Overconfident Distribution Channels

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We study the effects associated with overconfidence in distribution channels, where overconfidence is defined as a decision maker's cognitive bias in perceiving the expected outcome of an uncertain event as more certain than it likely is. Although overconfidence bias always leads to a lower expected profit for a centralized channel, we find that overconfidence can in fact enhance the performance of a decentralized channel comprising one overconfident manufacturer and retailer. That is, overconfidence can reduce the double marginalization effect so that, compared to a decentralized channel managed by unbiased firms, the profit of an overconfident decentralized channel can be higher. In a similar vein, overconfidence bias can benefit, rather than hurt, either or both channel members. Our results shed some light on the design and adoption of strategies aimed at enhancing decisions and curtailing overconfidence bias of supply chain executives.

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We're generally overconfident in our opinions and our impressions and judgments.

— Daniel Kahneman

1. Introduction

The management of distribution channels (or supply chains) is a key topic in the economics, marketing, and operations literature (Spengler 1950, Jeuland and Shugan 1983, Cachon 2003, Gao and Su 2016). Traditionally, this literature has focused largely on centralized channels, but more recent interest in the study of decentralized channel models has been burgeoning. Unlike in a centralized channel, in a decentralized channel, the manufacturing and retailing functions are separated between two independent firms. More specifically, in such models, the manufacturing and retailing functions of the channel are supplemented by an intermediate transfer function in which the manufacturer sells its product to the retailer in exchange for a wholesale price that is set by the manufacturer, and the transfer quantity is chosen by the retailer in response. Accordingly, a decentralized channel is characterized primarily by two prices: a wholesale price that the retailer pays to the manufacturer for a unit of production and a retail price that the retailer receives from an end consumer for a unit of sales. This differs from a centralized channel, which is characterized primarily by a single price, namely, the retail price that end consumers pay for a unit of production. This distinction between a decentralized versus a centralized channel is a manifestation of the independent objectives of the two firms within a decentralized channel (Spengler 1950).

As in a centralized channel, decisions within a decentralized channel can be affected by cognitive bias, as has been recently demonstrated in the literature (Katok and Wu 2009, Katok 2011, Goldfarb et al. 2012, Wu 2013). Of the many types of bias, overconfidence bias is known as a major factor in decision making, but has largely been ignored in the operations literature (Gino and Pisano 2008). Overconfidence refers to a cognitive bias in which decision makers behave as though the expected outcome of an uncertain event is more certain than it likely is, given the context of the event. This is one of the most consistent, powerful, and widespread cognitive biases for decision makers (Plous 1993). It has also been observed in a wide range of fields from psychology

(Oskamp 1965, Fischhoff et al. 1977, Moore and Healy 2008) to economics (Grubb 2009) to finance (Scheinkman and Xiong 2003) to strategy (Powell et al. 2011). This bias has also been observed anecdotally in practice. For example, Russo and Schoemaker (1992) report that when a leading firm relies on its marketing staff to project sales, then the range of projected sales was so narrow that the firm was unable to effectively respond to actual demand.

In the area of operations, Ren and Croson (2013) first introduce overconfidence as a plausible explanation for the so-called pull-to-center effect observed in various procurement laboratory controlled environments with subjects including both students and senior procurement managers (Schweitzer and Cachon 2000, Bostian et al. 2008, Ho et al. 2010, Zhang and Siemsen 2018). In these experiments, the trained subjects are often presented with unambiguous information on a random event, such as distribution. After providing full demand information, Bolton et al. (2012) observe a pull-to-center effect among purchasing managers who had worked for at least one year in a similar controlled experiment. These studies in laboratory-controlled environments suggest that managers can be affected by overconfidence bias even when the information for a random event is fully known. Building on these procurement experiments which are designed to test only single procurement decision, Kocabıyıkoğlu et al. (2016) and Ramachandran et al. (2017) design and conduct laboratory-controlled experiments to study decision making on joint quantity decision and pricing decision. They similarly observe detectable pull-to-center effects. Taken together, it seems that overconfidence remains a plausible explanation of cognitive bias for decision makers when they simultaneously make quantity and price decisions.

"[G]iven the current evidence on managerial overconfidence, further work on the *consequences* of such overconfidence is needed" (Goldfarb et al. 2012). We address this need by analyzing how overconfidence bias in decision making can affect the decisions and expected profits in distribution channels. To this end, we first develop a one-period model that incorporates the notion of overconfidence bias into a centralized channel where a single decision maker must jointly determine the production quantity and retail price of a product at the start of its selling season when the actual demand is unknown. Demand is dictated by the random market size (or potential) and price of the product. When facing uncertain demand, the decision maker can be overconfident by acting as if the random market size is less uncertain than it really is. This overconfidence bias always leads to non-optimal decisions that drag down the performance of the entire channel.

We then develop a decentralized analog for the centralized model where a manufacturer (*he*) sells his product to the retailer (*she*) who in turn sells the product to end consumers during a single period. The manufacturer begins this process by announcing a per-unit wholesale price to his retailer, after which the retailer chooses the quantity to purchase from the manufacturer and the retail price. The channel members (the manufacturer and retailer) can both be overconfident. We then assess the effects of overconfidence bias on the equilibrium outcome for this decentralized channel and compare these effects to their centralized channel analogs. In doing so, we find that firms operating within a decentralized channel are not destined to be hurt by overconfidence. Moreover, in contrast to the centralized channel, overconfidence can be a positive force for the decentralized channel as a whole. Intuitively, the decentralized channel suffers from inefficiency in the sense that the manufacturer would charge a wholesale price higher than his production cost so that the amount of stock (resp. retail price) in the decentralized channel is lower (resp. higher) than it is in the centralized analog. However, cognitive bias can bring about a lower wholesale price leading to a higher amount of stock, depending on the production cost of the channel. If this is the case, overconfidence could reduce the channel inefficiency, in turn boosting channel performance. More interestingly, when managed by overconfident firms, the decentralized channel can reap even greater profit compared to when it is managed by unbiased firms.

To more deeply understand the root interactions at play, we investigate the impacts of firms' respective biases. This analysis yields two key insights. First, overconfidence bias of one channel member can either benefit or harm the other channel member, depending on the production cost. In particular, overconfidence bias in the retailer (resp. manufacturer) can benefit the manufacturer (resp. retailer) when the production cost is relatively high (resp. low). Second, we find that, although retailer overconfidence always results in self-harm, ironically, manufacturer overconfidence can boost his *own* profit when his production cost is relatively moderate. This means that the more biased (wholesale price) decision resulting from his increasing overconfidence bias can benefit the manufacturer. In the extreme, this manufacturer overconfidence can even benefit both firms simultaneously, depending on the level of retailer overconfidence. In particular, in the case of an unbiased retailer, any benefit accrued to a manufacturer is at the expense of the retailer. However, when the retailer is also biased, then the manufacturer's overconfidence bias can lead to a mutually beneficial situation.

We also investigate the managerial implications of overconfidence on the broader aspect of distribution channels. In particular, within an overconfident decentralized channel, we show that the manufacturer may benefit from a higher production cost, depending on the retailer overconfidence level. This finding contributes to the literature studying the drivers for one interesting practice identified in previous studies that manufacturers purchase from more expensive rather than cheaper sources (Tomlin 2006, Cachon et al. 2007, Tereyağoğlu and Veeraraghavan 2012).

2. Literature Review and Our Contributions

This paper is related to the literature of behavioral operations management (see, for example, Loch and Wu 2007, Su 2008, Katok et al. 2011, Özer et al. 2011, Wu and Chen 2014, and Lu and Wu 2015). This emerging literature highlights that human beings are critical to the functioning of the vast majority of operating systems, influencing both the way these systems work and how they perform. Schweitzer and Cachon's (2000) seminal paper documents a pull-to-center effect, that is, a tendency of subjects to order between the optimal quantity and the mean demand in a laboratory experiment. This effect persists for a variety of settings (Benzion et al. 2008, Katok and Wu 2009, Kremer et al. 2010, Li et al. 2016, Feng and Zhang 2017). Ren and Croson (2013) find that overconfidence bias is robust across various controlled experiments, and it can reasonably explain the famous pull-to-center effect. They further introduce a new technique to reduce overconfidence bias. Croson et al. (2014) design manufacturer incentive contracts in order to mitigate the non-pricing retailer's overconfidence within a supply chain setting. Ren et al. (2017) analytically study the implications of overconfidence bias on the order decision and accordingly evaluate loss due to overconfidence bias for a non-pricing retailer. In contrast, we investigate overconfidence bias within a supply chain with an endogenous retail price, and find that overconfidence can potentially be a positive force.

This paper is therefore also related to the extensive literature on distribution channels and supply chain contracting. In a decentralized channel, whenever an upstream manufacturer charges a wholesale price in excess of his own production cost to his downstream retailer, double marginalization causes the retailer to order less than the channel-optimal amount (Spengler 1950). Prior literature has therefore traditionally focused on the analytical design of contracting arrangements in order to eliminate inefficiency (e.g., Zusman and Etgar 1981, Cachon 2003, 2004, Özer and Wei 2006). More recently, this literature has undertaken experimental analyses of supply chain contracting. For example, Loch and Wu (2008) find that concerns with status and relationship have significant effects on the performance of the wholesale price contract in a controlled laboratory experiment. Katok and Wu (2009) investigate various supply chain settings and find that coordinating contracts are significantly less effective than the theory suggests. Wu and Chen (2014), Davis (2015) and Davis et al. (2014) also find that the performance and effectiveness of coordinating contracts can be significantly affected by supply chain member behaviors. Other relevant behavioral studies include Zhang et al. (2015), Becker-Peth et al. (2013), and Davis and Hyndman (2018). We extend this literature by incorporating the prevalent notion of overconfidence as a cognitive bias into a channel model in order to investigate its theoretical impacts and implications. We thereby make three key contributions.

First, we find that the performance of the decentralized channel as a whole can be improved as the channel becomes more overconfident. As a result, interestingly, the overconfident decentralized channel can outperform the decentralized channel managed by unbiased firms. Second, we find although retailer overconfidence always leads to self-harm, manufacturer overconfidence can actually benefit the manufacturer, depending on the production cost. Third, we demonstrate that manufacturer overconfidence can potentially benefit both channel members, depending on the level of retailer overconfidence.

In showing these results, we employ a model where a decision maker (retailer) must jointly determine the price and quantity of a product. This joint decision is common and critical in practice, attracting significant theoretical as well as experimental attention in the literature (Emmons and Gilbert 1998, Petruzzi and Dada 1999, Agrawal and Seshadri 2000, Raz and Porteus 2006, Caro and Martínez-de Albéniz 2012, Caro and Gallien 2012). For example, Kocabıyıkoğlu et al. (2016) study price-setting newsvendors where the product demand is dictated by the uncertain market size and the retail price of the product, documenting significant deviations in their experimental observations from normative predictions. Furthermore, Ramachandran et al. (2017) thoroughly explore the behavioral drivers of joint price-quantity decisions within a centralized setting where the uncertain market (potential) can take one of two values. They experimentally demonstrate that joint price and quantity decisions can be affected by the anchoring behavior of the decision maker, exploring creative ways to improve joint decisions made within centralized settings. Motivated by these studies, we also investigate joint (quantity and price) decisions made within a centralized setting. We further introduce overconfidence into a decentralized setting, demonstrating that overconfidence affects the decentralized channel in non-intuitive ways.

3. Overconfident Centralized Channels

Consider a channel which produces a product at the unit cost $c(\geq 0)$ and then sells to end consumers at the unit price $p(\geq c)$ directly during a single period. This channel is managed by a single decision maker who decides the production quantity q and the unit retail price p before the customer demand is realized. We specify the random demand by stipulating an additive function of p as $X - bp$, where X is the market size taking either of two values $x_l(\geq 0)$ and $x_h(\geq x_l)$ with probabilities $1-\theta$ and θ respectively for $\theta \in [0,1]$, and $b \geq 0$. That is, x_h and x_l represent a good market and a bad market respectively. We assume that x_l is relatively large relatively to x_h, i.e., $\frac{x_l}{x_h} \geq \frac{\theta(4-\theta)}{4-\theta^2}$ as a sufficient condition, in order to avoid trivial cases with negative demands (see the proof of Lemma 1). This model reflects situations where firms must commit to their retail price in marketing actions such as promotions and advertisements before the market uncertainty is resolved (Emmons and Gilbert 1998, Petruzzi and Dada 1999).

The decision maker maximizes the channel's expected profit: $p\mathrm{E}[(X-bp)\wedge q]-cq$, where $x\wedge y=\min\{x,y\}$. A convenient expression for the channel's maximized profit can be obtained by working on the *stocking factor* $z:=q+bp$. The decision maker then solves:

$$\max_{z,p}\pi(z,p):=p\mathrm{E}(X\wedge z)-cz-bp(p-c). \tag{1}$$

This transformation of variables provides an alternative interpretation for the stocking decision: if the choice of z is larger than the realized value of X, then leftovers occur; if the choice of z is smaller than the realized value of X, then unsatisfied demands occur.

LEMMA 1 **(Ramachandran et al. 2017)**. *Define* $\tau:=\frac{\mu^2-x_l^2}{2(2x_h-x_l-\mu)b}$, *where* $\mu=E(X)$. *The optimal quantity and the optimal price are then:*

$$q^*=\begin{cases}\frac{2x_h-\mu-bc}{2}\\[2ex] \frac{x_l-bc}{2}\end{cases} \quad and \quad p^*=\begin{cases}\frac{\mu+bc}{2b}\\[2ex] \frac{x_l+bc}{2b}\end{cases} \quad if \quad \begin{cases}c\le\tau\\[2ex] c>\tau.\end{cases} \tag{2}$$

For the specification of demand uncertainty, if the cost of production is sufficiently low ($c\le\tau$), then the production quantity is relatively high. This is the case in which there is possible "overstocking," i.e., the production quantity is equal to the demand in the high state ($z=x_h$), but higher than the demand if the low state were to occur. We term this as the *overstocking* case. However, if the production cost is sufficiently high ($c>\tau$), the decision maker produces relatively low and the system possibly "understocks," i.e., the quantity produced by the channel is less than the demand in the high state, but equal to the demand in low state ($z=x_l$). We term this as the *understocking* case. This setting stems from Ramachandran et al. (2017), but we later extend it by evaluating a number of centralized and decentralized settings with overconfidence bias.

An overconfident decision maker exhibits cognitive bias by instead producing the product and setting the price *as though* the demand were D rather than the given X, where

$$D:=(1-\alpha)X+\alpha\mu, \tag{3}$$

for $\alpha\in[0,1]$. Consequently, D can take two values: $d_h:=(1-\alpha)x_h+\alpha\mu$ and $d_l:=(1-\alpha)x_l+\alpha\mu$ with probabilities θ and $1-\theta$ respectively. The parameter α can be interpreted as the overconfidence level. If $\alpha>0$, then it means that a decision maker is overconfident, behaving as though demand is less variable than is characterized by the given X. In the extreme $\alpha = 1$ denotes infinite overconfidence, meaning that the decision maker behaves as though demand is constant and equals to its mean. At the other extreme $\alpha = 0$ denotes a decision maker who is not at all overconfident. Ren and Croson (2013) and Ren et al. (2017) use data from procurement experiments to estimate the average level of overconfidence exhibited by participants, finding that the overconfidence level α can vary from 0.52 to 0.83. To contrast against overconfidence bias, we therefore refer to a decision maker defined by $\alpha = 0$ as an *unbiased* decision maker whose decisions are depicted in Lemma 1. Equation (3) has been used widely to model overconfidence bias. For example, it has been used to study situations in which agents tend to be overoptimistic regarding their likelihood of success (Van den Steen 2004), to study the optimal tariff design when consumers are overconfident (Grubb 2009). It also explains the pull-to-the-center phenomenon within a procurement setting (Ren and Croson 2013).

Given (3), an overconfident decision maker *behaves* as though it were maximizing:

$$p\mathrm{E}[(D - bp) \wedge q] - cq, \tag{4}$$

by setting the retail price p and the quantity q simultaneously in lieu of maximizing $p\mathrm{E}[(X - bp) \wedge q] - wq$. Analogous to the unbiased case, let $q + bp = (1-\alpha)z + \alpha\mu$. Then, the overconfident decision maker behaves as though it were solving $\max_{z,p}\ (1-\alpha)\pi(z,p) + \alpha(p-c)(\mu - bp)$. This is a weighted summation of the unbiased decision maker's objective function (i.e., $\pi(z,p)$), and profit without uncertainty (i.e., $(p-c)(\mu - bp)$) for which the optimal price is $p_n := \frac{\mu+bc}{2b}$ with the associated quantity $q_n := \mu - bp_n = \frac{\mu-bc}{2}$. Then, the production quantity and retail price without uncertainty are larger (resp. smaller) than those for the understocking (overstocking) case respectively, i.e., $\frac{2x_h-\mu-bc}{2} \geq q_n \geq \frac{x_l-bw}{2}$ and $\frac{\mu+bc}{2b} \geq p_n \geq \frac{x_l+bc}{2b}$. The stocking and pricing decisions for the overstocking (resp. understocking) case then follow the good (resp. bad) market situation and are higher (resp. lower) than those without uncertainty following the average market situation respectively.

LEMMA 2. *Define* $\hat{\tau}(\alpha) := \tau + \alpha\frac{(\mu-x_l)^2}{2(2x_h-x_l-\mu)b}$. *Given the market potential* X*:*

a) The decision maker described by the overconfidence parameter α sets its production quantity as $(1-\alpha)q^* + \alpha q_n$ and price as $(1-\alpha)p^* + \alpha p_n$. The stocking factor decreases in α when $c \le \hat{\tau}(\alpha)$ and increases in α when $c > \hat{\tau}(\alpha)$.

b) The centralized channel's resulting expected profit $\hat{\pi}^c(\alpha)$ is decreasing in α.

Analogous to the unbiased case (Lemma 1), if the production cost is sufficiently low ($c \le \hat{\tau}(\alpha)$), then the overconfident decision maker produces relatively high and is in the overstocking case ($z = x_h$). However, if the production cost is sufficiently high ($c > \hat{\tau}(\alpha)$), then the production quantity is relatively low and is in the understocking case ($z = x_l$). For both cases the biased production and price decisions are the weighted averages of the unbiased decisions and those without uncertainty. The overconfidence bias therefore pulls both the production and price decisions toward those without uncertainty. The stocking factor is similarly a linear function of its overconfidence level. Under the overstocking case, an overconfident decision maker sets its stocking factor lower relative to an unbiased decision maker, but always higher than the market mean. However, under the understocking case, the overconfident decision maker sets its stocking factor higher, but always lower than the market mean. This behavior is similar to the so-called pull-to-center (or mean anchoring) behavior observed in laboratory settings. For example, when using an overstocking (resp. understocking) case $x_h = 52, x_l = 22, b = 1, c = 8$, and $\theta = 0.5$ (resp. $\theta = 0.25$) as a simulated environment of our model, Ramachandran et al. (2017) find that the average sum of the stocking factors chosen by their subjects is 46.21. This falls short of (resp. ascends) the optimal level of 52 (resp. 22), helping validate our model. Moreover, Lemma 2b indicates that a channel's expected profit decreases with its overconfidence level α.

4. Overconfident Decentralized Channels

We now develop a decentralized analog for the centralized channel in §3 where each unit of the product is produced by a manufacturer at a unit production cost c and is sold to customers by a retailer for a unit retail price p. The manufacturer first decides the unit wholesale price w it charges the retailer; the retailer then decides the order quantity q purchased from the manufacturer and the retail price p charged to consumers. Adopting this wholesale price contract setting is frequently implemented in practice and commonly used in the literature (Lariviere and Porteus 2001); its rationalization is also addressed in the literature (Iyer and Villas-Boas 2003). See Figure 1 for a graphic illustration of the setting and key parameters.

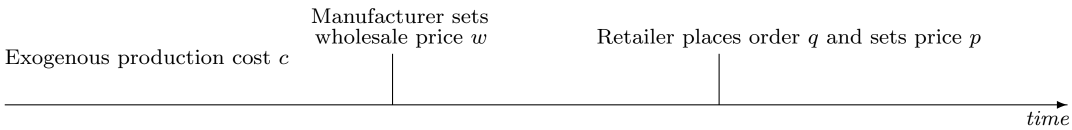


Figure 1 The model setting and the sequence of events.

As in the centralized channel, we first analyze the case of the *unbiased* channel where the retailer's decisions are as described by Lemma 4 but replacing c with w. On the one hand, if the wholesale price is relatively low ($w \leq \tau$) it is the overstocking case with optimal ordering quantity $\frac{2x_h-\mu-bw}{2}$. For this to be the equilibrium it must be the case where the retailer has no incentive to deviate toward any other order quantity and retail price given the wholesale price. The manufacturer's problem is therefore $\max_w (w-c)\frac{2x_h-\mu-bw}{2}$ subject to the retailer gaining at least as much profit as is available from the best possible deviation. On the other hand, if the wholesale price is relatively high ($w > \tau$), then it is the understocking case with the optimal ordering quantity $\frac{x_l-bw}{2}$. For this case to be the equilibrium the manufacturer's problem is accordingly $\max_w (w-c)\frac{x_l-bw}{2}$, again subject to the retailer gaining at least as much profit as the best possible deviation. Lemma 3 next depicts the equilibrium decision for the unbiased channel.

LEMMA 3. *a) For the unbiased decentralized channel, there exist unique production costs $c_l(>0)$ and $c_h(>c_l)$ such that the equilibrium wholesale price is*

$$\begin{cases} w_o := \frac{2x_h-\mu+bc}{2b} & \text{if } c \leq c_l \\ \tau \;= \frac{\mu^2-x_l^2}{2(2x_h-x_l-\mu)b} & \text{if } c_l < c \leq c_h \\ w_u := \frac{x_l+bc}{2b} & \text{if } c \geq c_h. \end{cases} \tag{5}$$

b) The resulting equilibrium retail price and order quantity in the decentralized channel are higher and lower than in the centralized channel respectively.

The manufacturer's equilibrium choice is therefore the *overstocking equilibrium* when the production cost is relatively low ($c \leq c_l$). In this equilibrium, the manufacturer is able to take advantage of the upside market if the high demand state is realized, which is significant when the production cost is relatively low. However, the *understocking equilibrium* is relatively desirable for the manufacturer when his production cost is high ($c > c_h$) where the stock fails to capitalize on the upside potential of a good market. When the production cost is relatively moderate ($c_l < c \leq c_h$), the manufacturer charges a wholesale price to prevent the retailer's leapfrogging from an overstocking to understocking equilibrium. We call this as *leapfrogging equilibrium*. Lemma 3b further shows that the retailer sets a higher retail price while placing a lower order than its centralized counterpart regardless of the equilibrium type. This is because the manufacturer would always charge a wholesale price higher than his production cost; this is a manifestation of the famous double marginalization effect for decentralized channels (Spengler 1950).

Note that, for the special case without uncertainty, the manufacturer's problem is $\max_w (w - c)\frac{\mu - bw}{2}$ with the optimal wholesale price $w_n := \frac{\mu + bc}{2b}$. Intuitively speaking, the manufacturer's pricing power over the retailer is affected by the retailer's ordering decision such that the higher retailer's order, the higher manufacturer's pricing power. In the overstocking (resp. understocking) equilibrium, the retailer's order $\frac{2x_h - \mu - bw}{2}$ (resp. $\frac{x_l - bw}{2}$) is more (resp. less) than the order $\frac{\mu - bw}{2}$ without uncertainty. The wholesale price w_n is consequently higher than the understocking case ($w_n > w_u$) while lower than the overstocking case ($w_n < w_o$).

We now incorporate the notion of overconfidence bias from the centralized analog (§3) into the decentralized channel. Recall that overconfidence is a cognitive bias where decision makers behave as though the market is less variable than specified by its given distribution. The overconfident channel therefore behaves as though operating within random market D instead of X as shown in (3). From the manufacturer's perspective, the retailer's ordering and pricing behaviors are characterized in Lemma 2 except replacing c with w. The manufacturer's problem is

$$\hat{\pi}_M(\alpha) := \max_{w} \ (w-c)\hat{q}(\alpha, w), \tag{6}$$

where

$$\hat{q}(\alpha, w) = \begin{cases} \frac{2d_h-\mu-bw}{2} & \text{if } w \le \hat{\tau}(\alpha) \\ \frac{d_l-bw}{2} & \text{if } w > \hat{\tau}(\alpha), \end{cases} \tag{7}$$

when the price is

$$\hat{p}(\alpha, w) = \begin{cases} \frac{\mu+bw}{2b} & \text{if } w \le \hat{\tau}(\alpha) \\ \frac{d_l+bw}{2b} & \text{if } w > \hat{\tau}(\alpha). \end{cases} \tag{8}$$

Note that here overconfidence biases are assumed to be symmetric across both the manufacturer and retailer. This assumption is relaxed in §§5-7; see Table 1 for various models.

	Unbiased Manufacturer	Biased Manufacturer
Unbiased Retailer	Unbiased Channel (§4)	Biased Manufacturer (§6)
Biased Retailer	Biased Retailer (§5)	Symmetric Overconfidence (§4) Asymmetric Overconfidence (§7)

Table 1 Our Main Models.

Lemma 4. *For the decentralized channel described by overconfidence parameter α, there exist $\hat{c}_l(\alpha)$ and $\hat{c}_h(\alpha)$ such that $\hat{c}_h(\alpha) > \hat{c}_l(\alpha)$. Moreover, the equilibrium wholesale price is*

$$\hat{w}(\alpha) = \begin{cases} (1-\alpha)w_o + \alpha w_n & \textit{if } \ c \le \hat{c}_l(\alpha) \\ \tau + \alpha \frac{(\mu-x_l)^2}{2(2x_h-x_l-\mu)b} & \textit{if } \ \hat{c}_l(\alpha) < c \le \hat{c}_h(\alpha) \\ (1-\alpha)w_u + \alpha w_n & \textit{if } \ c > \hat{c}_h(\alpha). \end{cases}$$

Lemma 4 extends the unbiased channel case (Lemma 3) in the sense that a biased decentralized channel also has overstocking, leapfrogging, and understocking equilibria, depending on the production cost value. It further extends the case for a biased centralized channel (Lemma 2) in the sense that the equilibrium wholesale price boils down to a weighted average of the wholesale price without bias (w_o or w_u) and the wholesale price without uncertainty (w_n) in both the understocking and overstocking equilibria. The distortion from overconfidence is therefore such that the equilibrium wholesale price increases (resp. decreases) linearly with respect to the overconfidence parameter α if the equilibrium wholesale price for the unbiased decision maker is greater (resp. smaller) than the optimal wholesale price without uncertainty. This implies that, for the overstocking equilibrium ($w_o > w_n$), the manufacturer's equilibrium wholesale price $\hat{w}(\alpha)$ decreases with the overconfidence level α. This is because the retailer tends to purchase a lower quantity from the manufacturer when the overconfidence level is higher (§3). In this sense, when the channel becomes more overconfident, the retailer's demand for the manufacturer's product becomes lower, and consequently, the manufacturer's pricing over the retailer is lower. However, for the understocking equilibrium ($w_u < w_n$), the manufacturer's equilibrium wholesale price $\hat{w}(\alpha)$ increases in α. Intuitively, for the understocking case, overconfidence bias leads to an increased order from the retailer (§3), enhancing the manufacturer's pricing power over the retailer.

Given the equilibrium wholesale price $\hat{w}(\alpha)$, the retailer's equilibrium order quantity is

$$\hat{q}(\alpha) := \hat{q}(\alpha, w = \hat{w}(\alpha)) = \begin{cases} \frac{2d_h - \mu - bc}{4} & \text{if } \ c \leq \hat{c}_l(\alpha) \\ \frac{2d_h - \mu - b\tau}{2} - \alpha \frac{(\mu - x_l)^2}{8x_h - 4(x_l + \mu)} & \text{if } \ \hat{c}_l(\alpha) < c \leq \hat{c}_h(\alpha) \\ \frac{d_l - bc}{4} & \text{if } \ c > \hat{c}_h(\alpha), \end{cases} \tag{9}$$

and the equilibrium price is

$$\hat{p}(\alpha) = \hat{p}(\alpha, w = \hat{w}(\alpha)) = \begin{cases} \frac{\mu + 2d_h + bc}{4b} & \text{if } \ c \leq \hat{c}_l(\alpha) \\ \frac{\mu + b\tau}{2b} + \alpha \frac{(\mu - x_l)^2}{4(2x_h - x_l - \mu)b} & \text{if } \ c_l(\alpha) < c \leq \hat{c}_h(\alpha) \\ \frac{3d_l + bc}{4b} & \text{if } \ c > \hat{c}_h(\alpha), \end{cases} \tag{10}$$

where $\hat{q}(\alpha, w)$ and $\hat{p}(\alpha, w)$ are from (7) and (8) respectively. Consequently, the ensuing retailer's equilibrium profit is

$$\hat{\pi}_R(\alpha) := \hat{p}(\alpha)\mathrm{E}[(X - b\hat{p}(\alpha)) \wedge \hat{q}(\alpha)] - \hat{w}(\alpha)\hat{q}(\alpha). \tag{11}$$

We next investigate the impact of overconfidence on the manufacturer's profit $\hat{\pi}_M(\alpha)$ as defined in (6), and the retailer's expected profit $\hat{\pi}_R(\alpha)$ defined above.

Proposition 1. *In the leapfrogging equilibrium where $\hat{c}_l(\alpha) < c \leq \hat{c}_h(\alpha)$, both the manufacturer's and retailer's equilibrium expected profits are decreasing in α. However:*

a) In the understocking equilibrium where $c > \hat{c}_h(\alpha)$, the retailer's expected profit $\hat{\pi}_R(\alpha)$ is decreasing in α, while the manufacturer's profit $\hat{\pi}_M(\alpha)$ is increasing in α.

b) In the overstocking equilibrium where $c \leq \hat{c}_l(\alpha)$, the manufacturer's equilibrium expected profit $\hat{\pi}_M(\alpha)$ is decreasing in α, while the retailer's expected profit $\hat{\pi}_R(\alpha)$ is increasing in α.

Overconfidence is always harmful for both the manufacturer and retailer in the leapfrogging equilibrium. In such a case, the qualitative effect on the manufacturer and retailer with the decentralized channel is accordingly analogous to that of the centralized channel. However, Proposition 1a shows that in the understocking equilibrium the manufacturer's profit $\hat{\pi}_M(\alpha)$ increases in α, meaning that the overconfidence bias can actually enhance the manufacturer's performance. If the channel is in an understocking situation and becomes more overconfident, then the manufacturer would charge a higher wholesale price (Lemma 4), which has a positive effect on the manufacturer's profit.

As per Proposition 1b, in the overstocking equilibrium, the impact of overconfidence on the manufacturer's equilibrium profit $\hat{\pi}_M(\alpha)$ is qualitatively similar to that in the centralized analog, albeit for a different reason. Overconfidence translates into a decreased operational efficiency within the centralized channel, whereas it translates into decreasing wholesale pricing for the manufacturer within the decentralized channel. Proposition 1b also shows that the retailer's expected profit $\hat{\pi}_R(\alpha)$ is increasing in α, meaning that the retailer would benefit from overconfidence bias. For insights, there are two drivers at play for the impact of α on the retailer's profit $\hat{\pi}_R(\alpha)$ for the overstocking equilibrium case. One driver, a direct driver, is the effect of α on the retailer's equilibrium expected profit for a given wholesale price. According to Lemma 2, the higher α, the lower the retailer's profit. The direct effect of α is accordingly such that overconfidence is a negative force on the retailer's profit because it converts the retailer to make non-optimal decisions, everything else being equal. The second driver, however, is an indirect driver. As per Proposition 4, a higher α translates into a lower wholesale price $\hat{w}(\alpha)$ for the overstocking equilibrium that in turn leads to a higher expected profit for the retailer according to (11). All told, the final effect on the retailer's expected profit depends on the relative impact of these two forces; the positive driver (a reduced wholesale price) outweighs the negative driver (a reduced operational efficiency) in the overstocking equilibrium.

For both the overstocking and understocking equilibria, we find that overconfidence within the decentralized channel stimulates an intra-channel trade-off for the firms. With overconfidence, the expected mismatch cost is increased, but that increasing cost can provide the manufacturer (resp. retailer) with the benefit of a higher (resp. lower) wholesale price for the understocking (resp. overstocking) equilibrium. Thus, for both the overstocking equilibrium and the understocking equilibrium, we find that $\hat{\pi}_M(\alpha)$ and $\hat{\pi}_R(\alpha)$ are both monotone in α. That is, overconfidence results in a win-lose situation in the sense even though overconfidence benefits the manufacturer (resp. retailer), it does so at the expense of the retailer (resp. manufacturer). Given these observations and those from §3 on the centralized channel we are particularly interested in the channel profit $\hat{\pi}_T(\alpha) := \hat{\pi}_M(\alpha) + \hat{\pi}_R(\alpha)$.

PROPOSITION 2. *Given a decentralized channel characterized by overconfidence parameter* α*,* $\hat{\pi}_T(\alpha)$ *always decreases in* α *in the leapfrogging equilibrium where* $\hat{c}_l(\alpha) < c \leq \hat{c}_h(\alpha)$*. However:*

a) In the overstocking equilibrium, $\hat{\pi}_T(\alpha)$ *increases in* α *when* $c > \frac{(4\theta-2)d_h-(1-\theta)(\mu-2x_l)}{(3-\theta)b}$.

b) In the understocking equilibrium, $\hat{\pi}_T(\alpha)$ *increases in* α *when* $c < \frac{6(1-\theta)x_l+(12\theta-9)d_l}{(5-2\theta)b}$.

To understand and explore the intuition behind Proposition 2, we recall that for the unbiased centralized channel, a central planner maximizes the combined expected profits of the manufacturer and retailer in order to determine the first-best quantity q^* and price p^* characterized by (2). Intuitively, the performance of the decentralized channel depends on the relationship between the equilibrium order quantity $\hat{q}(\alpha)$ (resp. price $\hat{p}(\alpha)$) and system-wide first-best order quantity q^* (resp. price p^*). The closer is $\hat{q}(\alpha)$ (resp. $\hat{p}(\alpha)$) to q^* (resp. p^*), the better is the equilibrium performance of the decentralized channel. We accordingly plot these quantities and prices in Figure 2. From this figure, q^* (resp. p^*) is always higher (resp. lower) than $\hat{q}(\alpha)$ (resp. $\hat{p}(\alpha)$) if the channel were unbiased ($\alpha = 0$); see Lemma 3b. Moreover, $\hat{q}(\alpha)$ and $\hat{p}(\alpha)$ vary for $\alpha \in [0, 1]$. This is formalized in Lemma 5.

LEMMA 5. *For the overconfident channel described by the overconfidence parameter* α*, the following relationships hold:*

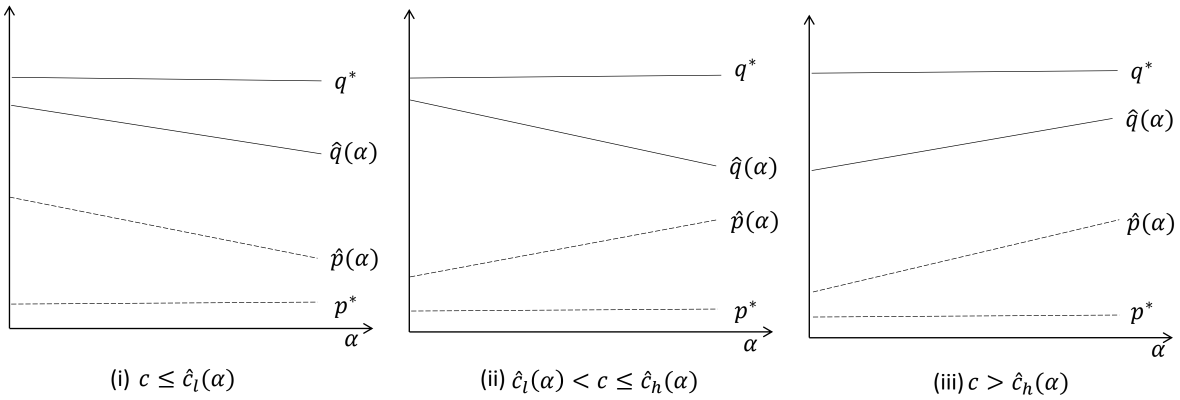


Figure 2 **The quantities and prices of the biased decentralized channel versus the unbiased centralized channel.**

$$\hat{q}'(\alpha) \left\{ \begin{array}{c} \leq \\ \leq \\ \geq \end{array} \right\} 0 \ and \ \hat{p}'(\alpha) \left\{ \begin{array}{c} \leq \\ \geq \\ \geq \end{array} \right\} 0, \ \ if \ \left\{ \begin{array}{r} c \leq \hat{c}_l(\alpha) \\ \hat{c}_l(\alpha) < c \leq \hat{c}_h(\alpha) \\ c > \hat{c}_h(\alpha). \end{array} \right.$$

When the channel is in the overstocking (resp. understocking) equilibrium, both $\hat{q}(\alpha)$ and $\hat{p}(\alpha)$ therefore decrease (resp. increase) in the overconfidence level α. This means that overconfidence leads to a lower (resp. higher) quantity and price for the overstocking (resp. understocking) equilibrium. This is qualitatively consistent with the centralized channel (Lemma 2). In the leapfrogging equilibrium, $\hat{q}(\alpha)$ decreases in α, consistent with the overstocking equilibrium. However, $\hat{p}(\alpha)$ increases in α so that the retail price becomes higher as the channel becomes more biased. This is because the manufacturer would charge a higher wholesale price as the channel becomes more overconfident in the leapfrogging equilibrium (Lemma 4).

This therefore means that decentralization within the distribution channel can be interpreted as a lens creating distortions for the quantity and price that the (unbiased) central planner would assess. In a similar vein, overconfidence affects an analogous distortion, and interestingly, can exact a counterbalance for the distortion of the decentralization. As illustrated by Figure 2, for the overstocking (resp. understocking) equilibrium, the retailer would price lower (resp. order higher) as the channel becomes more overconfident. This can be a counterbalance to the double marginalization effect producing an increased retail price with a decreasing order for the decentralized versus centralized channel. However, in the leapfrogging equilibrium, overconfidence implies both a higher retail price and a low order, which exacerbates the double marginalization effect. As a result, in both the overstocking and understocking (not the leapfrogging) equilibria, overconfidence can be a counterbalance for the double marginalization effect, benefiting the channel as a whole.

PROPOSITION 3. *For any* α, $\hat{\pi}_T(\alpha) \geq \hat{\pi}_T(0)$ *holds in the following conditions:*
(a) When $\theta < \frac{3}{4}$ *while* $c_h < c < \frac{3[x_l(1-\theta)(4\theta-1)-x_h(3-4\theta)\theta]}{(5-2\theta)b}$. *(b) When* $\theta > \frac{3}{4}$ *while* $c_h < c < \frac{3(2\theta-1)x_l}{(5-2\theta)b}$.

Proposition 3 shows that the profit of the overconfident decentralized channel $\hat{\pi}_T(\alpha)$ can be higher than the performance of the unbiased decentralized channel $\hat{\pi}_T(0)$. Overconfidence can therefore improve the performance of the overconfident decentralized channel (Proposition 2) to the extent that the biased channel outperforms the unbiased channel. This result again hinges on the fact that overconfidence can reduce the double marginalization effect of the decentralization channel. We further illustrate this result by plotting $\hat{\pi}_T(\alpha)$ in Figure 3 for two specific examples. In example (a), $\theta = 0.7 < \frac{3}{4}$ and $c_h = 4.7 < c = 5$ where c_h is from the proof of Lemma 3, while $\frac{3[x_l(1-\theta)(4\theta-1)-x_h(3-4\theta)\theta]}{5-2\theta} = 6.53 > c = 5$. However, in example (b), $\theta = 0.9 > \frac{3}{4}$, $c_h = 14.9 < c = 15$ while $\frac{3(2\theta-1)x_l}{5-2\theta} = 15.2 > c = 15$. Consequently, Proposition 3 implies that $\hat{\pi}_T(\alpha) \geq \hat{\pi}_T(0)$ for any α; in these two examples the biased decentralized channel can reap more than its unbiased analog when its overconfidence level falls into the estimated value range in the literature (Ren and Croson 2013).

5. Overconfident Retailer

In this section, we investigate a case where the manufacturer is unbiased while the retailer is the only overconfident firm. The objective of this section is two-fold: (i) to check the robustness of the key insights in §4 and (ii) to derive insights from retailer overconfidence alone.

When the manufacturer is unbiased, then the manufacturer's pricing behavior is prescribed by the standard theory. The manufacturer's wholesale price decision accordingly follows Lemma 3: if the production cost is relatively low ($c \leq c_l$), then the wholesale price is w_o, whereas if the production cost is relatively high ($c > c_h$), then the equilibrium wholesale price is w_u. For a retailer with

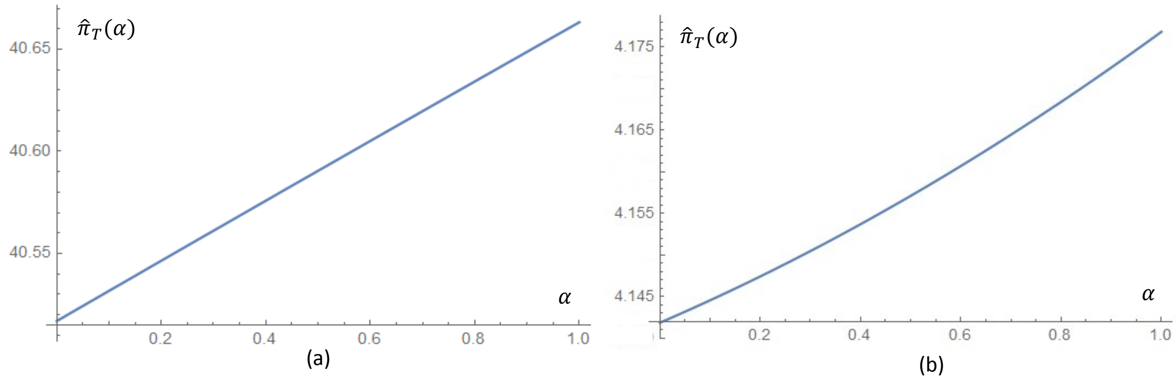


Figure 3 The channel's equilibrium profit when $x_h = 20$ and $x_l = 19.7$. For case (a), $\theta = 0.7$, and $c = 5$, whereas for case (b), $\theta = 0.91$ and $c = 15$.

an overconfidence parameter α, her equilibrium order quantity is $\hat{q}(\alpha, \hat{w}(0))$ and the equilibrium retail price is $\hat{p}(\alpha, \hat{w}(0))$, where $\hat{q}(\alpha, w)$ and $\hat{p}(\alpha, w)$ are from (7) and (8) respectively. The ensuing manufacturer's equilibrium profit is then:

$$\tilde{\pi}_M(\alpha) := [\hat{w}(0) - c]\hat{q}(\alpha, \hat{w}(0)), \tag{12}$$

while the retailer's equilibrium profit is

$$\tilde{\pi}_R(\alpha) := \hat{p}(\alpha, \hat{w}(0))\mathrm{E}[(X - b\hat{p}(\alpha, \hat{w}(0))) \wedge \hat{q}(\alpha, \hat{w}(0))] - \hat{w}(0)\hat{q}(\alpha, \hat{w}(0)). \tag{13}$$

As in §4, we next study how the channel profit $\tilde{\pi}_T(\alpha) := \tilde{\pi}_M(\alpha) + \tilde{\pi}_R(\alpha)$ changes with respect to the retailer's overconfidence bias parameter α.

PROPOSITION 4. *When the manufacturer is unbiased while the retailer is biased as described by overconfidence parameter α, then the channel profit $\tilde{\pi}_T(\alpha)$ decreases in α when $c \le c_l$, whereas $\tilde{\pi}_T(\alpha)$ can increase in α when $c > c_h$.*

Proposition 4 indicates that retailer overconfidence is always harmful for the channel when the production cost is relatively low ($c \le c_l$). For such a condition, however, the channel is not necessarily hurt by overconfidence bias when the manufacturer is also biased (Proposition 2). This is because $c \le c_l$ is a situation where overconfidence bias leads to a decreasing wholesale price in Proposition 2. However, the unbiased manufacturer does not reduce his wholesale price as the retailer becomes more biased in Proposition 4. Moreover, as in Proposition 2, Proposition 4 indicates that retailer overconfidence can benefit the distribution channel when the production cost is relatively high ($c > c_h$). Under such a situation, we next show that retailer overconfidence can in fact benefit the manufacturer.

PROPOSITION 5. *When the manufacturer is unbiased while the retailer is overconfident as described by overconfidence parameter α, then the retailer's profit $\tilde{\pi}_R(\alpha)$ always decreases in α. However, the manufacturer's profit $\tilde{\pi}_M(\alpha)$ can increase in α when $c > c_h$.*

Although retailer overconfidence always leads to self-harm, it can be a positive force for the manufacturer when the production cost is relatively high ($c > c_h$). This is qualitatively consistent with Proposition 1. If the gain from an increasing order quantity outweighs the loss due to the retailer overconfidence, then the channel performance as a whole improves (Proposition 4). Rather, if overconfidence bias leads to a lower order quantity, for example, when the production cost is moderate (see Figure 2), then overconfidence would hurt both the manufacturer and the channel.

6. Overconfident Manufacturer

In parallel to §5, we now investigate the case where the manufacturer is biased while the retailer is unbiased in order to study the impact of manufacturer overconfidence. If the manufacturer's overconfidence level is α, then the equilibrium order quantity and retail price are $\hat{q}(0, \hat{w}(\alpha))$ and $\hat{p}(0, \hat{w}(\alpha))$, where $\hat{q}(\alpha, w)$ and $\hat{p}(\alpha, w)$ are from (7) and (8) respectively. Consequently, the ensuing manufacturer's equilibrium profit is

$$\breve{\pi}_M(\alpha) := [\hat{w}(\alpha) - c]\hat{q}(0, \hat{w}(\alpha)), \tag{14}$$

while the retailer's equilibrium profit is

$$\breve{\pi}_R(\alpha) := \hat{p}(0, \hat{w}(\alpha))\mathrm{E}[(X - b\hat{p}(0, \hat{w}(\alpha))) \wedge \hat{q}(0, \hat{w}(\alpha))] - \hat{w}(\alpha)\hat{q}(0, \hat{w}(\alpha)). \tag{15}$$

Given (14)-(15), we next study how the channel profit $\breve{\pi}_T(\alpha) := \breve{\pi}_M(\alpha) + \breve{\pi}_R(\alpha)$ changes with respect to α.

Proposition 6. *When the retailer is unbiased while the manufacturer is described by overconfidence parameter α, then the channel's profit $\breve{\pi}_T(\alpha)$ decreases in α when $c > c_h$, whereas $\breve{\pi}_T(\alpha)$ can increase in α when $c \le c_l$.*

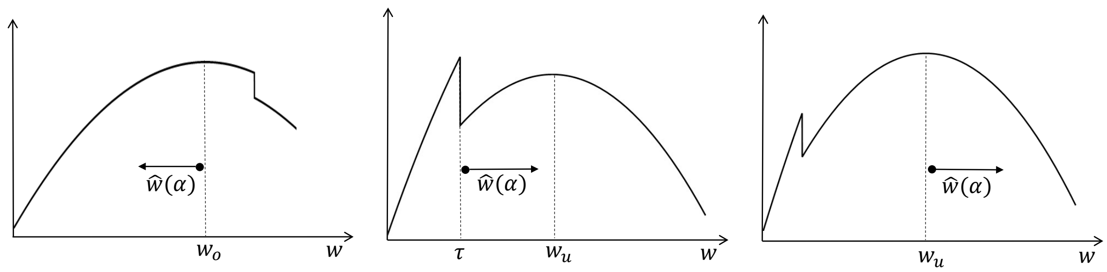
Proposition 6 is consistent with Propositions 2-4 in the sense that overconfidence bias can benefit the distribution channel as a whole. Manufacturer overconfidence specifically harms the channel when the production cost is relatively high ($c > c_h$), but can benefit the channel when the production cost is relatively low ($c \le c_l$), where the wholesale price can be reduced by overconfidence. Thus, for a moderate production cost, overconfidence always increases the wholesale price (Lemma 4), and consequently would hurt the channel.

Proposition 7. *When the retailer is unbiased while the manufacturer is biased with overconfidence parameter α:*

a) The manufacturer's profit $\breve{\pi}_M(\alpha)$ always decreases in α either when $c \le c_l$ or when $c > c_h$. However, the manufacturer's profit $\breve{\pi}_M(\alpha)$ can increase in α when $c_l < c \le c_h$.

b) The retailer's profit $\breve{\pi}_R(\alpha)$ decreases in α when $c > c_h$, whereas $\breve{\pi}_R(\alpha)$ increases in α when $c \le c_l$. Moreover, $\breve{\pi}_R(\alpha)$ decreases in α under the condition in a) where $\breve{\pi}_M(\alpha)$ increases in α.

In contrast to retailer overconfidence (Proposition 5), manufacturer overconfidence does not necessarily lead to self-harm. The manufacturer can benefit from his own bias when the production cost is relatively moderate ($c_l < c \le c_h$). This is interesting because, when the manufacturer is unbiased, the manufacturer can perfectly foresee the retailer's response to his wholesale price, and he accordingly decides the optimal wholesale price to charge. However, as the manufacturer becomes more biased, the manufacturer's wholesale price becomes more biased, i.e., the wholesale price $\hat{w}(\alpha)$ deviates more from the unbiased wholesale price $\hat{w}(0)$. We plot how $\hat{w}(\alpha)$ changes as α increases, as well as how the unbiased manufacturer's profit changes with respect to his wholesale price in Figure 4. From this figure, there are three cases for the manufacturer's profit. For a relatively low (resp. high) production cost, i.e., $c \le c_l$ (resp. $c > c_h$), the channel is in the overstocking (understocking) equilibrium. As the manufacturer becomes more biased, the manufacturer would charge a lower (resp. higher) wholesale price, harming his own performance. However, when the production cost is relatively moderate ($c_l < c \leq c_h$), as the manufacturer becomes more biased, then his wholesale price $\hat{w}(\alpha)$ increases. This increases the manufacturer's profit, particularly when $\hat{w}(\alpha) \in [\tau, w_u]$.



(a) $c \leq c_l$ (b) $c_l < c \leq c_h$ (c) $c > c_h$

Figure 4 **The manufacturer's profit with respect to his wholesale price $\hat{w}(\alpha)$, and how $\hat{w}(\alpha)$ changes with respect to α.**

Furthermore, Proposition 7b shows that the retailer benefits from the manufacturer overconfidence when the production cost is relatively low ($c \leq c_l$) because the manufacturer would charge a lower wholesale price as he becomes more overconfident. Proposition 7b therefore has two key managerial implications, along with Proposition 7a. First, for a relatively low production cost ($c \leq c_l$), if the benefit of manufacturer overconfidence outweighs its harm, the manufacturer overconfidence can benefit the entire channel. This helps explain Proposition 6. Second, even if manufacturer overconfidence benefits the manufacturer, this benefit comes at the retailer's expense. Manufacturer overconfidence never results in a mutually beneficial situation; however, this is not an absolute as shown below.

7. Overconfident Manufacturer and Overconfident Retailer

We now extend our analysis to allow both manufacturer and retailer overconfidence simultaneously, denoting their levels as α_m and α_r respectively where $\alpha_m, \alpha_r \in [0, 1]$. Given the random variable X in order to characterize the market size, the manufacturer and retailer both behave as though the random market is instead $D(\alpha_m)$ and $D(\alpha_r)$ respectively, where $D(\alpha_m) := (1 - \alpha_m)X + \alpha_m \mu$ and

$D(\alpha_r) := (1-\alpha_r)X + \alpha_r\mu$. Consequently, the manufacturer behaves as though its game with the retailer were described by

$$\max_{w}\ (w-c)\hat{q}(\alpha_m, w), \tag{16}$$

and

$$\max_{p,q}\ p\mathrm{E}[(D(\alpha_m) - bp) \wedge q] - wq. \tag{17}$$

The manufacturer therefore behaves as though it solves (16) by anticipating the retailer's problem (17), deriving the equilibrium wholesale price $\hat{w}(\alpha_m)$. The manufacturer sets the wholesale price as $\hat{w}(\alpha_m)$ while anticipating the retailer to order $\hat{q}(\alpha_m, w)$ as from (17).

Given the wholesale price $\hat{w}(\alpha_m)$, analogous to (4), the retailer actually behaves as though solving

$$\max_{p,q}\ p\mathrm{E}[(D(\alpha_r) - bp) \wedge q] - \hat{w}(\alpha_m)q \tag{18}$$

with the resulting order quantity $\hat{q}(\alpha_r, w = \hat{w}(\alpha_m))$ along with the retail price $\hat{p}(\alpha_r, w = \hat{w}(\alpha_m))$. This means that although (16)-(18) effectively describe how firms behave given X, the manufacturer's and retailer's resulting equilibrium expected profits are

$$\pi_M(\alpha_m, \alpha_r) := [\hat{w}(\alpha_m) - c]\hat{q}(\alpha_r, \hat{w}(\alpha_m)) \tag{19}$$

and

$$\pi_R(\alpha_m, \alpha_r) := \hat{p}(\alpha_r, \hat{w}(\alpha_m))\mathrm{E}[(X - b\hat{p}(\alpha_r, \hat{w}(\alpha_m))) \wedge \hat{q}(\alpha_r, \hat{w}(\alpha_m))] - \hat{w}(\alpha_m)\hat{q}(\alpha_r, \hat{w}(\alpha_m)) \tag{20}$$

respectively. Note that, when $\alpha_m = \alpha_r$, $\alpha_r > \alpha_m = 0$, and $\alpha_m > \alpha_r = 0$, the setting described by (19)-(20) reduces to the case in §4, §5 and §6, respectively. The main insights in §§4-6 that overconfidence can be a positive force for the distribution channel as well as individual firms therefore continuously hold in this general model. Thus, we are particularly interested in identifying the circumstances under which a mutually beneficial outcome is possible due to overconfidence, which does not prevail in previous cases (§§4-6).

PROPOSITION 8. *When both the manufacturer and retailer are overconfident, then retailer overconfidence never benefits both the manufacturer and retailer simultaneously. However, the manufacturer's profit $\pi_M(\alpha_m, \alpha_r)$, retailer's profit $\pi_R(\alpha_m, \alpha_r)$, and channel's profit increase in α_m when $c \leq \hat{c}_l(\alpha_m)$ and $\alpha_m < \alpha_r$.*

Although retailer overconfidence does not lead to a mutually beneficial outcome, manufacturer overconfidence does. The impact of manufacturer overconfidence depends on the relative value of manufacturer and retailer bias. When $\alpha_m < \alpha_r$, then a higher level of manufacturer overconfidence means that the level of manufacturer overconfidence is closer to that of retailer overconfidence. The manufacturer's anticipated order from the retailer is consequently less distorted from the retailer's real order. Furthermore, if the production cost is relatively low ($c \leq \hat{c}_l(\alpha_m)$), then manufacturer overconfidence can lead to a less generous wholesale price that hurts the retailer. In summary, when the production cost is relatively low while the manufacturer is less overconfident than the retailer, then both firms (and consequently the distribution channel) ironically benefit from manufacturer overconfidence.

8. Impacts of Production Costs

In this section, we investigate more broad implications of overconfidence on manufacturer sourcing. The common wisdom is that the manufacturer's profit always decreases in his production cost. However, we next demonstrate that the biased manufacturer can actually benefit from a higher production cost.

PROPOSITION 9. *For any overconfidence level α, the manufacturer's profit $\hat{\pi}_M(\alpha)$ defined in* (6) *always decreases in his own production cost c. However, the manufacturer's profit $\tilde{\pi}_M(\alpha)$ defined in* (12) *can increase in c.*

When the manufacturer and the retailer are symmetrically biased (§4), then the manufacturer's profit $\hat{\pi}_M(\alpha)$ always decreases in his own production cost c. However, when the manufacturer is unbiased while the retailer is biased (§5), then the manufacturer's profit $\tilde{\pi}_M(\alpha)$ can increase in his own production cost. We illustrate this using a special case of $\alpha = 1$ in Figure 5. In this figure, the equilibrium wholesale price $\hat{w}(0)$ follows (5). That is, $\hat{w}(0) = w_u$ is an inner solution when $c > c_h$, whereas $\hat{w}(0) = \tau$ is a corner solution when $c \le c_h$ where the manufacturer charges low in order to prevent the understocking by the retailer. Consequently, $\hat{w}(0)$ jumps around $c = c_h$ as indicated in Figure 5. As a result, $\tilde{\pi}_M(1)$ also increases around $c = c_h$, meaning the manufacturer benefits from an increasing production cost. Intuitively speaking, a higher production cost implies a higher wholesale price, which can be a counterbalance to the manufacturer's biased wholesale price. Note that Tomlin (2006) shows that a more expensive supply option is preferred if it provides a faster delivery or better reliability. Tereyağoğlu and Veeraraghavan (2012) show that the manufacturer may choose an expensive option to credibly commit to scarcity in the presence of conspicuous consumption. Proposition 9 helps provide one more reason on why the manufacturer may prefer a high production cost.

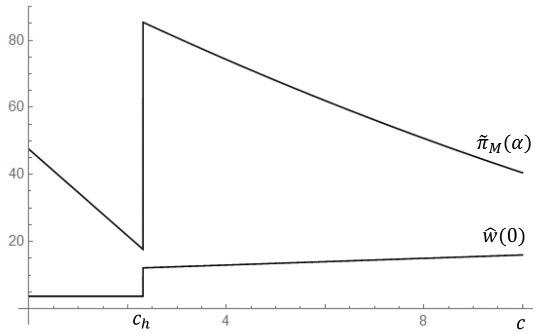


Figure 5 **The unbiased manufacturer's profit $\tilde{\pi}_M(\alpha)$ and wholesale price $\hat{w}(0)$ for the case of $\alpha = 1$, $x_h = 52$, $x_l = 22$, $\theta = 0.25$, and $b = 1$.**

9. Concluding Remarks

We study the local and global effects of overconfidence within a decentralized channel, and show that overconfidence can actually benefit, rather than hurt, channel members and even the channel as a whole. In particular, (i) firms in the decentralized channel and the decentralized channel as a whole can be better off as the channel becomes more overconfident. (ii) Although retailer overconfidence always leads to self-harm, manufacturer overconfidence can actually benefit the manufacturer, depending on the production cost. (iii) Manufacturer overconfidence can potentially benefit both the manufacturer and the retailer, depending on the level of retailer overconfidence.

Our analysis rests on two key assumptions. First, we assume that the retailer is a price-setter, i.e., the retail price is endogenously determined by the retailer. Alternatively, to expand the scope of our model, we employ a price-taking retailer to study the impacts of overconfidence in Appendix EC.1. Second, we adopt one specific type of decision bias (overconfidence) and study its impacts within a decentralized channel. Although this particular form of decision bias is widely observed in practice and has been experimentally validated in related settings (Moore and Healy 2008, Haran et al. 2010, Ren and Croson 2013, Lee and Siemsen 2016), we acknowledge that there exist other viable forms of decision bias such as anchoring that could be adopted instead; this is discussed in Appendix EC.2. In completing these two extensions, we find that, qualitatively consistent with the results of this paper, overconfidence ultimately can result in both firm-win and channel-win scenarios (Propositions EC.1-EC.8).

9.1. Managerial Insights

We hope that our results are of value for firms adopting strategies tied to overconfidence. Prior behavior research suggests that overconfidence bias is detrimental. This has led to the development of programs designed to achieve reduction in overconfidence among executives such as forecasters. A central aim of these programs is for these executives to either enhance their understanding of uncertainty or lessen their proclivity toward being overconfident (Haran and Moore 2014). One viable *overconfidence reduction program* (ORP) is supported by the work of Ren and Croson (2013) whose controlled experiment with subjects making procurement decisions produces a significant improvement in participant decisions. Since ORP can presumably be initiated by manufacturers, by retailers, or even by exogenous forces, our results suggest the following strategic considerations regarding ORP. (i) If exogenous forces, i.e., a government agency, want to improve system profit as a whole by initiating ORP, then ORP should be implemented when the system is centralized. However, when the channel is decentralized, the value of ORP depends on the production cost for the channel (Proposition 2). (ii) If a retailer can initiate ORP in order to entail overconfidence in her own executives, then the retailer should always implement ORP. When the production cost is relatively high, the manufacturer should resist relinquishing control of ORP efforts to the retailer. However, when the production cost is low, the manufacturer may need to help facilitate retailer-led ORP initiatives (Proposition 5). (iii) If the manufacturer can initiate ORP for their own executives, then such ORP may not help the manufacturer when the production cost is relatively moderate. In a similar vein, the retailer may resist manufacturer-led ORP when the production cost is relatively low. However, if production cost is high, the retailer should help facilitate manufacturer-led ORP initiatives (Proposition 7).

Our results indicate more generally that ORP within an uncoordinated decentralized channel runs the risk of benefiting only one of the channel members at the expense of the other. This suggests that the participant more exposed to the risk of "losing" from ORP might be best served by initiating efforts moving toward a coordinating contract such as a revenue sharing contract or a buyback contract as a predecessor to any ORP initiative. Under such contracts, the total expected profit of the decentralized channel in equilibrium would equal that of the centralized chain and each participant would receive a complementary percentage (Cachon 2003). From §3, we know not only that the size of the overall decentralized channel would increase with ORP under such coordinating contracts, but also that such efforts would result in a mutual benefit for both the manufacturer and retailer.

While we believe that our analytical results apply broadly to different distribution channels across different contexts where overconfidence bias exists, future work could extend our study toward experimental or empirical contexts. For example, future work can follow approaches in the experimental literature (Ren and Croson 2013, Lee and Siemsen 2016) to classify different decision biases and then accordingly determine decisions (such as production, pricing and ORP) and the associated firm performances. It also would be interesting to design experiments that tease out overconfidence versus alternative explanations such as anchoring. Such an effort would not only test the predictions of the current model, but also offer guidelines for the design and adoption of strategies aimed at enhancing decisions and curtailing executive bias.

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References

Agrawal, Vipul, Sridhar Seshadri. 2000. Impact of uncertainty and risk aversion on price and order quantity in the newsvendor problem. *Manufacturing & Service Operations Management* **2**(4) 410–423.

Becker-Peth, Michael, Elena Katok, Ulrich W Thonemann. 2013. Designing buyback contracts for irrational but predictable newsvendors. *Management Science* **59**(8) 1800–1816.

Benzion, Uri, Yuval Cohen, Ruth Peled, Tal Shavit. 2008. Decision-making and the newsvendor problem: An experimental study. *Journal of the Operational Research Society* **59**(9) 1281–1287.

Bolton, Gary E, Axel Ockenfels, Ulrich W Thonemann. 2012. Managers and students as newsvendors. *Management Science* **58**(12) 2225–2233.

Bostian, AJ A, Charles A Holt, Angela M Smith. 2008. Newsvendor "pull-to-center" effect: Adaptive learning in a laboratory experiment. *Manufacturing & Service Operations Management* **10**(4) 590–608.

Cachon, G, K Cattani, S Netessine. 2007. Where in the world is timbuk2? Outsourcing, offshoring, and mass customization. Wharton Teaching Case.

Cachon, Gerard P. 2003. Supply chain coordination with contracts. *Handbooks in Operations Research and Management Science* **11** 227–339.

Cachon, Gérard P. 2004. The allocation of inventory risk in a supply chain: Push, pull, and advance-purchase discount contracts. *Management Science* **50**(2) 222–238.

Caro, Felipe, Jérémie Gallien. 2012. Clearance pricing optimization for a fast-fashion retailer. *Operations Research* **60**(6) 1404–1422.

Caro, Felipe, Victor Martínez-de Albéniz. 2012. Product and price competition with satiation effects. *Management Science* **58**(7) 1357–1373.

Croson, David, Rachel Croson, Yufei Ren. 2014. How to manage an overconfident newsvendor. Working paper, Michigan State University, East Lansing, MI.

Davis, Andrew M. 2015. An experimental investigation of pull contracts in supply chains. *Production and Operations Management* **24**(2) 325–340.

Davis, Andrew M, Kyle Hyndman. 2018. Multidimensional bargaining and inventory risk in supply chains: An experimental study. Forthcoming at Management Science.

Davis, Andrew M, Elena Katok, Natalia Santamaría. 2014. Push, pull, or both? A behavioral study of how the allocation of inventory risk affects channel efficiency. *Management Science* **60**(11) 2666–2683.

Emmons, Hamilton, Stephen M Gilbert. 1998. The role of returns policies in pricing and inventory decisions for catalogue goods. *Management Science* **44**(2) 276–283.

Feng, Tianjun, Yinghao Zhang. 2017. Modeling strategic behavior in the competitive newsvendor problem: an experimental investigation. *Production and Operations Management* **26**(7) 1383–1398.

Fischhoff, Baruch, Paul Slovic, Sarah Lichtenstein. 1977. Knowing with certainty: The appropriateness of extreme confidence. *Journal of Experimental Psychology: Human perception and performance* **3**(4) 552–564.

Gao, Fei, Xuanming Su. 2016. Omnichannel retail operations with buy-online-and-pick-up-in-store. *Management Science* **63**(8) 2478–2492.

Gino, Francesca, Gary Pisano. 2008. Toward a theory of behavioral operations. *Manufacturing & Service Operations Management* **10**(4) 676–691.

Goldfarb, Avi, Teck-Hua Ho, Wilfred Amaldoss, Alexander L Brown, Yan Chen, Tony Haitao Cui, Alberto Galasso, Tanjim Hossain, Ming Hsu, Noah Lim, Mo Xiao, Botao Yang. 2012. Behavioral models of managerial decision-making. *Marketing Letters* **23**(2) 405–421.

Grubb, Michael D. 2009. Selling to overconfident consumers. *American Economic Review* **99**(5) 1770–1807.

Haran, Uriel, Don A Moore. 2014. A better way to forecast. *California Management Review* **57**(1) 5–15.

Haran, Uriel, Don A Moore, Carey K Morewedge. 2010. A simple remedy for overprecision in judgment. *Judgment and Decision Making* **5**(7) 467–476.

Ho, Teck-Hua, Noah Lim, Tony Haitao Cui. 2010. Reference dependence in multilocation newsvendor models: A structural analysis. *Management Science* **56**(11) 1891–1910.

Iyer, Ganesh, J Miguel Villas-Boas. 2003. A bargaining theory of distribution channels. *Journal of Marketing Research* **40**(1) 80–100.

Jeuland, Abel P, Steven M Shugan. 1983. Managing channel profits. *Marketing Science* **2**(3) 239–272.

Katok, Elena. 2011. Laboratory experiments in operations management. *Transforming Research into Action*. INFORMS, 15–35.

Katok, Elena, Diana Yan Wu. 2009. Contracting in supply chains: A laboratory investigation. *Management Science* **55**(12) 1953–1968.

Katok, Elena, et al. 2011. Using laboratory experiments to build better operations management models. *Foundations and Trends® in Technology, Information and Operations Management* **5**(1) 1–86.

Kocabıyıkoğlu, Ayşe, Celile Itır Göğüş, M Sinan Gönül. 2016. Decision making and the price setting newsvendor: Experimental evidence. *Decision Sciences* **47**(1) 157–186.

Kremer, Mirko, Stefan Minner, Luk N Van Wassenhove. 2010. Do random errors explain newsvendor behavior? *Manufacturing & Service Operations Management* **12**(4) 673–681.

Lariviere, Martin A, Evan L Porteus. 2001. Selling to the newsvendor: An analysis of price-only contracts. *Manufacturing & Service Operations Management* **3**(4) 293–305.

Lee, Yun Shin, Enno Siemsen. 2016. Task decomposition and newsvendor decision making. *Management Science* **63**(10) 3226–3245.

Li, Meng, Nicholas C Petruzzi, Jun Zhang. 2016. Overconfident competing newsvendors. *Management Science* **63**(8) 2637–2646.

Loch, Christoph H, Yaozhong Wu. 2007. Behavioral operations management. *Foundations and Trends® in Technology, Information and Operations Management* **1**(3) 121–232.

Loch, Christoph H, Yaozhong Wu. 2008. Social preferences and supply chain performance: An experimental study. *Management Science* **54**(11) 1835–1849.

Lu, Lijian, Yaozhong Wu. 2015. Preferences for contractual forms in supply chains. *European Journal of Operational Research* **241**(1) 74–84.

Moore, Don A, Paul J Healy. 2008. The trouble with overconfidence. *Psychological Review* **115**(2) 502–517.

Oskamp, Stuart. 1965. Overconfidence in case-study judgments. *Journal of Consulting Psychology* **29**(3) 261–265.

Özer, Özalp, Wei Wei. 2006. Strategic commitments for an optimal capacity decision under asymmetric forecast information. *Management Science* **52**(8) 1238–1257.

Özer, Özalp, Yanchong Zheng, Kay-Yut Chen. 2011. Trust in forecast information sharing. *Management Science* **57**(6) 1111–1137.

Petruzzi, Nicholas C, Maqbool Dada. 1999. Pricing and the newsvendor problem: A review with extensions. *Operations Research* **47**(2) 183–194.

Plous, Scott. 1993. *The psychology of judgment and decision making*. McGraw-Hill, New York, NY.

Powell, Thomas C, Dan Lovallo, Craig R Fox. 2011. Behavioral strategy. *Strategic Management Journal* **32**(13) 1369–1386.

Ramachandran, Karthik, Tereyagoglu Necati, Yusen Xia. 2017. Multi-dimensional decision making in operations: An experimental investigation of joint pricing and quantity decisions. Forthcoming at Management Science.

Raz, Gal, Evan L Porteus. 2006. A fractiles perspective to the joint price/quantity newsvendor model. *Management Science* **52**(11) 1764–1777.

Ren, Yufei, David C Croson, Rachel TA Croson. 2017. The overconfident newsvendor. *Journal of the Operational Research Society* **68**(5) 496–506.

Ren, Yufei, Rachel Croson. 2013. Overconfidence in newsvendor orders: An experimental study. *Management Science* **59**(11) 2502–2517.

Russo, J Edward, Paul JH Schoemaker. 1992. Managing overconfidence. *Sloan Management Review* **33**(2) 7–17.

Scheinkman, Jose A, Wei Xiong. 2003. Overconfidence and speculative bubbles. *Journal of Political Economy* **111**(6) 1183–1220.

Schweitzer, Maurice E, Gérard P Cachon. 2000. Decision bias in the newsvendor problem with a known demand distribution: Experimental evidence. *Management Science* **46**(3) 404–420.

Spengler, Joseph J. 1950. Vertical integration and antitrust policy. *Journal of Political Economy* **58**(4) 347–352.

Su, Xuanming. 2008. Bounded rationality in newsvendor models. *Manufacturing & Service Operations Management* **10**(4) 566–589.

Tereyağoğlu, Necati, Senthil Veeraraghavan. 2012. Selling to conspicuous consumers: Pricing, production, and sourcing decisions. *Management Science* **58**(12) 2168–2189.

Tomlin, Brian. 2006. On the value of mitigation and contingency strategies for managing supply chain disruption risks. *Management Science* **52**(5) 639–657.

Van den Steen, Eric. 2004. Rational overoptimism (and other biases). *American Economic Review* **94**(4) 1141–1151.

Wu, Diana Yan. 2013. The impact of repeated interactions on supply chain contracts: A laboratory study. *International Journal of Production Economics* **142**(1) 3–15.

Wu, Diana Yan, Kay-Yut Chen. 2014. Supply chain contract design: Impact of bounded rationality and individual heterogeneity. *Production and Operations Management* **23**(2) 253–268.

Zhang, Yinghao, Karen Donohue, Tony Haitao Cui. 2015. Contract preferences and performance for the loss-averse supplier: Buyback vs. revenue sharing. *Management Science* **62**(6) 1734–1754.

Zhang, Yinghao, Enno Siemsen. 2018. A meta-analysis of newsvendor experiments: Revisiting the pull-to-center asymmetry. Production and Operations Management, Forthcoming.

Zusman, Pinhas, Michael Etgar. 1981. The marketing channel as an equilibrium set of contracts. *Management Science* **27**(3) 284–302.

Appendix: Proofs

Proof of Lemma 1 From (1), the optimal stocking factor is either $z = x_h$ or $z = x_l$. If $z = x_h$, then $q = x_h - bp$. Consequently, the centralized channel's optimal profit is $\max_p p(\mu - bp) - (x_h - bp)c = \frac{\mu^2+b^2c^2-2bc(2x_h-\mu)}{4b}$. However, if $z = x_l$, then $q = x_l - bp$. Consequently, the centralized channel's profit is $\max_p (x_l - bp)(p - c) = \frac{(x_l-bc)^2}{4b}$. Moreover, $\frac{\mu^2+b^2c^2-2bc(2x_h-\mu)}{4b} > \frac{(x_l-bc)^2}{4b} \Longleftrightarrow c < \tau$. Thus, we have (2). Note that in order to ensure non-negative demand and price, we need the following. (i) For the understocking equilibrium, $bc \leq x_l$. (ii) For the overstocking equilibrium, $x_l - bp^* = x_l - \frac{\mu+bc}{2} \geq 0 \Longleftrightarrow bc \leq (1+\theta)x_l - \theta x_h$. From (i)-(ii), $c \leq \min\{\frac{x_l}{b}, \frac{(1+\theta)x_l-\theta x_h}{b}\} = \frac{(1+\theta)x_l-\theta x_h}{b}$. As a result, $c \leq \tau$ is possible when $\tau > \frac{(1+\theta)x_l-\theta x_h}{b} \Longleftrightarrow \frac{x_l}{x_h} > \frac{4\theta-\theta^2}{4-\theta^2}$.

When $c \leq \tau$, $c \leq \frac{\theta\mu}{2b(1-\theta)} \Longleftrightarrow c \leq \theta p = \frac{\theta(\mu+bc)}{2b}$, whereas when $c > \tau$, $c > \frac{\theta x_l}{b(2-\theta)} \Longleftrightarrow c > \theta p = \frac{\theta(x_l+bc)}{2b}$. This observation can be used for the forthcoming proofs. Q.E.D.

Proof of Lemma 2 a) For a decision maker described by the overconfidence parameter α, the decision maker solves (4) with demand D rather than X. Consequently, from $\mathrm{E}[D] = \mu$ and Lemma 1, the production and pricing decisions for the overconfident decision maker are shown as

$$(\hat{q}^c, \hat{p}^c) := (1-\alpha)q^* + \alpha q^* = \begin{cases} \left(\frac{2d_h-\mu-bc}{2}, \frac{\mu+bc}{2b}\right) & \text{if } c \leq \hat{\tau}(\alpha), \\ \left(\frac{d_l-bc}{2}, \frac{d_l+bc}{2b}\right) & \text{if } c > \hat{\tau}(\alpha), \end{cases} \tag{21}$$

where $\hat{\tau}(\alpha) = \frac{\mu^2-d_l^2}{2(2d_h-d_l-\mu)b} = \tau + \alpha\frac{(\mu-x_l)^2}{2(2x_h-x_l-\mu)b}$.

b) First, we show that $\hat{\pi}^c(\alpha)$ decreases in α either when $\alpha \le \hat{\tau}(\alpha)$ or when $\alpha > \hat{\tau}(\alpha)$. Given the production and price decisions in part (a), the channel's expected profit is $\hat{\pi}^c(\alpha) = \hat{p}^c(\alpha)\mathrm{E}[X \wedge [(1-\alpha)z + \alpha\mu]] - c[(1-\alpha)z + \alpha\mu] - b\hat{p}^c(\alpha)[\hat{p}^c(\alpha) - c]$. Consequently, if $c \le \hat{\tau}(\alpha)$, then $z = x_h$, where $\frac{d\hat{\pi}^c(\alpha)}{d\alpha} = (\mu - x_h)[\theta\hat{p}^c(\alpha) - c] \le 0$ from the proof of Lemma 1. However, if $c > \hat{\tau}(\alpha)$, then $z = x_l$, where $\hat{\pi}^c(\alpha) = \hat{p}^c(\alpha)[\theta d_l + (1-\theta)x_l] - cd_l - b\hat{p}^c(\alpha)[p^c(\alpha) - c] = \frac{(d_l - bc)^2}{4b} - \frac{d_l + bc}{2b}(1-\theta)(d_l - x_l)$. Therefore, $\frac{d\hat{\pi}^c(\alpha)}{d\alpha} = \frac{\mu - x_l}{2b}[bc(2-\theta) - \theta d_l + (1-\theta)\alpha(\mu - x_l)] < \frac{\mu - x_l}{2b}[b\tau(\alpha)(2-\theta) - \theta d_l + (1-\theta)\alpha(\mu - x_l)] = \frac{[(1-\alpha)(3\theta-2) - 2\theta + 2](\mu - d_l)}{2(1-\alpha)} < 0$ because $(1-\alpha)(3\theta - 2) - 2\theta + 2 > 0$. Second, we show that $\hat{\pi}^c(\alpha)$ drops around $\hat{\alpha}$, where $\hat{\alpha}$ is the solution of $c = \hat{\tau}(\alpha)$. The biased channel solves $\max_p (1-\alpha)\pi(x_h, p) + \alpha(p-c)(\mu - bp) = \max_p (1-\alpha)\pi(x_l, p) + \alpha(p-c)(\mu - bp)$ when $c = \hat{\tau}(\alpha)$. This means that $\frac{\mu+bc}{2b}\mathrm{E}[[(1-\alpha)X + \alpha\mu] \wedge [(1-\alpha)x_h + \alpha\mu]] - c[(1-\alpha)x_h + \alpha\mu] - \frac{\mu+bc}{2}[\frac{\mu+bc}{2b} - c] = \frac{d_l+bc}{2b}\mathrm{E}[[(1-\alpha)X + \alpha\mu] \wedge [(1-\alpha)x_l + \alpha\mu]] - c[(1-\alpha)x_l + \alpha\mu] - \frac{d_l+bc}{2}[\frac{d_l+bc}{2b} - c]$ when $c = \hat{\tau}(\alpha)$. Consequently, $\frac{\mu+bc}{2b}\mathrm{E}[[(1-\alpha)X + \alpha\mu] \wedge [(1-\alpha)x_h + \alpha\mu]] - c[(1-\alpha)x_h + \alpha\mu] - \frac{\mu+bc}{2}[\frac{\mu+bc}{2b} - c] - \hat{\pi}^c(\alpha)|_{c=\hat{\tau}^-(\alpha)} = \frac{\mu+bc}{2b}(1-\theta)(d_l - x_l) \ge \frac{d_l+bc}{2b}(1-\theta)(d_l - x_l) = \frac{d_l+bc}{2b}\mathrm{E}[[(1-\alpha)X + \alpha\mu] \wedge [(1-\alpha)x_l + \alpha\mu]] - c[(1-\alpha)x_l + \alpha\mu] - b\frac{d_l+bc}{2b}[\frac{d_l+bc}{2b} - c] - \hat{\pi}^c(\alpha)|_{c=\hat{\tau}^+(\alpha)} \Longrightarrow \hat{\pi}^c(\alpha)|_{c=\hat{\tau}^-(\alpha)} \le \hat{\pi}^c(\alpha)|_{c=\hat{\tau}^+(\alpha)}$. As a result, $\hat{\pi}^c(\alpha)$ drops at $\hat{\alpha}$ because $\hat{\tau}(\alpha)$ increases in α. From the above two steps, we conclude that $\hat{\pi}^c(\alpha)$ always decreases in α. Q.E.D.

Proof of Lemma 3 a) For the overstocking (resp. understocking) case, the manufacturer's profit is $\max_w (w-c)\frac{2x_h - \mu - bw}{2} = \frac{(2x_h - \mu - bc)^2}{8b}$ (resp. $\max_w (w-c)\frac{x_l - bw}{2} = \frac{(x_l - bc)^2}{8b}$) when $w_o = \frac{2x_h - \mu + bc}{2b}$ (resp. $w_u = \frac{x_l + bc}{2b}$). Since $w_o > w_u$, we have three cases.

First, when the production cost is relatively low ($c \le c_l := \frac{1}{b}[x_l - \frac{4(1-\theta)}{2-\theta}x_h] \Longleftrightarrow w_o \le \tau$), the wholesale price w_u leads to a higher a profit than the understocking case. Thus, w_o is the equilibrium choice of the manufacturer.

Second, when the production cost is relatively high ($c > \max\{c_l, c_h\} = c_h$), where c_h is the solution of the equation $L(c) = 0$ and $L(c) := (w-c)\frac{2x_h - \mu - bw}{2}|_{w=\tau} - \frac{(x_l - bc)^2}{8b}$, we show the equilibrium wholesale price for the manufacturer is w_u by the following observations. (i) $L'(c) = \frac{x_l - bc}{4} - \frac{2x_h - \mu - b\tau}{2} = \frac{x_l - bc - 4x_h + 2\mu + 2b\tau}{4} < \frac{x_l - 4x_h + 2\mu}{4} < 0$ as $c < \tau$. (ii) $c_h > c_l$ because $L'(c) < 0$ and $L(c)|_{c=c_l} = \frac{(x_h - x_l)[(\theta-12)\theta x_h + 12x_h - (\theta-2)^2 x_l]}{8b} > \frac{[(\theta-12)\theta x_l + 12x_l - (\theta-2)^2 x_l]}{8b} = \frac{8(1-\theta)x_l}{8b} > 0 = L(c_h)$. (iii) $w_u > \tau \Longleftrightarrow c >$

$\frac{(\theta-2)(\theta-1)x_l-\theta^2x_h}{b(\theta-2)}$ and $L(c)\big|_{c=\frac{(\theta-2)(\theta-1)x_l-\theta^2x_h}{b(\theta-2)}} = \frac{(x_h-x_l)[(2-\theta)^2x_l-\theta^2x_h]}{4b} > L(c_h) = 0$ which follows from $\frac{x_l}{x_h} > \frac{4\theta-\theta^2}{4-\theta^2} > \frac{\theta^2}{(2-\theta)^2}$.

Third, either $w_u < \tau < w_o \Longleftrightarrow c_l < c < \frac{1}{b}[\frac{\theta^2}{2-\theta}x_h - (1-\theta)x_l]$ or $c < c_h$ and $w_u > \tau \Longleftrightarrow \frac{1}{b}[\frac{\theta^2}{2-\theta}x_h - (1-\theta)x_l] \leq c$, the equilibrium choice for the manufacturer is τ. Thus, when the production cost is moderate ($c_l < c \leq c_h$), the equilibrium wholesale price is τ.

b) From (2), q^* decreases in c while p^* increases in c. Moreover, in the decentralized channel, the wholesale price is higher than c. Consequently, the equilibrium retail price (resp. order quantity) in the decentralized channel is higher (resp. lower) than in the centralized channel. Q.E.D.

Proof of Lemma 4 As in Lemma 3, the overconfident channel has three similar cases. (i) If the production cost is relatively low such that $c \leq \hat{c}_l(\alpha)$, where $\hat{c}_l(\alpha) = \frac{1}{b}[d_l - \frac{4(1-\theta)}{2-\theta}d_h]$, then the equilibrium wholesale price is $\frac{2d_h-\mu+bc}{2b} = (1-\alpha)w_o + \alpha w_n$. (ii) If the production cost is relatively high such that $c > \hat{c}_h(\alpha)$, where $\hat{c}_h(\alpha)$ is the unique c such that $\frac{2d_h-\mu-b\hat{\tau}(\alpha)}{2}[\hat{\tau}(\alpha)-c] = \frac{(d_l-bc)^2}{8b}$, then the equilibrium wholesale price is $\frac{d_l+bc}{2b} = (1-\alpha)w_u + \alpha w_n$. (iii) If the production cost is relatively moderate such that $\hat{c}_l(\alpha) < c \leq \hat{c}_h(\alpha)$, then the equilibrium wholesale price is $\hat{\tau}(\alpha)$. Q.E.D.

Proof of Proposition 1 When $\hat{c}_l(\alpha) < c \leq \hat{c}_h(\alpha)$, the manufacturer's profit is $\hat{\pi}_M(\alpha) = \max_w (w - c)\hat{q}(\alpha, w)$. From the envelope theorem, $\pi'_M(\alpha) < 0$ because $\hat{q}(\alpha, w) = \frac{2d_h-\mu-bw}{2}$ decreases in α for any w. For the retailer, we define $\hat{\pi}_R(\alpha, w) := \hat{p}(\alpha, w)\mathrm{E}[X \wedge [(1-\alpha)z + \alpha\mu]] - w[(1-\alpha)z + \alpha\mu] - b\hat{p}(\alpha, w)[\hat{p}(\alpha, w) - w]$. Then, $\frac{\partial\hat{\pi}_R(\alpha,w)}{\partial w} = \frac{\partial\hat{p}(\alpha,w)}{\partial w}\mathrm{E}[X \wedge [(1-\alpha)z + \alpha\mu]] - [(1-\alpha)z + \alpha\mu] - b\frac{\partial\hat{p}(\alpha,w)}{\partial w}[\hat{p}(\alpha, w) - w] \quad - b\hat{p}(\alpha, w)[\frac{\partial\hat{p}(\alpha,w)}{\partial w} - 1] = \frac{\partial\hat{p}(\alpha,w)}{\partial w}[\mathrm{E}[X \wedge [(1-\alpha)z + \alpha\mu]] - 2b\hat{p}(\alpha, w) + bw] - [(1-\alpha)z + \alpha\mu - b\hat{p}(\alpha, w)]$. (i) For either $z = x_h$ or $z = x_l$, for the above formula, $\frac{\partial\hat{p}(\alpha,w)}{\partial w} > 0$ and $(1-\alpha)z + \alpha\mu - b\hat{p}(\alpha, w) = \hat{q}(\alpha, w) \geq 0$. (ii) For the retailer, the first-order-condition of the retailer's profit with respect to p is $(1-\alpha)\mathrm{E}[X \wedge z] + \alpha\mu - 2b\hat{p}(\alpha, w) + bw = 0$. This implies that, when $z = x_h$, $(1-\alpha)\mathrm{E}[X \wedge z] + \alpha\mu = \mu \geq \theta d_h + (1-\theta)x_l = \mathrm{E}[X \wedge [(1-\alpha)z + \alpha\mu]]$, whereas, when $z = x_l$, $(1-\alpha)\mathrm{E}[X \wedge z] + \alpha\mu = d_l \geq \theta d_l + (1-\theta)x_l = \mathrm{E}[X \wedge [(1-\alpha)z + \alpha\mu]$. As a result, for both $z = x_h$ and $z = x_l$, $\mathrm{E}[X \wedge [(1-\alpha)z + \alpha\mu]] - 2b\hat{p}(\alpha, w) + bw = \mathrm{E}[X \wedge [(1-\alpha)z + \alpha\mu]] - (1-\alpha)\mathrm{E}[X \wedge z] - \alpha\mu \leq 0$. From (i)-(ii), we have the following two-part Lemma. Lemma 1(i): $\pi_R(\alpha, w)$ decreases in w for any α when $z = x_h$; Lemma 1(ii): $\pi_R(\alpha, w)$ decreases in w for any α when $z = x_l$. Consequently, when $\hat{c}_l(\alpha) < c \le \hat{c}_h(\alpha)$, $\pi_R(\alpha) = \hat{\pi}_R(\alpha, w = \hat{w}(\alpha))$ decreases in α because $\hat{w}(\alpha) = \tau + \alpha\frac{(\mu - x_l)^2}{2(2x_h - x_l - \mu)b}$ increases in α.

a) We now study the case of $c > \hat{c}_h(\alpha)$. For this case, from (11), the retailer's profit is $\hat{\pi}_R(\alpha) = \hat{p}(\alpha, \hat{w}(\alpha))\mathrm{E}[(X - b\hat{p}(\alpha, w)) \wedge \hat{q}(\alpha, \hat{w}(\alpha))] - \hat{w}(\alpha)\hat{q}(\alpha, \hat{w}(\alpha)) = \frac{(d_l - b\hat{w}(\alpha))^2}{4b} - \frac{d_l + b\hat{w}(\alpha)}{2b}(1-\theta)(d_l - x_l)$, where $\hat{q}(\alpha, w) = \frac{d_l - bw}{2}$, $\hat{p}(\alpha, w) = \frac{d_l + bw}{2b}$, and $\hat{w}(\alpha) = \frac{d_l + bc}{2b}$. Consequently, $\hat{\pi}'_R(\alpha) = \frac{\partial \hat{\pi}_R(\alpha, w)}{\partial \alpha}|_{w=\hat{w}(\alpha)} + \frac{\partial \hat{\pi}_R(\alpha, w)}{\partial w}|_{w=\hat{w}(\alpha)}\hat{w}'(\alpha) = \frac{\partial \hat{\pi}_R(\alpha, w)}{\partial \alpha}|_{w=\hat{w}(\alpha)} - [\frac{d_l - bw}{2} + \frac{(1-\theta)(d_l - x_l)}{2}]|_{w=\hat{w}(\alpha)}\frac{\mu - x_l}{2b} \le 0$ because $\frac{\partial \hat{\pi}_R(\alpha, w)}{\partial \alpha} < 0$ for any given wholesale price w (Lemma 2b). Moreover, $\hat{\pi}'_M(\alpha) = \frac{\mu - x_l}{2b}\hat{q}(\alpha) + [\hat{w}(\alpha) - c]\frac{\mu - x_l}{4} > 0$ because $\hat{\pi}_M(\alpha) = [\hat{w}(\alpha) - c]\hat{q}(\alpha) = [\hat{w}(\alpha) - c]\frac{d_l - bc}{4}$.

b) We then study the case of $c \le \hat{c}_l(\alpha)$. For the manufacturer, his profit is $\hat{\pi}_M(\alpha) = [\hat{w}(\alpha) - c]\hat{q}(\alpha)$ with $\hat{w}(\alpha) = \frac{2d_h - \mu + bc}{2b}$ and $\hat{q}(\alpha) = \frac{2d_h - \mu - bc}{4}$. Thus, $\hat{\pi}'_M(\alpha) = \frac{\mu - x_h}{b}\hat{q}(\alpha) + [\hat{w}(\alpha) - c]\frac{\mu - x_h}{2} < 0$. For the retailer, her profit is $\hat{\pi}_R(\alpha, w) = \frac{\mu^2 + b^2w^2 - 2bw(2x_h - \mu)}{4b} - \alpha(x_h - \mu)(\theta\frac{\mu + bw}{2b} - w)$. As a result, $\hat{\pi}'_R(\alpha) = \frac{\partial \hat{\pi}_R(\alpha, w)}{\partial \alpha}|_{w=\hat{w}(\alpha)} + \frac{\partial \hat{\pi}_R(\alpha, w)}{\partial w}|_{w=\hat{w}(\alpha)}\hat{w}'(\alpha) = (x_h - \mu)[\theta\frac{\mu + b\hat{w}(\alpha)}{2b} - \hat{w}(\alpha)] + [\frac{2b^2\hat{w}(\alpha) - 2b(2x_h - \mu)}{4b} + \frac{2-\theta}{2}\alpha(x_h - \mu)]\frac{x_h - \mu}{b} = \frac{x_h - \mu}{2b}K(\alpha)$, where $K(\alpha) := \theta[\mu + b\hat{w}(\alpha)] - b\hat{w}(\alpha) + (2-\theta)\alpha(x_h - \mu) - (2x_h - \mu)$. Consequently, $\hat{\pi}'_R(\alpha) < 0$ because $K(\alpha) < 0$ which follows from $K(0) = \theta[\mu + b\frac{\mu + bc}{2b}] - b\frac{\mu + bc}{2b} + (2 - \theta)(x_h - \mu) - (2x_h - \mu) = -\theta x_h - (1-\theta)\frac{\mu + bc}{2} < 0$ and $K'(\alpha) = (2\theta - 3)(x_h - \mu) < 0$. Q.E.D.

Proof of Proposition 2 If $\hat{c}_l(\alpha) < c \le \hat{c}_h(\alpha)$, $\hat{\pi}_T(\alpha)$ decreases in α because both $\hat{\pi}_M(\alpha)$ and $\hat{\pi}_R(\alpha)$ decrease in α from Proposition 1.

a) If $c \le \hat{c}_l(\alpha)$, the channel's profit is $\hat{\pi}_T(\alpha) = \hat{p}(\alpha)\mathrm{E}[X \wedge [(1-\alpha)z + \alpha\mu]] - c[(1-\alpha)z + \alpha\mu] - b\hat{p}(\alpha)[\hat{p}(\alpha) - c] = \hat{p}(\alpha)[\theta d_h + (1-\theta)x_l] - cd_h - b\hat{p}(\alpha)[\hat{p}(\alpha) - c]$, where $z = x_h$ and $\hat{p}(\alpha) = \frac{\mu + 2d_h + bc}{4b}$. As a result, $\hat{\pi}'_T(\alpha) = [\theta\hat{p}(\alpha) - c](\mu - x_h) - \hat{p}'(\alpha)[2b\hat{p}(\alpha) - bc - \theta d_h - (1-\theta)x_l] = (\mu - x_h)[\theta\hat{p}(\alpha) - c - \hat{p}(\alpha) + \frac{c}{2} + \frac{\theta d_h}{2b} + \frac{(1-\theta)x_l}{2b}] = (\mu - x_h)[\frac{(\theta-1)(\mu + 2d_h + bc)}{4b} - \frac{c}{2} + \frac{\theta d_h}{2b} + \frac{(1-\theta)x_l}{2b}] = \frac{\mu - x_h}{4b}[(\theta - 1)(\mu + 2d_h + bc) - 2bc + 2\theta d_h + 2(1-\theta)x_l] = \frac{\mu - x_h}{4b}[(4\theta - 2)d_h - (1-\theta)(\mu - 2x_l) - (3-\theta)bc]$. Thus, $\hat{\pi}'_T(\alpha) > 0 \Longleftrightarrow c > \frac{(4\theta - 2)d_h - (1-\theta)(\mu - 2x_l)}{b(3-\theta)}$.

b) If $c > \hat{c}_h(\alpha)$, the channel profit is $\hat{\pi}_T(\alpha) = \hat{p}(\alpha)\mathrm{E}[X \wedge [(1-\alpha)z + \alpha\mu]] - c[(1-\alpha)z + \alpha\mu] - b\hat{p}(\alpha)[\hat{p}(\alpha) - c] = \hat{p}(\alpha)[\theta d_l + (1-\theta)x_l] - cd_l - b\hat{p}(\alpha)[\hat{p}(\alpha) - c]$, where $z = x_l$ and $\hat{p}(\alpha) = \frac{3d_l + bc}{4b}$. Then, $\hat{\pi}'_T(\alpha) = \hat{p}(\alpha)\theta(\mu - x_l) + \hat{p}'(\alpha)[\theta d_l + (1-\theta)x_l] - c(\mu - x_l) - b\hat{p}(\alpha)\hat{p}'(\alpha) - b\hat{p}'(\alpha)[\hat{p}(\alpha) - c] = (\mu - x_l)[\theta\hat{p}(\alpha) + \frac{3}{4b}[\theta d_l + (1-\theta)x_l] - c - \frac{3\hat{p}(\alpha)}{4} - \frac{3}{4}[\hat{p}(\alpha) - c]] = (x_l - \mu)\frac{6x_l(1-\theta) + 3(4\theta - 3)d_l - (5 - 2\theta)bc}{8b}$. As a result, $\hat{\pi}_T'(\alpha) > 0 \Longleftrightarrow c < \frac{6x_l(1-\theta)+3(4\theta-3)d_l}{(5-2\theta)b}$. Q.E.D.

Proof of Lemma 5 From (9)-(10), we can conclude because d_h decreases in α while d_l increases in α. Q.E.D.

Proof of Proposition 3 We first show the following three-part Lemma. Lemma 3(i) If $c \leq c_l$, then $c \leq \hat{c}_l(\alpha)$ for any α; Lemma 3(ii) If $c > c_h$, then $c > \hat{c}_h(\alpha)$ for any α; Lemma 3(iii) If $c_l < c \leq c_h$, then there exists a threshold value $\tilde{\alpha}$ such that $\hat{c}_l(\alpha) < c \leq \hat{c}_h(\alpha)$ when $\alpha \leq \tilde{\alpha}$. However, when $\alpha > \tilde{\alpha}$, either $c > \hat{c}_h(\alpha)$ or $c < \hat{c}_l(\alpha)$.

Proof of Lemma 3(i) If $c \leq c_l$, then, from the proof of Lemma 3, $c \leq \frac{1}{b}[x_l - \frac{4(1-\theta)}{2-\theta}x_h] \leq \frac{1}{b}[d_l - \frac{4(1-\theta)}{2-\theta}d_h] = \hat{c}_l(\alpha)$ because $x_l \leq d_l$ and $x_h \geq d_h$.

Proof of Lemma 3(ii) If $c > c_h$, then, from the proof of Lemma 3, $L(c) = (w-c)\frac{2x_h-\mu-bw}{2}|_{w=\tau} - \frac{(x_l-bc)^2}{8b} < 0$. We next show that $(w-c)\frac{2d_h-\mu-bw}{2}|_{w=\hat{\tau}(\alpha)} - \frac{(d_l-bc)^2}{8b} < 0$ when $L(c) < 0$. Because both $2d_h - \mu - b\hat{\tau}(\alpha) = (1-\alpha)[\frac{\theta^2(x_h-x_l)}{2(2-\theta)} + 2(1-\theta)(x_h-x_l)] + \frac{2(1-\theta)\mu}{2-\theta}$ and $\frac{2d_h-\mu-b\hat{\tau}(\alpha)}{2}$ decrease in α, whereas $\frac{(d_l-bc)^2}{8b}$ increases in α, we have $[\hat{\tau}(\alpha)-c]\frac{2d_h-\mu-b\hat{\tau}(\alpha)}{2} < \frac{(d_l-bc)^2}{8b}$ when $L(c) < 0$. That is, $c > \hat{c}_h(\alpha)$ when $c > c_h$.

Proof of Lemma 3(iii) From part (i), $\hat{c}_l(\alpha)$ increases in α while $\hat{c}_h(\alpha)$ decreases in α. Thus, once $c > \hat{c}_h(\tilde{\alpha})$, then $c > \hat{c}_h(\alpha)$ for any $\alpha > \tilde{\alpha}$. Similarly, once $c < \hat{c}_l(\tilde{\alpha})$, then $c < \hat{c}_l(\alpha)$ for any $\alpha > \tilde{\alpha}$.

We are now ready to check the conditions (a)-(b). From the above Lemma, when $c > c_h$, then $c > \hat{c}_h(\alpha)$. For condition (a), when $\theta < \frac{3}{4}$, $c < \frac{3[x_l(1-\theta)(4\theta-1)-x_h(3-4\theta)\theta]}{(5-2\theta)b} < \frac{6(1-\theta)x_l+(12\theta-9)[(1-\alpha)x_l+\alpha\mu]}{(5-2\theta)b} = \frac{6(1-\theta)x_l+(12\theta-9)d_l}{(5-2\theta)b} \Longrightarrow \hat{\pi}_T'(\alpha) \geq 0$ from Proposition 2. For condition (b), when $\theta > \frac{3}{4}$, $c < \frac{3(2\theta-1)x_l}{(5-2\theta)b} < \frac{6(1-\theta)x_l+(12\theta-9)[(1-\alpha)x_l+\alpha\mu]}{(5-2\theta)b} = \frac{6(1-\theta)x_l+(12\theta-9)d_l}{(5-2\theta)b} \Longrightarrow \hat{\pi}_T'(\alpha) \geq 0$ from Proposition 2. Q.E.D.

Proof of Proposition 4 When $c \leq c_l$, the unbiased manufacturer's wholesale price $\hat{w}(0) \leq \tau$. Consequently, $\hat{w}(0) \leq \tau < \hat{\tau}(\alpha)$, meaning that the retailer overstocks, and the manufacturer's expected profit is $\tilde{\pi}_M(\alpha) = [\hat{w}(0)-c]\hat{q}(\alpha, \hat{w}(0)) = [\hat{w}(0)-c]\frac{2d_h-\mu-b\hat{w}(0)}{2}$. As a result, $\tilde{\pi}_M'(\alpha) = [\hat{w}(0)-c](x_h - \mu) > 0$. For the retailer's profit, since the wholesale price $\hat{w}(0)$ is independent with α, $\tilde{\pi}_R'(\alpha) < 0$ from Lemma 2. Thus, $\tilde{\pi}_T'(\alpha) = \tilde{\pi}_M'(\alpha) + \tilde{\pi}_R'(\alpha) < 0$ when $c \leq c_l$.

When $c > c_h$, the equilibrium wholesale price is w_u. For the understocking equilibrium, $\hat{\pi}_T'(\alpha) = \hat{p}(\alpha)\theta\frac{dd_l}{d\alpha} + \hat{p}'(\alpha)[\theta d_l + (1-\theta)x_l] - c\frac{dd_l}{d\alpha} - b\hat{p}(\alpha)\hat{p}'(\alpha) - b\hat{p}'(\alpha)[\hat{p}(\alpha)-c] = \frac{dd_l}{d\alpha}[\theta\hat{p}(\alpha) + \frac{\theta d_l+(1-\theta)x_l}{2b} -$

$c - \frac{\hat{p}(\alpha)}{2} - \frac{\hat{p}(\alpha)-c}{2}]$, where $\hat{p}(\alpha) = \frac{d_l + b\hat{w}(0)}{2b}$. As a result, $\tilde{\pi}'_T(\alpha)|_{\alpha=0} = \frac{dd_l}{d\alpha}[(\theta-1)\hat{p}(\alpha) + \frac{x_l}{2b} - \frac{c}{2}]|_{\alpha=0} = \frac{dd_l}{d\alpha}\frac{(3\theta-1)x_l - bc(3-\theta)}{4b} > 0$ when $c < \frac{x_l(3\theta-1)}{(3-\theta)b}$. Q.E.D.

Proof of Proposition 5 For a given wholesale price $\hat{w}(0)$, the retailer's profit always decreases in α following from Lemma 2. For the manufacturer, his profit $\tilde{\pi}_M(\alpha) = [\hat{w}(0) - c]\hat{q}(\alpha, \hat{w}(0))$, where $\hat{q}(\alpha, \hat{w}(0)) = \frac{2d_h - \mu - b\hat{w}(0)}{2}$ if $\hat{w}(0) \leq \hat{\tau}(\alpha)$ and $\hat{q}(\alpha, \hat{w}(0)) = \frac{d_l - b\hat{w}(0)}{2}$ otherwise. Because $\hat{w}(0) > c$, $\pi'_M(\alpha) = [\hat{w}(0) - c]\frac{\partial \hat{q}(\alpha, \hat{w}(0))}{\partial \alpha} > 0 \Longleftrightarrow \frac{\partial \hat{q}(\alpha, \hat{w}(0))}{\partial \alpha} > 0 \Longleftrightarrow \hat{w}(0) > \hat{\tau}(\alpha)$. If $c > c_h$, then $\hat{w}(0) > \hat{\tau}(\alpha) \Longleftrightarrow \frac{x_l + bc}{2b} > \frac{\mu^2 - d_l^2}{2(2d_h - d_l - \mu)b} \Longleftrightarrow c > \frac{\mu^2 - d_l^2}{(2d_h - d_l - \mu)} - x_l$. Q.E.D.

Proof of Proposition 6 For $c > c_h$, $c > \hat{c}_h(\alpha)$ from Lemma 3(ii). For the manufacturer profit defined in (14), $\breve{\pi}'_M(\alpha) = [(w - c)\frac{\partial \hat{q}(0,w)}{\partial w} + \hat{q}(0, w)]_{w=\hat{w}(\alpha)}\hat{w}'(\alpha) < 0$. This is because $\hat{w}'(\alpha) > 0$ when $c > \hat{c}_h(\alpha)$ (Proposition 4) and $\hat{w}(\alpha) > \hat{w}(0) = w_u \Longrightarrow [(w - c)\frac{\partial \hat{q}(0,w)}{\partial w} + \hat{q}(0, w)]_{w=\hat{w}(\alpha)} < [(w - c)\frac{\partial \hat{q}(1,w)}{\partial w} - \hat{q}(1, w)]_{w=w_u} = 0$. For the retailer, since $\hat{w}(\alpha) > \hat{\tau}(\alpha) > \tau$, $z = x_l$. From Lemma 1(ii) and $\hat{w}'(\alpha) > 0$, we have $\breve{\pi}'_R(\alpha) \leq 0$. Consequently, $\breve{\pi}'_T(\alpha) = \breve{\pi}'_M(\alpha) + \breve{\pi}'_R(\alpha) < 0$ when $c > c_h$.

For $c \leq c_l$, $c \leq \hat{c}_l(\alpha)$ always holds; see Lemma 3(i). Thus, the manufacturer would always charge $\hat{w}(\alpha) = (1 - \alpha)w_o + \alpha w_n$ from Lemma 4. Consequently, around $\alpha = 0$, $z = x_h$, and $\breve{\pi}_T(\alpha) = \hat{p}(0, \hat{w}(\alpha))\mathrm{E}[X \wedge z] - cz - b\hat{p}(0, \hat{w}(\alpha))[\hat{p}(0, \hat{w}(\alpha)) - c]$. As a result, $\breve{\pi}'_T(\alpha)|_{\alpha=0} = \frac{\partial \breve{\pi}_T}{\partial \hat{p}(0,\hat{w}(\alpha))}\frac{\partial \hat{p}(0,\hat{w}(\alpha))}{\partial \hat{w}(\alpha)}\hat{w}'(\alpha)|_{\alpha=0} > 0$ because $\frac{\partial \breve{\pi}_T}{\partial \hat{p}(0,\hat{w}(\alpha))} < 0$, $\frac{\partial \hat{p}(0,\hat{w}(\alpha))}{\partial \hat{w}(\alpha)} > 0$ and $\hat{w}'(\alpha) < 0$. Q.E.D.

Proof of Proposition 7 a) From the proof of Lemma 3, there are three cases for the profit of the unbiased manufacturer $(w - c)\hat{q}(0, w)$, where $\hat{q}(0, w)$ is from (7). (i) If $c \leq c_l$, then $(w - c)\hat{q}(0, w)$ increases in w when $w < w_o$, where w_o is the optimal wholesale price. For this case, the biased wholesale price $\hat{w}(\alpha) = (1 - \alpha)w_o + \alpha w_n$. Thus, $\hat{w}(\alpha) - \hat{w}(0) = (1 - \alpha)w_o + \alpha w_n - w_o = \alpha(w_n - w_o)$, which is negative and decreases in α. Consequently, the manufacturer's equilibrium profit $\breve{\pi}_M(\alpha) = [\hat{w}(\alpha) - c]\hat{q}(0, \hat{w}(\alpha))$ decreases in α. (ii) If $c > c_h$, then the manufacture's profit $(w - c)\hat{q}(0, w)$ decreases in w when $w > w_u$, where w_u is the optimal wholesale price. Moreover, $\hat{w}(\alpha) - \hat{w}(0) = (1 - \alpha)w_u + \alpha w_n - w_u = \alpha(w_n - w_u)$, which is positive and increases in α. Consequently, the manufacturer's equilibrium profit $\breve{\pi}_M(\alpha) = [\hat{w}(\alpha) - c]\hat{q}(0, \hat{w}(\alpha))$ decreases in α. (iii) If $c_l < c \leq c_h$, then τ is the optimal wholesale price. Furthermore, $(w - c)\hat{q}(0, w)$ increases in w when $w \in [\tau, w_u]$, whereas $\hat{w}(\alpha) - \hat{w}(0) = \alpha\frac{(\mu - x_l)^2}{2(2x_h - x_l - \mu)b}$ increases in α if $\hat{c}_l(\alpha) < c \leq \hat{c}_h(\alpha)$. Consequently,

$\hat{\pi}_M(\alpha)$ increases in α if $\hat{c}_l(\alpha) < c \leq \hat{c}_h(\alpha)$ and $\hat{w}(\alpha) \in [\tau, w_u]$.

b) When $c > c_h$, the retailer's profit $\breve{\pi}_R(\alpha)$ decreases in α; see the proof of Proposition 6. When $c \leq c_l$, the wholesale price $\hat{w}(\alpha)$ decreases in α from part (a). Moreover, when $c \leq c_l \Longrightarrow \hat{w}(0) \leq \tau$, $\hat{w}(\alpha) \leq \tau$ because $\hat{w}(\alpha)$ decreases in α. Consequently, $z = x_h$. From Lemma 1(i), the retailer's profit $\breve{\pi}_R(\alpha)$ increases in α. Lastly, from part (a), $\hat{\pi}_M(\alpha)$ can increase in α if $\hat{c}_l(\alpha) < c \leq \hat{c}_h(\alpha)$. For such a situation, the manufacturer's wholesale price $\hat{w}(\alpha) > \tau$. Consequently, the unbiased retailer understocks with $z = x_l$. From Lemma 1(ii), the retailer's profit $\breve{\pi}_R(\alpha)$ decreases in α because $\hat{w}(\alpha)$ increases in α. Q.E.D.

Proof of Proposition 8 Since $\hat{w}(\alpha_m)$ is independent with α_r, the retailer's equilibrium profit $\pi_R(\alpha_m, \alpha_r)$ defined in (20) always decreases in α_r from Lemma 2. We next study the impact of α_m on the equilibrium profits for two cases: $c > \hat{c}_h(\alpha_m)$ and $c \leq \hat{c}_l(\alpha_m)$.

When $c > \hat{c}_h(\alpha_m) \Longrightarrow \hat{w}(\alpha_m) > \hat{\tau}(\alpha_m)$ and $\alpha_m > \alpha_r \Longrightarrow \hat{\tau}(\alpha_m) > \hat{\tau}(\alpha_r)$, the retailer is in the understocking equilibrium ($z = x_l$) with the ordering quantity $\hat{q}(\alpha_r, \hat{w}(\alpha_m))$ from (7) and the equilibrium retail price $\hat{p}(\alpha_r, \hat{w}(\alpha_m))$ from (8). For the manufacturer's profit $\pi_M(\alpha_m, \alpha_r) = [\hat{w}(\alpha_m) - c]\hat{q}(\alpha_r, \hat{w}(\alpha_m))$, $\frac{\partial \pi_M(\alpha_m, \alpha_r)}{\partial \alpha_m} = \hat{w}'(\alpha_m)\hat{q}(\alpha_r, \hat{w}(\alpha_m)) + [\hat{w}(\alpha_m) - c]\frac{\partial \hat{q}(\alpha_r, \hat{w}(\alpha_m))}{\partial \alpha_m} = (w_n - w_u)[\frac{(1-\alpha_r)x_l + \alpha_r\mu - b\hat{w}(\alpha_m)}{2} - \frac{b\hat{w}(\alpha_m) - bc}{2}] = (w_n - w_u)b[\hat{w}(\alpha_r) - \hat{w}(\alpha_m)] < 0$, where the second inequality is from $\hat{w}(\alpha_m) = (1-\alpha_m)w_u + \alpha_m w_n$ while the third equality is from $\hat{w}(\alpha_r) = (1-\alpha_r)w_u + \alpha_r w_n$. For the retailer's profit $\tilde{\pi}_R(\alpha_m, \alpha_r)$, note that $\hat{w}'(\alpha_m) = w_n - w_u < 0$, i.e., the wholesale price increases as the manufacturer becomes more overconfident. Thus, from Lemma 1(ii), $\frac{\partial \pi_R(\alpha_m, \alpha_r)}{\partial \alpha_m} < 0$.

If $c \leq \hat{c}_l(\alpha_m) \Longrightarrow \hat{w}(\alpha_m) < \hat{\tau}(\alpha_m)$ and $\alpha_m < \alpha_r \Longrightarrow \hat{\tau}(\alpha_m) < \hat{\tau}(\alpha_m)$, the retailer is in the overstocking equilibrium ($z = x_h$) with the order quantity $\hat{q}(\alpha_r, \hat{w}(\alpha_m))$ from (7) and the equilibrium retail price $\hat{p}(\alpha_r, \hat{w}(\alpha_m))$ from (8). For the manufacturer's profit $\pi_M(\alpha_m, \alpha_r) = [\hat{w}(\alpha_m) - c]\hat{q}(\alpha_r, \hat{w}(\alpha_m))$, $\frac{\partial \pi_M(\alpha_m, \alpha_r)}{\partial \alpha_m} = \hat{w}'(\alpha_m)\hat{q}(\alpha_r, \hat{w}(\alpha_m)) - \frac{b\hat{w}'(\alpha_m)}{2}[\hat{w}(\alpha_m) - c] = (w_n - w_o)[\frac{2[(1-\alpha_r)x_h + \alpha_r\mu] - \mu - b\hat{w}(\alpha_m)}{2} - \frac{b\hat{w}(\alpha_m) - bc}{2}] = (w_n - w_o)b[\hat{w}(\alpha_r) - \hat{w}(\alpha_m)] > 0$, where the second inequality is from $\hat{w}(\alpha_m) = (1 - \alpha_m)w_o + \alpha_m w_n$ while the third equality is from $\hat{w}(\alpha_r) = (1-\alpha_r)w_o + \alpha_r w_n$. For the retailer's profit $\pi_R(\alpha_m, \alpha_r)$, note that $\hat{w}'(\alpha_m) = w_n - w_o < 0$, i.e., the wholesale price decreases as the manufacturer becomes more overconfident. Thus, from Lemma 1(i), $\frac{\partial \pi_R(\alpha_m, \alpha_r)}{\partial \alpha_m} > 0$, i.e., the retailer's profit increases as it becomes more overconfident. All told, both the manufacturer's profit $\pi_M(\alpha_m, \alpha_r)$ and the retailer's profit $\pi_R(\alpha_m, \alpha_r)$ increase in α_m when $c \le \hat{c}_l(\alpha_m)$ and $\alpha_m < \alpha_r$. Q.E.D.

Proof of Proposition 9 The objective function of (6) decreases in c for any wholesale price w and α. Consequently, $\hat{\pi}_M(\alpha) = \max_w (w - c)\hat{q}(\alpha, w)$ always decreases in c from the envelope theorem. For the manufacturer profit (12), we note that $\hat{\pi}_M(0)|_{c=c_h^-} = (\tau - c_h)\hat{q}(0, \tau) = (w_u - c_h)\hat{q}(0, w_u) = \hat{\pi}_M(0)|_{c=c_h^+}$. However, from (7)-(8), $\tilde{\pi}'_M(0)|_{c=c_h^-} = (\tau - c_h)\frac{\partial \hat{q}(\alpha,\tau)}{\partial \alpha}|_{\alpha=0} = (\tau - c_h)(\mu - x_h) < 0$, and $\tilde{\pi}'_M(0)|_{c=c_h^+} = (w_u - c_h)\frac{\partial \hat{q}(\alpha,w_u)}{\partial \alpha}|_{\alpha=0} = (w_u - c_h)(\mu - x_l) > 0$. Consequently, we can conclude. Q.E.D.

Electronic Companion To "Overconfident Distribution Channels"

In this technical supplement, we consider the case of non-pricing retailer (§EC.1) and the case of anchoring bias (§EC.2).

EC.1. Non-Pricing Retailer

For the non-pricing channel, the demand X can have x_h and x_l with probabilities θ and $1-\theta$ respectively. Thus, an overconfident decision maker exhibits cognitive bias by instead behaving as though the demand distribution were $D=(1-\alpha)X+\alpha\mu$ rather than the given X.

EC.1.1. Overconfident Centralized Channels

For the unbiased decision maker of the centralized channel, it maximizes the expected profit: $p\mathrm{E}[X\wedge q]-cq$. Thus, the decision maker produces a relatively high quantity (x_h) if the production cost is sufficiently low ($c\le\theta p$), whereas the decision maker produces a relatively low quantity (x_l) if the production cost is sufficiently high ($c>\theta p$). For an centralized channel, an overconfident decision maker is a decision maker that behaves as though it were maximizing $p\mathrm{E}[D\wedge q]-cq$. Let $q=(1-\alpha)z+\alpha\mu$. Then, the overconfident decision maker behaves as though it were solving

$$\max_{z,p}(1-\alpha)\mathrm{E}[p(X\wedge z)-cz]+\alpha(p-c)\mu. \tag{EC.1}$$

Next, Lemma EC.1 summarizes the decision maker's decisions and resulting expected profit.

Lemma EC.1. *Given the demand X:*

a) If $c\le\theta p$, the decision maker described by the overconfidence parameter α sets its production quantity as $d_h=(1-\alpha)x_h+\alpha\mu$. However, if $c>\theta p$, the production quantity is $d_l=(1-\alpha)x_l+\alpha\mu$.

b) The centralized channel's resulting expected profit $\hat{\pi}^c(\alpha)$ is decreasing in α.

Lemma EC.1a indicates that, analogous to the unbiased case, if the production cost is sufficiently low ($c\le\theta p$), the overconfident decision maker produces relatively high and is in the overstocking case ($z=x_h$). However, if the production cost is sufficiently high ($c>\theta p$), the production quantity is relatively low and is in the understocking case ($z=x_l$). Moreover, Lemma EC.1b indicates that a centralized channel's expected profit decreases in α.

EC.1.2. Overconfident Decentralized Channels

We now develop the decentralized analog of the centralized channel in §EC.1.1, and each unit of the product is produced by a manufacturer at a unit production cost c and is sold to customers by a retailer for a unit retail price p. The manufacturer first decides the unit wholesale price w it charges the retailer, and the retailer then decides the order quantity purchased from the manufacturer.

As in the centralized channel, we first analyze the case of *unbiased* retailer. If the wholesale price is relatively low ($w \leq \theta p$), it is the overstocking case with the optimal ordering quantity x_h. Thus, the manufacturer's problem is $\max_{w\in[c,\theta p]}(w-c)x_h$. Nonetheless, if the wholesale price is relatively low ($w > \theta p$), it is the understocking case with the optimal ordering quantity x_l. Thus, the manufacturer's problem is $\max_{w\in(\theta p,p]}(w-c)x_l$. Lemma 3 next depicts the optimal wholesale decision for the manufacturer.

LEMMA EC.2. *With an exogenous retail price, if $c > \frac{p(\theta x_h - x_l)}{x_h - x_l}$, the equilibrium wholesale price is p. However, if $c \leq \frac{p(\theta x_h - x_l)}{x_h - x_l}$, the equilibrium wholesale price is θp.*

We now incorporate the notion of overconfidence bias into the decentralization channel. The manufacturer's problem is

$$\hat{\pi}_M(\alpha) := (w-c)\hat{q}(\alpha, w), \tag{EC.2}$$

where

$$\hat{q}(\alpha, w) = \begin{cases} d_h & \text{if } w \leq \theta p \\ d_l & \text{if } w > \theta p. \end{cases} \tag{EC.3}$$

Next, we solve (EC.2)-(EC.3) to obtain the equilibrium wholesale price.

LEMMA EC.3. *With an exogenous retail price, if $c \leq \frac{p(\theta d_h - d_l)}{d_h - d_l}$, then the equilibrium wholesale price $\hat{w}(\alpha) = \theta p$, whereas, if $c > \frac{p(\theta d_h - d_l)}{d_h - d_l}$, then the equilibrium wholesale price $\hat{w}(\alpha) = p$.*

Given the equilibrium wholesale price, the retailer's equilibrium order quantity is $\hat{q}(\alpha) = \hat{q}(\alpha, w = \hat{w}(\alpha))$, where $\hat{q}(\alpha, w)$ is from (EC.3). As a result, the ensuing retailer's equilibrium profit is

$$\hat{\pi}_R(\alpha) := \hat{p}(\alpha)\mathrm{E}[(X - b\hat{p}(\alpha)) \wedge \hat{q}(\alpha)] - \hat{w}(\alpha)\hat{q}(\alpha). \tag{EC.4}$$

We next investigate the impact of overconfidence parameter α on the manufacturer's profit $\hat{\pi}_M(\alpha)$ defined in (EC.2) and the retailer's expected profit $\hat{\pi}_R(\alpha)$ defined above.

PROPOSITION EC.1. *With an exogenous retail price, the retailer's expected profit $\hat{\pi}_R(\alpha)$ is decreasing in α. However, the manufacturer's expected profit $\hat{\pi}_M(\alpha)$ is increasing in α when $c > \frac{p(\theta x_h - x_l)}{x_h - x_l}$.*

Thus, the retailer's expected profit $\hat{\pi}_R(\alpha)$ decreases in α. Accordingly, in such a case, the qualitative effect on the retailer in the decentralized channel is analogous to that on the centralized channel. However, Proposition EC.1 shows that the manufacturer's profit $\hat{\pi}_M(\alpha)$ can increase in α, which means that the overconfidence bias can actually enhance the manufacturer's performance.

Given the above observations, we next identify that the system-win case due to overconfidence is possible.

PROPOSITION EC.2. *With an exogenous retail price and a biased channel with overconfidence parameter α, the channel's expected profit $\hat{\pi}_T(\alpha)$ increases in α when $\frac{p(\theta d_h - d_l)}{d_h - d_l} < c < \theta p$.*

Proposition EC.2 demonstrates that the retailer's overconfidence bias can boost the channel profit as a whole. That is, overconfidence bias can be counterbalances for the double marginalization effect, thus benefiting the channel as a whole.

EC.1.3. The Overconfident Retailer

When the manufacturer is unbiased, the manufacturer's pricing behavior is prescribed by the standard theory. That is, the manufacturer anticipates the retailer orders x_h for the overstocking case, whereas anticipates the retailer orders x_l for the understocking case. Accordingly, the manufacturer's wholesale price decision follows Lemma EC.2: If the production cost is relatively low ($c \leq \frac{p(\theta x_h - x_l)}{x_h - x_l}$), the wholesale price is θp, whereas, if the production cost is relatively high ($c > \frac{p(\theta x_h - x_l)}{x_h - x_l}$), the equilibrium wholesale price is p.

PROPOSITION EC.3. *With an exogenous retail price and a biased retailer with overconfidence parameter α, the channel's profit increases in α when $\frac{p(\theta x_h - x_l)}{x_h - x_l} < c < \theta p$.*

Proposition EC.3 shows that overconfidence can be beneficial for the distribution channel.

EC.1.4. The Biased Manufacturer

We now extend our analysis in §EC.1.3 to allow manufacturer overconfidence, and denote the manufacturer's and the retailer's overconfidence levels as α_m and α_r respectively. Accordingly, given the random variable X to characterize the market size, the manufacturer the retailer behave as though random market is instead $D(\alpha_m)$ and $D(\alpha_r)$, respectively. As a result, the manufacturer behaves as though its game with the retailer were described by

$$\max_w (w-c)\hat{q}(\alpha_m, w), \tag{EC.5}$$

and

$$\max_q p\mathrm{E}[(D(\alpha_m) - bp) \wedge q] - wq. \tag{EC.6}$$

Thus, the manufacturer behaves as though it solves (EC.5) by anticipating the retailer's problem (EC.6), thereby deriving the equilibrium wholesale price $\hat{w}(\alpha_m)$.

Given the wholesale price $\hat{w}(\alpha_m)$, the retailer actually behaves as though solving

$$\max_q p\mathrm{E}[(D(\alpha_r) - bp) \wedge q] - wq \tag{EC.7}$$

with the resulted order quantity $\hat{q}(\alpha_r, w = \hat{w}(\alpha_m))$ along with the retail price $\hat{p}(\alpha_r, w = \hat{w}(\alpha_m))$. All told, this means that although (EC.5)-(EC.7) effectively describe how the manufacturer and the retailer behave given X, the manufacturer's and retailer's resulting equilibrium expected profits are $\pi_M(\alpha_m, \alpha_r) := [\hat{w}(\alpha_m) - c]\hat{q}(\alpha_r, \hat{w}(\alpha_m))$ and $\pi_R(\alpha_m, \alpha_r) := \hat{p}(\alpha_r, \hat{w}(\alpha_m))\mathrm{E}[(X - b\hat{p}(\alpha_r, \hat{w}(\alpha_m))) \wedge \hat{q}(\alpha_r, \hat{w}(\alpha_m))] - \hat{w}(\alpha_m)\hat{q}(\alpha_r, \hat{w}(\alpha_m))$, respectively. Thus, we next examine the impact of manufacturer overconfidence on his own profit.

PROPOSITION EC.4. *With an exogenous retail price, the manufacturer's profit $\pi_M(\alpha_m, \alpha_r)$ increases in α_m if $\alpha_m < \frac{c(x_h - x_l) + p(x_l - x_h\theta)}{c(x_h - x_l) + p[(\theta-1)\mu - \theta x_h + x_l]} < \alpha_r$.*

Proposition EC.4 indicates that the manufacturer's profit can be higher as the manufacturer becomes more biased.

Proposition EC.5. *The overconfident decentralized channel can achieve the expected profit of the biased centralized channel.*

Proposition EC.5 shows that the overconfident decentralized channel can achieve the performance of its centralized analog.

Proofs of Appendix EC.1

Proof of Lemma EC.1 a) For a biased channel with overconfidence parameter α, the decision maker solves $\max_q \mathrm{E}[D\wedge q]-cq$. Thus, if $c\le\theta p$, the decision maker described by the overconfidence parameter α sets its production quantity as d_h. However, if $c>\theta p$, the production quantity is d_l.

b) The channel's profit $\hat{\pi}^c(\alpha)=\mathrm{E}[X\wedge q]-cq$, where q is the decision described in part a). Thus, when $c\le\theta p$, $\hat{\pi}^c(\alpha)=p\mathrm{E}[X\wedge d_h]-cd_h=p[\theta d_h+(1-\theta)x_l]-cd_h$ with $\frac{d\hat{\pi}^c(\alpha)}{d\alpha}=(p\theta-c)(\mu-x_h)\le 0$. However, when $c>\theta p$, $\hat{\pi}^c(\alpha)=p\mathrm{E}[X\wedge d_l]-cd_l=p[\theta d_l+(1-\theta)x_l]-cd_l$ with $\frac{d\hat{\pi}^c(\alpha)}{d\alpha}=(p\theta-c)(\mu-x_l)\le 0$. Thus, $\hat{\pi}^c(\alpha)$ always decreases in α. Q.E.D.

Proof of Lemma EC.2 When $w\le\theta p$, the manufacturer's profit is $\max_w(w-c)x_h=(\theta p-c)x_h$ with the optimal wholesale price θp. However, when $\theta p<w\le p$, the manufacturer's profit is $\max_w(w-c)x_l=(p-c)x_l$ with the optimal wholesale price p. Thus, if $(p-c)x_l>(\theta p-c)x_h \Longleftrightarrow c>\frac{p(\theta x_h-x_l)}{x_h-x_l}$, the optimal wholesale price is p. Otherwise, the optimal wholesale price is θp. Q.E.D.

Proof of Lemma EC.3 The proof follows the proof of Lemma EC.2 but replacing x_h and x_l by d_h and d_l, respectively. Q.E.D.

Proof of Proposition EC.1 Since $\frac{p(\theta d_h-d_l)}{d_h-d_l}=p[\theta-\frac{(1-\theta)d_l}{d_h-d_l}]=p[\theta-\frac{1-\theta}{\frac{d_h}{d_l}-1}]$ increases in $\frac{d_h}{d_l}$ which decreases in α, the manufacturer charges a higher wholesale price as the retailer becomes more overconfident. Because for a given wholesale price, the retailer's profit decreases in α (Lemma EC.1), the retailer's profit $\hat{\pi}_R(\alpha)$ always decreases in α.

For the manufacturer's profit, $\hat{\pi}_M(\alpha)=(\theta p-c)d_l$ increases in α when $c>\frac{p(\theta x_h-x_l)}{x_h-x_l}$. Q.E.D.

Proof of Proposition EC.2 We have two cases. (i) When $c>\frac{p(\theta d_h-d_l)}{d_h-d_l}$, the retailer's order quantity is d_l. Consequently, the channel's expected profit is $\hat{\pi}_T(\alpha)=p\mathrm{E}[X\wedge d_l]-cd_l=p[\theta d_l+(1-\theta)x_l]-cd_l$. As a result, $\hat{\pi}_T'(\alpha)=(\theta p-c)(\mu-x_l)>0$ when $\theta p>c$. This means when $\frac{p(\theta d_h-d_l)}{d_h-d_l}<$

$c < \theta p$, $\hat{\pi}_T'(\alpha) > 0$. (ii) When $c < \frac{p(\theta d_h - d_l)}{d_h - d_l}$, the retailer's order quantity is d_h. Consequently, the channel's expected profit is $\hat{\pi}_T(\alpha) = p\mathrm{E}[X \wedge d_h] - cd_h = p[\theta d_h + (1-\theta)x_l] - cd_h$. As a result, $\hat{\pi}_T'(\alpha) = (\theta p - c)(\mu - x_h) > 0$ when $\theta p < c$. This means when $\theta p < c < \frac{p(\theta d_h - d_l)}{d_h - d_l}$, $\hat{\pi}_T'(\alpha) > 0$.

From (i)-(ii), $\hat{\pi}_T'(\alpha) > 0$ when $\frac{p(\theta d_h - d_l)}{d_h - d_l} < c < \theta p$ because $\frac{p(\theta d_h - d_l)}{d_h - d_l} < \theta p$. Q.E.D.

Proof of Proposition EC.3 When $c > \frac{p(\theta x_h - x_l)}{x_h - x_l}$, the equilibrium wholesale price is $w = p$, and the equilibrium order quantity is d_l. The channel's expected profit is consequently $p\mathrm{E}[X \wedge d_l] - cd_l = p[\theta d_l + (1-\theta)x_l] - cd_l$, which increases in α when $c < \theta p$. Thus, the channel's profit increases in α when $\frac{p(\theta x_h - x_l)}{x_h - x_l} < c < \theta p$. Q.E.D.

Proof of Proposition EC.4 From Lemma EC.2, when $c < \frac{p\theta[(1-\alpha_m)x_h + \alpha_m \mu] - p[(1-\alpha_m)x_l + \alpha_m \mu]}{[(1-\alpha_m)x_h + \alpha_m \mu] - [(1-\alpha_m)x_l + \alpha_m \mu]} \iff \alpha_m < \frac{c(x_h - x_l) + p(x_l - \theta x_h)}{c(x_h - x_l) + p[(\theta-1)\mu - \theta x_h + x_l]}$, the manufacturer charges a wholesale price at p and the retailer is in the understocking equilibrium with the ordering quantity $(1-\alpha_r)x_l + \alpha_r \mu$. Thus, the manufacturer's profit is $\pi_M(\alpha_m, \alpha_r) = (p-c)[(1-\alpha_r)x_l + \alpha_r \mu]$. However, when $\alpha_m > \frac{c(x_h - x_l) + p(x_l - \theta x_h)}{c(x_h - x_l) + p[(\theta-1)\mu - \theta x_h + x_l]}$, the manufacturer charges the wholesale price at θp with the associated profit $\pi_M(\alpha_m, \alpha_r) = (\theta p - c)[(1-\alpha_r)x_h + \alpha_r \mu]$. Moreover, $(\theta p - c)[(1-\alpha_r)x_h + \alpha_r \mu] > (p-c)[(1-\alpha_r)x_l + \alpha_r \mu] \iff \alpha_r > \frac{c(x_h - x_l) + p(x_l - x_h \theta)}{c(x_h - x_l) + p[(\theta-1)\mu - \theta x_h + x_l]}$. Thus, around $\alpha_m = \frac{c(x_h - x_l) + p(x_l - x_h \theta)}{c(x_h - x_l) + p[(\theta-1)\mu - \theta x_h + x_l]}$, the manufacturer's profit $\pi_M(\alpha_m, \alpha_r)$ increases in α_m for a given α_r. Q.E.D.

Proof of Proposition EC.5 With exogenous retail price, the centralized channel's problem is $\max_z (1-\alpha)[p\mathrm{E}(X \wedge z) - cz - bp(p-c)] + \alpha(p-c)(\mu - bp)$. Consequently, if $c > \theta p$, the production quantity is $d_l - bp$, whereas, if $c \le \theta p$, the production quantity is $d_h - bp$. For the decentralized channel, when $w \le \theta p$, the manufacturer's profit is $\max_w (w-c)(d_h - bp) = (\theta p - c)(d_h - bp)$ with the optimal wholesale price θp. However, when $\theta p < w \le p$, the manufacturer's profit is $\max_w (w - c)(d_l - bp) = (p-c)(d_l - bp)$ with the optimal wholesale price p. Thus, if $(p-c)(d_l - bp) > (\theta p - c)(d_h - bp) \iff c > \frac{p(\theta d_h - d_l) + bp^2(1-\theta)}{d_h - d_l}$, the equilibrium order quantity is $d_l - bp$. Otherwise, the equilibrium order quantity is $d_h - bp$. All told, if $c \le \min\{\theta p, \frac{p(\theta d_h - d_l) + bp^2(1-\theta)}{d_h - d_l}\}$, both the centralized and decentralized channels have production quantity $d_h - bp$. However, if $c \ge \max\{\theta p, \frac{p(\theta d_h - d_l) + bp^2(1-\theta)}{d_h - d_l}\}$, both the centralized and decentralized channels have production quantity $d_l - bp$. That is, under these conditions, the decentralize channel achieves the profit of the centralized channel. Q.E.D.

EC.2. Anchoring Bias

Motivated by the experimental studies in Schweitzer and Cachon (2000) and Ramachandran et al. (2017), we model the anchoring effect in both centralized and decentralized channels.

EC.2.1. Biased Centralized Channels

For the centralized channel, we specify an anchoring parameter α that assigns a weight of α to the mean demand potential μ and a weight of $(1-\alpha)$ to the unbiased order q^* defined in (2). Similarly, we specify an anchoring parameter α_p that assigns a weight of α_p to the cost and a weight $(1-\alpha_p)$ to the unbiased price p^* defined in (2). We restrict the parameters to $0 \leq \alpha \leq 1$, and $0 \leq \alpha_p \leq 1$ and $2x_h - 3\mu > bc$ to avoid unreasonable results. Thus, the resulting profit for the centralized channel is

$$\begin{aligned}\hat{\pi}^c(\alpha, \alpha_p) := &[(1-\alpha_p)p^* + \alpha_p c]\mathrm{E}[(X - b(1-\alpha_p)p^* - b\alpha_p c) \wedge ((1-\alpha)q^* + \alpha\mu)] \\ &- c[(1-\alpha)q^* + \alpha\mu]. \end{aligned} \tag{EC.8}$$

Next, Lemma EC.4 summarizes the impacts of anchoring bias on the expected profit.

LEMMA EC.4. *Given the demand X:*

a) The centralized channel's profit $\hat{\pi}^c(\alpha, \alpha_p)$ always decreases in α when $\alpha_p = 0$.

b) The centralized channel's profit $\hat{\pi}^c(\alpha, \alpha_p)$ always decreases in α_p when $\alpha = 0$.

Lemma EC.4 indicates that a centralized channel's expected profit decreases in the demand mean (resp. price) anchoring given the decision maker is unbiased on the price (resp. demand mean). Next, we investigate whether anchoring bias can be a positive force for the decentralized channel. To this end, it suffices to consider the case of $\alpha_p = 0$ in the remainder.

EC.2.2. Biased Decentralized Channels

We now develop the decentralized analog of the centralized channel in §EC.2.1, and each unit of the product is produced by a manufacturer at a unit production cost c and is sold to customers by a retailer for a unit retail price p. The manufacturer first decides the unit wholesale price w it charges the retailer, and the retailer then decides the order quantity purchased from the manufacturer.

For this biased channel, the manufacturer's problem is

$$\hat{\pi}_M(\alpha) := (w-c)\hat{q}(\alpha, w), \tag{EC.9}$$

where

$$\hat{q}(\alpha, w) = \begin{cases} (1-\alpha)\frac{2x_h-\mu-bw}{2} + \alpha\mu & \text{if } w \le \tau \\ (1-\alpha)\frac{x_l-bw}{2} + \alpha\mu & \text{if } w > \tau. \end{cases} \tag{EC.10}$$

Next, in Proposition EC.5, we solve (EC.9)-(EC.10) to obtain the manufacturer's equilibrium outcome.

Lemma EC.5. *With an anchoring bias, there are three types of equilibrium.*

a) In the overstocking equilibrium, $\hat{w}(\alpha) = \frac{2x_h-\mu+bc}{2b} + \frac{\alpha\mu}{(1-\alpha)b}$. *Consequently, the equilibrium order is* $\hat{q}(\alpha) = (1-\alpha)\frac{2x_h-\mu-bc}{4} + \alpha\frac{\mu}{2}$, *while the equilibrium retail price is* $\hat{p}(\alpha) = \frac{\mu+2x_h+bc}{4b} + \frac{\alpha\mu}{2(1-\alpha)b}$.

b) In the understocking equilibrium, $\hat{w}(\alpha) = \frac{x_l+bc}{2b} + \frac{\alpha\mu}{(1-\alpha)b}$. *Consequently, the equilibrium order is* $\hat{q}(\alpha) = (1-\alpha)\frac{x_l-bc}{4} + \alpha\frac{\mu}{2}$, *while the equilibrium retail price is* $\hat{p}(\alpha) = \frac{3x_l+bc}{4b} + \frac{\alpha\mu}{2(1-\alpha)b}$.

c) In the leapfrogging equilibrium, $\hat{w}(\alpha) = \tau$. *Consequently, the equilibrium order is* $\hat{q}(\alpha) = (1-\alpha)\frac{2x_h-\mu-b\tau}{2} + \alpha\mu$, *while the equilibrium retail price is* $\hat{p}(\alpha) = \frac{\mu+b\tau}{2b}$.

Given Lemma EC.5, we next investigate the impact of anchoring bias on the manufacturer's profit.

Proposition EC.6. *In the understocking equilibrium,* $\hat{\pi}_M(\alpha)$ *increases in* α.

The retailer's equilibrium profit is

$$\hat{\pi}_R(\alpha) := \hat{p}(\alpha)\mathrm{E}[(X - b\hat{p}(\alpha)) \wedge \hat{q}(\alpha)] - \hat{w}(\alpha)\hat{q}(\alpha). \tag{EC.11}$$

We next investigate the impact of anchoring bias on the channel's profit $\hat{\pi}_T(\alpha) := \hat{\pi}_M(\alpha) + \hat{\pi}_R(\alpha)$, and show that the system-win case due to anchoring bias is possible in Proposition EC.7.

Proposition EC.7. *In the understocking equilibrium, the channel's equilibrium profit* $\hat{\pi}_T(\alpha)$ *can increase in* α.

Proposition EC.7 demonstrates that, consistent with the overconfidence bias, the anchoring bias can boost the channel profit as a whole.

EC.2.3. The Biased Retailer

When the manufacturer is unbiased, the manufacturer's pricing behavior is prescribed by the standard theory. That is, the manufacturer anticipates the retailer orders $\frac{2x_h-\mu-bw}{2}$ for the overstocking case, whereas anticipates the retailer orders $\frac{x_l-bw}{2}$ for the understocking case. Accordingly, the manufacturer's wholesale price decision follows Lemma 4, and the retailer's equilibrium order quantity is

$$\hat{q}(\alpha)=\begin{cases}(1-\alpha)\frac{2x_h-\mu-bw}{2}+\alpha\mu & \text{if } w\le\tau\\ (1-\alpha)\frac{x_l-bw}{2}+\alpha\mu & \text{if } w>\tau.\end{cases} \tag{EC.12}$$

Given (EC.12), we next evaluate the channel's profit when the retailer is biased.

PROPOSITION EC.8. *With a biased retailer of an anchoring parameter α, the channel's profit increases in α when $c>c_h$.*

Proofs of Appendix EC.2

Proof of Lemma EC.4 a) When $\alpha_p=0$, then $\hat{\pi}^c(\alpha,0)=p^*\mathrm{E}[(X-bp^*)\wedge((1-\alpha)q^*+\alpha\mu)]-c[(1-\alpha)q^*+\alpha\mu]$, where p^* and q^* are from (2). Thus, if $c\le\tau$,

$$\begin{aligned}\hat{\pi}^c(\alpha,0)&=\frac{\mu+bc}{2b}\mathrm{E}\left[\left(X-\frac{\mu+bc}{2}\right)\wedge\left((1-\alpha)\frac{2x_h-\mu-bc}{2}+\alpha\mu\right)\right]-c\left[(1-\alpha)\frac{2x_h-\mu-bc}{2}+\alpha\mu\right]\\&=\frac{\mu+bc}{2b}\left[\theta\left((1-\alpha)\frac{2x_h-\mu-bc}{2}+\alpha\mu\right)+(1-\theta)\left(\frac{2x_l-\mu-bc}{2}\right)\right]\\&\quad-c\left[(1-\alpha)\frac{2x_h-\mu-bc}{2}+\alpha\mu\right].\end{aligned}$$

Because the channel's profit $\hat{\pi}^c(\alpha,0)$ is maximized when $q=q^*$ given that $p=p^*$,

$$\frac{\partial\hat{\pi}^c(\alpha,0)}{\partial\alpha}=\frac{\mu+bc}{2b}\left[\theta\left(\mu-\frac{2x_h-\mu-bc}{2}\right)+(1-\theta)\left(\frac{2x_l-\mu-bc}{2}\right)\right]+c\left(\frac{2x_h-3\mu-bc}{2}\right)\le 0.$$

If $c>\tau$,

$$\begin{aligned}\hat{\pi}^c(\alpha,0)&=\frac{x_l+bc}{2b}\mathrm{E}\left[\left(X-\frac{x_l+bc}{2}\right)\wedge\left((1-\alpha)\frac{x_l-bc}{2}+\alpha\mu\right)\right]-c\left[(1-\alpha)\frac{x_l-bc}{2}+\alpha\mu\right]\\&=\frac{x_l+bc}{2b}\left[\theta\left((1-\alpha)\frac{x_l-bc}{2}+\alpha\mu\right)+(1-\theta)\left(\frac{x_l-bc}{2}\right)\right]-c\left[(1-\alpha)\frac{x_l-bc}{2}+\alpha\mu\right].\end{aligned}$$

As a result,

$$\frac{\partial \hat{\pi}^c(\alpha,0)}{\partial \alpha} = \frac{x_l+bc}{2b}\left[\theta\left(\mu - \frac{x_l-bc}{2}\right)\right] + c\left(\frac{x_l-2\mu-bc}{2}\right) \leq 0.$$

b) When $\alpha=0$, then $\hat{\pi}^c(0,\alpha_p) = [(1-\alpha_p)p^* + \alpha_p c]\mathrm{E}[(X - b(1-\alpha_p)p^* - b\alpha_p c)\wedge q^*] - cq^*$, where p^* and q^* are from (2). Thus, following a similar proof in (a), we can show that $\hat{\pi}^c(0,\alpha_p)$ decreases in α_p. Q.E.D.

Proof of Lemma EC.5 a) In the overstocking equilibrium, the manufacturer's profit $(w-c)[(1-\alpha)\frac{2x_h-\mu-bw}{2} + \alpha\mu]$. Consequently, from (EC.10), the equilibrium order is $\hat{q}(\alpha) = (1-\alpha)\frac{2x_h-\mu-bc}{4} + \alpha\frac{\mu}{2}$, while the equilibrium retail price is $\hat{p}(\alpha) = \frac{\mu+2x_h+bc}{4b} + \frac{\alpha\mu}{2(1-\alpha)b}$.

b) In the overstocking equilibrium, the manufacturer's profit $(w-c)[(1-\alpha)\frac{x_l-bw}{2} + \alpha\mu]$. Consequently, the first-order-condition yields $\hat{q}(\alpha) = (1-\alpha)\frac{x_l-bc}{4} + \alpha\frac{\mu}{2}$. As a result, from (EC.10), the equilibrium order is $\hat{q}(\alpha) = (1-\alpha)\frac{x_l-bc}{4} + \alpha\frac{\mu}{2}$, while the equilibrium retail price is $\hat{p}(\alpha) = \frac{3x_l+bc}{4b} + \frac{\alpha\mu}{2(1-\alpha)b}$.

c) In the leapfrogging equilibrium, $\hat{w}(\alpha) = \tau$. Consequently, from (EC.10), we can conclude. Q.E.D.

Proof of Proposition EC.6 In the understocking equilibrium, both the equilibrium wholesale price $\hat{w}(\alpha) = \frac{x_l+bc}{2b} + \frac{\alpha\mu}{(1-\alpha)b}$ and the equilibrium order $\hat{q}(\alpha) = (1-\alpha)\frac{x_l-bc}{4} + \alpha\frac{\mu}{2}$ increase in α. Consequently, the manufacturer's equilibrium profit $\hat{\pi}_M(\alpha) = [\hat{w}(\alpha) - c]\hat{q}(\alpha)$ also increases in α. Q.E.D.

Proof of Proposition EC.7 For the channel described by the anchoring bias parameter α, we have $\hat{\pi}_T'(\alpha) = \hat{p}(\alpha)\mathrm{E}[-\mathbb{1}_{X-b\hat{p}(\alpha)<\hat{q}(\alpha)}b\hat{p}'(\alpha) + \mathbb{1}_{X-b\hat{p}(\alpha)>\hat{q}(\alpha)}\hat{q}'(\alpha)] + \hat{p}'(\alpha)\mathrm{E}[(X-b\hat{p}(\alpha))\wedge\hat{q}(\alpha)] - c\hat{q}'(\alpha)$, where $\mathbb{1}$ is the indicator function. For the understocking equilibrium, we have

$$\hat{\pi}_T'(\alpha)|_{\alpha=c=0} = \frac{x_l[4\mu(3\theta-1) - 3\theta x_l]}{16b} > 0$$

when $\theta > \frac{4}{9}$. Then, we can conclude. Q.E.D.

Proof of Proposition EC.8 If $c > c_h$, then the equilibrium wholesale price is w_u while the equilibrium order is $\hat{q}(\alpha) = (1-\alpha)\frac{x_l - bw_u}{2} + \alpha\mu = (1-\alpha)\frac{x_l - bc}{4} + \alpha\mu$ from the proof of Lemma 3 and $w_u > \tau$. As a result, the equilibrium retail price is $\frac{3x_l+bc}{4b}$, and the channel's profit is

$$\begin{aligned}\tilde{\pi}_T(\alpha) &= \frac{3x_l+bc}{4b}\mathrm{E}\left[\left(X - \frac{3x_l+bc}{4}\right) \wedge \hat{q}(\alpha)\right] - c\hat{q}(\alpha)\\ &= \frac{3x_l+bc}{4b}\left[(1-\theta)\frac{x_l-bc}{4} + \theta\left(\frac{4x_h - 3x_l - bc}{4} \wedge \hat{q}(\alpha)\right)\right] - c\hat{q}(\alpha).\end{aligned}$$

Moreover, when $2x_h > \mu + 3x_l$, $\frac{4x_h - 3x_l - bc}{4} > \mu$ because $2x_h - 3\mu > bc$. Thus, when $2x_h > \mu + 3x_l$,

$$\tilde{\pi}_T(\alpha) = \frac{3x_l+bc}{4b}\left[(1-\theta)\frac{x_l-bc}{4} + \theta\hat{q}(\alpha)\right] - c\hat{q}(\alpha).$$

Thus, $\tilde{\pi}'_T(\alpha) = \frac{\partial \tilde{\pi}_T(\alpha)}{\partial \hat{q}(\alpha)}\hat{q}'(\alpha) = \left(\theta\frac{3x_l+bc}{4b} - c\right)\left(\mu - \frac{x_l-bc}{4}\right) \geq 0.$ Q.E.D.