{N\_seq} = \varphi_i^{F\_seq} > \varphi_i^{N\_sim} > \varphi_i^{F\_sim}$, where $\varphi_i^{N\_seq} = \varphi_i^{F\_seq} = \frac{1}{4}$, $\varphi_i^{N\_sim} = \frac{2(2-b^2)}{(4-b^2)^2}$ and $\varphi_i^{F\_sim} = \frac{1}{(2+b)^2}$.

We have the following observations. First, the coefficient of information value in a sequential game is always larger than that in a simultaneous game (i.e., $\varphi_i^{I\_seq} > \varphi_i^{I\_sim}$). Thus, given σ_i^2, a firm's information value is larger in a sequential game than that in a simultaneous game. The explanation is that, the competition between the two firms is intensified when they choose PS simultaneously, which diminishes the value of PS. On the contrary, the competition is softened by strategic deviation from PS in a sequential game, and this results in larger information value. We name it as the *cooperation effect* on information value. Second, the coefficient of information value in a simultaneous game is smaller with CDD than that without (i.e., $\varphi_i^{N\_sim} > \varphi_i^{F\_sim}$). This indicates that the manufacturer following the CDD reduces the value of information, which is named as *transparency effect*. Note that the OEM and the manufacturer conduct product design independently. Therefore, if the manufacturer does not follow the CDD, they do not know each other's market acceptance, and have to make decisions based on expectations. However, if the manufacturer follows the CDD, market acceptance becomes common knowledge between the two firms. This change in information transparency results in the difference between the coefficients with and without the CDD. Further, the manufacturer following the CDD has another negative effect on information value, by directly reducing market acceptance uncertainty σ_i^2, which is named as *accuracy effect*. *Accuracy effect* has an impact on the manufacturer while *transparency effect* has an impact on both firms. For the convenience of reference, the three effects are summarized as follows.

1. *Cooperation effect*: given σ_i^2, a firm's information value is larger in a sequential game than that in a simultaneous game.
2. *Accuracy effect*: the negative effect of following the CDD on information value by directly reducing uncertainty σ_i^2.
3. *Transparency effect*: the negative effect of following the CDD on information value in a simultaneous game by reducing the coefficient of information value due to the change of information transparency.

We then present the lemma that characterizes the effect of competition intensity on the commitment value.

Lemma 6. The commitment value of the manufacturer is larger than that of the OEM if and only if $0 < b < b^{*}$.

Using these two lemmas, we can analyze how following the CDD affects the equilibrium. When the manufacturer follows the OEM's CDD, both *accuracy effect* and *transparency effect* reduce the two firms' information value (or the firms' operational risk), resulting in an intermediate state, where both firms have the same information values and make their AS/PS choices based on the trade-off between the commitment value and the information value. When $0 < b < b^{*}$, the commitment value of the manufacturer is larger than that of the OEM. Therefore, when the information value of the manufacturer reduces to a level lower than its commitment value, the information value of the OEM still dominates the commitment value. In this case, following the CDD changes the equilibrium from (*P*, *P*) to (*P*, *A*); that is, the manufacturer changes his decision to AS while the OEM remains on PS. When $b^{*} < b < 1$, following the CDD changes the equilibrium from (*P*, *P*) to (*A*, *P*); that is, the OEM changes his decision to AS while the manufacturer remains on PS. See Figure 7 for an illustration, which summarizes the most interesting results in the shadow region.[8] We analyze the results of Figure 7a and b in Proposition 1 and 7c in Proposition 1.

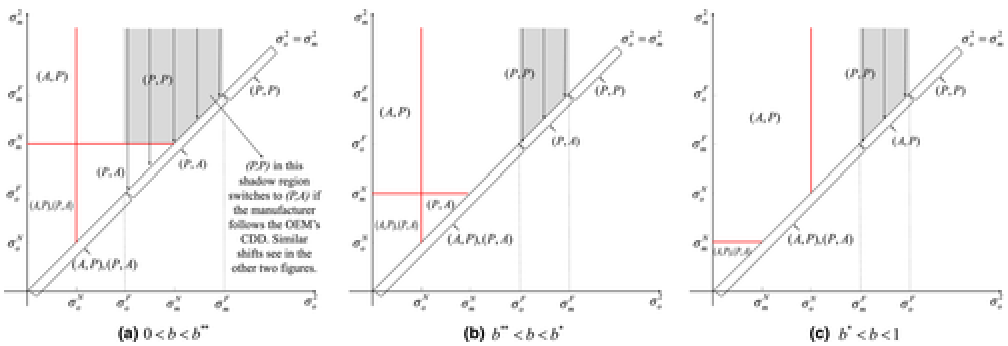

Figure 7 Equilibrium Changes if Following the CDD

Proposition 3. In the case where $0 < b < b^{**}$ ($b^{**} < b < b^{*}$, respectively), if $\sigma_o^F < \sigma_o^2 < \sigma_m^F$ and $\sigma_m^2 > \sigma_m^N$ ($\sigma_m^2 > \sigma_o^F$, respectively), the manufacturer following the CDD results in the outcome that the equilibrium moves from (*P*, *P*) to (*P*, *A*), that is, the OEM remains on PS while the manufacturer changes to AS. The expected profits of the OEM and the manufacturer have the following properties:

1. $\Pi_o^{F\_PA*} > \Pi_o^{N\_PP*}$, that is, the OEM is better off if the manufacturer follows the CDD;
2. $\Pi_m^{F\_PA*} < \Pi_m^{N\_PP*}$, that is, the manufacturer is worse off if it follows the CDD.

Proposition 3 indicates that, in the case where there is less competition, the OEM benefits from the manufacturer's following the CDD if the manufacturer faces high market acceptance uncertainty and the OEM's uncertainty is moderate. This will change a simultaneous equilibrium with direct competition on postponement strategy (i.e., PS) into a sequential equilibrium with deviation from PS. The mitigation of competition results in two positive effects on the OEM's profit. First, *cooperation effect* endows the OEM with a larger information value in a sequential game. Second, the OEM has a larger market share because it can determine a higher production quantity in the market with less competition.

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[8] If the manufacturer follows the OEM's CDD, we have $\sigma_o^2 = \sigma_m^2$. Then, the equilibrium lies on the line $\sigma_o^2 = \sigma_m^2$ as shown in Figure 7.

However, it is interesting that more accurate information hurts rather than benefits the manufacturer. By following the OEM's CDD, the manufacturer tries to reduce the operational risk of AS so that it can benefit from early commitment. However, this is not a wise decision. Note that the manufacturer has high market acceptance uncertainty if it does not follow the OEM's CDD to design products. Although following the CDD can reduce the manufacturer's uncertainty risk, it significantly reduces the information value from PS. Thus, the manufacturer suffers from following the CDD.

Proposition 4. In the case where $b^* < b < 1$, if $\sigma_m^F < \sigma_o^2 < \sigma_o^F$, the manufacturer following the CDD results in the outcome that the equilibrium moves from (*P*, *P*) to (*A*, *P*), that is, the OEM changes to AS while the manufacturer remains on PS. Let $B_L = \frac{a^2b^2(1-b)^2(2-b)^2(2+b)^2(96+32b-44b^2-20b^3-5b^4)}{32(2-b^2)^2(64-64b^2+15b^4)}$, and $B_H = \frac{a^2b^2(1-b)^2(2-b)^2(2+b)^2(256-192b^2+64b^3+40b^4-36b^5-9b^6)}{4(2-b^2)(64-64b^2+15b^4)^2}$, and then we have $B_L < B_H$ .The expected profits of the OEM and the manufacturer have the following properties:

1. $\Pi_o^{F\_AP*} < \Pi_o^{N\_PP*}$, that is, the OEM is worse off if the manufacturer follows the CDD;
2. $\Pi_m^{F\_AP*} > \Pi_m^{N\_PP*}$ if $\sigma_m^2 \leq B_L$, and $\Pi_m^{F\_AP*} < \Pi_m^{N\_PP*}$ if $\sigma_m^2 \geq B_H$, that is, the manufacturer is better off by following the OEM's CDD if σ_m^2 is small and it is worse off if σ_m^2 is large.

This proposition indicates that, given tense competition, when both the OEM and the manufacturer face high demand uncertainty, the OEM will be hurt by the manufacturer's following the CDD. Note that the OEM is more sensitive to the reduction of information value when $b^* < b < 1$ (see Lemma 1). *Transparency effect* reduces the OEM's information value to a level lower than the early commitment value, and thus the OEM changes to AS. However, the benefit of early commitment cannot offset the loss of information value and hence, the OEM is worse off. This provides managerial implications in practice. Taking a co-opetition relationship into consideration, it might not be good for Google to simply require the Android-based phone makers to follow the CDD, especially when competition is intense and Google's CDD does not fit consumer expectation well.

Note that, even if the manufacturer fails to change to AS by following the OEM's CDD, there may be benefits. Overall, following the CDD has both negative and positive effects on the manufacturer; that is, *accuracy effect* reduces the information value while *cooperation effect* increases the benefits from information in a sequential game. Conversely, remaining on PS endows the manufacturer with *spillover value* from the OEM's early commitment. It is worth noting that, when the manufacturer faces low uncertainty (i.e., with small σ_m^2), *accuracy effect* becomes insignificant, which is dominated by *cooperation effect* and *spillover value*. Therefore, the manufacturer is better off. However, the manufacturer is worse off with high uncertainty. A large σ_m^2 induces *accuracy effect* to be significant, which enlarges the loss of information value. In this case, following the CDD makes both the OEM and the manufacturer worse off, resulting in a *lose-lose* dilemma.

7 Extensions

In this section, we have four extensions: (i) revenue-sharing contract, (ii) the manufacturer's postponement of wholesale pricing, (iii) correlation of two firms' market acceptance uncertainty, and (iv) non-zero production cost. We use the following subscripts, *r*, *w*, *d*, and *c*, to represent the corresponding extensions, if necessary.

7.1 Revenue-Sharing Contract

We have assumed the manufacturer signs a wholesale price contract with the OEM, following previous literature on contract manufacturing. In practice, the manufacturer and the OEM are possible to sign a revenue-sharing contract with two parameters (w, ϕ) (Cachon 2003), where w is the wholesale price, and $\phi \in [0, 1]$ is the OEM's share of revenue. The manufacturer's share is $1 - \phi$. Following Cachon and Lariviere (2005), ϕ is exogenous. Firms' expected profits are, respectively,

$$\begin{aligned}\Pi_o &= E[\phi(a + \varepsilon_o - q_o - bq_m)q_o - wq_o],\\ \Pi_m &= E[(a + \varepsilon_m - q_m - bq_o)q_m\\ &\quad +(1-\phi)(a + \varepsilon_o - q_o - bq_m)q_o + wq_o].\end{aligned}$$

The following proposition shows how ϕ affects the equilibrium.

Proposition 5. For any given $\phi \in [0, 1]$, there exists a threshold $b_r(\phi) \in [0,\ 1]$, where $b_r(1) = 0$, such that: When $b \in (0,\ b_r(\phi))$, without (with) following the CDD, PS is the OEM's dominant strategy. In this case, (P, A) is the unique pure NE if $\sigma_m^2 < \sigma_{m,r}^N$ ($\sigma_o^2 < \sigma_{m,r}^F$), while ($P$, P) is the unique pure NE if $\sigma_m^2 > \sigma_{m,r}^N$ ($\sigma_o^2 > \sigma_{m,r}^F$).

When $\phi = 1$, the revenue sharing model is the same as the base model. In this case, $b_r(\phi) = 0$ and the equilibrium is exactly the same as shown in Propositions 1 and 2. When $\phi < 1$, the equilibrium has different structures for three regions of b: $(0,\ b_r(\phi))$, $[b_r(\phi),\ b^*(\phi))$, and $[b^*(\phi),\ 1)$. The equilibrium structures for $b \in [b_r(\phi),\ b^*(\phi))$ and $b \in [b^*(\phi),\ 1)$ are similar to those for $b \in (0,\ b^*)$ and $b \in [b^*,\ 1)$ in the base model. The equilibrium structure for $b \in (0,\ b_r(\phi))$ is specified in Proposition 1.

Proposition 5 shows that under a revenue-sharing contract, (A, P) cannot be an equilibrium in a less competitive market. This is because the manufacturer has an additional source of income from revenue-sharing, which encourages the manufacturer to lower the wholesale price and to attract a larger order size from the OEM. This incentive of the manufacturer is strong, especially when competition is mild (b is small). In this case, a larger production quantity of the OEM does not have much of a negative impact on the manufacturer's profit through competition, but has a positive impact on the manufacturer's profit through revenue sharing. Recall that in the base model, the manufacturer adopts a low-pricing strategy in the scenario (A, P) to spur the OEM to purchase more (see Lemma 1). Under the revenue-sharing contract, the further adoption of a low-pricing strategy in (A, P) with a small b is not necessary, because over-stimulation of the OEM's order (q_o) might cut down p_o hurting the shared revenue ($\phi p_o q_o$). Thus, the manufacturer raises w^{N_AP*} to make a balance between the profits from contract manufacturing and revenue sharing. This reduces the OEM's early commitment value in (A, P), and induces PS to be the OEM's dominant strategy.

7.2 Postponement of Wholesale Pricing

In our main body, we assumed that the wholesale price w is determined before uncertainty resolves, regardless of the OEM's timing decisions (*AS* or *PS*). In this subsection, we investigate a case in which the manufacturer postpones the wholesale price decisions until the market uncertainty is resolved if the OEM adopts the PS strategy to take advantage of the information value. There are two possible scenarios in this case: (P, A) and (P, P). In (P, A), the sequence of events is as follows: (i) the manufacturer determines q_m before demand is realized; (ii) after uncertainty is resolved, the manufacturer decides w and then the OEM determines q_o. Regarding (P, P), the sequence of events is the same as in the base model, except that the decision of w is postponed until demand realizes.

Our main results qualitatively hold, except that two slight differences arise. First, in the case where the manufacturer does not follow the CDD, when firms' uncertainty is moderate, (P, A) is an equilibrium $\forall b \in (0, 1)$. Recall that in the base model, as b increases, the equilibrium changes from (P, A) to (A, P). As b becomes larger, the OEM suffers from a higher wholesale price. In addition, the information value also decreases with b. Therefore, the OEM shifts from PS to AS. In response to this change, the manufacturer shifts from AS to PS to take advantage of the *spillover value* from the OEM's early commitment. However, in the case in which the wholesale price decisions are postponed, the OEM benefits from this postponement because it learns ε_m through *w* and uses it as additional information to determine q_o. This extra information compensates the OEM and hence, it remains to choose PS even if *b* is large.

Second, the impact of the manufacturer's following the CDD is slightly different when the competition intensity *b* is small. Recall that in Proposition 1, if the manufacturer follows the CDD, the equilibrium might change from (*P*, *P*) to (*P*, *A*). This change makes the manufacturer worse off and the OEM better off. However, if the wholesale price is determined after uncertainty is resolved, we can show that this change of equilibrium makes the manufacturer worse off only if σ_m^2 is sufficiently large, and it makes the OEM better off only if σ_o^2 is sufficiently small. This is because the manufacturer still has information benefits (from the postponement of wholesale pricing) even if it switches to AS, which compensates its loss of information value from PS. However, since the manufacturer decides the wholesale price after uncertainty is resolved, it has more pricing power than in the base model. The impact of this larger pricing power is greater when σ_o^2 is large. As a result, the OEM is better off only if σ_o^2 is sufficiently small.

7.3 Market Acceptance Uncertainty Correlation

In this subsection, we extend our base model by considering market acceptance uncertainty correlation: the manufacturer faces $\varepsilon_m = \varepsilon_o$ if he follows the CDD, and he sees $\varepsilon_m = \varepsilon_o + \delta$ if he does not follow the CDD. The random term δ is independent of ε_o, with zero mean and variance σ^2. Here, δ captures the extra uncertainty because of the non-compliance with the OEM's CDD. It is a measure of the degree of the manufacturer's non-compliance. A δ with a larger σ^2 represents a manufacturer with less compliance with the CDD. If the manufacturer does not follow the CDD, the mean and the variance of ε_m are as follows: $E[\varepsilon_m] = E[\varepsilon_o + \delta] = 0$, and $Var[\varepsilon_m] = Var[\varepsilon_o + \delta] = \sigma_o^2 + \sigma^2$. The correlation between ε_o and ε_m is as follows: $\rho = \frac{Cov[\varepsilon_o, \varepsilon_m]}{\sqrt{Var[\varepsilon_o]Var[\varepsilon_m]}} = \frac{\sigma_o}{\sqrt{\sigma_o^2 + \sigma^2}}$. When $\sigma^2 = 0$, that is, δ is 0, we have $\rho = 1$.

Our main results qualitatively hold, except that the manufacturer's following the CDD does not benefit itself any more. Recall that in Proposition 1, the manufacturer benefits from following the CDD if σ_m^2 is relatively small. However, if the manufacturer's uncertainty is correlated with the OEM's uncertainty, a small σ_m^2 indicates that σ^2 is small for a given σ_o^2 (note that $\sigma_m^2 = \sigma_o^2 + \sigma^2$), and thus the correlation $\rho = \frac{\sigma_o}{\sqrt{\sigma_o^2 + \sigma^2}}$ is large. Given the large correlation, the manufacturer already captures some benefit of following the CDD, and it does not see much benefit from actually following it.

7.4 Non-Zero Production Cost

If the manufacturer incurs a marginal production cost *c* with $c < a$, firms' expected profits are, respectively,

$$\begin{aligned}\Pi_o &= E[(a + \varepsilon_o - q_o - bq_m)q_o - wq_o],\\ \Pi_m &= E[(a + \varepsilon_m - q_m - bq_o - c)q_m + (w - c)q_o].\end{aligned}$$

By comparing the above two expressions with the expressions in 2 and 3 of the main body, one can see that the expressions of Π_o are the exactly the same, and the expressions of $\Pi_m$differ by a single term $c(q_m + q_o)$. Actually by simply replacing *a* with $a - c$, we can get the new equilibrium outcomes and threshold values (except *w*, which is a weighted average of *a*and *c*). As a result, the main results in the main body still hold with slightly different threshold values.

8 Conclusion

Technology specifications such as Android's CDD are often viewed as Google's important strategy to improve the user experience of Android devices, and they are closely linked with production timing decisions due to the market acceptance uncertainty. In this study, we develop a model to study the production timing decisions in a co-opetitive supply chain, which comprises an OEM (e.g., Google in our motivating example) and a competitive manufacturer, which acts both as the OEM's upstream partner and downstream competitor. The two firms sell partially substitutable products in a market with market acceptance uncertainty, which can be resolved after a certain time spot. As the CDD is based on mainstream preference, the OEM has lower uncertainty, resulting in more stable demand. They can choose either AS or PS, depending on the relative magnitude of the commitment value and the information value.

We find that, both market acceptance uncertainty and competition intensity have a significant impact on firms' strategic choices between AS and PS. Both firms choose PS when they are at the risk of high uncertainty, while only one firm chooses PS when the uncertainty is low/moderate. This implies that, market acceptance uncertainty determines the nature of competition and cooperation between the OEM and the manufacturer. A simultaneous equilibrium occurs when both firms face high uncertainty and a sequential equilibrium occurs otherwise. When market acceptance uncertainty of the two firms varies in a moderate range, their strategic choices between AS and PS are affected by competition intensity in an interesting way. When competition is fierce, intuitively both firms have strong incentives to choose AS. However, we find that the OEM chooses AS but the manufacturer chooses PS in spite of his low information value. In this way, it can benefit from the OEM's early commitment, which is named as *spillover value* because of the co-opetition relationships between the two firms. When competition is not very intense, a completely different outcome occurs. By intuition, the OEM is likely to choose AS because of low uncertainty and, thus, low operational risk. However, the OEM chooses PS, because choosing AS incurs a significant cost increment for production outsourcing. The manufacturer chooses AS because of high wholesale price and self-branded price, resulting in better performances in both manufacturing business and self-branded business.

We further investigate the impact of following the CDD on firms' choices between AS and PS. We show that information value is influenced by three effects including *cooperation effect*, *accuracy effect* and *transparency effect*, the scales of which are respectively modulated by strategic deviation from PS, signal accuracy and information transparency. These effects change the trade-off between the commitment value and the information value, and correspondingly determine the profit performance of the two firms. They also influence the manufacturer's incentives of following the OEM's CDD. Based on the analysis, we identify the conditions under which following the CDD benefits the manufacturer.

These findings provide the following managerial implications to operation managers, especially those in Google, HTC, and LG. Note that they have co-opetition relationships bilaterally but HTC (LG) chose PS (AS) strategy when "full screen" phone design was launched. Specifically, we suggest that

1. the competitive manufacturer chooses PS when market uncertainty is large. Our suggestion can be consistent with practice because we observe that, in the Indian smartphone market with large variability, the followers gain prominent benefits from PS.
2. the competitive manufacturer implements AS in a market with small variability and intense competition, because the information benefits from PS are limited. This result is consistent with the observation that these years LG has launched new Android smartphones ahead of MWC due to the "unabated competition".
3. in a market with moderate uncertainty and intense competition, the OEM is better to choose AS while the manufacturer chooses PS. This finding explains HTC's late product launch in "full screen" phone design. However, we find that Google's late launch practice might be a blunder.

4. the OEM might either benefit from or be hurt by the manufacturer's following the CDD, depending on competition intensity. In reality, as competition intensifies, Google has been witnessed to take an increasingly strict control over specifications on Android phone designs. Google might gain, if competition is not that intense, from such tightening which ensures the user experience on Android phones. However, Google has to be cautious if competition continues to intensify, because it might be exposed to the threat from its rivals.

Regarding the future research directions, we recommend to study newsvendor models under push (ordering before demand realization) and pull (ordering after demand realization) contracts, although the analysis can be challenging. In practice, it is also possible that firms only obtain an updated signal of the market rather than the full information. However, that requires new models based on Bayesian updating, and hence, is beyond the scope of our study.

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Appendix A

In this Appendix, we provide the derivation of Table 2 with regard to how to solve the four subgames for the case in which the manufacturer does not follow the CDD. Proofs for results in the main body and extensions are available in the online Appendices.

A.1. Derivation of Table 2

(*A*, *A*) Simultaneous Game: Given wholesale price *w*, the OEM and the manufacturer maximize their expected profits by, respectively,

$$\begin{aligned}\Pi_o(q_o, q_m, w) &= (a + E[\varepsilon_o] - q_o - bE[q_m])q_o - wq_o,\\ \Pi_m(q_o, q_m, w) &= (a + E[\varepsilon_m] - q_m - bE[q_o])q_m + wE[q_o].\end{aligned}$$

Then we have the best responses $q_o(q_m,\ w) = \frac{a - bq_m - w}{2}$ and $q_m(q_o) = \frac{a - bq_o}{2}$, resulting in the quantities $q_o(w) = \frac{(2-b)a - 2w}{4-b^2}$ and $q_m(w) = \frac{(2-b)a + bw}{4-b^2}$. The manufacturer maximizes his expected profit by setting the wholesale price as $w = \frac{(8-4b^2+b^3)a}{2(8-3b^2)}$. The equilibrium outcomes are as follows: $w^{N\_AA*} = \frac{(8-4b^2+b^3)a}{2(8-3b^2)}$, $q_o^{N\_AA*} = \frac{2(1-b)a}{8-3b^2}$, $q_m^{N\_AA*} = \frac{(2-b)(4+b)a}{2(8-3b^2)}$, $\Pi_o^{N\_AA*} = \frac{4(1-b)^2a^2}{(8-3b^2)^2}$, $\Pi_m^{N\_AA*} = \frac{(2-b)(6-b)a^2}{4(8-3b^2)}$.

(*P*, *P*) Simultaneous Game: Note that, market acceptance is uncertain at time 0 while the uncertainty is resolved at time 1. Thus, a firm maximizes its expected profit if choosing AS while it solves a deterministic problem if choosing PS. Given the wholesale price *w* and the market acceptance condition ε_i, the OEM and the manufacturer maximize their expected profits by, respectively

$$\begin{aligned}\Pi_o(q_o, q_m, w, \varepsilon_o) &= (a + \varepsilon_o - q_o - bE[q_m])q_o - wq_o,\\ \Pi_m(q_o, q_m, w, \varepsilon_m) &= (a + \varepsilon_m - q_m - bE[q_o])q_m + wE[q_o].\end{aligned}$$

Then the best responses are $q_o(q_m, w, \varepsilon_o) = \frac{a+\varepsilon_o - bE[q_m] - w}{2}$ and $q_m(q_o, \varepsilon_m) = \frac{a+\varepsilon_m - bE[q_o]}{2}$, resulting in the quantities $q_o(w, \varepsilon_o) = \frac{(2-b)a - 2w + 2\varepsilon_o}{4-b^2}$ and $q_m(w, \varepsilon_m) = \frac{(2-b)a + bw + 2\varepsilon_m}{4-b^2}$. Anticipating the quantities above, the manufacturer maximizes the expected profit by setting wholesale price as $w = \frac{(8-4b^2+b^3)a}{2(8-3b^2)}$. The equilibrium outcomes are: $w^{N\_PP*} = \frac{(8-4b^2+b^3)a}{2(8-3b^2)}$, $q_o^{N\_PP*} = \frac{2(1-b)a}{8-3b^2}$, $q_m^{N\_PP*} = \frac{(2-b)(4+b)a}{2(8-3b^2)}$, $\Pi_o^{N\_PP*} = \frac{4(1-b)^2a^2}{(8-3b^2)^2} + \frac{2(2-b^2)}{(4-b^2)^2}\sigma_o^2$, $\Pi_m^{N\_PP*} = \frac{(2-b)(6-b)a^2}{4(8-3b^2)} + \frac{2(2-b^2)}{(4-b^2)^2}\sigma_m^2$.

(*A*, *P*) Sequential Game: This scenario begins with the event that the manufacturer sets the wholesale price. Then we have a Stackelberg setting where the OEM decides quantity q_o at time 0, and the manufacturer makes the quantity decision at time 1 after observing q_o and the market acceptance condition ε_m. At time 1, given q_o and ε_m, the manufacturer maximizes the profit by solving a deterministic problem:

$$\Pi_m(q_o, q_m, w, \varepsilon_m) = (a + \varepsilon_m - q_m - bq_o)q_m + wq_o,$$

and produces $q_m(q_o, \varepsilon_m) = \frac{a+\varepsilon_m - bq_o}{2}$. Anticipating the response of the manufacturer, the OEM makes a quantity decision to maximize the expected profit by

$$\Pi_o(q_o, w) = (a + E[\varepsilon_o] - q_o - bE[q_m(q_o, \varepsilon_m)])q_o - wq_o.$$

It can be verified that the OEM's quantity is $q_o(w) = \frac{(2-b)a - 2w}{2(2-b^2)}$. Then the manufacturer's quantity is $q_m(w, \varepsilon_m) = \frac{(4-2b-b^2)a + 2bw + (4-2b^2)\varepsilon_m}{4(2-b^2)}$. According to the quantities, the manufacturer maximizes the expected profit

$$\Pi_m(w) = E[(a + \varepsilon_m - q_m(w, \varepsilon_m) - bq_o(w))q_m(w, \varepsilon_m) + wq_o(w)],$$

by setting the wholesale price as $w = \frac{(8-6b^2+b^3)a}{2(8-5b^2)}$. The equilibrium outcomes are: $w^{N\_AP*} = \frac{(8-6b^2+b^3)a}{2(8-5b^2)}$, $q_o^{N\_AP*} = \frac{2(1-b)a}{8-5b^2}$, $q_m^{N\_AP*} = \frac{(8-2b-3b^2)a}{2(8-5b^2)}$, $\Pi_o^{N\_AP*} = \frac{2(1-b)^2(2-b^2)a^2}{(8-5b^2)^2}$, $\Pi_m^{N\_AP*} = \frac{(12-8b-b^2)a^2}{4(8-5b^2)} + \frac{1}{4}\sigma_m^2$.

(*P*, *A*) Sequential Game: In this scenario, the manufacturer first sets the wholesale price and then decides the quantity level q_m at time 0. After observing q_m and the market acceptance condition ε_o, the OEM makes a quantity decision at time 1. Given q_m and ε_o, the OEM maximizes the profit by solving a deterministic problem

$$\Pi_o(q_o, q_m, w, \varepsilon_o) = (a + \varepsilon_o - q_o - bq_m)q_o - wq_o.$$

The best response is $q_o(q_o, w, \varepsilon_o) = \frac{a+\varepsilon_o - bq_m - w}{2}$. In anticipation of the response above, the manufacturer makes a quantity decision to maximize the expected profit by

$$\Pi_m(q_m, w) = (a + E[\varepsilon_m] - q_m - bE[q_o(q_m, w, \varepsilon_o)])q_m + wE[q_o(q_m, w, \varepsilon_o)].$$

The manufacturer's quantity can be derived as $q_m = \frac{(2-b)a}{2(2-b^2)}$, and that of the OEM is $q_o(w, \varepsilon_o) = \frac{(4-2b-b^2)a - 2(2-b^2)(w-\varepsilon_o)}{4(2-b^2)}$. Conjecturing on the quantities, the manufacturer sets the wholesale price to maximize the expected profit by

$$\Pi_m(w) = E[(a + \varepsilon_m - q_m - bq_o(w, \varepsilon_o))q_m + wq_o(w, \varepsilon_o)].$$

The wholesale price is $w = \frac{a}{2}$. We have the equilibrium outcomes as follows: $w^{N\_PA*} = \frac{a}{2}$, $q_o^{N\_PA*} = \frac{(1-b)a}{2(2-b^2)}$, $q_m^{N\_PA*} = \frac{(2-b)a}{2(2-b^2)}$, $\Pi_o^{N\_PA*} = \frac{(1-b)^2a^2}{4(2-b^2)^2} + \frac{1}{4}\sigma_o^2$, $\Pi_m^{N\_PA*} = \frac{(3-2b)a^2}{4(2-b^2)}$.

Table A1. Equilibrium Outcomes of the Case with Following the CDD

	Scenario (*A*, *A*)	Scenario (*P*, *P*)	Scenario (*A*, *P*)	Scenario (*P*, *A*)
$w^{F\_\alpha*}$	$\frac{(8-4b^2+b^3)a}{2(8-3b^2)}$	$\frac{(8-4b^2+b^3)a}{2(8-3b^2)}$	$\frac{(8-6b^2+b^3)a}{2(8-5b^2)}$	$\frac{a}{2}$
$q_o^{F\_\alpha*}$	$\frac{2(1-b)a}{8-3b^2}$	$\frac{2(1-b)a}{8-3b^2}$	$\frac{2(1-b)a}{8-5b^2}$	$\frac{(1-b)a}{2(2-b^2)}$
$q_m^{F\_\alpha*}$	$\frac{(2-b)(4+b)a}{2(8-3b^2)}$	$\frac{(2-b)(4+b)a}{2(8-3b^2)}$	$\frac{(8-2b-3b^2)a}{2(8-5b^2)}$	$\frac{(2-b)a}{2(2-b^2)}$
$\Pi_o^{F\_\alpha*}$	$\frac{4(1-b)^2a^2}{(8-3b^2)^2}$	$\frac{4(1-b)^2a^2}{(8-3b^2)^2} + \frac{1}{(b+2)^2}\sigma_o^2$	$\frac{2(1-b)^2(2-b^2)a^2}{(8-5b^2)^2}$	$\frac{(1-b)^2a^2}{4(2-b^2)^2} + \frac{1}{4}\sigma_o^2$
$\Pi_m^{F\_\alpha*}$	$\frac{(2-b)(6-b)a^2}{4(8-3b^2)}$	$\frac{(2-b)(6-b)a^2}{4(8-3b^2)} + \frac{1}{(b+2)^2}\sigma_o^2$	$\frac{(12-8b-b^2)a^2}{4(8-5b^2)} + \frac{1}{4}\sigma_o^2$	$\frac{(3-2b)a^2}{4(2-b^2)}$

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A. Proofs

Proof of Lemma 1.

Lemma 1 can be easily derived by comparing the difference of $w^{N\_\alpha*}$, $q_o^{N\_\alpha*}$, and $q_m^{N\_\alpha*}$, $\alpha \in \{AA, PP, AP, PA\}$, respectively. We omit the proof here.

Proof of Lemma 2.

Here we prove the monotonicity of $q_m^{N\_AA*}$ regarding b. Proofs of the others are similar. The first derivative of $q_m^{N\_AA*}$ with respect to b is $\frac{\partial q_m^{N\_AA*}}{\partial b} = \frac{a(-8+16b-3b^2)}{(8-3b^2)^2}$. By solving the equation $\frac{\partial q_m^{N\_AA*}}{\partial b} = 0$, we have an extreme point $b = \frac{2(4-\sqrt{10})}{3} \in (0,1)$. The second derivative of $q_m^{N\_AA*}$ with respect to b, which is evaluated at $b = \frac{2(4-\sqrt{10})}{3}$, is $\frac{\partial^2 q_m^{N\_AA*}}{\partial b^2}\Big|_{b=\frac{2(4-\sqrt{10})}{3}} = -\frac{45(-4+\sqrt{10})a}{64(-5+2\sqrt{10})^3} > 0$. So $b = \frac{2(4-\sqrt{10})}{3}$ is a minimum point. Therefore, $q_m^{N\_AA*}$ is decreasing in b when $b \in (0, \frac{2(4-\sqrt{10})}{3})$, and is increasing in b when $b \in (\frac{2(4-\sqrt{10})}{3}, 1)$.

Proof of Lemma 3.

(1) $\Pi_o^{N\_AA*} - \Pi_o^{N\_PA*} = \frac{4(1-b)^2a^2}{(8-3b^2)^2} - \left[\frac{(1-b)^2a^2}{(4(2-b^2)^2} + \frac{1}{4}\sigma_o^2\right] = \frac{a^2(-1+b)^2b^2(-16+7b^2)-(16-14b^2+3b^4)^2\sigma_o^2}{4(8-3b^2)^2(-2+b^2)^2} < 0.$

(2) $$\Pi_o^{N\_AP*} - \Pi_o^{N\_PP*} = \frac{2(1-b)^2(2-b^2)a^2}{(8-5b^2)^2} - \left[\frac{4(1-b)^2a^2}{(8-3b^2)^2} + \frac{2(2-b^2)}{(4-b^2)^2}\sigma_o^2\right] = \frac{2\left[a^2b^4(-16+9b^2)(4-4b-b^2+b^3)^2+(2-b^2)(64-64b^2+15b^4)^2\sigma_o^2\right]}{(-2+b)^2(2+b)^2(8-5b^2)^2(8-3b^2)^2}.$$

By solving the equation $\Pi_o^{N\_AP*} - \Pi_o^{N\_PP*} = 0$, we have $\sigma_o^N = \frac{a^2b^4(1-b)^2(4-b^2)^2(16-9b^2)}{(2-b^2)(64-64b^2+15b^4)^2}$. If $\sigma_o^2 < \sigma_o^N$, then $\Pi_o^{N\_AP*} > \Pi_o^{N\_PP*}$; if $\sigma_o^2 > \sigma_o^N$, then $\Pi_o^{N\_AP*} < \Pi_o^{N\_PP*}$.

Proof of Lemma 4 is similar to that of lemma 3. In lemma 4 we have $\sigma_m^N = \frac{a^2b^2(1-b)^2(4-b^2)^2}{8(2-b^2)^2(8-3b^2)}$.

Proof of Proposition 1.

(A, A) cannot be an equilibrium because $\Pi_o^{N\_AA*} < \Pi_o^{N\_PA*}$ and $\Pi_m^{N\_AA*} < \Pi_m^{N\_AP*}$.

(A, P) is an equilibrium if it satisfies $\Pi_o^{N\_AP*} > \Pi_o^{N\_PP*}$ and $\Pi_m^{N\_AP*} > \Pi_m^{N\_AA*}$, i.e., $\sigma_o^2 < \sigma_o^N$.

(P, A) is an equilibrium if it satisfies $\Pi_o^{N\_PA*} > \Pi_o^{N\_AA*}$ and $\Pi_m^{N\_PA*} > \Pi_m^{N\_PP*}$, i.e., $\sigma_m^2 < \sigma_m^N$.

(P, P) is an equilibrium if it satisfies $\Pi_o^{N\_PP*} > \Pi_o^{N\_AP*}$ and $\Pi_m^{N\_PP*} > \Pi_m^{N\_PA*}$, i.e., $\sigma_o^2 > \sigma_o^N$

and $\sigma_m^2 > \sigma_m^N$. So we preliminarily obtain the following equilibrium conditions

$$\begin{cases} (A, P), & \text{if } \sigma_o^2 < \sigma_o^N \\ (P, A), & \text{if } \sigma_m^2 < \sigma_m^N \\ (P, P), & \text{if } \sigma_o^2 > \sigma_o^N \text{ and } \sigma_m^2 > \sigma_m^N \end{cases}$$

The equilibrium conditions for further derivation depend on the relative sizes of σ_o^N and σ_m^N: $\sigma_o^N - \sigma_m^N = \frac{a^2(-2+b)^2(-1+b)^2b^2(2+b)^2(-512+1088b^2-712b^4+147b^6)}{8(8-5b^2)^2(8-3b^2)^2(-2+b^2)^2}$. By solving the equation $\sigma_o^N - \sigma_m^N = 0$, we have a unique threshold $b^* = 0.9565$. If $0 < b < b^*$, then $\sigma_o^N < \sigma_m^N$; if $b^* < b < 1$, then $\sigma_o^N > \sigma_m^N$. Consider case I where $0 < b < b^*, \sigma_o^N < \sigma_m^N$. We have

(1) when $\sigma_o^2 < \sigma_o^N$,
 if $\sigma_m^2 < \sigma_o^N$, then (A, P) and (P, A) are the two NE;
 if $\sigma_o^N < \sigma_m^2 < \sigma_m^N$, then (A, P) and (P, A) are the two NE;
 if $\sigma_m^2 > \sigma_m^N$, then (A, P) is the unique pure NE.

(2) when $\sigma_o^N < \sigma_o^2 < \sigma_m^N$,
 if $\sigma_m^2 < \sigma_m^N$, then (P, A) is the unique pure NE;
 if $\sigma_m^2 > \sigma_m^N$, then (P, P) is the unique pure NE.

(3) when $\sigma_o^2 > \sigma_m^N$,
 if $\sigma_m^2 > \sigma_m^N$, then (P, P) is the unique pure NE.

Then we arrive at the results as follows:

(1) If $\sigma_o^2 < \sigma_o^N$ and $\sigma_m^2 < \sigma_m^N$, then (A, P) and (P, A) are the two NE;

(2) If $\sigma_o^2 < \sigma_o^N$ and $\sigma_m^2 > \sigma_m^N$, then (A, P) is the unique pure NE;

(3) If $\sigma_o^N < \sigma_o^2 < \sigma_m^N$ and $\sigma_m^2 < \sigma_m^N$, then (P, A) is the unique pure NE;

(4) If $\sigma_o^2 > \sigma_o^N$ and $\sigma_m^2 > \sigma_m^N$, then (P, P) is the unique pure NE.

Proof of case II where $b^* < b < 1, \sigma_o^N > \sigma_m^N$ is similar to that of case I.

Proof of Proposition 2.

Before we give the proof of Proposition 2, we first derive the equilibrium outcomes of the case where the manufacturer follows the OEM's CDD. Similar to the case without following the CDD, we study four basic games and draw the equilibrium outcomes listed in Table 5.

Comparing the equilibrium outcomes in Table 5 with those in Table 2, we find that the manufacturer's following the CDD has no effect on the equilibrium wholesale prices and quantities, but makes a difference in the equilibrium profits. For convenience of explanation, we adopt a unified expression format of the equilibrium wholesale prices (quantities) in the case with and without following the CDD as follows:

$$w^{\alpha *} = w^{N\_\alpha *} = w^{F\_\alpha *}, q_i^{\alpha *} = q_i^{N\_\alpha *} = q_i^{F\_\alpha *}.$$

The OEM and the manufacturer make their AS/PS choices by comparing the profits in profit matrix. With an analysis on the matrix, we draw the following results. For the OEM, there exists a threshold $\sigma_o^F = \frac{2a^2b^4(-2+b+b^2)^2(16-9b^2)}{(64-64b^2+15b^4)^2}$, where (1) $\Pi_o^{F\_AA*} < \Pi_o^{F\_PA*}$, and (2) $\Pi_o^{F\_AP*} > \Pi_o^{F\_PP*}$ if and only if $\sigma_o^2 < \sigma_o^F$. For the manufacturer, there exists a threshold $\sigma_m^F = \frac{a^2b^2(-1+b)^2(2+b)^2}{4(-2+b^2)(-8+3b^2)}$, where (1) $\Pi_m^{F\_AA*} < \Pi_m^{F\_AP*}$, and (2) $\Pi_m^{F\_PA*} > \Pi_m^{F\_PP*}$ if and only if $\sigma_o^2 < \sigma_m^F$. The format of the results is similar to that of Lemma 3 and 4. The detailed explanation is ignored here for its robustness regardless whether the manufacturer follows the OEM's CDD or not.

The equilibrium outcomes of the extended timing game in the case with following the CDD can be derived and summarized as follows. Similar to the proofs of Proposition 1, one can easily derive that there exists a unique threshold b^*, where we have $\sigma_o^F < \sigma_m^F$ when $b \in (0, b^*)$, and $\sigma_o^F > \sigma_m^F$ when $b \in (b^*, 1)$. Then,

I. $0 < b < b^*, \sigma_o^F < \sigma_m^F$

(1) If $\sigma_o^2 < \sigma_o^F$ then (A, P) and (P, A) are the two NE;

(2) If $\sigma_o^F < \sigma_o^2 < \sigma_m^F$ then (P, A) is the unique pure NE;

(3) If $\sigma_o^2 > \sigma_m^F$, then (P, P) is the unique pure NE.

II. $b^* < b < 1, \sigma_o^F > \sigma_m^F$

(1) If $\sigma_o^2 < \sigma_m^F$ then (A, P) and (P, A) are the two NE;

(2) If $\sigma_m^F < \sigma_o^2 < \sigma_o^F$ then (A, P) is the unique pure NE;

(4) If $\sigma_o^2 > \sigma_o^F$, then (P, P) is the unique pure NE.

One can see the equilibrium structure is similar as in Proposition 1. Detailed explanation is ignored here. With the results above, we prove Proposition 2 as follows.

(1) $\sigma_o^N - \sigma_o^F = \frac{a^2b^4(-16+9b^2)(4-4b-b^2+b^3)^2}{(-2+b^2)(64-64b^2+15b^4)^2} - \frac{2a^2b^4(-2+b+b^2)^2(16-9b^2)}{(64-64b^2+15b^4)^2} = \frac{a^2b^5(4+3b)(4-3b)^2(-2+b+b^2)^2}{(-2+b^2)(64-64b^2+15b^4)^2} < 0$,
$\sigma_m^N - \sigma_o^F = \frac{a^2b^2(4-4b-b^2+b^3)^2}{8(-2+b^2)^2(8-3b^2)} - \frac{a^2b^2(-1+b)^2(2+b)^2}{4(-2+b^2)(-8+3b^2)} = \frac{a^2b^3(4-3b)(-2+b+b^2)^2}{8(2-b^2)^2(-8+3b^2)} < 0$.
(2) $\sigma_m^N - \sigma_o^F = \frac{a^2b^2(4-4b-b^2+b^3)^2}{8(-2+b^2)^2(8-3b^2)} - \frac{2a^2b^4(-2+b+b^2)^2(16-9b^2)}{(64-64b^2+15b^4)^2}$. By solving the equation $\sigma_m^N - \sigma_o^F = 0$, we have a unique threshold $b^{**} = 0.808675$, where $\sigma_m^N > \sigma_o^F$ when $0 < b < b^{**}$, and $\sigma_m^N < \sigma_o^F$ when $b^{**} < b < 1$. In addition, $\sigma_o^N - \sigma_m^F = \frac{a^2b^4(-16+9b^2)(4-4b-b^2+b^3)^2}{(-2+b^2)(64-64b^2+15b^4)^2} - \frac{a^2b^2(-1+b)^2(2+b)^2}{4(-2+b^2)(-8+3b^2)} = \frac{a^2b^2(1-b)^2(2+b)^2(-512+1088b^2-256b^3-520b^4+144b^5+39b^6)}{4(2-b^2)(8-3b^2)^2(8-5b^2)^2} < 0$. Combining the above comparison, we arrive at the following results:

i) $\sigma_o^N < \sigma_o^F < \sigma_m^N < \sigma_m^F$ when $0 < b < b^{**}$,

ii) $\sigma_o^N < \sigma_m^N < \sigma_o^F < \sigma_m^F$ when $b^{**} < b < b^*$,

iii) $\sigma_m^N < \sigma_o^N < \sigma_m^F < \sigma_o^F$ when $b^* < b < 1$.

Proof of Table 6 and Table 7.

Table 6: Changes of Equilibria in the Case where $0 < b < b^*$

$\sigma_o^N < \sigma_o^F < \sigma_m^N < \sigma_m^F$ when $0 < b < b^{**}$		
Equilibrium without following the CDD	Condition of equilibrium without following the CDD	Equilibrium with following the CDD
$\{(A,P),(P,A)\}$	$\sigma_o^2 < \sigma_o^N$ and $\sigma_m^2 < \sigma_m^N$	$\{(A,P),(P,A)\}$
(A,P)	$\sigma_o^2 < \sigma_o^N$ and $\sigma_m^2 > \sigma_m^N$	$\{(A,P),(P,A)\}$
(P,A)	$\sigma_o^N < \sigma_o^2 < \sigma_o^F$ and $\sigma_m^2 < \sigma_m^N$	$\{(A,P),(P,A)\}$
	$\sigma_o^F < \sigma_o^2 < \sigma_m^N$ and $\sigma_m^2 < \sigma_m^N$	(P,A)
(P,P)	$\sigma_o^N < \sigma_o^2 < \sigma_o^F$ and $\sigma_m^2 > \sigma_m^N$	$\{(A,P),(P,A)\}$
	$\sigma_o^F < \sigma_o^2 < \sigma_m^F$ and $\sigma_m^2 > \sigma_m^N$	(P,A)
	$\sigma_o^2 > \sigma_m^F$	(P,P)
$\sigma_o^N < \sigma_m^N < \sigma_o^F < \sigma_m^F$ when $b^{**} < b < b^*$		
$\{(A,P),(P,A)\}$	$\sigma_o^2 < \sigma_o^N$ and $\sigma_m^2 < \sigma_m^N$	$\{(A,P),(P,A)\}$
(A,P)	$\sigma_o^2 < \sigma_o^N$ and $\sigma_m^2 > \sigma_m^N$	$\{(A,P),(P,A)\}$
(P,A)	$\sigma_o^N < \sigma_o^2 < \sigma_m^N$ and $\sigma_m^2 < \sigma_m^N$	$\{(A,P),(P,A)\}$
(P,P)	$\sigma_o^N < \sigma_o^2 < \sigma_o^F$ and $\sigma_m^2 > \sigma_m^N$	$\{(A,P),(P,A)\}$
	$\sigma_o^F < \sigma_o^2 < \sigma_m^F$	(P,A)
	$\sigma_o^2 > \sigma_m^F$	(P,P)

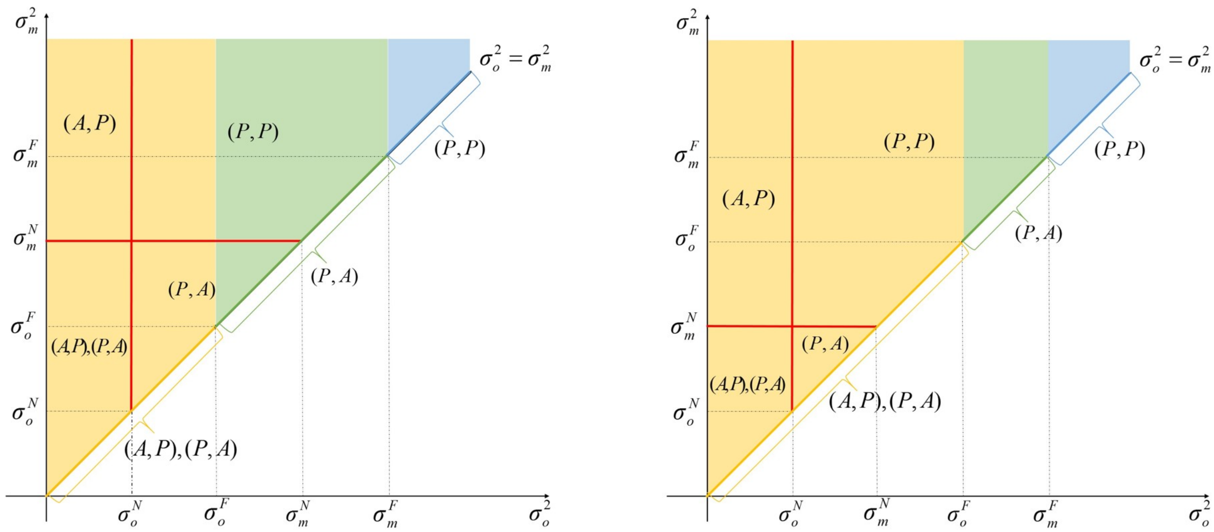
Table 6 states the changes of equilibria in the case where $0 < b < b^*$, including two subcases where $0 < b < b^{**}$ and $b^{**} < b < b^*$. The results in the two subcases are basically

Table 7: Changes of Equilibria in the Case where $b^* < b < 1$

$\sigma_m^N < \sigma_o^N < \sigma_m^F < \sigma_o^F$ when $b^* < b < 1$		
Equilibrium without following the CDD	Condition of equilibrium without following the CDD	Equilibrium with following the CDD
$\{(A, P), (P, A)\}$	$\sigma_o^2 < \sigma_m^N$ and $\sigma_m^2 < \sigma_m^N$	$\{(A, P), (P, A)\}$
(A, P)	$\sigma_o^2 < \sigma_m^N$ and $\sigma_m^2 > \sigma_m^N$	$\{(A, P), (P, A)\}$
	$\sigma_m^N < \sigma_o^2 < \sigma_o^N$	
(P, P)	$\sigma_o^N < \sigma_o^2 < \sigma_m^F$	$\{(A, P), (P, A)\}$
	$\sigma_m^F < \sigma_o^2 < \sigma_o^F$	(A, P)
	$\sigma_o^2 > \sigma_o^F$	(P, P)

the same, except for the equilibrium (P, A). Note that the manufacturer following the CDD either makes no change or makes it move toward $\{(A, P), (P, A)\}$ when $0 < b < b^{**}$,while only the latter occurs when $b^{**} < b < b^*$. As illustrated in Figure 8, the two red lines partition the upper-left region into four parts, corresponding to the four equilibrium outcomes without following the CDD; the curve $\sigma_o^2 = \sigma_m^2$ is divided into three sections with different colors, corresponding to the three equilibrium outcomes with following the CDD. After the manufacturer follows the OEM's CDD, equilibria in the part with a certain color of the upper-left region will move toward equilibria in the section with the corresponding color of the curve $\sigma_o^2 = \sigma_m^2$. For example, equilibria in the yellow part will move toward $\{(A, P), (P, A)\}$.

Generally, three situations can be observed, including remaining unchanged, moving towards the equilibrium with two NE, and moving towards the equilibrium with a pure NE. This can be explained as follows. Following the OEM's CDD endows the manufacturer with more stable market acceptance, which increases the incentives to choose AS but reduces the incentives to choose PS (i.e., affecting the trade-off between the commitment value and the information value). Specifically, the second situation indicates that following the CDD increases the possibility of a sequential game. For example, when the equilibrium moves from (A, P) to $\{(A, P), (P, A)\}$, following the CDD increases the possibility of another equilibrium of sequential game (P, A). When the equilibrium moves from (P, P) to $\{(A, P), (P, A)\}$, following the CDD changes a simultaneous game into a sequential game, altering the main properties of competition between the OEM and the manufacturer. In the third situation, we observe that one and only one case occurs where the equilibrium moves from (P, P) to (P, A). Following the CDD diminishes the manufacturer's operational risk of AS and information benefits from PS, thus reducing the incentives to choose PS. Therefore, the manufacturer



$a)\ \ 0 < b < b^{**}$ $\qquad$ $b)\ \ b^{**} < b < b^{*}$

Figure 8: Comparison of Equilibria with and without following the CDD when $0 < b < b^*$

chooses AS after acquiring stable market acceptance by following the OEM's CDD.

Similarly, Table 7 states the changes of equilibria in the case where $b^* < b < 1$. In line with the results shown in Table 6, there also exist three situations in Table 7. The major difference is that in the third situation, the equilibrium moves from (P, P) to (A, P), rather than (P, A). See Figure 9 for an illustration.

Proof of Lemma 5.

From Table 4, we have $\varphi_i^{N\_seq} = \varphi_i^{F\_seq} = \frac{1}{4}, \varphi_i^{N\_sim} = \frac{2(2-b^2)}{(4-b^2)^2}, \varphi_i^{F\_sim} = \frac{1}{(b+2)^2}$. One can easily prove that $\varphi_i^{N\_seq} = \varphi_i^{F\_seq} > \varphi_i^{N\_sim} > \varphi_i^{F\_sim}$ by comparing the relative sizes of the four coefficients.

Proof of Lemma 6.

Based on Definition 1, the commitment value of the OEM (CV_o) is the difference between the riskless profits of $\Pi_o^{F\_AP}$ and $\Pi_o^{F\_PP}$, i.e., $CV_o = \frac{2a^2b^4(1-b)^2(16-9b^2)}{(64-64b^2+15b^4)^2}$. Similarly, the commitment value of the manufacturer (CV_m) is the difference between the riskless profits of $\Pi_m^{F\_AP}$ and $\Pi_m^{F\_PP}$, i.e., $CV_m = \frac{a^2b^2(1-b)^2}{4(2-b^2)(8-3b^2)}$. $CV_o - CV_m = \frac{a^2b^2(1-b)^2(-512+1088b^2-712b^4+147b^6}{4(2-b^2)(8-3b^2)^2(8-5b^2)^2}$. One can easily derive that there exists a unique threshold b^*, where we have $CV_o < CV_m$ when $0 < b < b^*$, and $CV_o > CV_m$ when $b^* < b < 1$. That is, the commitment value of the

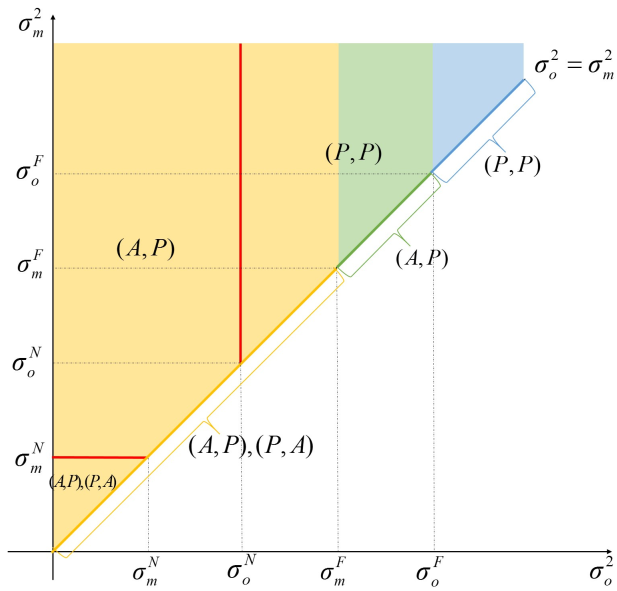


Figure 9: Comparison of Equilibria with and without following the CDD when $b^* < b < 1$

manufacturer is larger (smaller) than that of the OEM if $0 < b < b^*(b^* < b < 1)$.

Proof of Proposition 3.

Table 6 shows that, in the case where $0 < b < b^{**}(b^{**} < b < b^*, resp.)$, if $\sigma_o^F < \sigma_o^2 < \sigma_m^F$ and $\sigma_m^2 > \sigma_m^N(\sigma_m^2 > \sigma_o^F, resp.)$, the manufacturer following the CDD results in the outcome that the equilibrium moves from (P, P) to (P, A), i.e., the OEM remains on PS while the manufacturer changes to AS. We then compare the profits of the OEM (manufacturer) with and without the manufacturer following the CDD.

$$\Pi_o^{F\_PA*} - \Pi_o^{N\_PP*} = \frac{a^2(1-b)^2}{4(2-b^2)^2} + \frac{1}{4}\sigma_o^2 - \left(\frac{4a^2(1-b)^2}{(8-3b^2)^2} + \frac{2(2-b^2)}{(4-b^2)^2}\sigma_o^2\right) = \frac{a^2b^2(1-b^2)(16-7b^2)}{4(2-b^2)^2(8-3b^2)^2} + \frac{b^4\sigma_o^2}{4(2-b)^2(2+b)^2} > 0$$

$$\Pi_m^{F\_PA*} - \Pi_m^{N\_PP*} = \frac{a^2(3-2b)}{4(2-b^2)} - \left(\frac{a^2(6-b)(2-b)}{4(8-3b^2)} + \frac{2(2-b^2)}{(4-b^2)^2}\sigma_m^2\right) = \frac{a^2b^2(1-b^2)}{4(2-b^2)(8-3b^2)} - \frac{2(2-b^2)}{(4-b^2)^2}\sigma_m^2$$

In the case where $\sigma_m^2 > \sigma_m^N(\sigma_m^2 > \sigma_o^F, resp.)$, $\Pi_m^{F\_PA*} - \Pi_m^{N\_PP*} < 0$.

Proof of Proposition 4.

Table 7 shows that, in the case where $b^* < b < 1$, if $\sigma_m^F < \sigma_o^2 < \sigma_o^F$, the manufacturer following the CDD results in the outcome that the equilibrium moves from (P, P) to (A, P), i.e., the OEM changes to AS while the manufacturer remains on PS. We then compare the profits of the OEM (manufacturer) with and without the manufacturer following the CDD.

$$\Pi_o^{F\_AP*} - \Pi_o^{N\_PP*} = \frac{2a^2(1-b)^2(2-b^2)}{(8-5b^2)^2} - \left(\frac{4a^2(1-b)^2}{(8-3b^2)^2} + \frac{2(2-b^2)}{(4-b^2)^2}\sigma_o^2\right)$$

$$= -\frac{2\left(a^2b^4(-16+9b^2)(4-4b-b^2+b^3)^2+(2-b^2)(64-64b^2+15b^4)^2\sigma_o^2\right)}{(-2+b)^2(2+b)^2(8-5b^2)^2(8-3b^2)^2}.$$

In the case where $\sigma_m^F < \sigma_o^2 < \sigma_o^F$, $\Pi_o^{F\_AP*} - \Pi_o^{N\_PP*} < 0$.

$$\Pi_m^{F\_AP*} - \Pi_m^{N\_PP*} = \left(\frac{a^2(12-8b-b^2)}{4(8-5b^2)} + \frac{1}{4}\sigma_o^2\right) - \left(\frac{a^2(2-b)(6-b)}{4(8-3b^2)} + \frac{2(2-b^2)}{(4-b^2)^2}\sigma_m^2\right)$$
$$= \frac{\left(8a^2b^2(4-4b-b^2+b^3)^2+(64-64b^2+15b^4)\right)\left((4-b^2)^2\sigma_o^2-8(2-b^2)\sigma_m^2\right)}{4(4-b^2)^2(64-64b^2+15b^4)}.$$

By solving the equation $\Pi_m^{F\_AP*} - \Pi_m^{N\_PP*} = 0$, we have $\sigma_o^2 = \frac{8(2-b^2)}{(4-b^2)^2}\sigma_m^2 - \frac{8a^2b^2(4-4b-b^2+b^3)^2}{(4-b^2)^2(64-64b^2+15b^4)}$. Let $t = \frac{8(2-b^2)}{(4-b^2)^2}\sigma_m^2 - \frac{8a^2b^2(4-4b-b^2+b^3)^2}{(4-b^2)^2(64-64b^2+15b^4)}$. The relative sizes of $\Pi_m^{F\_AP*}$ and $\Pi_m^{N\_PP*}$ depend on those of σ_o^2 and t. Consider $\sigma_m^F < \sigma_o^2 < \sigma_o^F$. Then we have:

(1) if $t \leq \sigma_m^F$, it satisfies $t < \sigma_o^2$, and then we have $\Pi_m^{F\_AP*} > \Pi_m^{N\_PP*}$. By solving the inequality $t \leq \sigma_m^F$, i.e., $\frac{8(2-b^2)}{(4-b^2)^2}\sigma_m^2 - \frac{8a^2b^2(4-4b-b^2+b^3)^2}{(4-b^2)^2(64-64b^2+15b^4)} \leq \frac{a^2b^2(-1+b)^2(2+b)^2}{4(-2+b^2)(-8+3b^2)}$, we have $\sigma_m^2 \leq \frac{a^2b^2(1-b)^2(2-b)^2(2+b)^2(96+32b-44b^2-20b^3-5b^4)}{32(2-b^2)^2(64-64b^2+15b^4)} = B_L$;

(2) if $t \geq \sigma_o^F$, it satisfies $t > \sigma_o^2$, and then we have $\Pi_m^{F\_AP*} < \Pi_m^{N\_PP*}$. By solving the inequality $t \geq \sigma_o^F$, i.e., $\frac{8(2-b^2)}{(4-b^2)^2}\sigma_m^2 - \frac{8a^2b^2(4-4b-b^2+b^3)^2}{(4-b^2)^2(64-64b^2+15b^4)} \geq \frac{2a^2b^4(-2+b+b^2)^2(16-9b^2)}{(64-64b^2+15b^4)^2}$, we have $\sigma_m^2 \geq \frac{a^2b^2(1-b)^2(2-b)^2(2+b)^2(256-192b^2+64b^3+40b^4-36b^5-9b^6)}{4(2-b^2)(64-64b^2+15b^4)^2} = B_H$.

B. Revenue-sharing Contract

Following the same procedure as in the main body, we derive the equilibrium outcomes for the case in which the manufacturer does not follow the CDD. The following summarizes the results.

Scenario (A, A):

$w^{N\_AA*} = \frac{a\phi\left(b^3(2-\phi)\phi-b^2(-2\phi^2+2\phi+4)+4b(1-\phi)+8\phi\right)}{8(\phi+1)-2b^2(4-\phi^2)}$;

$q_o^{N\_AA*} = \frac{2a(1-b)}{4(\phi+1)-b^2(4-\phi^2)}$, $q_m^{N\_AA*} = \frac{a(b^2(\phi-2)\phi+2b(\phi-2)+4(\phi+1))}{8(\phi+1)-2b^2(4-\phi^2)}$;

$\Pi_o^{N\_AA*} = \frac{4a^2(1-b)^2\phi}{(4(\phi+1)-b^2(4-\phi^2))^2}$, $\Pi_m^{N\_AA*} = \frac{a^2(b^2\phi^2-8b+4\phi+8)}{4(4(\phi+1)-b^2(4-\phi^2))}$.

Scenario (P, P):

$w^{N\_PP*} = \frac{a\phi\left(b^3(2-\phi)\phi-b^2(-2\phi^2+2\phi+4)+4b(1-\phi)+8\phi\right)}{8(\phi+1)-2b^2(4-\phi^2)}$;

$q_o^{N\_PP*} = \frac{2a(1-b)}{4(\phi+1)-b^2(4-\phi^2)}$, $q_m^{N\_PP*} = \frac{a(b^2(\phi-2)\phi+2b(\phi-2)+4(\phi+1))}{8(\phi+1)-2b^2(4-\phi^2)}$;

$\Pi_o^{N\_PP*} = \frac{4a^2(1-b)^2\phi}{(4(\phi+1)-b^2(4-\phi^2))^2} + \frac{2\phi(b^2\phi-2b^2+2)}{(b^2\phi-2b^2+4)^2}\sigma_o^2$, $\Pi_m^{N\_PP*} = \frac{a^2(b^2\phi^2-8b+4\phi+8)}{4(4(\phi+1)-b^2(4-\phi^2))} + \frac{2(b^2\phi-2b^2+2)}{(b^2\phi-2b^2+4)^2}\sigma_m^2 + \frac{2(1-\phi)(b^2\phi-2b^2+2)}{(b^2\phi-2b^2+4)^2}\sigma_o^2$.

Scenario (A, P):

$w^{N\_AP*} = \frac{a\phi\left(b^3(-(3\phi^2-8\phi+4))-6b^2(2-\phi)\phi+4b(1-\phi)+8\phi\right)}{b^2(6\phi^2-8\phi-8)+8(\phi+1)}$;

$q_o^{N\_AP*} = \frac{2a(1-b)}{b^2(3\phi^2-4\phi-4)+4(\phi+1)}$, $q_m^{N\_AP*} = \frac{a\left(3b^2(\phi-2)\phi+2b(\phi-2)+4(\phi+1)\right)}{b^2(6\phi^2-8\phi-8)+8(\phi+1)}$;

$\Pi_o^{N\_AP*} = \frac{2a^2(1-b)^2\phi(b^2\phi-2b^2+2)}{(3b^2\phi^2-4b^2\phi-4b^2+4\phi+4)^2}$, $\Pi_m^{N\_AP*} = \frac{a^2(3b^2\phi^2-4b^2\phi-8b+4\phi+8)}{4(3b^2\phi^2-4b^2\phi-4b^2+4\phi+4)} + \frac{1}{4}\sigma_m^2$.

Scenario (P, A)**:**
$w^{N\_PA*} = \frac{a\phi(-b^2-b\phi+b+2\phi)}{2(-b^2+\phi+1)}$;
$q_o^{N\_PA*} = \frac{a(1-b)}{2(-b^2+\phi+1)}$, $q_m^{N\_PA*} = \frac{a(-b+\phi+1)}{2(-b^2+\phi+1)}$;
$\Pi_o^{N\_PA*} = \frac{a^2(1-b)^2\phi}{4(-b^2+\phi+1)^2} + \frac{\phi}{4}\sigma_o^2$, $\Pi_m^{N\_PA*} = \frac{a^2(-2b+\phi+2)}{4(-b^2+\phi+1)} + \frac{1-\phi}{4}\sigma_o^2$.

For the case in which the manufacturer follows the CDD, the results are basically the same as those above, except for some minor changes in the profits as: $\Pi_o^{F\_PP*} = \frac{4a^2(1-b)^2\phi}{(4(\phi+1)-b^2(4-\phi^2))^2} + \frac{(b-2)^2\phi}{(b^2\phi-2b^2+4)^2}\sigma_o^2$, $\Pi_m^{F\_PP*} = \frac{a^2(b^2\phi^2-8b+4\phi+8)}{4(4(\phi+1)-b^2(4-\phi^2))} + \frac{b^3\phi^2-3b^3\phi+2b^3-b^2\phi^2+3b^2\phi-b^2+4b\phi-8b-4\phi+8}{(b^2\phi-2b^2+4)^2}\sigma_o^2$, and $\Pi_m^{N\_AP*} = \frac{a^2(3b^2\phi^2-4b^2\phi-8b+4\phi+8)}{4(3b^2\phi^2-4b^2\phi-4b^2+4\phi+4)} + \frac{1}{4}\sigma_o^2$.

We next prove Proposition 5 for the case in which the manufacturer follows the CDD. Similar proofs apply to the case without following the CDD, which we omit here.

For the OEM,

$\Pi_o^{F\_AA*} - \Pi_o^{F\_PA*} = \frac{4a^2(1-b)^2\phi}{(4(\phi+1)-b^2(4-\phi^2))^2} - \left(\frac{a^2(1-b)^2\phi}{4(-b^2+\phi+1)^2} + \frac{\phi}{4}\sigma_o^2\right) < 0.$

$\Pi_o^{F\_AP*} - \Pi_o^{F\_PP*} = \frac{2a^2(1-b)^2\phi(b^2\phi-2b^2+2)}{(3b^2\phi^2-4b^2\phi-4b^2+4\phi+4)^2} - \left(\frac{4a^2(1-b)^2\phi}{(4(\phi+1)-b^2(4-\phi^2))^2} + \frac{(b-2)^2\phi}{(b^2\phi-2b^2+4)^2}\sigma_o^2\right)$. By solving the equation $\Pi_o^{F\_AP*} - \Pi_o^{F\_PP*} = 0$, we derive a threshold

$\sigma_{o,r}^F = \frac{2a^2(b-1)^2(b^2(\phi-2)+4)^2}{(b-2)^2}\left(\frac{b^2(\phi-2)+2}{(b^2(3\phi^2-4\phi-4)+4(\phi+1))^2} - \frac{2}{(b^2(\phi^2-4)+4(\phi+1))^2}\right)$,

under which we have $\Pi_o^{F\_AP*} > \Pi_o^{F\_PP*}$ if and only if $\sigma_o^2 < \sigma_{o,r}^F$. Note that, there exists a threshold $b_r(\phi) \in (0,1)$ satisfying $\sigma_{o,r}^F = 0$, under which we have $\sigma_{o,r}^F > 0$ if and only if $b_r(\phi) < b < 1$. Therefore, we have

$$\begin{cases} \Pi_o^{F\_AP*} < \Pi_o^{F\_PP*}, & \text{if } 0 < b < b_r(\phi), \\ \Pi_o^{F\_AP*} < \Pi_o^{F\_PP*}, & \text{if } b_r(\phi) < b < 1 \text{ and } \sigma_o^2 > \sigma_{o,r}^F, \\ \Pi_o^{F\_AP*} > \Pi_o^{F\_PP*}, & \text{if } b_r(\phi) < b < 1 \text{ and } \sigma_o^2 < \sigma_{o,r}^F. \end{cases}$$

For the manufacturer,

$\Pi_m^{F\_AA*} - \Pi_m^{F\_AP*} = \frac{a^2(b^2\phi^2-8b+4\phi+8)}{4(4(\phi+1)-b^2(4-\phi^2))} - \left(\frac{a^2(3b^2\phi^2-4b^2\phi-8b+4\phi+8)}{4(3b^2\phi^2-4b^2\phi-4b^2+4\phi+4)} + \frac{1}{4}\sigma_o^2\right) < 0.$

$\Pi_m^{F\_PA*} - \Pi_m^{F\_PP*} = \frac{a^2(-2b+\phi+2)}{4(-b^2+\phi+1)} + \frac{1-\phi}{4}\sigma_o^2 - \left(\frac{a^2(b^2\phi^2-8b+4\phi+8)}{4(4(\phi+1)-b^2(4-\phi^2))} + \frac{b^3\phi^2-3b^3\phi+2b^3-b^2\phi^2+3b^2\phi-b^2+4b\phi-8b-4\phi+8}{(b^2\phi-2b^2+4)^2}\sigma_o^2\right)$ $= \frac{a^2(b-1)^2b^2\phi^2}{4(1+\phi-b^2)(b^2\phi^2-4b^2+4\phi+4)} - \frac{(b\phi-2b+2)^2(b^2\phi-b^2+4)}{4(b^2\phi-2b^2+4)^2}\sigma_o^2$. By solving the equation $\Pi_m^{F\_PA*} - \Pi_m^{F\_PP*} = 0$, we derive a threshold $\sigma_{m,r}^F = \frac{a^2(b-1)^2b^2\phi^2\left(b^2(\phi-2)+4\right)^2}{(b(\phi-2)+2)^2(b^2(\phi-1)+4)(1+\phi-b^2)(b^2(\phi^2-4)+4(\phi+1))} > 0$, under which we have $\Pi_m^{F\_PA*} > \Pi_m^{F\_PP*}$ if and only if $\sigma_o^2 < \sigma_{m,r}^F$. That is,

$$\begin{cases} \Pi_m^{F\_PA*} < \Pi_m^{F\_PP*}, & \text{if } \sigma_o^2 > \sigma_{m,r}^F, \\ \Pi_m^{F\_PA*} > \Pi_m^{F\_PP*}, & \text{if } \sigma_o^2 < \sigma_{m,r}^F. \end{cases}$$

Combining the results for the OEM and the manufacturer, we derive a threshold $b^*(\phi) \in (b_r(\phi), 1)$ satisfying $\sigma_{o,r}^F = \sigma_{m,r}^F$, under which we have $\sigma_{o,r}^F > \sigma_{m,r}^F$ if and only if $b^*(\phi) < b < 1$.

Consequently, we have three regions of b: $(0, b_r(\phi))$, $[b_r(\phi), b^*(\phi))$, and $[b^*(\phi), 1)$. When $\phi = 1$, the revenue sharing model is the same as the base model. In this case, $b_r(\phi) = 0$ and the equilibrium is exactly the same as in Propositions 1 and 2. When $\phi < 1$, the equilibrium structures for $b \in [b_r(\phi), b^*(\phi))$ and $b \in [b^*(\phi), 1)$ are similar to those for $b \in (0, b^*)$ and $b \in [b^*, 1)$ in the base model. The equilibrium structure for $b \in (0, b_r(\phi))$ is specified in Proposition 5. In this region, for the OEM, we have $\Pi_o^{F\_AA*} < \Pi_o^{F\_PA*}$ and $\Pi_o^{F\_AP*} < \Pi_o^{F\_PP*}$; that is, PS is the OEM's dominant strategy. For the manufacturer, we have $\Pi_m^{F\_PA*} > \Pi_m^{F\_PP*}$ if and only if $\sigma_o^2 < \sigma_{m,r}^F$. Therefore, we reach the result in Proposition 5.

C. Postponement of Wholesale Pricing

In this section, we extend our base model to a setting in which the manufacturer postpones the wholesale price decisions until the market uncertainty is resolved if the OEM adopts the PS strategy to take advantage of the information value. There are two possible scenarios in this case: (P, A) and (P, P). In (P, A), the sequence of events is: 1) the manufacturer determines q_m before demand is realized; 2) after uncertainty is resolved, the manufacturer decides w and then the OEM determines q_o. Regarding (P, P), the sequence of events is the same as in the base model, except that the decision of w is postponed until demand realizes. Following the same procedure as in the main body, we derive the equilibrium outcomes for the case in which the manufacturer does not follow the CDD. The following summarizes the results for (P, P) and (P, A). The results for (A, A) and (A, P) are the same as in the base model.

Scenario (P, P)**:** $w^{N\_PP*} = \frac{(8-4b^2+b^3)a}{2(8-3b^2)}$; $q_o^{N\_PP*} = \frac{2(1-b)a}{8-3b^2}$, $q_m^{N\_PP*} = \frac{(2-b)(4+b)a}{2(8-3b^2)}$; $\Pi_o^{N\_PP*} = \frac{4(1-b)^2a^2}{(8-3b^2)^2} + \frac{2(2-b^2)}{(4-b^2)^2}\sigma_o^2 + \frac{b^2(20-7b^2)}{(4-b^2)(8-3b^2)^2}\sigma_m^2$, $\Pi_m^{N\_PP*} = \frac{(2-b)(6-b)a^2}{4(8-3b^2)} + \left(\frac{2(2-b^2)}{(4-b^2)^2} + \frac{b^2}{4(8-3b^2)}\right)\sigma_m^2$.

Scenario (P, A)**:** $w^{N\_PA*} = \frac{a}{2}$; $q_o^{N\_PA*} = \frac{(1-b)a}{2(2-b^2)}$, $q_m^{N\_PA*} = \frac{(2-b)a}{2(2-b^2)}$; $\Pi_o^{N\_PA*} = \frac{(1-b)^2a^2}{4(2-b^2)^2} + \frac{1}{4}\sigma_o^2$, $\Pi_m^{N\_PA*} = \frac{(3-2b)a^2}{4(2-b^2)}$.

The corresponding thresholds are (in contrast with those in Proposition 1): $\sigma_{o,w}^N = \frac{a^2(1-b)^2b^4(4-b^2)^2(16-9b^2)}{(2-b^2)(64-64b^2+15b^4)^2} - \frac{b^2(4-b^2)(20-7b^2)}{2(2-b^2)(8-3b^2)^2}\sigma_m^2$ and $\sigma_{m,w}^N = \frac{a^2(2-b)^2(1-b)^2b^2(2+b)^2}{(2-b^2)(128-96b^2+16b^4+b^6)}$.

Similarly, for the case in which the manufacturer follows the CDD, we have

Scenario (P, P)**:** $w^{F\_PP*} = \frac{(8-4b^2+b^3)a}{2(8-3b^2)}$; $q_o^{F\_PP*} = \frac{2(1-b)a}{8-3b^2}$, $q_m^{F\_PP*} = \frac{(2-b)(4+b)a}{2(8-3b^2)}$; $\Pi_o^{F\_PP*} = \frac{4(1-b)^2a^2}{(8-3b^2)^2} + \frac{4(1-b)^2}{(8-3b^2)^2}\sigma_o^2$, $\Pi_m^{F\_PP*} = \frac{(2-b)(6-b)a^2}{4(8-3b^2)} + \frac{(2-b)(6-b)}{4(8-3b^2)}\sigma_o^2$.

Scenario (P, A)**:** $w^{F\_PA*} = \frac{a}{2}$; $q_o^{F\_PA*} = \frac{(1-b)a}{2(2-b^2)}$, $q_m^{F\_PA*} = \frac{(2-b)a}{2(2-b^2)}$; $\Pi_o^{F\_PA*} = \frac{(1-b)^2a^2}{4(2-b^2)^2} + \frac{1}{16}\sigma_o^2$, $\Pi_m^{F\_PA*} = \frac{(3-2b)a^2}{4(2-b^2)} + \frac{1}{8}\sigma_o^2$.

The corresponding thresholds are (in contrast with those in Proposition 2): $\sigma_{o,w}^F = \frac{a^2b^4(16-9b^2)}{2(8-5b^2)^2}$ and $\sigma_{m,w}^F = \frac{2a^2(1-b)^2b^2}{32-32b-6b^2+16b^3-5b^4}$.

Our main results qualitatively hold in this new setting, except that two slight differences arise, as we present in the extension section. We provide proofs as follows.

Proof of the first difference. By calculating the intersection of $\sigma_{o,w}^N$ and $\sigma_{m,w}^N$, we have that these two lines intersect at point $(x,y) = \left(\frac{a^2(1-b)^2b^4(4-b^2)^2(6b^8+31b^6-248b^4+528b^2-384)}{2(8-5b^2)^2(2-b^2)^2(8-3b^2)(b^6+16b^4-96b^2+128)}, \frac{a^2(2-b)^2(1-b)^2b^2(2+b)^2}{(2-b^2)(b^6+16b^4-96b^2+128)}\right)$, where $x(y)$-axis represents $\sigma_o^2(\sigma_m^2)$. By some simple calculation, we have $0 < x < y$; that is, there exists one and only one intersection point which falls in the region above the line $\sigma_o^2 = \sigma_m^2$. Therefore, we have similar equilibrium structure as in Proposition 1(I). The difference is that it holds for $b \in (0,1)$ in this new setting.

Proof of the second difference. For the OEM, $\Pi_o^{F\_PA*} - \Pi_o^{N\_PP*} = \frac{a^2(b-1)^2(16-7b^2)b^2}{4(8-3b^2)^2(b^2-2)^2} - \frac{(-b^4-24b^2+48)}{16(b^2-4)^2}\sigma_o^2 - \frac{(b^2(20-7b^2))}{(4-b^2)(8-3b^2)^2}\sigma_m^2$. Following the same procedure as in the proof of Proposition 4, one can derive the following results: $\Pi_o^{F\_AP*} > \Pi_o^{N\_PP*}$ if $\sigma_o^2 \leq O_L$, and $\Pi_o^{F\_AP*} < \Pi_o^{N\_PP*}$ if $\sigma_o^2 \geq O_H$, i.e., the OEM is better off by the manufacturer's following the CDD if σ_o^2 is small and it is worse off if σ_o^2 is large, where $O_L = \frac{4a^2(b-1)^2b^2(4-b^2)(21b^6+112b^5-164b^4-704b^3+704b^2+1024b-1024)}{(8-3b^2)^2(b^2-2)^2(5b^2-16b+16)(b^4+24b^2-48)}$, and $O_H = \frac{4a^2b^2(7b^4-48b^2+80)}{(8-3b^2)^2(b^4+24b^2-48)}\left(\frac{(b-1)^2(b^2-4)(7b^2-16)}{(b^2-2)^2(7b^2-20)} - \frac{2b^4(9b^2-16)}{(8-5b^2)^2}\right)$. Similarly, for the manufacturer, $\Pi_m^{F\_PA*} - \Pi_m^{N\_PP*} = \frac{a^2(b-1)^2b^2}{4(b^2-2)(3b^2-8)} + \frac{\sigma_o^2}{8} - \left(\frac{b^2}{4(8-3b^2)} + \frac{2(2-b^2)}{(4-b^2)^2}\right)\sigma_m^2$. Then we have: $\Pi_m^{F\_AP*} > \Pi_m^{N\_PP*}$ if $\sigma_m^2 \leq M_L$, and $\Pi_m^{F\_AP*} < \Pi_m^{N\_PP*}$ if $\sigma_m^2 \geq M_H$, where $M_L = \frac{a^2b^2\left(\frac{4(b-1)^2}{(b^2-2)(3b^2-8)} + \frac{16b^2-9b^4}{(8-5b^2)^2}\right)}{16\left(\frac{b^2}{32-12b^2} - \frac{2(b^2-2)}{(b^2-4)^2}\right)}$, and $M_H = \frac{2a^2(6-b)(b-2)^3(b-1)^2b^2(b+2)^2}{(b^2-2)(5b^2-16b+16)(b^6+16b^4-96b^2+128)}$.

D. Correlation between ε_o and ε_m

We extend our base model by considering market acceptance uncertainty correlation: The manufacturer faces $\varepsilon_m = \varepsilon_o$ if he follows the CDD, and he sees $\varepsilon_m = \varepsilon_o + \delta$ if not. The random term δ is independent of ε_o, with zero mean and variance σ^2. A δ with a larger σ^2 represents a manufacturer with less compliance with the CDD. If the manufacturer does not follow the CDD, the mean and the variance of ε_m are: $E[\varepsilon_m] = E[\varepsilon_o + \delta] = 0$, and $Var[\varepsilon_m] = Var[\varepsilon_o + \delta] = \sigma_o^2 + \sigma^2$. The correlation between ε_o and ε_m is: $\rho = \frac{Cov[\varepsilon_o, \varepsilon_m]}{\sqrt{Var[\varepsilon_o]Var[\varepsilon_m]}} = \frac{\sigma_o}{\sqrt{\sigma_o^2+\sigma^2}}$. The expected profit functions of the OEM and the manufacturer are, respectively,

$$\Pi_o = E[(a + \varepsilon_o - q_o - bq_m)q_o - wq_o],$$

$$\Pi_m = E[(a + \varepsilon_o + \delta - q_m - bq_o)q_m + wq_o].$$

If the manufacturer follows the CDD, it shares the same uncertainty with the OEM; that is, $\delta = 0$, and $\rho = 1$. The expected profit of the manufacturer is

$$\Pi_m = E[(a + \varepsilon_o - q_m - bq_o)q_m + wq_o].$$

Following the same procedure as in the main body, we derive the equilibrium outcomes for the case in which the manufacturer does not follow the CDD, which are summarized as follows. The results for the case in which the manufacturer follows the CDD are the same as in the base model.

Scenario (A, A)**:** $w^{N\_AA*} = \frac{(8-4b^2+b^3)a}{2(8-3b^2)}$; $q_o^{N\_AA*} = \frac{2(1-b)a}{8-3b^2}$, $q_m^{N\_AA*} = \frac{(2-b)(4+b)a}{2(8-3b^2)}$; $\Pi_o^{N\_AA*} = \frac{4(1-b)^2a^2}{(8-3b^2)^2}$, $\Pi_m^{N\_AA*} = \frac{(2-b)(6-b)a^2}{4(8-3b^2)}$.

Scenario (P, P)**:** $w^{N\_PP*} = \frac{(8-4b^2+b^3)a}{2(8-3b^2)}$; $q_o^{N\_PP*} = \frac{2(1-b)a}{8-3b^2}$, $q_m^{N\_PP*} = \frac{(2-b)(4+b)a}{2(8-3b^2)}$; $\Pi_o^{N\_PP*} = \frac{4(1-b)^2a^2}{(8-3b^2)^2} + \frac{1}{(2+b)^2}\sigma_o^2$, $\Pi_m^{N\_PP*} = \frac{(2-b)(6-b)a^2}{4(8-3b^2)} + \frac{1}{(2+b)^2}\sigma_o^2 + \frac{2(2-b^2)}{(4-b^2)^2}\sigma^2$.

Scenario (A, P)**:** $w^{N\_AP*} = \frac{(8-6b^2+b^3)a}{2(8-5b^2)}$; $q_o^{N\_AP*} = \frac{2(1-b)a}{8-5b^2}$, $q_m^{N\_AP*} = \frac{(8-2b-3b^2)a}{2(8-5b^2)}$; $\Pi_o^{N\_AP*} = \frac{2(1-b)^2(2-b^2)a^2}{(8-5b^2)^2}$, $\Pi_m^{N\_AP*} = \frac{(12-8b-b^2)a^2}{4(8-5b^2)} + \frac{1}{4}(\sigma_o^2 + \sigma^2)$.

Scenario (P, A)**:** $w^{N\_PA*} = \frac{a}{2}$; $q_o^{N\_PA*} = \frac{(1-b)a}{2(2-b^2)}$, $q_m^{N\_PA*} = \frac{(2-b)a}{2(2-b^2)}$; $\Pi_o^{N\_PA*} = \frac{(1-b)^2a^2}{4(2-b^2)^2} + \frac{1}{4}\sigma_o^2$, $\Pi_m^{N\_PA*} = \frac{(3-2b)a^2}{4(2-b^2)}$.

We derive the thresholds in this new setting as: $\sigma_{o,d}^N = \frac{2a^2b^4(2-b-b^2)^2(16-9b^2)}{(64-64b^2+15b^4)^2}$, $\sigma_{m,d}^N = \frac{a^2b^2(1-b)^2(4-b^2)^2}{8(2-b^2)^2(8-3b^2)} + \frac{b(4-3b)}{(4-b^2)^2}\sigma_o^2$, $\sigma_{o,d}^F = \frac{2a^2b^4(2-b-b^2)^2(16-9b^2)}{(64-64b^2+15b^4)^2}$, $\sigma_{m,d}^F = \frac{a^2b^2(1-b)^2(2+b)^2}{4(2-b^2)(8-3b^2)}$, and $b_d^* = 0.9565$, which correspond to, respectively, σ_o^N, σ_m^N, σ_o^F, σ_m^F, and b^* in the base model. Our main results qualitatively hold, except that the manufacturer's following the CDD does not benefit itself anymore (recall that in Proposition 4 where $b^* < b < 1$, the manufacturer benefits from following the CDD if σ_m^2 is relatively small). We provide the proof of this difference as follows.

Proof. When $b^* < b < 1$, we have $\sigma_{m,d}^N < \sigma_{m,d}^F < \sigma_{o,d}^N = \sigma_{o,d}^F$. Consider the region where $\sigma_{m,d}^F < \sigma_o^2 < \sigma_{o,d}^F$ (which is similar to that in Proposition 4), the equilibrium is (A, P) despite whether the manufacturer follows the CDD or not. Therefore, we only need to compare the manufacturer's profits in (A, P) in these two cases. The manufacturer is worse off by following the OEM's CDD, as demonstrated as follows.

$$\Pi_m^{F\_AP*} - \Pi_m^{N\_AP*} = \left(\frac{(12-8b-b^2)a^2}{4(8-5b^2)} + \frac{1}{4}\sigma_o^2\right) - \left(\frac{(12-8b-b^2)a^2}{4(8-5b^2)} + \frac{1}{4}(\sigma_o^2 + \sigma^2)\right) = -\frac{1}{4}\sigma^2 < 0$$

E. Non-zero Production Cost

If the manufacturer incurs a marginal production cost c with $c < a$, firms' expected profits are, respectively,

$$\Pi_o = E[(a + \varepsilon_o - q_o - bq_m)q_o - wq_o],$$
$$\Pi_m = E[(a + \varepsilon_m - q_m - bq_o - c)q_m + (w - c)q_o].$$

We summarize as follows the equilibrium outcomes for the case in which the manufacturer does not follow the CDD.

Scenario (A, A)**:** $w^{N\_AA*} = \frac{(8-4b^2+b^3)a+(8-2b^2-b^3)c}{2(8-3b^2)}$; $q_o^{N\_AA*} = \frac{2(1-b)(a-c)}{8-3b^2}$, $q_m^{N\_AA*} = \frac{(2-b)(4+b)(a-c)}{2(8-3b^2)}$; $\Pi_o^{N\_AA*} = \frac{4(1-b)^2(a-c)^2}{(8-3b^2)^2}$, $\Pi_m^{N\_AA*} = \frac{(2-b)(6-b)(a-c)^2}{4(8-3b^2)}$.

Scenario (P, P)**:** $w^{N\_PP*} = \frac{(8-4b^2+b^3)a+(8-2b^2-b^3)c}{2(8-3b^2)}$; $q_o^{N\_PP*} = \frac{2(1-b)(a-c)}{8-3b^2}$, $q_m^{N\_PP*} = \frac{(2-b)(4+b)(a-c)}{2(8-3b^2)}$; $\Pi_o^{N\_PP*} = \frac{4(1-b)^2(a-c)^2}{(8-3b^2)^2} + \frac{2(2-b^2)}{(4-b^2)^2}\sigma_o^2$, $\Pi_m^{N\_PP*} = \frac{(2-b)(6-b)(a-c)^2}{4(8-3b^2)} + \frac{2(2-b^2)}{(4-b^2)^2}\sigma_m^2$.

Scenario (A, P)**:** $w^{N\_AP*} = \frac{(8-6b^2+b^3)a+(8-4b^2-b^3)c}{2(8-5b^2)}$; $q_o^{N\_AP*} = \frac{2(1-b)(a-c)}{8-5b^2}$, $q_m^{N\_AP*} = \frac{(8-2b-3b^2)(a-c)}{2(8-5b^2)}$; $\Pi_o^{N\_AP*} = \frac{2(1-b)^2(2-b^2)(a-c)^2}{(8-5b^2)^2}$, $\Pi_m^{N\_AP*} = \frac{(12-8b-b^2)(a-c)^2}{4(8-5b^2)} + \frac{1}{4}\sigma_m^2$.

Scenario (P, A)**:** $w^{N\_PA*} = \frac{a+c}{2}$; $q_o^{N\_PA*} = \frac{(1-b)(a-c)}{2(2-b^2)}$, $q_m^{N\_PA*} = \frac{(2-b)(a-c)}{2(2-b^2)}$; $\Pi_o^{N\_PA*} = \frac{(1-b)^2(a-c)^2}{4(2-b^2)^2} + \frac{1}{4}\sigma_o^2$, $\Pi_m^{N\_PA*} = \frac{(3-2b)(a-c)^2}{4(2-b^2)}$.

The results for the case in which the manufacturer follows the CDD are basically the same as the results above, except for some minor changes in firms' profits as: $\Pi_o^{F\_PP*} = \frac{4(1-b)^2(a-c)^2}{(8-3b^2)^2} + \frac{1}{(b+2)^2}\sigma_o^2$, $\Pi_m^{F\_PP*} = \frac{(2-b)(6-b)(a-c)^2}{4(8-3b^2)} + \frac{1}{(b+2)^2}\sigma_o^2$, $\Pi_m^{F\_AP*} = \frac{(12-8b-b^2)(a-c)^2}{4(8-5b^2)} + \frac{1}{4}\sigma_o^2$.

The thresholds in this extended model are $\sigma_{o,c}^N = \frac{(a-c)^2b^4(1-b)^2(4-b^2)^2(16-9b^2)}{(2-b^2)(15b^4-64b^2+64^2)}$, $\sigma_{m,c}^N = \frac{(a-c)^2b^2(1-b)^2(4-b^2)^2}{8(2-b^2)^2(8-3b^2)}$, $\sigma_{o,c}^F = \frac{2(a-c)^2b^4(2-b-b^2)^2(16-9b^2)}{(64-64b^2+15b^4)^2}$, $\sigma_{m,c}^F = \frac{(a-c)^2b^2(1-b)^2(2+b)^2}{4(2-b^2)(8-3b^2)}$, and $b_c^* = 0.9565$, which correspond to, respectively, σ_o^N, σ_m^N, σ_o^F, σ_m^F, and b^* in the base model.

One can see that compared with the results in the base model, by simply replacing a with $a - c$, we can get the new equilibrium outcomes and threshold values (except w, which is a weighted average of a and c). Therefore, our main results still qualitatively hold when non-zero production cost is incorporated.