Manufacturer encroachment with quality decision under asymmetric demand information

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Highlights

- Encroachment with quality decision under asymmetric information is studied
- Encroachment may lead to a lower quality
- Encroachment always benefits the manufacturer and may also benefit the retailer
- Asymmetric information may lead to a higher or lower quality
- The manufacturer may prefer to keep information disadvantages

Manufacturer encroachment with quality decision under asymmetric demand information

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Abstract

This paper investigates manufacturer encroachment with both endogenous quality decision and asymmetric demand information to examine the effects of encroachment and information structure on quality and profits for chain members. Manufacturer encroachment results in a signaling game where at equilibrium the retailer has to distort the order quantity downward under low market size. Our result shows that encroachment leads to a lower quality when the manufacturer's direct selling cost is intermediate. The manufacturer always benefits from encroachment, and the retailer benefits from encroachment under an intermediate direct selling cost of the manufacturer since she can deter the manufacturer from selling directly to avoid channel competition. Results provide several information management implications. Compared to the full and no information cases, asymmetric information may increase quality when direct selling is relatively efficient while decrease quality otherwise. The manufacturer may prefer to keep information disadvantages when his direct selling cost is relatively large and the prior probability of large market size is high. Additionally, the informed retailer may be willing to share information to avoid the unexpected order quantity downward distortion in the case of asymmetric information when direct selling is efficient. As a result, the chain members reach a consensus on information sharing when the manufacturer's direct selling cost is quite small or relatively large.

Keywords: Supply chain management, Encroachment, Asymmetric information, Product quality, Signaling game

1. Introduction

The rapid development of e-commerce has enabled many manufacturers to build online channels and sell products directly to consumers, aside from the existing traditional

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channel where products are sold through a retailer (Tedeschi, 2000). Such phenomenon of manufacturers establishing online channels is usually termed as "manufacturer encroachment", which has been observed in a variety of industries (Tannenbaum, 1995). For instance, a great deal of electronic product makers, e.g., Apple and HP, sell their products through both third-party retail stores and their own websites (Chen et al., 2017). Another example is in the apparel and fashion industry, manufacturers, such as Nike, Adidas, Coach, also develop dual-channel supply chains consisting of both direct and retail channels (Li et al., 2015).

Manufacturer encroachment gives rise to channel competition between the upstream manufacturer and the downstream retailer. To manage these dual distribution channels successfully, different manufacturers have adopted a variety of strategies (Wang et al., 2017). In order to avoid potential channel conflict, manufacturers, such as Daimler, Nikon, and Rubbermaid, only use the online direct channel as a virtue showroom to provide users with product information and in-stock information of nearby retail stores without offering any products in the direct channel. In addition, as quality plays a paramount role in product design of a manufacturer (Jerath et al., 2017), different channel structures may be applied to different levels of product quality (Chen et al., 2017). A survey in 2014 indicated that 47% of 67 US sales channel managers held the opinion that opening a direct online channel is beneficial for product quality improvement (Forrester Research, Inc., 2014). In apparel industry, it is shown that the transition to a dual-channel setting with both retail and direct channels could allow a manufacturer to deliver a better quality product (Mount, 2013). As a result, a question naturally arises that will manufacturer encroachment always increase product quality.

In practice, in a retail channel which consists of upstream manufacturers and downstream retailers, the retailers are often closer to the consumers and have more expertise and superior forecasting abilities in the selling process. Therefore, the retailers usually hold a better knowledge about the market demand than the manufacturers. Taking into such practical demand information asymmetry and following the backdrop of Li et al. (2013), in this paper, we investigate manufacturer encroachment when the retailer knows the true market size while the manufacturer with encroachment capacity only knows the prior distribution of the market size.

Among the studies of manufacturer encroachment, some researches are based on a framework of asymmetric demand information without considering quality decisions (Li et al., 2013, 2015), while others incorporate product quality-setting problem under a full information case (Chen et al., 2017; Ha et al., 2015). Based on the above-mentioned considerations, this paper contributes to bridge the research gap by investigating the endogenous product quality decision under asymmetric information, and intend to address the following questions:

(1) *Quality decisions*: How will the manufacturer encroachment affect the equilibrium quality decision? How will the information structure affect the product quality?

(2) *Effects of encroachment*: What are the effects of encroachment on the profits of chain members under different information structures?

(3) *Effects of information structures:* What are the effects of different information structures on the profits of chain members with manufacturer encroachment? What are the insights for information management?

To answer the above questions, this paper considers a supply chain consisting of one manufacturer (he) who decides on the product quality, wholesale price and the selling quantity in the direct/online channel if he encroaches, and one retailer (she) who sets the order quantity in the retail channel. In order to investigate the effects of information structures and obtain implications for information management, we look into cases with and without manufacturer encroachment under *full information* (both players know the true market size), *asymmetric information* (only the retailer knows the true market size), and *no information* (neither player knows the true market size), respectively. By analyzing the effects of encroachment on product quality and profits for the chain members, we come to the following results. First of all, regardless of the information structures, encroachment decreases product quality when the manufacturer's direct selling cost is intermediate, and the impact of the direct selling cost on product quality under manufacturer encroachment is not monotone. In addition, the retailer may be better off with manufacturer encroachment under an intermediate direct selling cost of the manufacturer where she can deter the manufacturer from selling directly to avoid channel competition. Moreover, for the manufacturer, encroachment is always beneficial by adding an additional direct channel, though under asymmetric information, launching a direct channel can result in costly signaling behavior on the retailer (the retailer who observes a low market size has to distort her order quantity downward to signal the true market size).

The effects of information structures on quality and profits of chain members can be concluded as follows. Different from the results of prior literature that the manufacturer always prefers the full information case, compared to the asymmetric information case when encroaching (Li et al., 2013), our results indicate that with an endogenous quality, the manufacturer with encroachment may prefer to keep the information disadvantages when the manufacturer's direct selling cost is relatively large and the prior probability of large market size is high. The reason is that although asymmetric information structure can generate a loss for the manufacturer by the downward distorted order quantity, it also can benefit him by better balancing the quality investment cost and the retail market revenue from a lower quality. When the benefit outweighs the loss, asymmetric information can ultimately benefit the manufacturer. Besides, the uninformed manufacturer is more willing to sell to an informed retailer such that he can screen the true market size. For the retailer, when she is informed, she may prefer to share the market information with the manufacturer credibly; when she is uninformed, she may prefer not to develop advanced information when direct selling is efficient. Moreover, both players reach a consensus on information sharing when the manufacturer's direct selling cost is quite small or relatively large; however, there also exists a case where the manufacturer prefers a full-information scenario while the retailer prefers to keep the market information private when the direct selling cost is relatively small.

It should be mentioned that if the wholesale price is exogenously given (Dong and Rudi, 2004), some of our results change. First, encroachment always generates a higher quality when the wholesale price is exogenous, whereas it may decrease quality when the wholesale price is endogenous. Second, with an exogenous wholesale price, the manufacturer may be worse off from encroachment under asymmetric information, whereas he always benefits with an endogenous wholesale price. The reason is that with endogenous quality and wholesale price decisions, the manufacturer not only can use the quality decision but also can adjust the wholesale price to influence the retailer's demand, and benefits from encroachment. However, the other results of our paper about the impacts of encroachment on the retailer and impacts of information structure on the quality and both players hold under both exogenous and endogenous cases. In particular, our main result that the manufacturer may prefer to an asymmetric-information case rather than a full-information case still holds given an exogenous wholesale price.

The remainder of our paper is organized as follows. Section 2 reviews the related literature. Section 3 presents the models and gives the corresponding equilibrium solutions with and without encroachment under three information structures. In Section 4, we analyze the effects of encroachment and information structures on the product quality and the profits of chain members. Section 5 extends the basic model to a case where an alternative timing of quantity decisions is considered. Finally, conclusions and future research directions are given in Section 6.

2. Literature Review

Studies related to our work with regard to manufacturer encroachment can be categorized into the following three streams: the effects of manufacturer encroachment on the profits of chain members, product quality decisions under dual-channel structure, and manufacturer encroachment under asymmetric information.

The effects of manufacturer encroachment have been investigated by many previous studies. Conventional wisdom points to that manufacturer encroachment benefits the manufacturer by adding an additional channel, while harms the retailer by arising competition. Such result has been extensively demonstrated by various studies. For instance, Liu and Zhang (2006) consider the interaction of manufacturer encroachment and personalized pricing, and find that the manufacturer is better off while the retailer is worse off with the entry of a direct selling channel. Considering two-part tariff contracts, Pan (2016) indicates that encroachment may aggravate double marginalization and harm the consumer welfare by introducing higher prices. However, more studies on manufacturer encroachment have come to a contrary result that encroachment may benefit both players. Chiang et al. (2003) suggest that encroachment can benefit both players by reducing inefficient double marginalization. Tsay and Agrawal (2004) discuss manufacturer encroachment by embedding the strategy of sales effort which is influential to demands in both channels. Results find that the additional direct channel is not necessarily detrimental to the retailer, since the manufacturer with encroachment may adjust his price to mitigate channel conflict. Arya et al. (2007) demonstrate that the retailer can benefit from encroachment when the manufacturer's direct selling cost is quite large. Cai (2010) shows that both the manufacturer and the retailer may benefit from adding a direct channel when the retailer's channel power is relatively large. Arya and Mittendorf (2013) investigate manufacturer encroachment with strategic investment, and find that when both players have incentives to invest to improve profitability, the manufacturer is more likely to promote the brand broadly, while the retailer is more interested in investment that benefits its own channel. In addition, encroachment can benefit both parties. Matsui (2016) focuses on the product distribution strategies for two competing manufacturers, and shows that when facing a dual-channel rival, the manufacturer is not always better off to adopt dual-channel strategy. Yan et al. (2018) develop a two-period model to investigate whether the manufacturer should encroach if the product is durable. Their conclusion indicates that the best strategy for the manufacturer is to build an inactive direct channel. Additionally, when the durability of the product is very high or very low, both the manufacturer and the retailer benefit from encroachment. While all of the above literature studies manufacturer encroachment without any quality decisions and asymmetric information, this paper differs from encoding the important strategy of quality for the manufacturer. Our results about the effects of encroachment show that the manufacturer always benefits from encroachment, and the retailer may either gain a revenue or get a loss from encroachment.

Product quality decision, as a key element in supply chain management, has attracted a lot of attention (Jeuland and Shugan, 1983; Shi et al., 2013). Jeuland and Shugan (1983) investigate quality-setting problem in a single retail channel, and demonstrate that both product quality and profits of chain members hinder in a decentralized channel. Shi et al. (2013) show that product quality relies heavily on distribution structures as well as the distribution of consumer heterogeneity. Wang et al. (2017) develop a model involving two manufacturers who compete in price and quality. Results show that in a quality sensitive market, the pure integration structure is more likely to be the equilibrium, and the manufacturer with higher consumer loyalty earns more profit. Some recent studies investigate product quality in dual-channel supply chains and focus on the effects of manufacturer encroachment on the quality. For instance, Ha et al. (2015) demonstrate that with manufacturer encroachment, the manufacturer distorts product quality either upward or downward. In addition, the manufacturer always prefers to sell the high-quality product through the direct channel if he is capable to differentiate product qualities in different channels. Chen et al. (2017) investigate price and quality decisions in dual-channel supply chains, and show that adding a new channel can lead to quality enhancement and supply chain performance improvement. Following the latter two studies, we also examine the effects of encroachment on product quality. Differently, we base our setting in an asymmetric information framework to better approximate reality. Our results are similar to Ha et al. (2015) that encroachment may either lead to a higher or a lower product quality. Additionally, we investigate the impacts of information structure on product quality, and find that product quality under asymmetric information is the highest when direct selling is relatively efficient, while it is the lowest when direct selling is relatively inefficient.

Related to our work, there exist a few studies that explore manufacturer encroachment under asymmetric information. Li et al. (2013) investigate supplier encroachment by incorporating asymmetric information, and find that supplier encroachment might also lead to "lose-lose" and "lose-win" outcomes for the supplier and the retailer, in addition to "win-win" and "win-lose" under a full information setting. Li et al. (2015) look into supplier encroachment by jointly considering asymmetric information and nonlinear pricing. Two main results are concluded. For one thing, nonlinear pricing cannot mitigate double marginalization. For another thing, apart from the downward distortion effect, the upward distortion may also occur when the retailer purchases more than the efficient quantity. Huang et al. (2018) examine the retailer's incentive of sharing the private demand information with a supplier who chooses to encroach or not. They point out that the retailer may voluntarily share demand information in anticipation of supplier encroachment, since sharing the low demand information may prevent the supplier's intention to establish the direct selling channel. Our paper distinguishes from the above studies in investigating the problem of supplier encroachment with both asymmetric information and endogenous quality decision. Our results about the retailer's information sharing problem are in line with those of Li et al. (2013) and Huang et al. (2018) that the retailer may prefer to share demand information with the manufacturer credibly. However, our results about the manufacturer's preference on the information structures differ from the existing literature such as Li et al. (2013) which indicates that the manufacturer always prefers the full information case. On the contrary, we find that the manufacturer may prefer the asymmetric information case and to keep uninformed since asymmetric information can allow the manufacturer to better balance the quality investment cost and retail market revenue by setting a lower quality.

To summarize, different from the existing literature which either investigates quality strategies of firms under full information or delves into impacts of different information structures on enterprises in supply chains, we take a comprehensive and more practical consideration by jointly taking into account both the endogenous quality decision and asymmetric information into manufacturer encroachment in our research setting. Our results provide managerial hints by exploring the effects of encroachment and information structures on the product quality and profits of chain members.

3. The model

We consider a supply chain with one manufacturer and one retailer. The manufacturer produces a product with a quality level u and sells it to the retailer at a wholesale price w, after which the retailer resells it to end consumers at a retail price p. The manufacturer may also sell products directly to consumers via a direct channel, which incurs an additional direct selling cost due to lack of marketing skills and experience, compared to the tactful retailer (Kapner, 2014). Without loss of generality, we normalize the selling cost of the retailer to zero, while that of the manufacturer is $c > 0$ for each unit sold in the direct channel (Arya et al., 2007; Li et al., 2013).

The manufacturer incurs a total investment cost for a given quality level u as

$$C(u) = \frac{1}{2}ku^2, \tag{1}$$

where $k > 0$ represents the manufacturer's cost efficiency of quality investment. Such a quadratic function form, which capturers the fact that raising quality is increasingly costly, has been widely used in literature (Kim and Chhajed, 2000; Moorthy, 1992).

Consider that the market size α is ex ante, random, which can be either high ($\alpha = \alpha_h$) with probability λ or low ($\alpha = \alpha_l$) with probability $1 - \lambda$, where $\alpha_h > \alpha_l > 0$. Therefore, the expected market size μ is given as $\mu = \lambda\alpha_h + (1 - \lambda)\alpha_l$.

Since product design often takes a long time to decide and is hard to adjust once production operations initiate, we assume that the manufacturer determines the quality level before the selling season begins when market demand is unknown for all (Granot and Yin, 2008). At the beginning of the selling season, the retailer who is closer to consumers and retail market learns the true market size, while the manufacturer only knows the prior distribution because of the lack of data and information.

A consumer's utility from purchasing a product with quality u and price p is $U = \theta u - p$, where θ represents the consumer's sensitivity to quality. Following Ronnen (1991), Lehmann (1997) and Zhou et al. (2002), we assume that consumers are heterogenous and θ is uniformly distributed on [0,1]. Besides, the value consumer obtained from external option is assumed to zero. Thus, only the consumer whose utility is greater than zero will buy the product, i.e., $U = \theta u - p > 0$. Accordingly, with the market size α, the consumer demand is formulated as $q = \alpha(1 - \frac{p}{u})$. The inverse demand function, therefore, is given as

$$p = u\left(1 - \frac{q}{\alpha}\right), \tag{2}$$

where p is the market clearing price and q is the total number of the product for sale.

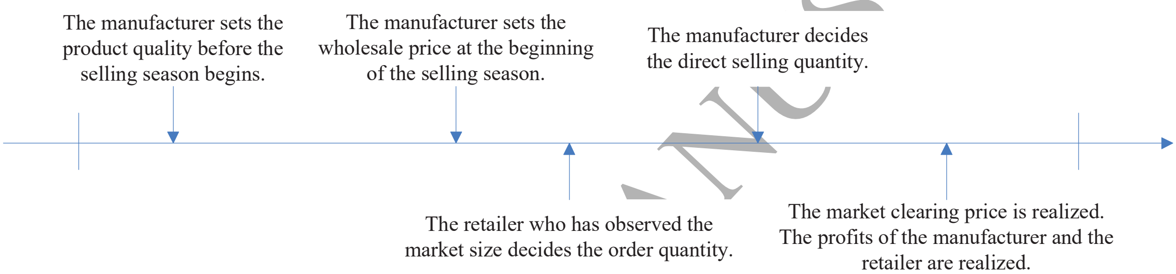


Figure 1: The sequence of events

As shown in Figure 1, sequence of events are: (1) the manufacturer sets the product quality u before the selling season begins; (2) at the beginning of the selling season, the manufacturer sets the wholesale price w; (3) the retailer who has observed the actual market size decides her order quantity q_R; (4) the manufacturer decides his direct selling quantity q_M if he encroaches; (5) the market clearing price is realized as $p = u(1 - \frac{q_R + q_M}{\alpha_i})$ for $i \in \{h, l\}$, and the chain members collect their profits.

We assume that after receiving the retailer's order, the manufacturer decides on the quantity that he wants to sell directly. On one hand, since encroachment gives rise to channel conflict, this desire to use both channel types may compel a manufacturer to pay careful attention to the relationship with his retail partners. In reality, to appease the retailers, the manufacturer usually gives up the first-mover advantages on quantity decisions. For example, while IBM may take orders for PCs over the Web, it gives priority to the sales of its distributors in an attempt to mitigate channel conflict (Tsay and Agrawal, 2004). Another example is that when the Air Jordan 2011 shoe was first launched, it was only available at independent retail stores for several months before Nike sells it on the official website (Business Wire, 2011). On the other hand, the manufacturer can observe the retailer's order decision, whereas the manufacturer's own quantity decision is usually unknown to the retailer; that is, the manufacturer cannot credibly commit to not changing his quantity after receiving the retailer's order. This assumption is in line with numerous studies on manufacturer encroachment, such as Arya et al. (2007), Li et al. (2013), Ha et al. (2015). In addition, we also consider an extended case that the manufacturer first credibly commits the direct selling quantity, and then the retailer sets the order quantity in Section 5.

3.1. No encroachment under asymmetric information

We begin by a benchmark case where the manufacturer does not encroach under asymmetric information, which is denoted by a superscript "*AN*". Strategies of the manufacturer and retailer are derived by applying backward induction. Therefore, given a wholesale price w and a quality level u, the retailer chooses order quantity q_R to maximize her profit

$$\pi_R = \left(u\left(1 - \frac{q_R}{\alpha_i}\right) - w\right) q_R, \quad i = h, l, \tag{3}$$

which yields

$$q_R^{AN} = \frac{(u-w)\alpha_i}{2u}. \tag{4}$$

As the retailer knows the market size exactly, she chooses her order quantity according to the actual market size, that is, the high-type retailer (who finds $\alpha = \alpha_h$) will set $q_R = \frac{(u-w)\alpha_h}{2u}$ and the low-type retailer (who finds $\alpha = \alpha_l$) will set $q_R = \frac{(u-w)\alpha_l}{2u}$. Anticipating this, the uninformed manufacturer chooses wholesale price w to maximize his expected profit

$$\pi_M = \mathbb{E}\left[\frac{(u-w)w\alpha}{2u} - \frac{ku^2}{2}\right], \tag{5}$$

which renders

$$w^{AN} = \frac{u}{2}. \tag{6}$$

Substituting (6) into Equation (5), we can obtain the equilibrium quality level is

$$u^{AN} = \frac{\mu}{8k}. \tag{7}$$

At equilibrium, the wholesale price, order quantity, expected profits of the chain members respectively are

$$w^{AN} = \frac{\mu}{16k}, \quad q_R^{AN} = \frac{\alpha_i}{4}\,(i \in \{h,l\}), \quad \pi_M^{AN} = \pi_R^{AN} = \frac{\mu^2}{128k}. \tag{8}$$

3.2. Encroachment under asymmetric information

In this subsection, we focus on the scenario that allows for manufacturer encroachment under asymmetric information, which is denoted by a superscript "*AE*".

Under asymmetric information, the manufacturer does not know the actual market size, but he can make rational inference about it according to the retailer's order quantity. As shown in (2), a higher price indicates less products to be sold in the market. Hence, for any given q_R, the retailer prefers the manufacturer to set a lower direct selling quantity q_M, which in turn enables her to tag a higher price. However, the manufacturer's selling quantity will be higher if he infers a large value of market size. As a result, the high-type retailer has an incentive to mimic a low-type one to mislead the manufacturer of a low market size. On the other hand, the low-type retailer intends to separate herself from the high-type retailer so that the manufacturer will set a lower direct selling quantity. In order to separate from the high-type one, the low-type retailer needs to distort her order quantity downward until the high-type retailer finds it unprofitable to mimic the low-type retailer.

On another front, the retailer can set a same order quantity no matter the market size is high or low. In such case, the manufacturer cannot gain any information from the retailer's order quantity.

The former case represents a *separating outcome*, whereas the latter corresponds to a *pooling outcome*. We refer to the manufacturer in the former case as the "informed" manufacturer, and that in the latter case as the "uninformed" manufacturer. In the separating equilibrium, the low-type retailer distorts her order quantity downward to prevent the high-type retailer's mimicking. In the pooling equilibrium, the two types of retailers choose the same order quantity.

We first consider the separating case with a superscript "*s*". According to backward induction, we first solve the manufacturer's optimal direct selling quantity. Now that the manufacturer knows the actual market size based on the inference from the retailer's order quantity, then the informed manufacturer chooses his direct selling quantity q_M to maximize

$$\pi_M^{AE} = wq_R + \left(u\left(1 - \frac{q_M + q_R}{\alpha_i}\right) - c\right)q_M - \frac{ku^2}{2}, \quad i = h, l. \tag{9}$$

According to the first-order condition, we generate the optimal direct selling quantity as

$$q_M^s = \left[\frac{(\alpha_i - q_R)u - c\alpha_i}{2u}\right]^+, \quad i = h, l, \tag{10}$$

where $x^+ = \max\{x, 0\}$. Therefore, anticipating the manufacturer's optimal reaction on the direct selling quantity, the retailer decides her order quantity q_R so as to maximize

$$\pi_R^{AE} = \left(u\left(1 - \frac{q_M + q_R}{\alpha_i}\right) - w\right)q_R, \quad i = h, l. \tag{11}$$

In the separating equilibrium, we consider that the manufacturer's belief is $\alpha = \alpha_h$ if $q_R > q_R^s$, while $\alpha = \alpha_l$ if $q_R \leq q_R^s$. There exists a Perfect Bayesian Equilibrium (PBE) if and only if the retailer's strategy of quantity q_R satisfies

$$\begin{cases} \max \pi_R(q_R > q_R^s|\alpha_h) \geq \max \pi_R(q_R \leq q_R^s|\alpha_h), & (12) \\ \max \pi_R(q_R \leq q_R^s|\alpha_l) \geq \max \pi_R(q_R > q_R^s|\alpha_l), & (13) \\ q_R^s \geq 0. & (14) \end{cases}$$

If the market size is large, inequality (12) guarantees that, compared to pretending that the market size is small, the retailer is better off by signaling the manufacturer the actual large market size. If the market size is small, inequality (13) leads to a lower profit for the retailer if she signals the manufacturer a large market size. Inequality (14) ensures a non-negative order quantity for the retailer. Solving inequalities (12)-(14), we generate the following lemma.

Lemma 1. *With the threshold value*

$$q_R^s = \begin{cases} \dfrac{\alpha_l}{2u}\left[c+u-2w\right]^+, & \text{if } w \leq \tilde{w}, \\ \dfrac{1}{2u}\Big[((2\alpha_h-\alpha_l)u + c\alpha_l - 2w\alpha_h \\ -\sqrt{((\alpha_h+\alpha_l)c + (3\alpha_h-\alpha_l)u - 4w\alpha_h)(u-c)(\alpha_h-\alpha_l))}\Big]^+, & \text{otherwise,} \end{cases}$$

the most profitable separating equilibrium for retailer is: when $\alpha = \alpha_h$, the retailer sets $q_R = \bar{q}_R^{AE} = \frac{(c+u-2w)\alpha_h}{2u} > q_R^s$; when $\alpha = \alpha_l$, the retailer's order quantity $q_R = \underline{q}_R^{AE} = q_R^s$. Here, $\tilde{w} = \frac{u(\alpha_h-3\alpha_l)+c(\alpha_h+\alpha_l)}{2(\alpha_h-\alpha_l)}$.

According to Lemma 1, we find that in the separating equilibrium, the high-type retailer can set her first-best order quantity, while the low-type one signals the true small market size at the expense of an order quantity downward distortion when $w > \tilde{w}$. Only when $w \leq \tilde{w}$, the order quantity of the low-type retailer $\underline{q}_R^{AE}$ would coincide with the first-best order quantity $\frac{\alpha_l[c+u-2w]^+}{2u}$. When the wholesale price $w > \tilde{w}$, the low-type retailer will order less under asymmetric information than she would under full information. The low-type retailer needs to downward distort the order quantity to a level such that the high-type retailer would have no incentive to mimic. Consequently, the market size is credibly signaled; that is, the manufacturer can always learn the market size from the retailer's order quantity and decide his direct selling quantity accordingly.

Next, we turn to the pooling case denoted by a superscript "o". Based on the expected market size, the uninformed manufacturer chooses the direct selling quantity q_M to maximize

$$\pi_M^{AE} = \mathbb{E}\left[wq_R + \left(u\left(1 - \frac{q_M+q_R}{\alpha}\right) - c\right)q_M - \frac{ku^2}{2}\right], \tag{15}$$

which gives

$$q_M^o = \left[\frac{((q_R - \lambda q_R - \alpha_l)u + c\alpha_l)\alpha_h + \lambda u q_R \alpha_l}{2u((\lambda - 1)\alpha_h - \lambda\alpha_l)}\right]^+. \tag{16}$$

For the pooling equilibrium, we consider that the manufacturer's belief is the same as his prior belief if $q_R \leq q_R^o$, and his belief is $\alpha = \alpha_h$ if $q_R > q_R^o$. There exists a PBE if and only if the retailer's strategy satisfies

$$\begin{cases} \max \pi_R(q_R \leq q_R^o|\alpha_h) = \pi_R(q_R = q_R^o|\alpha_h), & (17) \\ \max \pi_R(q_R \leq q_R^o|\alpha_l) = \pi_R(q_R = q_R^o|\alpha_l), & (18) \\ \max \pi_R(q_R \leq q_R^o|\alpha_h) \geq \max \pi_R(q_R > q_R^o|\alpha_h), & (19) \\ \max \pi_R(q_R \leq q_R^o|\alpha_l) \geq \max \pi_R(q_R > q_R^o|\alpha_l), & (20) \\ q_R^o \geq 0. & (21) \end{cases}$$

Equalities (17)-(18) demonstrate: if the retailer wants the manufacturer to remain uninformed, her order quantity needs to satisfy $q_R \leq q_R^o$, and her profit is highest when $q_R = q_R^o$ no matter how large the market size is. Inequalities (19)-(20) make sure that, compared to the case that the manufacturer believes in a large market size, it is more profitable for the retailer to keep the manufacturer uninformed. Solving (17)-(21) renders the following lemma.

Lemma 2. *The most profitable pooling equilibrium for the retailer is*

$$q_R = q_R^o = \left[\frac{((c + u - 2w)\alpha_h - 2\lambda(\alpha_h - \alpha_l)(u - w))\alpha_l}{2u((1 - \lambda)\alpha_h + \lambda\alpha_l)}\right]^+, \tag{22}$$

no matter how large the market size is. Such a pooling equilibrium exists only when conditions (A13) and (A14) in the Appendix are satisfied.

To refine multiple equilibria, we adopt intuitive criterion (Cho and Kreps, 1987) and obtain the following proposition.

Proposition 1. *Any pooling equilibrium and any other separating equilibrium, except those presented in Lemma 1, cannot survive the intuitive criterion.*

By Proposition 1, we only need to focus on the separating equilibrium where the manufacturer can perfectly infer the market size from the retailer's order quantity.

At the beginning of the selling season, anticipating the subgame equilibrium in Lemma 1, the manufacturer chooses the wholesale price w to maximize

$$\pi_M^{AE} = \mathbb{E}\left[w q_R + \left(u\left(1 - \frac{q_M^s + q_R}{\alpha}\right) - c\right) q_M^s - \frac{k u^2}{2}\right], \tag{23}$$

in which, $q_R = \bar{q}_R^{AE}$ when $\alpha = \alpha_h$, and $q_R = \underline{q}_R^{AE}$ when $\alpha = \alpha_l$ as shown in Lemma 1. Finally, before the sell season begins, the manufacturer sets the optimal quality. Due to the complexity of manufacturer's profit function, analytical expression for the equilibrium quality and wholesale price are hard to derive. Hence, we resort to numerical analysis in Section 4 to gain some managerial insights.

3.3. Full information

In order to investigate how information about market size affects the chain members' decisions, in this subsection, we look into the case where both the retailer and the manufacturer know the actual market size at the beginning of the selling season. Superscripts "*FN*" and "*FE*" represent the cases without and with manufacturer encroachment under full information, respectively.

We begin by Case *FN*. Solving the game backwards, we first obtain the retailer's optimal order quantity as

$$q_R^{FN} = \frac{(u-w)\alpha_i}{2u}. \tag{24}$$

Substituting (24) into the manufacturer's profit

$$\pi_M = wq_R - \frac{ku^2}{2}, \quad i = h, l, \tag{25}$$

we can get the optimal wholesale price is $w^{FN} = \frac{u}{2}$ for either $i = h$ or $i = l$. Finally, before the selling season begins, the manufacturer chooses the quality level to maximize the expected profit as

$$\pi_M = \mathbb{E}\left[\frac{(u-w^{FN})w^{FN}\alpha}{2u} - \frac{ku^2}{2}\right], \tag{26}$$

which yields the optimal quality level as $u^{FN} = \frac{\mu}{8k}$. The equilibrium wholesale price, order quantity, expected profits of the chain members are the same as those under asymmetric information, which can be seen in (8).

Next, we turn to Case *FE*. If the manufacturer encroaches, the manufacturer who also knows the true market size chooses his direct selling quantity to maximize

$$\pi_M = wq_R + \left(u\left(1 - \frac{q_R + q_M}{\alpha_i}\right) - c\right) q_M - \frac{ku^2}{2}, \quad i = h, l. \tag{27}$$

The first-order condition of (27) indicates

$$q_M^{FE} = \left[\frac{(\alpha_i - q_R)u - c\alpha_i}{2u}\right]^+, \quad i = h, l. \tag{28}$$

The retailer chooses her order quantity after anticipating the manufacturer's response. The retailer's profit is

$$\pi_R = \left(u\left(1 - \frac{q_R + q_M}{\alpha_i}\right) - w\right) q_R, \quad i = h, l, \tag{29}$$

according to which we derive the retailer's optimal order quantity as

$$q_R^{FE} = \left[\frac{(u+c-2w)\alpha_i}{2u}\right]^+, \quad i = h, l. \tag{30}$$

Substituting (30) and (28) into (27) renders the optimal wholesale price for the manufacturer as

$$w^{FE} = \frac{3u-c}{6}, \quad i = h, l, \tag{31}$$

with the corresponding quantities

$$q_R^{FE} = \frac{2c\alpha_i}{3u}, \quad i = h, l, \tag{32}$$

$$q_M^{FE} = \frac{(3u-5c)\alpha_i}{6u}, \quad i = h, l. \tag{33}$$

Lastly, before the selling begins, we can obtain the optimal quality level to maximize the manufacturer's expected profit as shown in Lemma 3. The equilibrium wholesale price, order quantity, expected profits for both players can be obtained correspondingly.

Lemma 3. *Under full information with encroachment, the optimal quality level is*

$$u^{FE} = \begin{cases} u_1, & \text{if } c < c_1, \\ u_2, & \text{if } c_1 \le c < c_2, \\ u^{FN}, & \text{if } c \ge c_2. \end{cases} \tag{34}$$

Here, c_j and u_j $(j = 1, 2)$ can be seen in Appendix.

Lemma 3 distinguishes three cases: (1) if $c < c_1$, the optimal quality level is $u^{FE} = u_1$, and the manufacturer encroaches with $q_M^{FE} > 0$; (2) if $c_1 \le c < c_2$, $u^{FE} = u_2$, and the retailer deters the manufacturer from selling directly by choosing an order quantity $q_R^{FE} = \frac{\alpha_i(u-c)}{u}$ $(i \in \{h, l\})$ such that $q_M^{FE} = 0$ (according to Equation (28)); (3) if $c \ge c_2$, then $u^{FE} = u^{FN}$, and the existence of the direct channel shows no influence on the chain members' decisions, that is, the equilibrium results under encroachment are the same as those under no encroachment.

It should be mentioned that the case of $q_M^{FE} = 0$ with encroachment (no sales in the direct channel) is not necessarily the same as the case without encroachment (no direct channel exists). As shown in Lemma 3, if $c_1 \le c < c_2$, although we can get $q_M^{FE} = 0$, this case which is caused by the retailer's order quantity decision differs from the case without encroachment. This can illustrate the phenomenon in reality that with manufacturer encroachment, a large variety of products are exclusively sold in the retailer. For example, Dell and Toshiba have developed exclusive high-end personal computers for their retail partners like Best Buy and Circuit City (Lawton, 2007). In the apparel industry, companies such as Ralph Lauren, the Armani Group, Hugo Boss, and Baravade have developed exclusive lines for the independent retailers (Ha et al., 2015). It also highlights the business reality that manufacturers, such as Daimler, Nikon, and Rubbermaid, used the direct channel merely as a medium to provide consumers with both product information and availability information such that consumers can buy products from the nearest in-stock retailer. They do not offer the products for sale directly, in order to avoid potential channel conflict (Wang et al., 2017).

3.4. No information

In this subsection, we discuss the case that neither the manufacturer nor the retailer knows the actual market size during the whole planning horizon. As in the above analysis, we first investigate the no encroachment case denoted by a superscript "*NN*". The retailer decides q_R to maximize

$$\pi_R = \mathbb{E}\left[\left(u\left(1-\frac{q_R}{\alpha}\right)-w\right)q_R\right], \tag{35}$$

which renders

$$q_R^{NN} = \frac{(u-w)m}{2u}, \tag{36}$$

where $m = \frac{\alpha_h\alpha_l}{\alpha_h-\lambda\alpha_h+\lambda\alpha_l}$. Anticipating this, the manufacturer chooses the optimal wholesale price as $w^{NN} = \frac{u}{2}$. Lastly, the optimal quality level is

$$u^{NN} = \frac{m}{8k}. \tag{37}$$

The equilibrium wholesale price, order quantity, expected profits of the chain members respectively are

$$w^{NN} = \frac{m}{16k}, \quad p_R^{NN} = \frac{m}{4}, \quad \pi_M^{NN} = \pi_R^{NN} = \frac{m^2}{128k}. \tag{38}$$

Next, we consider the case with manufacturer encroachment under no information, which is denoted by a superscript "*NE*". The manufacturer chooses q_M to maximize

$$\pi_M = \mathbb{E}\left[wq_R + \left(u\left(1-\frac{q_R+q_M}{\alpha}\right)-c\right)q_M - \frac{ku^2}{2}\right], \tag{39}$$

which yields

$$q_M^{NE} = \left[\frac{(m-q_R)u-cm}{2u}\right]^+. \tag{40}$$

Based on this, we can obtain the optimal order quantity for the retailer as

$$q_R^{NE} = \left[\frac{(c+u-2w)m}{2u}\right]^+. \tag{41}$$

Plugging (40) and (41) into (39), we can get the optimal wholesale price for the manufacturer as $w = \frac{3u-c}{6}$. Finally, before the selling begins, the optimal quality level to maximize the manufacturer's expected profit is shown in Lemma 4. The equilibrium wholesale price, order quantity, expected profits for both players can be obtained correspondingly.

Lemma 4. *Under no information with encroachment, the optimal quality level is*

$$u^{NE} = \begin{cases} \tilde{u}_1, & \text{if } c < \tilde{c}_1, \\ \tilde{u}_2, & \text{if } \tilde{c}_1 \leq c < \tilde{c}_2, \\ u^{NN}, & \text{if } c \geq \tilde{c}_2. \end{cases} \tag{42}$$

Here, $\tilde{c}_j$ and $\tilde{u}_j$ $(j = 1, 2)$ can be seen in Appendix.

Similar to the case under full information, there are also three cases under no information: (1) if $c < \tilde{c}_1$, the manufacturer encroaches, and $u^{NE} = \tilde{u}_1$; (2) if $\tilde{c}_1 \leq c < \tilde{c}_2$, the retailer prevents the manufacturer from selling directly by setting an order quantity $q_R^{NE} = \frac{m(u-c)}{u}$, and $u^{NE} = \tilde{u}_2$; (3) if $c \geq \tilde{c}_2$, the existence of the direct channel shows no influence on the chain members' decisions, and $u^{NE} = u^{NN}$.

4. Analysis

In this section, we investigate the effects of encroachment and information on the equilibrium quality and profits of chain members. With numerical analysis, we consider the following parameters: $\alpha_h = 1.5$, $\alpha_l = 1$, $\lambda = 0.5$, $k = 0.2$.

4.1. Encroachment vs. no encroachment

In this subsection, we examine the effects of manufacturer encroachment under different information structures.

4.1.1. Full information

Proposition 2. *Under full information,*

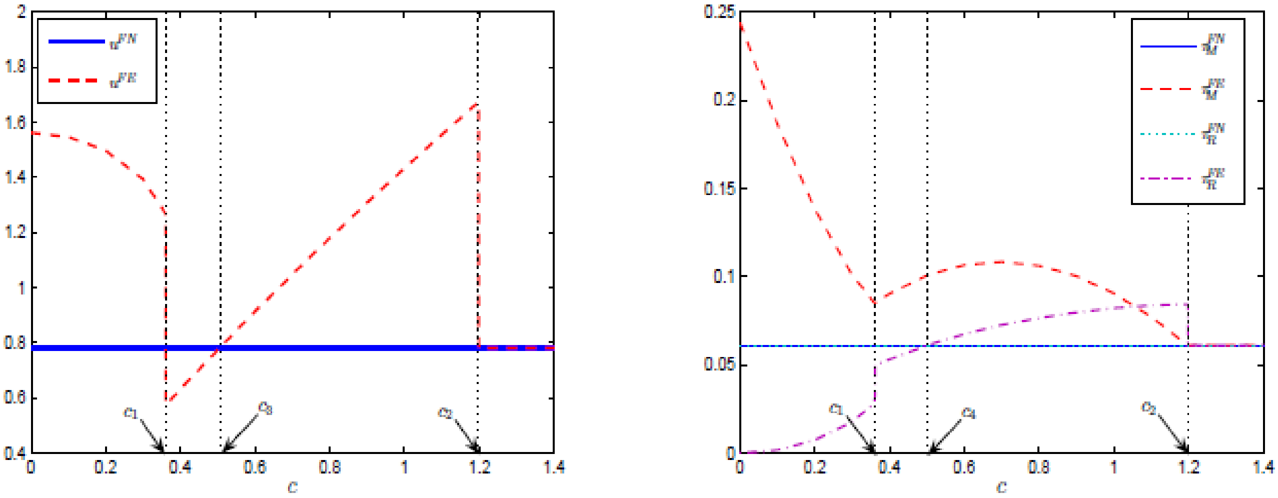
(1) if $c < c_2$, the optimal quality level with encroachment u^{FE} first decreases and then increases with c, and if $c \geq c_2$, u^{FE} is independent of c;

(2) there exists a threshold value c_3 such that $u^{FE} < u^{FN}$ if $c_1 < c < c_3$, and $u^{FE} \geq u^{FN}$ otherwise.

Proposition 2 and Figure 2(a) indicate the impacts of the manufacturer's direct selling cost c on the optimal quality level u^{FE}. We find that the impact of c on the product quality u^{FE} is not monotone. The reason can be explained as follows. (1) If $c < c_1$, the manufacturer sells products through both the retail channel and the direct channel. According to Equations (32) and (33), we get $\frac{\partial q_M^{FE}}{\partial c} = -\frac{5\alpha_i}{6u} < 0$ and $\frac{\partial q_R^{FE}}{\partial c} = \frac{2\alpha_i}{3u} > 0$, $i \in \{h, l\}$, implying that with c increasing, demand in the direct channel drops while that in the retail channel enhances. On the other hand, when u is smaller, the decreased demand in the direct channel and the increased demand in the retail channel by increasing c are larger, i.e., more demand is shifted from the direct channel to the retail channel.

Thus, when c increases, i.e., direct selling is less efficient, a smaller u is adopted to shift more demand from the direct channel to the retail channel. (2) If $c_1 \leq c < c_2$, the retailer deters the manufacturer from selling directly by setting an order quantity $q_R^{FE} = \frac{\alpha_i(u-c)}{u}$ ($i \in \{h, l\}$). Obviously, $\frac{\partial q_R^{FE}}{\partial c} = -\frac{\alpha_i}{u} < 0$, $i \in \{h, l\}$, implying that the demand in the retail channel decreases with c; that is, when direct selling is less efficient, a smaller order quantity is needed to help the retailer to deter the manufacturer from selling directly. In addition, with a larger u, the decreased demand in the retail channel by increasing c is smaller. Consequently, when c increases, a larger u is set to allow the manufacturer to retain the retail demand at a certain level (less retail demand is reduced). (3) If $c \geq c_2$, the equilibrium results keep the same as those without encroachment, and u^{FE} is independent of c. Note that with c increasing, the optimal quality level u^{FE} exhibit a downside jump at $c = c_1$ and $c = c_2$. With c increasing, the retailer will have incentive to prevent the manufacturer from selling directly, which leads to a lower quality of the manufacturer (when $c = c_1$); when c is relatively large, both players are willing to adopt the strategies in the case without encroachment, which also reduces the quality (when $c = c_2$).

Furthermore, Proposition 2 and Figure 2(a) also imply that encroachment decreases quality only when c is intermediate, i.e., $c_1 < c < c_3$. More specifical results are concluded as follows. (1) In the dual-channel selling case (i.e., $c < c_1$), a higher quality is set by encroachment. The reason is that compared to the no-encroachment case, a higher quality will lead to more marginal revenue in the encroachment scenario where there exists a direct channel free of double marginalization. Such result can be supported by some business practices. For example, it is shown that in apparel industry, dual-channel selling is beneficial for product quality improvement (Mount, 2013). (2) In the case where the retailer prevent the manufacturer from selling directly by setting an order quantity (i.e., $c_1 < c < c_2$), encroachment may decrease the quality when c is relatively small (i.e., $c < c_3$). Here, under both the cases with and without encroachment, the manufacturer only relies on the retailer to sell the products. Without encroachment, the manufacturer' optimal quality level $u^{FN} = \frac{\mu}{8k}$, which is independent of c. Nevertheless, with encroachment, the manufacturer's direct selling cost c will affect the retailer's order quantity reaction, and thus affect the manufacturer's quality decision. Specifically, the retailer's order quantity reaction is $q_R^{FE} = \alpha_i \left(1 - \frac{c}{u}\right)$ ($i \in \{h, l\}$) in order to ensure $q_M^{FE} = 0$. Note that increasing quality can help the manufacturer to reach a higher order quantity from the retailer, but it also incurs a larger quality investment cost. The manufacturer should strike a balance between the benefit from more retail demand and the loss from larger investment cost by rasing quality. As a result, when c is relatively large, investing in quality can greatly enhance the order quantity from the retailer, and the manufacturer will raise quality with encroachment; while when c is relatively small,



(a) Product quality

(b) Profits

Figure 2: Product quality and profits with different c under full information

he will lower the quality to save cost. (3) If $c \geq c_2$, encroachment shows no influence on the quality level.

Figure 2(b) depicts profits for the chain members with different c under full information. When $c \geq c_2$, encroachment does not affect the chain members' profits. For the manufacturer, the impact of c on his profit with encroachment π_M^{FE} is not monotone. If $c < c_1$, the manufacturer's profit π_M^{FE} decreases with c since his profit from the direct channel reduces when direct selling becomes less efficient. If $c_1 \leq c < c_2$, π_M^{FE} first increases and then decreases with c. On one hand, the optimal quality level, and correspondingly the wholesale price increase with c. On the other hand, the order quantity from the retailer decreases with c. As a result, π_M^{FE} first increases and then decreases with c. For the retailer, her profit with encroachment π_R^{FE} increases with c if $c < c_2$ due to the increased competitive power of the retail channel. In addition, the retailer's profit π_R^{FE} exhibits an upside jump when she has incentive to prevent the manufacture from selling directly (at $c = c_1$) and a downside jump when both chain members are willing to use the equilibrium strategies under the case without encroachment (at $c = c_2$).

Proposition 3. *Under full information,*

(1) the manufacturer always prefers to encroach, i.e., $\pi_M^{FE} \geq \pi_M^{FN}$*;*

(2) there exist a threshold value c_4 *such that* $\pi_R^{FE} > \pi_R^{FN}$ *if* $c_4 < c < c_2$*, and* $\pi_R^{FE} \leq \pi_R^{FN}$ *otherwise.*

Proposition 3 and Figure 2(b) also demonstrate the effects of encroachment on profits for the chain members. For the manufacturer, he is always better off with encroachment since the added direct channel not only can enhance demand (when $c < c_1$), but also can serve as an effective threat to the retailer and allow the manufacturer to use the quality and wholesale price decisions more aggressively to extract profit from the retailer channel (when $c_1 \leq c < c_2$). For the retailer, she can also benefit from encroachment when $c_4 < c < c_2$. Note that encroachment has three effects on the retailer: *a negative competition effect* (adding a direct channel gives rise to channel competition, which hurts the retailer), and *a wholesale price change effect* (a different level of wholesale price is adopted by the manufacturer with encroachment), and *a quality change effect* (encroachment changes the quality). If $c < c_1$, the negative competition effect dominates the other two effects, and encroachment hurts the retailer. If $c_1 \leq c < c_2$, there are no sales in the direct channel, and only the later two effects play a part. In other words, the retailer deters the manufacturer from selling directly to avoid channel competition successfully. In this single-channel selling case, only under a relatively large c (when $c > c_4$), encroachment increases quality or/and decreases wholesale price, which will benefit the retailer.

In sum, encroachment can lead to a "win-win" outcome for the manufacturer and the retailer when there are no sales in the direct channel. This result may offer a possible explanation for manufacturers like Daimler and Nikon to use the direct channel merely as a virtual showroom to provide information where products are not available.

4.1.2. No information

Proposition 4. *Under no information,*

(1) if $c < \tilde{c}_2$, the optimal quality level with encroachment u^{NE} first decreases and then increases with c, and if $c \geq \tilde{c}_2$, u^{NE} is independent of c;

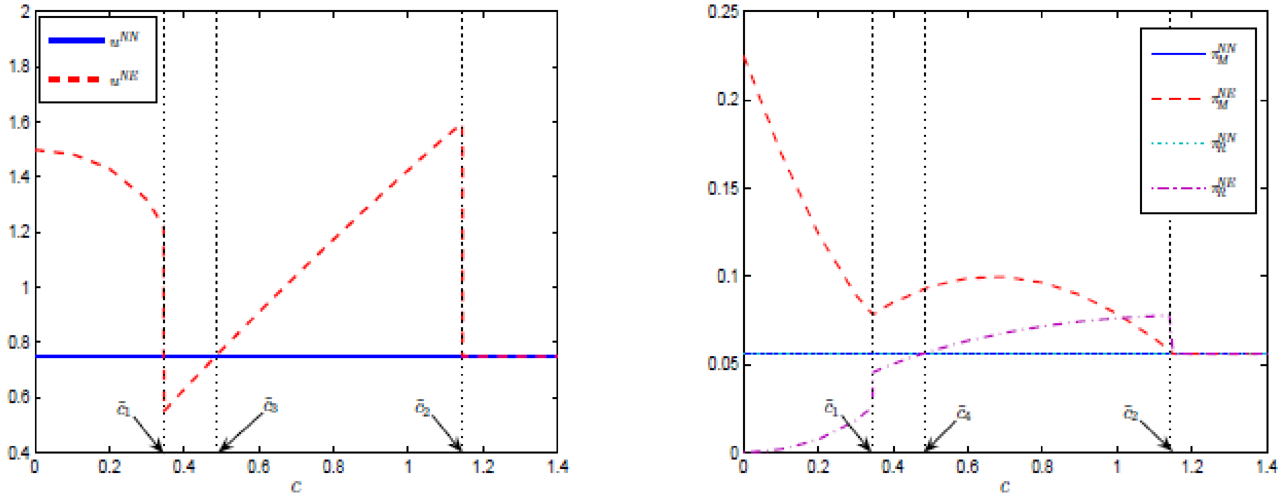
(2) there exist a threshold value $\tilde{c}_3$ such that $u^{NE} < u^{NN}$ if $\tilde{c}_1 < c < \tilde{c}_3$, and $u^{NE} \geq u^{NN}$ otherwise.

Proposition 4 and Figure 3(a) indicate the impacts of c on u^{NE} and the impacts of manufacturer encroachment on the quality. The results are similar to the case under full information. Specifically, except the case that the existence of the direct channel does not affect the chain members' decisions, or say, when $c < \tilde{c}_2$, the optimal quality level u^{NE} first decreases and then increases with c. In addition, encroachment decreases quality when the manufacturer's direct selling cost c is medium, i.e., $\tilde{c}_1 < c < \tilde{c}_3$, since a lower quality can help the manufacturer to better balance the quality investment cost and the retail market revenue.

Proposition 5. *Under no information,*

(1) the manufacturer always prefers to encroach, i.e., $\pi_M^{NE} \geq \pi_M^{NN}$;

(2) there exist a threshold value $\tilde{c}_4$ such that $\pi_R^{NE} > \pi_R^{NN}$ if $\tilde{c}_4 < c < \tilde{c}_2$, and $\pi_R^{NE} \leq \pi_R^{NN}$ otherwise.



(a) Product quality (b) Profits

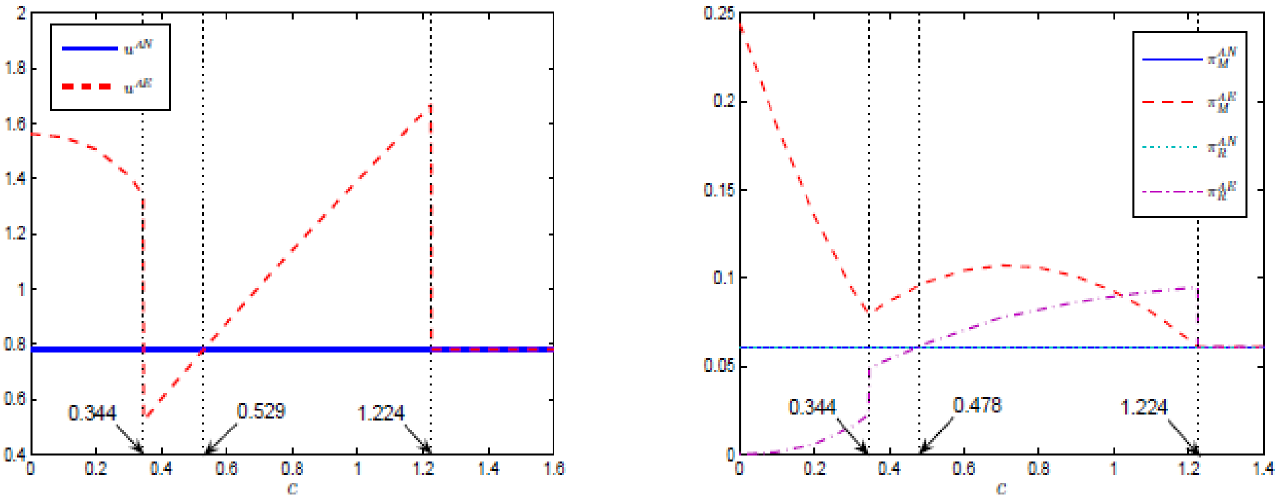
Figure 3: Product quality and profits with different c under no information

Proposition 5 and Figure 3(b) suggest the impacts of manufacturer encroachment on the chain members' profits and the impacts of c on π_M^{NE} and π_R^{NE}. Similar to the results under full information, if c is relatively small such that different strategies are adopted between the cases with and without encroachment ($c < \tilde{c}_2$), the manufacturer's profit with encroachment π_M^{NE} first decreases, and then increases, and lastly decreases again with c; while the retailer's profit with encroachment π_R^{NE} increases with c. In addition, the manufacturer always benefits from encroachment, while the retailer is better off with encroachment only under a medium direct selling cost ($\tilde{c}_4 < c < \tilde{c}_2$) where she avoids channel competition and benefits from an increased quality or/and a decreased wholesale price.

4.1.3. Asymmetric information

Since it is challenging to derive the analytical results, we examine the effects of manufacturer encroachment under asymmetric information by carrying out a numerical study. Figure 4 shows product quality and profits for the manufacturer and the retailer with different c under both the cases with and without encroachment. The results are similar to those under full or no information. If $c < 0.344$, the manufacturer sells products through both the retail channel and the direct channel. The increase of c leads to a lower quality u^{AE}, a lower manufacturer's product π_M^{AE}, and a higher retailer's profit π_R^{AE}. If $0.344 \leq c < 1.224$, the retailer deters the manufacturer from selling directly. With c increasing, u^{AE} and π_R^{AE} increase, and π_M^{AE} first increases and then decreases. If $c \geq 1.224$, the results remain the same as those without encroachment, and the chain members' decisions are independent of c.

In addition, encroachment decreases quality when $0.344 < c < 0.529$ since anticipating the retailer's reaction to deter him from selling directly, the manufacturer can lower the quality to achieve a balance between the quality investment cost and the retail market revenue. It should be mentioned that although encroachment leads to order quantity downward distortion under asymmetric information, the manufacturer can still benefit from encroachment. This result differs from that in Li et al. (2013) where in the absence of quality decisions, the manufacturer may be worse off with encroachment since the order quantity is downward distorted by the retailer to signal the true market size. The reason is that with endogenous quality decision, the manufacturer not only can use the quality decision but also can adjust the wholesale price to influence the retailer's demand. As a result, despite of the downward distorted order quantity, the additional direct channel always benefits the manufacturer by increasing demand or serving as an effective threat to help him to extract profit from the retail channel more aggressively. Furthermore, the retailer can also benefit from encroachment when $0.478 < c < 1.224$ since she avoids channel competition by preventing the manufacturer from selling directly and enjoys the increased quality or/and reduced wholesale price by encroachment.



(a) Product quality

(b) Profits

Figure 4: Product quality and profits with different c under asymmetric information

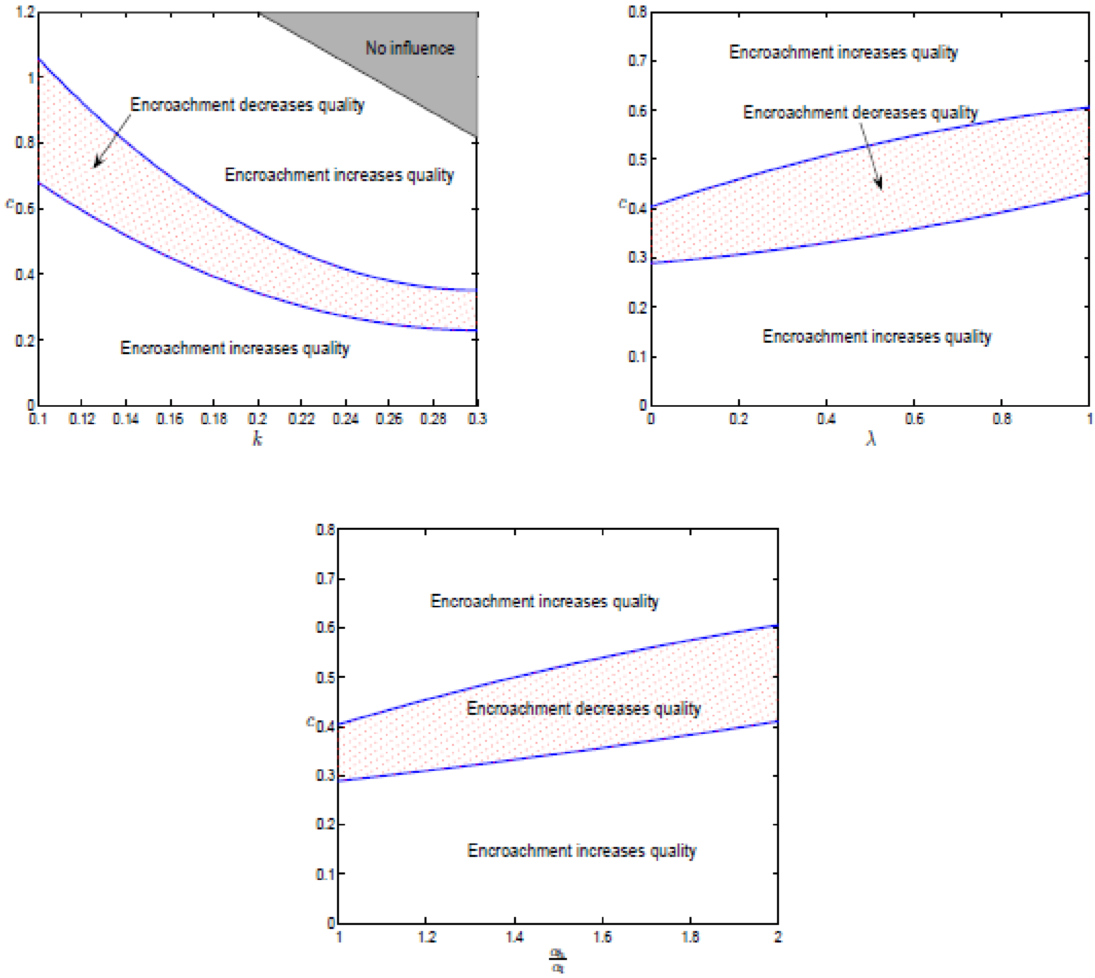


Figure 5: The effects of manufacturer encroachment on the quality via different system parameters

Figure 5 demonstrates more subtle results about the impacts of encroachment on product quality with respect to c, k, λ, and $\frac{\alpha_h}{\alpha_l}$. Under asymmetric information, the ability to encroaching can either enhance or hinder a manufacturer's quality investment, depending on the demand distribution parameters (i.e., λ, α_h and α_l), his cost disadvantage (i.e., c) and quality investment cost efficiency (i.e., k). First, we can find that encroachment decreases quality only when the manufacturer's direct selling cost c is intermediate, the reason of which has been given in previous analysis. Second, the region where encroachment decreases quality shrinks with k increasing. When quality investment is less efficient, i.e., k is larger, the manufacturer has less incentive to lower quality with encroachment. Third, encroachment is more likely to reduce quality when λ (the prior probability of

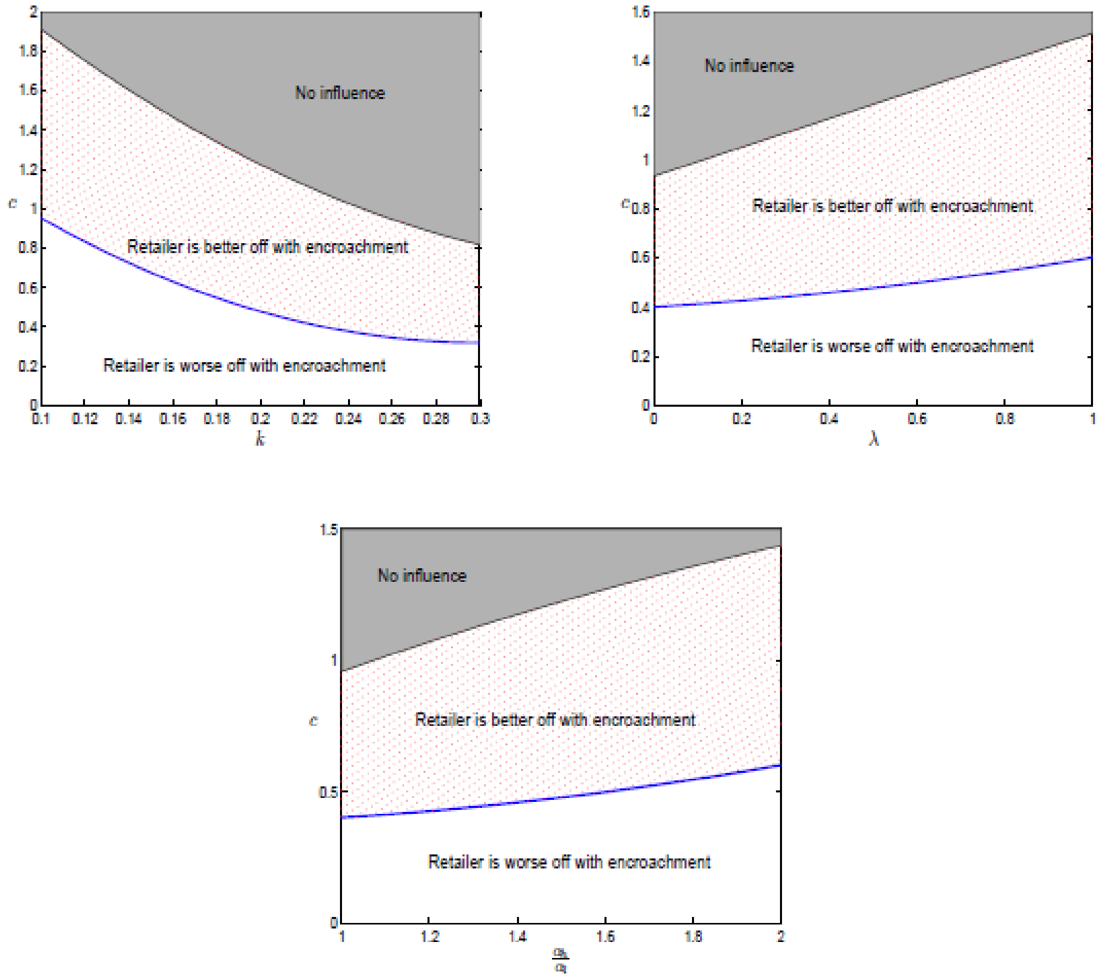


Figure 6: The effects of manufacturer encroachment on the retailer via different system parameters

the large market size) is intermediate. Finally, we can find that with the ratio of the two market sizes (i.e., $\frac{\alpha_h}{\alpha_l}$) increasing, the region where encroachment decreases quality expands. When the difference of two market sizes is larger, the retailer who observes a large market size has more incentive to mimic the low-type retailer. As a result, the low-type retailer has to distort the order quantity downward more severely. Anticipating the retailer's effort on preventing him from selling directly by setting a greatly downward distorted order quantity, the manufacturer is more likely to reduce the quality to match this lower order quantity from the retailer in the encroachment case.

Figure 6 indicates the impacts of encroachment on the retailer's profit with respect to c, k, λ, and $\frac{\alpha_h}{\alpha_l}$. As depicted in Figure 6, the retailer can benefit from manufacturer encroachment when c is intermediate. By adjusting the order quantity, the retailer can deter the manufacturer from selling directly with an intermediate c, which indeed eliminates the negative competition effect of encroachment. Consequently, although the retailer has to downward distort the order quantity to signal the true market size under asymmetric information, she still can gain more profits with encroachment due to a reduced wholesale price or/and an increased quality. Furthermore, the region where the retailer is better off with encroachment shrinks with k increasing, while expands with λ or $\frac{\alpha_h}{\alpha_l}$ increasing. When the quality investment is efficient (i.e., k is small), or the probability of large market size is high (i.e., λ is large), or the ratio of two market sizes is large (i.e., $\frac{\alpha_h}{\alpha_l}$ is large), the retailer is more likely to benefit from encroachment.

4.2. Asymmetric information vs. full information vs. no information

In this subsection, we investigate the impacts of information structure on the product quality and profits of the chain members with manufacturer encroachment. Main results are illustrated in Figure 7.

Figure 7(a) depicts the product quality under different information structures. First, the quality under no information (i.e., u^{NE}) is always lower than that under full information. The reason is that under no information, neither of the players know the true market size, and the manufacturer is cautious in setting product quality. Therefore, he sets a lower quality to avoid the potential loss when the actual market size turns out to be α_l. Second, when $c < 0.344$, $u^{AE} > u^{FE}$ holds; when $0.344 < c < 1.198$, $u^{FE} > u^{AE}$ stands; when $c \geq 1.198$, encroachment does not affect the chain members' decisions under full information (thus we pay special attention to the former two cases). This attributes to *the order quantity downward distortion effect* (the low-type retailer has to downward distort the order quantity to separate herself from the high-type one) in the presence of asymmetric information. In a dual-channel selling case ($c < 0.344$), such distortion effect has two aspects: on one hand, it has a direct effect by reducing the order quantity in the retail channel; on the other hand, it has an indirect effect by alleviating the competition between the manufacturer and the retailer, which in turn increases the marginal revenue in the direct channel. To match the lower order quantity from the retailer caused by the direct distortion effect, the manufacturer would decrease the quality; however, since the marginal revenue in the direct channel enlarges due to the indirect distortion effect, the manufacturer has incentives to improve the quality. Since the indirect distortion effect dominates the direct one, the manufacturer sets a higher quality to expand profit from the direct channel. In a single-channel selling case ($0.344 < c < 1.198$), as shown in Section 3, the retailer deters the manufacturer from direct selling by setting $q_R = \frac{\alpha_i(u-c)}{u}$ ($i \in \{h, l\}$), which implies that a lower quality corresponds to a lower order quantity. Thus, the manufacturer lowers the quality to corresponding to the lower retail demand (the order quantity is downward distorted) under asymmetric information, compared to the case with full information.

Figure 7(b) demonstrates the impacts of different information structures on the manufacturer's profit. For one thing, we find that $\pi_M^{FE} > \pi_M^{AE}$ when c is relatively small ($c < 0.855$), and $\pi_M^{FE} < \pi_M^{AE}$ when c is relatively large ($0.855 < c < 1.224$), and $\pi_M^{FE} = \pi_M^{AE}$ when c is quite large ($c \geq 1.224$ and encroachment does not affect the chain members' decisions under both full and asymmetric information). When c is relatively large, the result is counterintuitive, where the manufacturer who faces an informed retailer prefers to be uninformed and keep the information disadvantages, rather than grasping the true market information; that is, $\pi_M^{FE} < \pi_M^{AE}$. Such conclusion differs from that in Li et al. (2013) where the manufacturer always prefers the full information case. The reason is as follows. Under the case that the retailer has capacity to deter the manufacturer from selling directly, if c is relatively large, investing in quality brings a small benefit from increasing order quantity, however, it incurs a significant quality investment cost. Compared to the full-information case, the order quantity downward distortion effect under asymmetric information can allow the manufacturer to lower the quality (as shown in Figure 7(a)). When $0.855 < c < 1.224$, such a decreased quality can help the manufacturer to avoid the great quality investment cost in return for a negligible benefit (i.e., better balance the quality investment cost and retail market revenue), and it compensates for the loss of order quantity downward distortion; that is, asymmetric information eventually benefits the manufacturer. However, when $c < 0.855$ such that the direct channel is relatively efficient, the loss from the downward distorted order quantity is significant for the manufacturer. As a result, he gets a loss from asymmetric information. For another thing, we find that $\pi_M^{NE} < \pi_M^{AE}$, which means the uninformed manufacturer prefers to interact with an informed retailer, since he can screen the true market size from the separated order quantity and tailor his optimal direct selling quantity to the true market size so as to generate more profits.

Figure 7(c) shows how different information structures affect the retailer's profit. According to Figure 7(c), when c is quite small ($c < 0.344$), the retailer prefers to share her information credibly, i.e., $\pi_R^{FE} > \pi_R^{AE}$; when c is intermediate ($0.344 < c < 1.224$), she benefits from the information advantages and is reluctant to share information, i.e., $\pi_R^{FE} < \pi_R^{AE}$; when c is large ($c \geq 1.224$), encroachment shows no influence on the chain members' decisions, and $\pi_R^{FE} = \pi_R^{AE}$. Sharing information with the manufacturer is a double-edged sword for the retailer. On one hand, sharing information means giving up the information advantages for the retailer, and allows the manufacturer to tailor his optimal wholesale price and direct selling quantity to extract more profits from the retailer, which hurts the retailer. On the other hand, information sharing can also cure the retailer's incentive to distort her order quantity. Such an avoidance from the order quantity distortion may benefit the retailer. As a result, the retailer may or may not prefer to share her information with the manufacturer when the latter establishes a direct channel channel. In addition, we conclude that $\pi_R^{NE} > \pi_R^{AE}$ when c is small ($c < 0.344$) while $\pi_R^{NE} < \pi_R^{AE}$ when c is not small ($c > 0.344$). Having a better knowledge can allow the retailer to tailor her order quantity to each market size, but it can also generate an unexpected order quantity distortion. Thus, the retailer prefers to keep uninformed when c is small while is willing to develop the informational capability when c is not small.

Moreover, combining Figures 7(b) and 7(c) shows that in most cases, the chain members can reach a consensus on information sharing. Specifically, both the manufacturer and the retailer have incentives to eliminate the information advantages of the retailer and reach a full-information case when c is quite small ($c < 0.344$) while both of them benefit from the information advantages over the manufacturer when c is relatively large (i.e. $0.855 < c < 1.224$). In addition, there also exists a case where the chain members have different preferences on information sharing when c is relatively small (i.e., $0.344 < c < 0.855$). Specifically, the retailer prefers to keep the market information private; however, the manufacturer prefers to a full-information case.

To gain a deeper intuition, we further demonstrate the results about when the manufacturer prefers asymmetric information rather than full information with respect to different c, k, λ, and $\frac{\alpha_h}{\alpha_l}$ in Figure 8. First, compared to a full-information case, the manufacturer prefers to keep uninformed when his direct selling cost c is relatively large, which is in line with the previous analysis. Second, it should be mentioned that when λ is small, the manufacturer always prefers a full-information case. Facing a market with a high probability of small market size (i.e., λ is small), there are more opportunities for a low-type retailer to distort order quantity downward. Thus, the manufacturer prefers a full-information case due to such a strong order quantity distortion effect when λ is small. Third, Figure 8 also indicates that the manufacturer is more likely to prefer an asymmetric-information case when k and $\frac{\alpha_h}{\alpha_l}$ are intermediate, or λ is large. It should be mentioned that when $\lambda = 1$, no information asymmetry exists. In fact, there will be a discontinuity between the equilibrium results with a λ close to 1 and with a λ equaling to 1. Such a discontinuity is common among signaling games, which can also be seen in Li et al. (2013).

5. Extension: alternative timing of quantity decisions

In the basic model, we assumed that the manufacturer sets the direct selling quantity after observing the retailer's order quantity decision. Here, we examine the case where the manufacturer commits a direct selling quantity before the retailer's order quantity decision. Before receiving the retailer's order quantity q_R, the manufacturer cannot infer the market size according to q_R, thus needs to predict the retailer's order quantity reaction and decides the optimal direct selling quantity q_M to maximize his expected profit. Solving the game backwards, we first get the retailer's optimal order quantity as

$$q_R^D = \left[\frac{(\alpha_i - q_M)u - \alpha_i w}{2u}\right]^+, \quad i \in \{h, l\}. \tag{43}$$

Here, the superscript "D" denotes the case that the manufacturer's direct selling quantity is set before the retailer's order quantity. Anticipating the retailer's order quantity reaction, to maximize the manufacturer's expected profit, we can obtain the optimal direct selling quantity as

$$q_M^D = \left[\frac{(u - 2c)m}{2u}\right]^+. \tag{44}$$

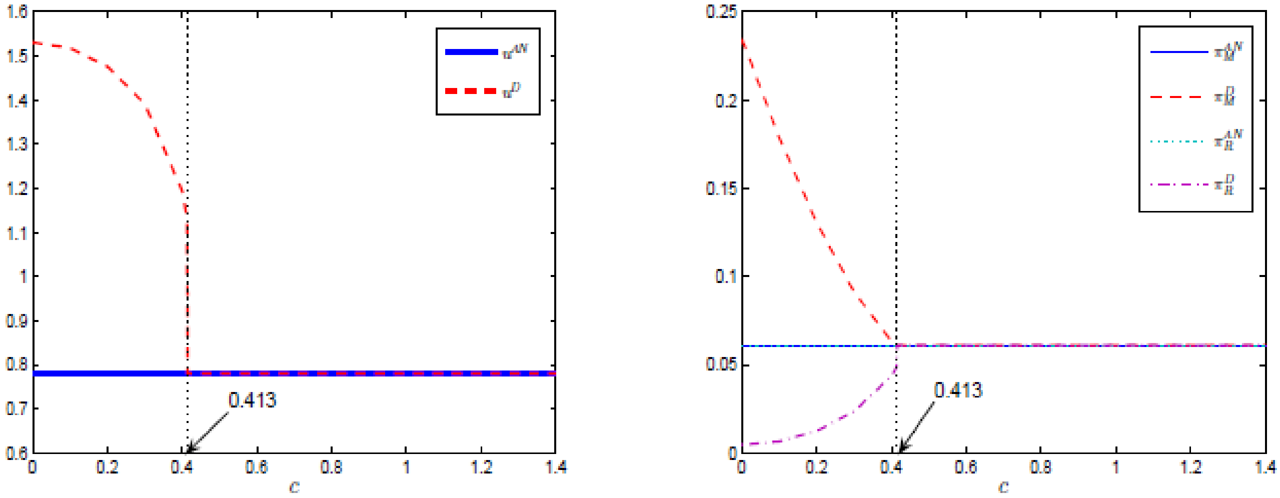
Based on this, the manufacturer's optimal wholesale price under a given u is

$$w^D = \frac{u}{2}. \tag{45}$$

Finally, the manufacturer's expected profit can be given by

$$\pi_M^D = \begin{cases} \frac{2c^2m+u^2m-2ku^3-2ucm}{4u} + \frac{\lambda u(\alpha_h-\alpha_l)^2(1-\lambda)}{8(\alpha_h-\lambda\alpha_h+\lambda\alpha_l)}, & \text{if } u > 2c, \\ \frac{u(\mu-4ku)}{8}, & \text{if } u \le 2c. \end{cases} \tag{46}$$

When $u > 2c$, we have $q_M^D > 0$, and the manufacturer sells products through dual channels; when $u \le 2c$, we have $q_M^D = 0$, where the manufacturer sells products only through the retail channel, and the existence of the direct channel does not affect the chain members' decisions. It should be mentioned that in the basic model where the retailer has first-move advantages to decide the order quantity, she can choose an order quantity to deter the manufacturer from selling directly; however, in this case where the manufacturer first commits a direct selling quantity, the retailer cannot control the manufacturer's direct selling quantity through her order quantity decision. As a result, the case that the retailer deters the manufacturer from selling directly does not exist.



(a) Product quality

(b) Profits

Figure 9: Product quality and profits with different c under a direct selling quantity commitment

Figure 9 shows the effects of encroachment on product quality and profits for chain members when the manufacturer's direct selling quantity is set before the retailer's order quantity decision. The manufacturer is still always better off with encroachment due to the increased demand of an additional channel. Different from the basic case, the results show that encroachment always increases product quality and the retailer is always worse off with encroachment. The reason is that in this case, the retailer cannot avoid channel competition caused by encroachment, which adversely affects her profit.

Figure 10 shows the comparison of manufacturer's profits with different timings of quantity decisions. It indicates that the manufacturer can gain more profits when he sets the direct selling quantity later (i.e., the basic case). Thus, the manufacturer has incentive to revise his direct selling quantity after receiving the retailer's order. In other words, the manufacturer's direct selling quantity commitment aforehand indeed is not credible.

6. Conclusion

We consider manufacturer encroachment with endogenous product quality under three different information structures, i.e., full information, asymmetric information, and no information, to explore the effects of encroachment and information on the product quality and profits of chain members. Under the case of asymmetric information where a signaling game arises, only the separating equilibrium satisfies the intuitive criterion so that the low-type retailer has to distort her order quantity downward to costly signal her type.

By examining the effects of encroachment on the quality, we find that encroachment decreases quality if the manufacturer's direct selling cost is intermediate, and increases quality otherwise. Under each information structure, encroachment benefits the retailer under an intermediate direct selling cost when she deters the manufacturer from selling directly (which eliminates the negative competition effect caused by encroachment). The manufacturer is always better off with encroachment since the added channel can either increase demand or serve as an effective threat to the retailer and allow the manufacturer to use the quality and wholesale price decisions more aggressively to extract profit from the retailer channel.

We further explore the implications with manufacturer encroachment for information management and generate the following results. (1) Quality may be upward changed by asymmetric information when direct selling is relatively efficient, but may be downward changed when direct selling is relatively inefficient. (2) The manufacturer may prefer to keep the information disadvantages, rather than having a better knowledge about the market size when his direct selling cost is relatively large and the prior probability of large market size is high. The rationale behind it is that asymmetric information not only leads to a downward distorted order quantity, but also allows the manufacturer to set the quality at a different level. Specifically, asymmetric information can help the manufacturer to better balance the quality investment cost and retail market revenue by setting a lower quality, which compensates for the loss of order quantity downward distortion. This result complements prior literature that has shown that without quality decisions, the manufacturer with encroachment always prefers a full-information case. (3) The manufacturer prefers to sell to an informed retailer since he can screen the true market size from the separated order quantity. (4) To avoid the negative effects of order distortion caused by asymmetric information, an informed retailer may be willing to share the information with the manufacturer when direct selling is efficient. (5) Both players can reach a consensus on information sharing when the manufacturer's direct selling cost is quite small or relatively large; however, there also exists a case where the manufacturer prefers a full-information case while the retailer prefers to keep information advantages when the direct selling cost is relatively small.

In addition, we also investigate an extended case where the manufacturer has a priority on setting the direct selling quantity. In this case, encroachment is still beneficial to the manufacturer; however, different from the case where the retailer has a first-mover advantages on quantity decisions, encroachment always hurts the retailer since she cannot avoid channel competition. Moreover, comparing the two cases with different timings of quantity decisions, we find that the manufacturer always prefers to a later quantity decision on the direct channel; that is, an aforehand direct selling quantity commitment may be not credible.

Despite the importance of the managerial insights for manufacturer encroachment with quality decisions and information management, our study also has a few limitations. First, we focus on the common linear wholesale price contract. However, it is also of interest to study a nonlinear pricing contract where the issue under asymmetric information changes from signaling to screening. Second, more generalized quality investment cost function may be considered in the future study. Third, in this paper, we consider the case of asymmetric demand information where the retailer has a better knowledge about the true market size. We can also encode the asymmetric cost information where the manufacturer privately knows his direct selling cost in the future works.

Acknowledgments

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Appendix

Proof of Lemma 1. If the retailer wants to separate, she will set different order quantities under different market sizes. As shown in (12) and (13), the manufacturer's belief is $\alpha = \alpha_h$ if $q_R > q_R^s$, and is $\alpha = \alpha_l$ if $q_R \leq q_R^s$.

As

$$\pi_R(q_R > q_R^s|\alpha_h) = \frac{((c+u-2w)\alpha_h - uq_R)q_R}{2\alpha_h}, \tag{A1}$$

and

$$\pi_R(q_R \leq q_R^s|\alpha_h) = \frac{(2(u-w)\alpha_h - u(q_R+\alpha_l) + c\alpha_l)q_R}{2\alpha_h}, \tag{A2}$$

in order to satisfy inequality constraint (12), we need

$$q_R^s \leq \tilde{q}_R \triangleq \frac{(2\alpha_h - \alpha_l)u + c\alpha_l - 2w\alpha_h}{2u} - \frac{1}{2u}\sqrt{((\alpha_h+\alpha_l)c + (3\alpha_h-\alpha_l)u - 4w\alpha_h)(u-c)(\alpha_h-\alpha_l)}.$$

When $\alpha = \alpha_h$, it is optimal for the retailer to set the first-best order quantity as

$$\bar{q}_R^{AE} = \frac{(c+u-2w)\alpha_h}{2u}. \tag{A3}$$

Noting that

$$\pi_R(q_R \leq q_R^s|\alpha_l) = \frac{((c+u-2w)\alpha_l - uq_R)q_R}{2\alpha_l}, \tag{A4}$$

$$\pi_R(q_R > q_R^s|\alpha_l) = \frac{(2(u-w)\alpha_l - (q_R+\alpha_h)u + c\alpha_h)q_R}{2\alpha_l}, \tag{A5}$$

it is straightforward to get the retailer's first-best order quantity $q_R = \frac{(c+u-2w)\alpha_l}{2u}$ when $\alpha = \alpha_l$. Then, we can easily get the most profitable order quantity when $\alpha = \alpha_l$ as

$$\underline{q}_R^{AE} = q_R^s = \min\left\{\tilde{q}_R, \frac{(c+u-2w)\alpha_l}{2u}\right\}. \tag{A6}$$

When $q_R^s = \frac{(u+c-2w)\alpha_l}{2u}$, constraint (13) is obviously satisfied; when $q_R^s = \tilde{q}_R$, it can also be verified that constraint (13) is satisfied. In addition, denoting $\Delta = \frac{(u+c-2w)\alpha_l}{2u} - \tilde{q}_R$, we can find

$$\frac{\partial\Delta}{\partial w} = \frac{\alpha_h - \alpha_l}{u} - \frac{\alpha_h(u-c)(\alpha_h-\alpha_l)}{u\sqrt{((\alpha_h+\alpha_l)c+(3\alpha_h-\alpha_l)u-4w\alpha_h)(u-c)(\alpha_h-\alpha_l)}}, \tag{A7}$$

$$\frac{\partial^2\Delta}{\partial w^2} = -\frac{2\alpha_h^2(u-c)^2(\alpha_h-\alpha_l)^2}{u\sqrt{(((\alpha_h+\alpha_l)c+(3\alpha_h-\alpha_l)u-4w\alpha_h)(u-c)(\alpha_h-\alpha_l))^3}} < 0, \tag{A8}$$

which implies that Δ is concave in w. Solving $\Delta = 0$, we can get $w = \frac{u(\alpha_h-3\alpha_l)+c(\alpha_h+\alpha_l)}{2(\alpha_h-\alpha_l)} \triangleq \tilde{w}$, and $w = \frac{u+c}{2}$. By virtue of $w \le \frac{u+c}{2}$ and $\tilde{w} < \frac{u+c}{2}$, we have $\Delta = \frac{(u+c-2w)\alpha_l}{2u} - \tilde{q}_R \le 0$ when $w \le \tilde{w}$; otherwise, $\Delta > 0$ holds. In other words, $q_R^s = \frac{(u+c-2w)\alpha_l}{2u}$ if $w \le \tilde{w}$ and $q_R^s = \tilde{q}_R$ if $w > \tilde{w}$.

The proof is complete.

Proof of Lemma 2. If the retailer wants the manufacturer to remain uninformed, she will set the same order quantity for different market sizes. As shown in (17)-(21), the manufacturer does not know the actual market size if $q_R \le q_R^o$, and the manufacturer's belief is $\alpha = \alpha_h$ if $q_R > q_R^o$.

Since

$$\begin{aligned}\pi_R(q_R \le q_R^o|\alpha_h) =& \frac{q_R}{2\alpha_h((1-\lambda)\alpha_h+\lambda\alpha_l)}(2(1-\lambda)(u-w)\alpha_h^2 + (((q_R+2\alpha_l)\lambda - q_R - \alpha_l)u \\ &+ \alpha_l(c-2\lambda w))\alpha_h - \lambda u q_R \alpha_l),\end{aligned} \tag{A9}$$

and

$$\begin{aligned}\pi_R(q_R \le q_R^o|\alpha_l) =& \frac{q_R}{2\alpha_l((1-\lambda)\alpha_h+\lambda\alpha_l)}(2\lambda(u-w)(\alpha_l)^2 + (((2w-2u)\lambda + c + u - 2w)\alpha_h \\ &- u\lambda q_R)\alpha_l + u\alpha_h q_R(\lambda-1)),\end{aligned} \tag{A10}$$

in order to satisfy constraints (17)-(18), we need

$$q_R^o \le \frac{\alpha_l}{2u((1-\lambda)\alpha_h+\lambda\alpha_l)}(((2w-2u)\lambda + c + u - 2w)\alpha_h + 2\lambda\alpha_l(u-w)), \tag{A11}$$

and noting that the larger q_R^o is, the larger $\pi_R(q_R \le q_R^o|\alpha_h)$ and $\pi_R(q_R \le q_R^o|\alpha_l)$ are, we set

$$q_R^o = \frac{\alpha_l}{2u((1-\lambda)\alpha_h+\lambda\alpha_l)}(((2w-2u)\lambda + c + u - 2w)\alpha_h + 2\lambda\alpha_l(u-w)). \tag{A12}$$

In addition, we need to satisfy constraints (19)-(20), which hold if

$$2\lambda(u-w)(\alpha_l-\alpha_h)+(u+s-2w)\alpha_h \geq 0, \tag{A13}$$

and

$$\begin{aligned}&(\lambda-1)^2\,(u+c-2\,w)^2\,{\alpha_h}^3-(\lambda-1)\left(\left(9\,u^2+(2\,c-20\,w)\,u+c^2-4\,sw+12\,w^2\right)\lambda\right.\\&\left.+(-3\,u+c+2\,w)\,(u+c-2\,w)\right)\alpha_l\,{\alpha_h}^2+12\,{\alpha_l}^2\lambda\,(u-w)^2\left(\lambda-\frac{2}{3}\right)\alpha_h\\&-4\,{\alpha_l}^3\lambda^2\,(u-w)^2\leq 0.\end{aligned} \tag{A14}$$

The proof is complete.

Proof of Proposition 1. We adopt intuitive criterion to refine the two equilibria existing in our model. For a signaling game that contains one signal sender and one signal receiver, the intuitive criterion uses two steps to examine an equilibrium.

Firstly, define a set of types of sender, denoted by Ω, with which the highest profit that a sender can obtain by adopting an off-equilibrium is lower than the profit by adopting the equilibrium strategy. In our model, suppose the equilibrium order quantity for the retailer is q^e_{Rl} when the actual market size is small and the equilibrium order quantity is q^e_{Rh} when the actual market size is large. For any off-equilibrium q_{Ri},

$$\Omega=\{\alpha_i : V(q^e_{Ri}) > \overline{V}(q_{Ri})\}, \tag{A15}$$

where $V(q^e_{Ri})$ denotes retailer's equilibrium profit, while $\overline{V}(q_{Ri})$ denotes the highest profit the retailer can obtain by setting q_R as off-equilibrium quantity q_{Ri}. Note that for a given q_{Ri}, the retailer obtains the highest profit if the manufacturer believes the actual market size is small, i.e.,

$$\overline{V}(q_{Ri})=\left(u\left(1-\frac{q_{Ri}+q_{Ml}}{\alpha_i}\right)-w\right)q_{Ri}, \tag{A16}$$

where q_{Mi} is the manufacturer's most profitable order quantity if he believes the actual market size is α_i.

Therefore, Ω contains the market sizes with which the equilibrium dominates all the off-equilibrium strategy. Define Ω^C as the complement of Ω^C, if Ω^C is an empty set, which means under each market size, all off-equilibrium is dominated by the equilibrium strategy, then the second step becomes unnecessary. If Ω^C is not empty, we need to implement the second step.

Secondly, for a market size in Ω^C, we examine whether there exist an off-equilibrium quantity that such deviation leads the manufacturer to believe that the actual market size is $\alpha_i \in \Omega^C$ and the retailer's equilibrium profit is lower than the lowest profit the retailer can obtain by ordering an off-equilibrium quantity. If there is such a type, then the equilibrium cannot survive intuitive criterion. In our model, we denote $\underline{V}(q_{Ri})$ as the lowest profit the retailer obtains by adopting an off-equilibrium strategy,

$$\underline{V}(q_{Ri}) = \begin{cases} \left(u\left(1 - \frac{q_{Ri}+q_{Mh}}{\alpha_i}\right) - w\right) q_{Ri}, & \text{if } \alpha_h \in \Omega^C, \\ \left(u\left(1 - \frac{q_{Ri}+q_{Ml}}{\alpha_i}\right) - w\right) q_{Ri}, & \text{otherwise.} \end{cases} \tag{A17}$$

If $\alpha_h \in \Omega^C$, then the retailer will obtain the lowest profit after a deviation from equilibrium quantity, which leads the manufacturer to believe the actual market size is large; otherwise, $\underline{V}(q_{Ri})$ denotes the lowest profit the retailer can obtain under a deviation from equilibrium quantity that leads the manufacturer to believe the actual market size is small. If there exist such a $\alpha_i \in \Omega^C$ such that $V(q^e_{Ri}) < \underline{V}(q_{Ri})$, then the equilibrium cannot survive intuitive criterion.

Following above two steps, we examine whether separating equilibrium or pooling equilibrium can survive intuitive criterion.

If the retailer chooses pooling strategy, we define her profit as

$$V_{io}(q_R) = \left(u\left(1 - \frac{q_R + q^o_M}{\alpha_i}\right) - w\right) q_R, \quad i = h, l, \tag{A18}$$

in which α_i is the true market size observed by the retailer and the manufacturer is uninformed.

If the retailer chooses separating strategy, we define her profit as

$$V_{ij}(q_R) = \left(u\left(1 - \frac{q_R + q^j_M}{\alpha_i}\right) - w\right) q_R, \quad i = h, l, \tag{A19}$$

in which α_i is the actual market size observed by the retailer, while α_j is the belief held by the manufacturer and the corresponding direct selling quantity is q^j_M.

First, we demonstrate that any pooling equilibrium cannot survive intuitive criterion. Given the product quality u, there exists a pooling equilibrium where the retailer sets the same order quantity q^o_R for different market sizes. Noting that

$$V_{ll}\left(q^A_R\right) = \left(u\left(1 - \frac{q^A_R + q^l_M}{\alpha_l}\right) - w\right) q^A_R, \tag{A20}$$

$$V_{lo}\left(q^o_R\right) = \left(u\left(1 - \frac{q^o_R + q^o_M}{\alpha_l}\right) - w\right) q^o_R, \tag{A21}$$

we can always find a $q^A_R < q^o_R$ such that $V_{ll}\left(q^A_R\right) = V_{lo}\left(q^o_R\right)$.

Substituting q^A_R into $V_{hl}(q_R)$, and plugging q^o_R into $V_{ho}(q_R)$, we can get

$$V_{hl}\left(q^A_R\right) = \left(u\left(1 - \frac{q^A_R + q^l_M}{\alpha_h}\right) - w\right) q^A_R, \tag{A22}$$

$$V_{ho}\left(q^o_R\right) = \left(u\left(1 - \frac{q^o_R + q^o_M}{\alpha_h}\right) - w\right) q^o_R. \tag{A23}$$

As a result,

$$V_{hl}\left(q_R^A\right) - V_{ll}\left(q_R^A\right) = \left(\frac{u}{\alpha_l} - \frac{u}{\alpha_h}\right)\left(q_R^A + q_M^l\right) q_R^A, \tag{A24}$$

$$V_{ho}\left(q_R^o\right) - V_{lo}\left(q_R^o\right) = \left(\frac{u}{\alpha_l} - \frac{u}{\alpha_h}\right)\left(q_R^o + q_M^o\right) q_R^o, \tag{A25}$$

in which,

$$q_M^l = \frac{\left(\alpha_l - q_R^A\right) u - s\alpha_l}{2u}, \tag{A26}$$

$$q_M^o = \frac{\left(\left(q_R^o - \lambda q_R^o - \alpha_l\right) u + s\alpha_l\right)\alpha_h + u\lambda q_R^o \alpha_l}{2u\left(\left(\lambda - 1\right)\alpha_h - \lambda\alpha_l\right)}. \tag{A27}$$

By virtue of $q_R^A < q_R^o$ and $V_{ll}\left(q_R^A\right) = V_{lo}\left(q_R^o\right)$, it is obvious that

$$V_{ho}\left(q_R^o\right) - V_{lo}\left(q_R^o\right) > V_{hl}\left(q_R^A\right) - V_{ll}\left(q_R^A\right), \tag{A28}$$

and thus,

$$V_{ho}\left(q_R^o\right) > V_{hl}\left(q_R^A\right). \tag{A29}$$

Based on the above statements, as demonstrated in Figure 11, we can find a $q_R^B = q_R^A + \epsilon$, and ϵ is small enough such that the retailer has an incentive to deviate from the pooling equilibrium q_R^o to q_R^B if she finds that the market size is small, but she will not deviate from the pooling equilibrium if she finds that the market size is large. We assume that such a deviation always leads the manufacturer to believe that the actual market size is small, i.e.,

$$V_{ho}\left(q_R^o\right) > V_{hl}\left(q_R^B\right), \tag{A30}$$

$$V_{lo}\left(q_R^o\right) < V_{ll}\left(q_R^B\right). \tag{A31}$$

Hence, the pooling equilibrium cannot survive the intuitive criterion.

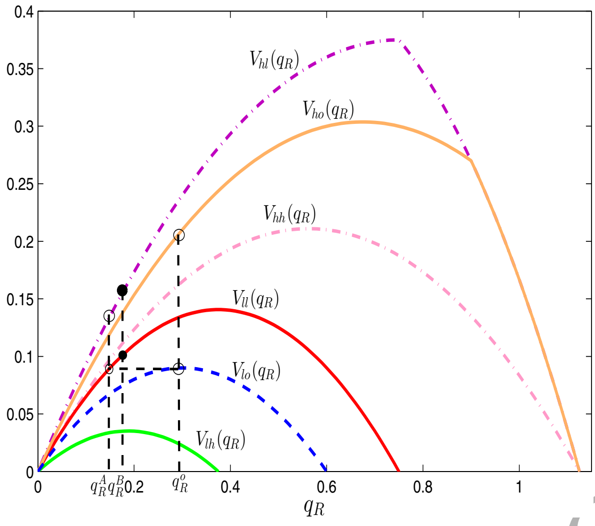

Figure 11: Refinement over pooling equilibrium

Now, we prove that any other separating equilibrium cannot survive the intuitive criterion except the separating equilibrium presented in Lemma 1. In order to convince the manufacturer that the actual market size is small, the retailer needs to set her order quantity $q_R \leq q_R^s$, then a retailer will set $q_R = q_R^s$ to maximize her profit. As a result, a retailer who observes the small market size has no incentive to deviate her order quantity to a lower q_R^C such that $q_R^C < q_R^s$. Without doubt, a retailer who observes a large market size will not deviate her first-best order quantity to any other quantity. Hence, any other separating equilibrium cannot survive the intuitive criterion except the separating equilibrium presented in Lemma 1.

The proof is complete.

Proof of Lemma 3. Note that the manufacturer's optimal quantity decision in the last stage is $q_M^{FE} = \left[\frac{(\alpha_i - q_R)u - c\alpha_i}{2u}\right]^+$. We distinguish three cases: (A_1) if $(\alpha_i - q_R)u - c\alpha_i > 0$, then $q_M^{FE} > 0$, and the manufacturer encroaches; (A_2) if $(\alpha_i - q_R)u - c\alpha_i = 0$, then $q_M^{FE} = 0$, and the retailer chooses q_R to deter the manufacturer from selling directly (which follows the corner solution); (A_3) if $(\alpha_i - q_R)u - c\alpha_i < 0$, then $q_M^{FE} = 0$, and the existence of the direct channel does not affect the chain members' decisions. According to the backward induction, for a given u, the manufacturer's expected profit for each of the three cases can be given by

$$\pi_M^{FE} = \begin{cases} \frac{7\mu c^2 - 6\mu cu + 3\mu u^2 - 6ku^3}{12u}, & \text{if } u \geq \frac{5c}{3}, \\ \frac{\mu(4uc - u^2 - 3c^2) - ku^3}{2u}, & \text{if } \frac{6c}{5} \leq u \leq \frac{5c}{3}, \\ \frac{(\mu - 4ku)u}{8}, & \text{if } u \leq \frac{6c}{5}. \end{cases} \tag{A32}$$

We solve each of the three constrained maximization problems (denoted by A_1, A_2, and

A_3) and then compare the maximized π_M^{FE} in the three cases to find the global maximum.

Problem A_1: $u \geq \frac{5c}{3}$.

We can get the first-order derivative and the second-order derivative of π_M^{FE} as

$$f(u) \triangleq \frac{\partial \pi_M^{FE}}{\partial u} = \frac{(3u^2 - 7c^2)\mu - 12ku^3}{12u^2}, \tag{A33}$$

$$f'(u) \triangleq \frac{\partial^2 \pi_M^{FE}}{\partial u^2} = \frac{7\mu c^2 - 6ku^3}{6u^3}, \tag{A34}$$

respectively. When $f'(\frac{5c}{3}) > 0$, i.e, $c < \frac{63\mu}{250k}$, $f(u)$ first increases and then decrease with u; when $c \geq \frac{63\mu}{250k}$, $f(u)$ always decreases with u. It means there exists a unique u_1 satisfying $f(u_1) = 0$ and $f'(u_1) \leq 0$.

We can get the following results. (1) If $f((\frac{7\mu c^2}{6k})^{\frac{1}{3}}) \leq 0$, i.e., $c \geq \frac{\mu}{6\sqrt{7}k}$, we can get $f(u) \leq 0$, which means π_M^{FE} decreases with u. The unique maximizer is $u^* = \frac{5c}{3}$. (2) If $f(\frac{5c}{3}) < 0$ and $f((\frac{7\mu c^2}{6k})^{\frac{1}{3}}) > 0$, i.e, $\frac{3\mu}{125k} < c < \frac{\mu}{6\sqrt{7}k}$, π_M^{FE} first decreases, then increases and finally decreases again with u increasing. The maximizer is either $u^* = \frac{5c}{3}$ or $u^* = u_1$. It needs to compare $\pi_M^{FE}|_{u=\frac{5c}{3}}$ and $\pi_M^{FE}|_{u=u_1}$. (3) If $f(\frac{5c}{3}) \geq 0$, i.e., $c \leq \frac{3\mu}{125k}$, π_M^{FE} first increases and then decreases with u increasing. The unique maximizer is $u^* = u_1$.

If $\frac{3\mu}{125k} < c < \frac{\mu}{6\sqrt{7}k}$, comparing $\pi_M^{FE}|_{u=\frac{5c}{3}}$ and $\pi_M^{FE}|_{u=u_1}$, we have

$$\begin{aligned}
\pi_M^{FE}|_{u=\frac{5c}{3}} - \pi_M^{FE}|_{u=u_1} &= \frac{c(24\mu - 125kc)}{90} - \frac{7\mu c^2 - 6\mu c u_1 + 3\mu u_1^2 - 6ku_1^3}{12u_1} \\
&= \frac{c(24\mu - 125kc)}{90} - \frac{\mu u_1 - \mu c - 3ku_1^2}{2}.
\end{aligned} \tag{A35}$$

According to the implicit function theorem, we can get $6\mu u_1 u_1'(c) - 14\mu c - 36ku_1^2 u_1'(c) = 0$. i.e., $u_1'(c) = \frac{7\mu c}{3(\mu - 6ku_1)u_1}$. In addition, by virtue of $f'(u_1) < 0$, we have $7\mu c^2 - 6ku_1^3 = 3u_1^2(\mu - 6ku_1) < 0$. Then we can get

$$\begin{aligned}
\frac{\partial[\pi_M^{FE}|_{u=\frac{5c}{3}} - \pi_M^{FE}|_{u=u_1}]}{\partial c} &= \frac{12\mu - 125kc}{45} - \frac{\mu u_1'(c) - \mu - 6ku_1 u_1'(c)}{2} \\
&= \frac{(69\mu - 250kc)u_1 - 105\mu c}{90u_1} \\
&> \frac{(69\mu - 250kc)\frac{\mu}{6k} - 105\mu c}{90u_1} > 0,
\end{aligned} \tag{A36}$$

which implies that $[\pi_M^{FE}|_{u=\frac{5c}{3}} - \pi_M^{FE}|_{u=u_1}]$ increases with c. There exists a unique $c = c_0 \in (\frac{3\mu}{125k}, \frac{\mu}{6\sqrt{7}k})$ which satisfying $[\pi_M^{FE}|_{u=\frac{5c}{3}} - \pi_M^{FE}|_{u=u_1}] = 0$. As a result, if $c < c_0$, the maximizer is $u^* = u_1$, and if $c \geq c_0$, the maximizer is $u^* = \frac{5c}{3}$.

Problem A_2: $\frac{6c}{5} \leq u \leq \frac{5c}{3}$.

We can get the first-order derivative and the second-order derivative of π_M^{FE} as

$$\frac{\partial \pi_M^{FE}}{\partial u} = \frac{(3c^2 - u^2)\mu - 2ku^3}{2u^2}, \tag{A37}$$

$$\frac{\partial^2 \pi_M^{FE}}{\partial u^2} = -\frac{3\mu c^2 + ku^3}{u^3} < 0, \tag{A38}$$

respectively. From (A38), we can find that π_M^{FE} is concave in u. Denote the unique interior maximizer as $u = u_2$, which satisfying $(3c^2 - u_2^2)\mu - 2ku_2^3 = 0$. We can get the following results. (1) If $\frac{\partial \pi_M^{FE}}{\partial u}|_{u=\frac{5c}{3}} = \frac{\mu}{25} - \frac{5kc}{3} \geq 0$, i.e., $c \leq \frac{3\mu}{125k}$, we can get $\frac{\partial \pi_M^{FE}}{\partial u} \geq 0$; that is π_M^{FE} increases with c. The unique maximizer is $u^* = \frac{5c}{3}$. (2) If $\frac{\partial \pi_M^{FE}}{\partial u}|_{u=\frac{6c}{5}} = \frac{13\mu}{24} - \frac{6kc}{5} \leq 0$, i.e., $c \geq \frac{65\mu}{144k}$, we can get $\frac{\partial \pi_M^{FE}}{\partial u} \leq 0$; that is π_M^{FE} decreases with c. The unique maximizer is $u^* = \frac{6c}{5}$. (3) If $\frac{3\mu}{125k} < c < \frac{65\mu}{144k}$, the manufacturer's profit π_M^{FE} reaches the maximum when $u^* = u_2$.

Problem A_3: $u \leq \frac{5c}{6}$.

Obviously, π_M^{FE} is concave in u. The unique interior maximizer is $u = u^{FN} = \frac{\mu}{8k}$. If $u^{FN} < \frac{5c}{6}$, i.e., $c > \frac{3\mu}{20k}$, the unique maximizer of π_M^{FE} is $u^* = u^{FN}$; if $c \leq \frac{3\mu}{20k}$, π_M^{FE} increases with c, and the unique maximizer is $u^* = \frac{6c}{5}$.

Comparison to find the global maximum.

It should be mentioned that $\pi_M^{FE}(u)$ is continuous. Based on the preceding analysis, we can get the following results.

(1) If $c < \frac{3\mu}{125k}$, π_M^{FE} first increases and then decreases with c, and the unique maximizer is $u^* = u_1$.

(2) If $\frac{3\mu}{125k} < c < \frac{\mu}{6\sqrt{7}k}$, π_M^{FE} first increases, then decreases, and then increases and decreases again with c. The maximizer is either $u^* = u_1$ or $u^* = u_2$. Next, we compare $\pi_M^{FE}|_{u=u_1}$ and $\pi_M^{FE}|_{u=u_2}$. We have

$$\begin{aligned}\pi_M^{FE}|_{u=u_2} - \pi_M^{FE}|_{u=u_1} &= \frac{\mu(4u_2c - u_2^2 - 3c^2) - ku_2^3}{2u_2} - \frac{7\mu c^2 - 6\mu c u_1 + 3\mu u_1^2 - 6ku_1^3}{12u_1} \\ &= \frac{4\mu c - 2\mu u_2 - 3ku_2^2}{2} - \frac{\mu u_1 - \mu c - 3ku_1^2}{2}.\end{aligned} \tag{A39}$$

According to the implicit function theorem, we can get $6\mu c - 2\mu u_2 u_2'(c) - 6ku_2^2 u_2'(c) = 0$. i.e., $u_2'(c) = \frac{3\mu c}{(\mu + 3ku_2)u_2}$. Then we can get

$$\begin{aligned}\frac{\partial[\pi_M^{FE}|_{u=u_2} - \pi_M^{FE}|_{u=u_1}]}{\partial c} &= \frac{4\mu - 2\mu u_2'(c) - 6ku_2 u_2'(c)}{2} - \frac{\mu u_1'(c) - \mu - 6ku_1 u_1'(c)}{2} \\ &= \frac{\mu(5 - \frac{6c}{u_2} - \frac{7c}{3u_1})}{2} > 0,\end{aligned} \tag{A40}$$

by virtue of $u_1 > \frac{\mu}{6k}$ and $\frac{c}{u_2} = \sqrt{\frac{\mu + 2ku_2}{3\mu}} < 0.6351$, which implies that $[\pi_M^{FE}|_{u=u_2} - \pi_M^{FE}|_{u=u_1}]$ increases with c. There exists a unique $c = c_1 \in (\frac{3\mu}{125k}, \frac{\mu}{6\sqrt{7}k})$ which satisfying $[\pi_M^{FE}|_{u=u_2} -$

$\pi_M^{FE}|_{u=u_1}] = 0$. As a result, if $c < c_1$, the maximizer is $u^* = u_1$, and if $c \geq c_1$, the maximizer is $u^* = u_2$.

(3) If $\frac{\mu}{6\sqrt{7}k} < c \leq \frac{3\mu}{20k}$, π_M^{FE} first increases, and then decreases with c. The unique maximizer is $u^* = u_2$.

(4) If $c > \frac{3\mu}{20k}$. The maximizer is either $u^* = u_2$ or $u^* = u^{FN}$. Comparing $\pi_M^{FE}|_{u=u_2}$ and $\pi_M^{FE}|_{u=u^{FN}}$, we have

$$\pi_M^{FE}|_{u=u^{FN}} - \pi_M^{FE}|_{u=u_2} = \frac{\mu^2}{128k} - \frac{4\mu c - 2\mu u_2 - 3ku_2^2}{2}, \tag{A41}$$

$$\frac{\partial[\pi_M^{FE}|_{u=u^{FN}} - \pi_M^{FE}|_{u=u_2}]}{\partial c} = \frac{\mu(\frac{6c}{u_2} - 4)}{2} > 0, \tag{A42}$$

by virtue of $\frac{c}{u_2} = \sqrt{\frac{\mu+2ku_2}{3\mu}} > 0.6733$, which implies that $[\pi_M^{FE}|_{u=u^{FN}} - \pi_M^{FE}|_{u=u_2}]$ increases with c. There exists a unique $c = c_2 > \frac{3\mu}{20k}$ which satisfying $[\pi_M^{FE}|_{u=u^{FN}} - \pi_M^{FE}|_{u=u_2}]$. As a result, if $c < c_2$, the maximizer is $u^* = u_2$, and if $c \geq c_2$, the maximizer is $u^* = u^{FN}$. In summary, we can get the optimal quality level as shown in Lemma 3.

The proof is complete.

Proof of Proposition 2. According to Proof of Lemma 3, we can get $u_1'(c) < 0$ and $u_2'(c) > 0$. Thus, if $c \leq c_1$, $u^{FE} = u_1$ decreases with c; if $c_1 < c \leq c_2$, $u^{FE} = u_2$ increases with c; if $c > c_2$, the increase of c shows no influence on u^{FE}. Next, we prove that $u^{FE} < u^{FN}$ when $c_1 < c < c_3$. Here, c_3 satisfies $u_2 = u^{FN}$. If $c \leq c_1$, $u^{FE} = u_1$. As shown in Proof of Lemma 3, $u_1 \geq \frac{\mu}{6k} > \frac{\mu}{8k} = u^{FN}$. If $c_1 < c < c_2$, we can observe that if $c = 0.06\frac{\mu}{k}$, $u^{FE} \approx 0.9542\frac{\mu}{k} < u^{FN}$, while if $c = 0.1\frac{\mu}{k}$, $u^{FE} \approx 0.152\frac{\mu}{k} > u^{FN}$. Thus, there exists a unique c_3 satisfying $u_2 = u^{FN}$. If $c \geq c_2$, we can get $u^{FE} = u^{FN}$.

The proof is complete.

Proof of Proposition 3. First, we consider the effects of encroachment on the manufacturer's profit. Under encroachment, the manufacturer's profit decreases with c if $c < c_1$ since

$$\frac{\partial \pi_M^{FE}|_{u=u_1}}{\partial c} = \frac{\mu u_1'(c) - \mu - 6ku_1u_1'(c)}{2} = \frac{(\mu - 6ku_1)u_1'(c) - \mu}{2} = \frac{\mu(7c - 3u_1)}{6u_1} < 0. \tag{A43}$$

It means if $\pi_M^{FE}|_{c=c_1} > \pi_M^{FN}$, we can get $\pi_M^{FE} > \pi_M^{FN}$ holds for all $c < c_1$. When $c = \frac{\mu}{16k}$, we can get $\pi_M^{FE}|_{u=u_1} - \pi_M^{FE}|_{u=u_2} < 0$, which means $c_1 < \frac{\mu}{16k}$. Thus, we can get

$$\pi_M^{FE}|_{c=c_1} > 0.0102\frac{\mu^2}{k} > \frac{\mu^2}{128k} = \pi_M^{FN}, \tag{A44}$$

which means that $\pi_M^{FE} > \pi_M^{FN}$ holds for all $c < c_1$. Next, we prove that if $c_1 < c \leq c_2$, π_M^{FE} first increases and then decreases with c. Since

$$\frac{\partial \pi_M^{FE}|_{u=u_2}}{\partial c} = \frac{\mu(2u_2 - 3c)}{u_2}, \tag{A45}$$

$$\frac{\partial \pi_M^{FE}|_{u=u_2}}{\partial c} = \frac{3\mu(cu_2'(c) - u_2)}{(u_2)^2} = \frac{3\mu(3\mu c^2 - u_2^2(\mu + 3ku_2))}{u_2^3(\mu + 3ku_2)} = -\frac{3\mu k}{\mu + 3ku_2} < 0, \tag{A46}$$

π_M^{FE} is concave in the interval $c \in [c_1, c_2]$. Observe that, when $c = 0.06\frac{\mu}{k}$, $\frac{\partial \pi_M^{FE}|_{u=u_2}}{\partial c} = \frac{\mu(2u_2-3c)}{u_2} > 0$. Thus, we can get that if $c_1 < c \leq c_2$, π_M^{FE} first increases and then decreases with c, and $\pi_M^{FE} \geq \pi_M^{FN}$ holds. When $c > c_2$, we have $\pi_M^{FE} = \pi_M^{FN}$. In sum, $\pi_M^{FE} \geq \pi_M^{FN}$ always holds.

Second, we consider the effects of encroachment on the retailer's profit. If $c \leq c_2$, we prove that the retailer's profit increases with c. If $c < c_1$, we can get

$$\frac{\partial \pi_R^{FE}}{\partial c} = \frac{2\mu c(2u_1 - cu_1'(c))}{9u_1^2} > 0. \tag{A47}$$

If $c_1 < c \leq c_2$, we can get

$$\begin{aligned}\frac{\partial \pi_R^{FE}}{\partial c} &= \frac{\mu(u_2-c)((u_2+c)u_2'(c) - 2u_2)}{2u_2^2} = \frac{\mu(u_2-c)(3\mu c - \mu u_2 - 4ku_2^2)}{2u_2^2} \\ &> \frac{\mu(u_2-c)(3\mu c - \mu\frac{6}{5}c - 4k(\frac{6}{5}c)^2)}{2u_2^2} > 0. \end{aligned} \tag{A48}$$

Observe that if $c = 0$, $\pi_R^{FE} = 0 < \pi_R^{FN}$, while if $c = 0.15\frac{\mu}{k}$, $\pi_R^{FE} \approx 0.0103\frac{\mu^2}{k} > \pi_R^{FN}$. Thus, we can find a unique threshold value c_4 satisfying $\pi_R^{FE} = \pi_R^{FN}$ such that $\pi_R^{FE} > \pi_R^{FN}$ if $c_4 < c < c_2$, and $\pi_R^{FE} \leq \pi_R^{FN}$ otherwise.

The proof is complete.

Proof of Lemma 4. Similar to Proof of Lemma 3, we can find a unique $c = \tilde{c}_1 \in (\frac{3m}{125k}, \frac{m}{6\sqrt{7}k})$ which satisfying $[\pi_M^{NE}|_{u=u_2} - \pi_M^{NE}|_{u=\tilde{u}_1}] = 0$, where $\tilde{u}_1$ and $\tilde{u}_2$ are the possible interior maximizers. As a result, if $c < \tilde{c}_1$, the maximizer is $u^* = \tilde{u}_1$, and if $\tilde{c}_1 < c \leq \tilde{c}_2$, the maximizer is $u^* = \tilde{u}_2$, and if $c > \tilde{c}_2$, the maximizer is $u^* = u^{NN}$.

Proof of Proposition 4. The proof is similar to Proof of Proposition 2, thus it is omitted. Here, $\tilde{c}_3$ satisfies $\tilde{u}_2 = u^{NN}$.

Proof of Proposition 5. The proof is similar to Proof of Proposition 3, thus it is omitted. Here, $\tilde{c}_4$ is a threshold value satisfying $\pi_R^{NE} = \pi_R^{NN}$ such that $\pi_R^{NE} > \pi_R^{NN}$ if $\tilde{c}_4 < c < \tilde{c}_2$, and $\pi_R^{NE} \leq \pi_R^{NN}$ otherwise.

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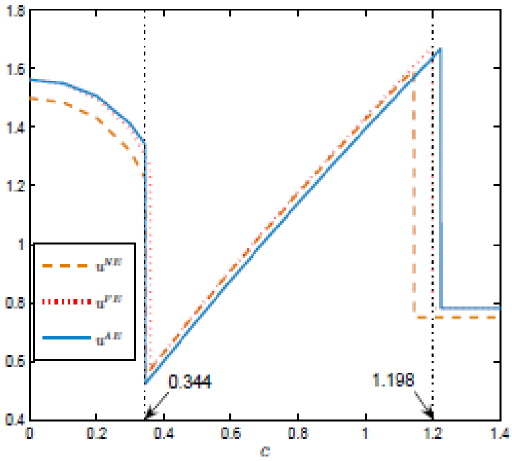
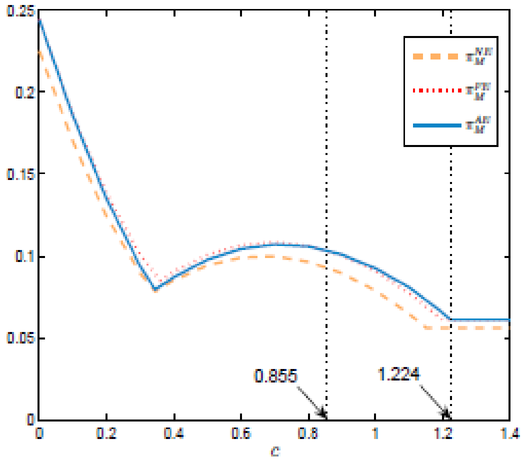
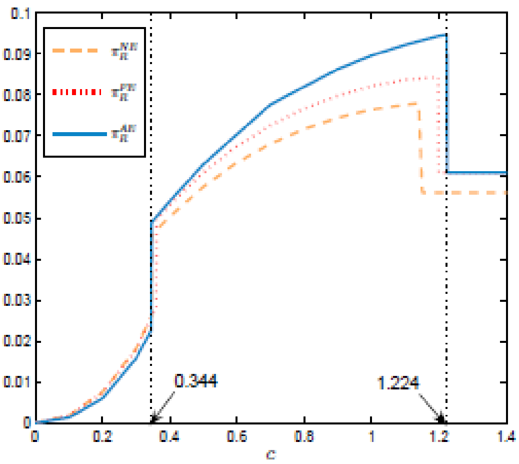


(a) For the product quality



(b) For the manufacturer



(c) For the retailer

Figure 7: Asymmetric information vs. full information vs. no information

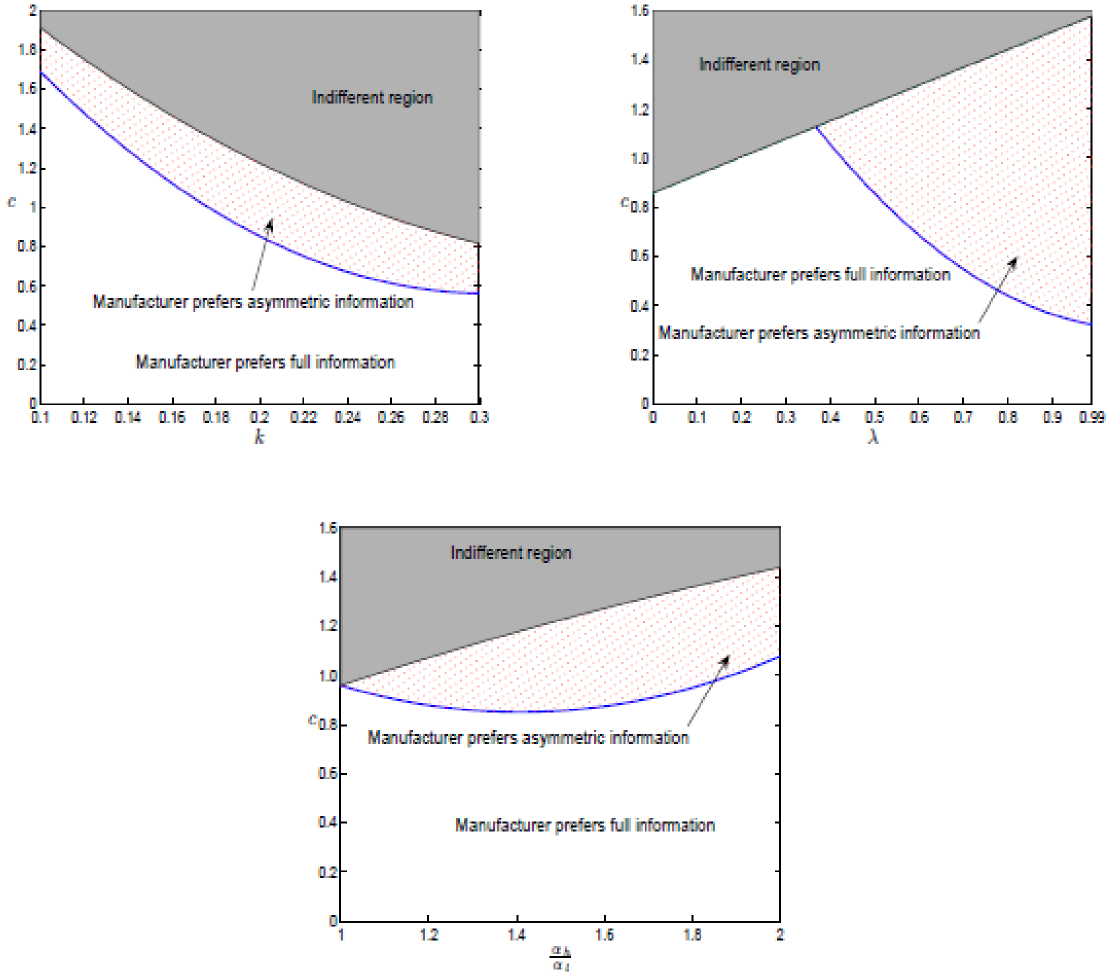


Figure 8: When the manufacturer prefers asymmetric information

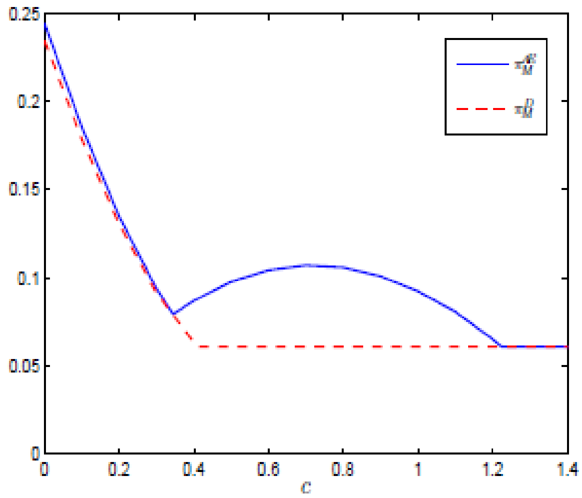


Figure 10: Comparison of manufacturer's profits with different timings of quantity decisions