RESEARCH ON IMPACTS OF ONLINE REVIEWS FROM CHANNEL PERSPECTIVES

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PhD

The Hong Kong Polytechnic University

This programme is jointly offered by The Hong Kong Polytechnic University and Tongji University

2020

The Hong Kong Polytechnic University

Department of Logistics and Maritime Studies

Tongji University

School of Economics and Management

Research on Impacts of Online Reviews from Channel Perspectives

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A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

May 2020

CERTIFICATE OF ORIGINALITY

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Abstract

In recent years, with the development of the Internet and information technology, online reviews, as one form of user-generated information, has begun to show its tremendous influence on consumers' purchase decisions. Compared with traditional media, such as newspapers or TV commercials, online reviews are more powerful and truthful because they are user-oriented and reveal more information about product attributes. A growing body of empirical research also has found that this information plays significant roles on firm's product sales and pricing strategies; yet theoretical work on the impacts of this emerging media is not sufficient. Besides, most prior work focus on the scenario where the retailer sells the products directly to consumers. In practice, abundant products are sold through distribution channels with manufacturers and retailers. Understanding the implication of online reviews on the pricing decisions and profits of players from channel perspectives is of academic interest and practical interest. However, the studies from this perspective are still limited. Thus, this dissertation attempts to fill this gap and studies the impacts of online reviews on the performance of channel members by considering different channel contexts.

First, we investigate the effects of online reviews in a dual channel where a manufacturer distributes a product through a retail channel and an Internet channel. We develop game-theoretic models to capture the pricing decisions and profits of the manufacturer and the retailer with online reviews, under two different channel structures. In specific, under the centralized channel, online reviews may increase or decrease the direct price but always lower the retail price. Under the decentralized channel, we show that the manufacturer has a higher probability to charge

a higher direct price than under the centralized channel, and the retailer also has the chance to improve the retail price. Further, under the two channel settings, it is not necessarily wise for the manufacturer to provide online reviews in the Internet channel unless the information revealed by online reviews is sufficiently favorable.

Second, we examine the impacts of online reviews in a supply chain with two competing manufacturers and a common retailer. The products are imperfectly substitutable with different qualities. By a two-period game model, we show that whether the retailer can increase or reduce the price difference of the two products in period 2 depends largely on the quality difference of the two products. Besides, online reviews affect the pricing decisions in the upstream and it is possible for the manufacturers to be better off simultaneously; the retailer can embrace the positive effect of online reviews only when consumers heavily underestimate the quality difference of the products but online reviews reveal an obvious quality difference. In addition, contrary to the conventional wisdom, we demonstrate that online reviews with more accurate information may be detrimental to the retailer and consumers.

Third, given the tremendous influence of online reviews on consumers' purchase decisions, more firms engage in promotions of online reviews by taking some strategies to encourage more positive online reviews. We provide the theoretical analysis to investigate the impacts of such behavior in a manufacturer-retailer supply chain. Two channel structures are considered: the centralized structure and the decentralized structure. We assume that the retailer can make promotion decisions in a reasonable range and the manufacturer shares some cost. By comparing the results without and with promotions of online reviews, we discover that it is necessary to analyze the change of variance, which may enhance or undermine the effect of review promotions. Moreover, promoting online reviews may impair the demand under both channel structures, and the demand under the centralized channel is more likely to be affected. The surprised finding is that promotions

of online reviews may not always favor the retailer and the manufacturer or hurt consumers. Last but not least, we reveal that, under the decentralized channel, the manufacturer has a greater threshold interval to benefit from the promotions of online reviews than the retailer; for the retailer, it is more likely to benefit from promotions of online reviews under the centralized channel than under the decentralized channel.

Publications Arising from the Thesis

Yang, W., Zhang J., Yan H.. Impacts of online consumer reviews on a dual-channel supply chain. Omega, 2020,102266.

Nie J., Zhong L., Yan H., Yang W*.. Retailers' distribution channel strategies with cross-channel effect in a competitive market[J]. International Journal of Production Economics, 2019, 213: 32-45.

Yang, W., Yan H., Zhang J.. Impacts of online reviews on two competing manufacturers and a common retailer. International Journal of Production Economics. Under Review.

Yang, W., Yan H., Zhang J.. Promotions of online reviews from a channel perspective. Transportation Research Part E: Logistics and Transportation Review. Under Review.

Acknowledgements

Firstly, I would like to express my sincere gratitude to Prof. Yan Hong and Dr Luo Meifeng, my supervisors in The Hong Kong Polytechnic University (PolyU), and Prof. Zhang Jiantong, my supervisor in Tongji University. Without their expert guidance and generous support, I would not have completed this thesis. I feel fortunate to have them in my PhD study in the two universities. Their constructive suggestions and profound knowledge enlighten me a lot not only in my research study but also in my life.

Secondly, I greatly acknowledge other academic staff in and out of the Department of Logistics and Maritime Studies of PolyU and the School of Economics and Management of Tongji University. Their kind suggestions mean a lot. In PolyU, my special thanks go to Dr Song Miao for her helpful suggestions on my confirmation of registration. In Tongji University, my thanks go to Prof. Duan Yongrui and Prof. Liang Zhe for their valuable advices in my research work, and Ms. Tang Haiyan for her kindness in dealing with many things related to my graduation.

Thirdly, I want to thank all my dear friends in the two universities. Without their sincere friendship, I would not have a completed and wonderful journey in my PhD study.

Lastly, I would like to express my deepest thanks to my parents and my brother for their consistent and unconditional support.

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Chapter 1

Introduction

With rapid development of e-commerce and social media, consumers today become more active and rational in sharing product and service experience. Before buying products, they can reach thousands of opinions of other consumers all over the world within seconds, and after purchasing the products, they also have opportunities to leave their reviews. These new user-generated contents — online reviews, are now widely available on websites of manufacturers or retailers. Specifically, online reviews can be described as "any positive or negative statements made by potential, actual or formal customers about a product or a service" and this information can be reached by customers on a worldwide scale, in an extensive range of markets (Hennig-Thurau et al. 2004). For instance, TripAdvisor.com provides online reviews about the hotels, Netflix.com publishes movie ratings and Amazon.com offers almost over 10 million reviews about all kinds of consumer products. In China, online reviews are also very popular in Taobao.com, JD.com and other sites. Compared with product descriptions or other traditional marketing communications provided by sellers, such as newspapers or TV commercials, online reviews are more appealing because they are user-oriented and the information revealed by online reviews is more related with product attributes, such as the product quality or the extent to which the product fit consumers (Chen and Xie 2008). Moreover, consumers can reach these reviews with significantly low cost and fast delivery (Brynjolfsson and Smith 2000). Therefore, this powerful information has become one of the most important product information sources

that influence the purchasing behavior of consumers (Arndt 1967, Bickart and Schindler 2001, Kostyra et al. 2016, Mathwick and Mosteller 2017). According to ChannelAdvisor (2011), 90% of consumers read online reviews and 83% say that these reviews have a significant impact on their purchase behaviors. Local Consumer Review Survey (2018) suggests that 86% of online shoppers read online reviews and 78% of them state that they trust online reviews and rely on such information to make purchase decisions. Recently, Nielsen's 2019 Global Trust in Advertising Report indicates that consumers continue to trust the opinions of others more than those traditional paid advertising.

Given the importance of online reviews, a great amount of literature examines the implications of online reviews. In general, these work can be classified into two levels: consumer level and market level (Lee and Lee 2009, Cheung and Thadani 2012). At consumer level, Banerjee (1992, 1993) suggest that consumers may ignore their private information and look at the decisions of previous consumers, which leads to "herding" information. Similarly, Bikhchandani et al. (1992) support for the idea that consumers tend to follow the actions of the preceding consumers regardless of their own information. In the following, scholars focus specifically on the impacts of online reviews on consumers' purchase intention (Park et al. 2007, Park and Kim 2008, Lee and Lee 2009, Jiménez and Mendoza 2013, Zhang et al. 2014, Ruiz-Mafe et al. 2018), attitudes or judgments of the product (Lee et al. 2008, Lee and Youn 2009) and perceptions of product quality (Koh et al. 2010, Hu et al. 2017).

At market level, one stream of the literature focuses on the relationship between online reviews and product sales. Typically, different metrics of online reviews are considered and findings are inconsistent. For example, Chevalier and Mayzlin (2006) study the impacts of the valence (average rating) on book sales and find a positive association between favorable reviews and sales. Chintagunta et al. (2010) also suggest that the valence plays a more important role in driving box office sales.

Differently, some researchers indicate that the volume of reviews has a stronger impact on product sales (Liu et al. 2016, Duan et al. 2008, Kostyra et al. 2016, Babić Rosario et al. 2016), while Clemons et al. (2006) address the impacts of the variance of reviews on sales and their findings indicate that the variance of rating is positively correlated with sales growth. Recently, Chong et al. (2017) investigate the impacts of online review variables and online promotional marketing variables on product sales in Amazon.com.

Another stream of market-level literature emphasizes the relationship between online reviews and firms' marketing strategies. For instance, Chen and Xie (2005, 2008) model consumer reviews as the information elements to help consumers to identify products that match their needs. Their findings suggest that firms should adjust their marketing strategies in response to reviews. Li et al. (2011) study the influence of online reviews on firm profitability for repeat purchase products and illustrate that the impact depend on the level of informativeness. Sun (2012) highlights the interaction of average rating and variance of product ratings and examines the impact of these two metrics on market outcomes. Recently, He and Chen (2018) provide a new model to study impacts of consumer reviews on the dynamic pricing of electronic products. However, these aforementioned papers are typically based on a framework that firms sell products to consumers directly.

In practice, abundant products are sold through distribution channels with manufacturers and retailers. The pricing problem and the interaction between the manufacturers and the retailers play a significant role in supply chain management (Ailawadi et al. 1995, Shi et al. 2013, Xiao et al. 2014a, Shi and Feng 2016, Chen et al. 2017c). Thus, understanding the effects of online reviews is not only important for retailers but also necessary for manufacturers. However, the literature investigating the implication of online reviews from channel perspectives is still limited. Shaffer and Zettelmeyer (2002) analyze a multiproduct distribution channel consisting of two competing manufactures and a retailer. They demon-

strate that the provision of the third-party information plays an important role in dividing channel profits and further point out that the similar information may have different impacts on firms' profitability. Kwark et al. (2014) extend the work of Shaffer and Zettelmeyer (2002) and address the impacts of online reviews in the context of a channel structure consisting two competing manufacturers and a common retailer. By viewing online consumer reviews as the information that can mitigate the uncertainty in consumers' valuation, they find that different dimensions of online consumer reviews affect the competition between manufacturers and the retailer differently. In the following, Dou and Chen (2015) capture a channel setting composing a manufacturer and a retailer and indicate that online consumer reviews can modify consumers' willingness to pay and thus affect the pricing decisions and profits of the manufacturer and the retailer. In this dissertation, we extend these theoretical studies and focus on understanding how online reviews affect the pricing decisions and profits of members by considering different supply chain contexts.

In specific, we first consider the impact of online reviews on consumers' perception of a single product sold in a dual channel context, and explore how online reviews affect the pricing decisions and profits of the manufacturer and the retailer. Then, we consider a supply chain with two competing manufacturers and a common retailer. By developing a game theoretical model to capture the impact of online reviews on consumers' valuation of differentiated products, we investigate the influence of online reviews on the competition of manufacturers in the upstream and on the pricing decision of the retailer. Lastly, we incorporate online reviews into the cooperation of a manufacturer-retailer supply chain and investigate whether promoting average rating of online reviews is beneficial for the manufacturer and the retailer.

In addition, it is worth noting that the products studied in this dissertation are those experience consumer products. It is widely accepted that consumers'

purchase behavior changes with the characteristic of product types. In particular, Nelson (1970, 1974) suggest that products can be classified to search products and experience products based on whether products are predominated by search attributes or experience attributes. Specifically, search products are those goods whose qualities can be easily determined prior to purchase, such as, furniture, hardware and sporting equipment. Bloom and Reve (1990) also claim that search products are high in search characteristics which can be readily assessed before making a purchase decision. By contrast, experience products are those products or services that are dominated by attributes that consumers can evaluate only after the use of the products. Examples of experience products include books, CDs, watches and food. Extensive studies further indicate that consumers tend to have a higher uncertainty about the quality of experience products (Jain and Posavac 2001, Franke et al. 2004, Otterbacher 2008, Girard and Dion 2010, Xiao and Benbasat 2011). Because of the higher evaluation uncertainty about the quality of experience products, consumers tend to rely on more extrinsic hints to evaluate the experience products' quality (Zeithaml 1988). This may be the reason why firms invest in the product quality provision (Klein and Leffler 1981, Chan and Leland 1982, Shapiro 1982, 1983, Wolinsky 1983, Farrell 1986, Judd and Riordan 1994). In this Internet age, online reviews, as one of most convincing online information, seem especially influential for experience products (Gogoi 2007, Park and Lee 2009, Rubera and Kirca 2012, Luan et al. 2016). That means, it is possible for firms to signal the product quality by online reviews. In this dissertation, we follow this research stream and theoretically study the impacts of online reviews on these experience products, from different channel perspectives.

In chapter 2, we focus on the impact of online reviews in a dual channel context. That is, a manufacturer sells a single experience product through both a retail channel and an Internet channel. To illustrate, many manufacturers, such as computer firms Apple, IBM and Dell, sports marketing giant Nike and cosmetic manufacturer Estee Lauder, are marketing their products through a dual chan-

nel. As one of the most important issues in dual-channel management, pricing decision in the two channels has drawn considerable attention (Dumrongsiri et al. 2008, Hsiao and Chen 2014, Pu et al. 2017, Chen et al. 2017a, Tsay and Agrawal 2004, Nie et al. 2019). However, little research has considered the impacts of user-generated information on consumers' purchasing behavior in a dual channel context. Therefore, in this chapter, we aim to fill this gap and answer the following questions: can the manufacturer always profit from online consumer reviews in a dual channel? Are the demand in the retail channel and the retailer's pricing decision and profit also influenced by this online information? These questions are especially important to both players in a dual channel. First, the manufacturer can make better use of these influential online user-generated comments to improve its profit. Second, it is also necessary for the retailer to advance the understanding of the impacts of online reviews on its pricing and profit. However, these aspects do not gain enough attention in the existing literature.

We show that online reviews affect the pricing decision and profit performance of channel members differently under different channel structures. In specific, online reviews may increase or decrease the direct price but always lower the retail price under the centralized channel, whereas all prices can be higher or lower under the decentralized channel. Besides, the presence of online reviews always damages the demand of retail channel under the centralized structure but has no impact on the demand of retail channel under the decentralized structure. Further, we demonstrate that under the two channel settings, it is not necessarily wise for the manufacturer to provide online reviews in the Internet channel unless the information revealed by online reviews is significantly favorable.

In chapter 3, we consider a supply chain with two competing manufacturers and a common retailer. The competing products are differentiated in two dimensions: vertical dimension and horizontal dimension. In the vertical dimension, we use "quality" to refer to a combination of attributes with "more-is-better"

property. For example, the processor and the pixel of smart phones are about "quality". We consider the products are vertically differentiated, and in this dimension, consumers always prefer high quality to low quality. Differently, in the horizontal dimension (e.g., color or size of smart phones), we claim that consumers are heterogeneous, which means different consumers have different preferences for a same attribute. This assumption is also widely accepted by scholars (Chen and Xie 2008, Li et al. 2011, Gu and Xie 2013, Kwark et al. 2014). In addition, we propose a two-period theoretic framework to derive the implication of online reviews. In specific, consumers in the first period make purchase decisions based on the product prices and their expectations about the product qualities. After the purchase, they leave the truthful online reviews. With these reviews, consumers in the second period can learn the true product qualities and their preference uncertainty would be reduced as well. We aim to investigate the influence of online reviews on the demand, equilibrium prices and profits of the players in the supply chain. Overall, we address the following questions. How do online reviews affect the pricing competition in the upstream? Do online reviews always favor the high-quality manufacturer or hurt the low-quality manufacturer? How should the retailer set the price differences of the two products in different periods? Is it wise for the retailer to provide more informative online reviews?

Our results first demonstrate that whether the retailer should increase or reduce the price difference of the two products in period 2 depends largely on the quality difference of the two products. Second, we find that online reviews affect the pricing decisions of the competing manufacturers in the upstream and it is possible for the manufacturers to be better off simultaneously. Third, the retailer can embrace the positive effect of online reviews only when consumers heavily underestimate the quality difference of the products. In addition, contrary to the conventional wisdom, we illustrate that online reviews with more accurate information may be detrimental to the retailer and consumers.

In chapter 4, we investigate promotions of online reviews in a supply chain with a manufacturer and a retailer. Not surprise, with the importance of online reviews, a growing number of firms pay attention to the issue of providing incentives to encourage customers to give positive online reviews about their products. To illustrate, numerous retailers in Taobao.com or Jingdong.com tend to offer rewards to consumers who give positive online reviews. We study this issue from a manufacturer-retailer channel. We assume that the retailer can take some strategies to promote online reviews and the manufacturer should share some costs. By deriving two channel structures: the centralized supply chain and the decentralized supply chain, we answer the following questions: Is the promotions of online reviews always beneficial for the whole supply chain? Under the decentralized supply chain, how does the manufacturer share the promotion cost with the retailer? Do promotions of online reviews always increase the profit of both the manufacturer and the retailer?

Comparing the results without and with promotions of online reviews, we discover that it is essential to analyze the change of variance, which may enhance or undermine the effect of review promotions. First, we find that promoting online reviews may impair the demand under both channel structures, and the demand under the centralized channel is more likely to be affected than that under the decentralized channel. Second, contrary to the common belief, we show that the promotions of online reviews may not always favor the retailer and the manufacturer or hurt consumers. Third, we reveal that the manufacturer has a greater threshold interval to benefit from promotions of online reviews than the retailer under the decentralized channel; for the retailer, paying more attention to the change of variance in the process of promotions of online reviews under the decentralized channel structure is especially necessary.

Chapter 2

Impacts of online reviews on a dual-channel supply chain

2.1 Introduction

The rapid development of the Internet and information technology has resulted in unprecedented growth in the electronic commerce industry. This change provides new opportunities for manufacturers to redesign their distribution channels. In practice, an increasing number of manufacturers in different industries have established an Internet channel to sell products to consumers directly while keeping the traditional channel. For example, Apple Inc., one of the leading firms in the information technology industry, sells products directly online and operates more than 400 retail stores in different countries. In the cosmetics industry, manufacturers such as Estee Lauder also operate both online and offline channels to distribute products. Comparatively speaking, the Internet channel may positively help the manufacturers to create new market segments and avoid the market domination by the retailer. However, the retail channel is also necessary to capture those consumers who are loyal to the offline channel or who may have some difficulties to purchase the product online (Chen et al. 2012). Although the introduction of the Internet channel would induce the channel conflict between the manufacturer and the retailer since they share the same consumer set, studies still show that the

dual channel can reduce the wholesale price in the retail channel and thus benefit both firms (Hua et al. 2010).

There is no doubt that when the manufacture adopt a dual channel, how to adjust their pricing decisions in the two channel is quite important and complex. Thus, in the literature on dual channels, pricing decisions have attracted considerable attention. To illustrate, Chiang et al. (2003) built a price-setting game between a manufacturer who operates a dual channel and its independent retailer to study the impacts of the existence of the direct Internet on the traditional retail channel. They show that the introduction of Internet channel can constrain the pricing of the retailer and thus reduce the degree of double marginalization. Cattani et al. (2006) also consider a dual channel structure with one manufacturer and one retailer; their findings suggest that the manufacturer's direct pricing strategy mainly depends on the convenience degree of the Internet channel. Kumar and Ruan (2006) address the pricing problems in a dual channel by assuming that consumers are either brand-oriented or store-oriented. Their results highlight the positive impact of the Internet channel on the manufacturer. Based on these studies, more researchers examine the pricing issues in the context of dual channels by considering inventory control (Chiang and Monahan 2005, Fruchter and Tapiero 2005, Batarfi et al. 2016, 2019), retail services (Dan et al. 2012, Li and Li 2016, Wang et al. 2017, Dumrongsiri et al. 2008), strategic motive(Hsiao and Chen 2014), coordination contract (Chen et al. 2012, Cao 2014, Xu et al. 2014), and other issues (Hua et al. 2010, Chen et al. 2017a, Zhou et al. 2019, Li et al. 2019). However, to the best of our knowledge, few of these studies addresses the impacts of user-generated information on consumers' purchasing behavior in dual channels. In fact, it is common for manufacturers who operate a dual channel, to expose online reviews on their Internet platforms. In other words, consumers today increasingly rely on online reviews to make purchase decision in the Internet channel but how online reviews affect pricing decisions and profits of players in a dual channel has not gained enough attention.

Therefore, in this chapter, we attempt to bridge this gap and explore the implications of online reviews in a dual channel context. In specific, we consider a single-product supply chain where one manufacturer distributes the product through a dual channel: a retail channel and an Internet channel. Such channel structure has been widely studied (Dumrongsiri et al. 2008, Xiao and Shi 2016, Liu et al. 2016). We follow this stream of research by incorporate the implications of online reviews. First, we focus on those consumer experience products, whose attributes cannot be fully observed before purchase, such as, books, CD and shoes. Therefore, for these products, the touch-and-feel is crucial for consumers (Jiang and Yang 2019, Luo and Sun 2016), and they cannot perfectly perceive the true product quality before purchase(Nelson 1974). Second, following Chambers et al. (2006) and Chen et al. (2017a), we use the term "quality" to represent a combination of attributes exhibiting the "more-is-better" property. That is, we assume that the product quality is one-dimensional. For example, consumers always prefer a notebook with a better functionality. Third, we assume that a higher level of uncertainty perception in product quality exists in the Internet channel than in the retail channel. This is because consumers can only make their purchase decisions based on the virtual product descriptions online. Therefore, we characterize consumers' willingness-to-pay in the Internet channel as λq, where λ means the acceptance of the Internet channel and q represents the value that consumers can derive in the retail channel. This assumption is consistent with the studies of Chiang et al. (2003) and Luo and Sun (2016). Moreover, Luo and Sun (2016) provide the empirical evidence that the consumers' willingness-to-pay for a product in the Internet channel is 70.46% of its equivalent in the retail channel for apparel, 85.33% for consumer electronics and 87.17% for books. A variety of studies also indicate that a single product with the uniform quality level distributed through different channels may incur different quality perceptions (Chen et al. 2017b, Dukes et al. 2014, Gao et al. 2015). It is worthwhile to note that online consumer reviews can mitigate such uncertainty, especially for those experience

products (Li and Hitt 2008, Jiang and Yang 2019).

In addition, other than answering the question whether a manufacturer should add the Internet channel to its existing physical channel, we explore the scenario where the manufacturer has already managed a dual channel. By incorporating online reviews into consumer utilities and develop game theoretic models, we aim to investigate the effects of online reviews on the pricing decisions and profits of the manufacturer and the retailer. Besides, we consider two typical channel structures: the centralized channel structure (i.e., the manufacturer and the retailer act as a system to maximize the total profit of the supply chain) and the decentralized structure (i.e., the manufacturer and the retailer make their own decision to maximize profits), and explain whether the impacts of online reviews are different in different channel structures.

First, we show that online reviews play different roles in affecting the pricing decisions of the manufacturer and the retailer under different channel settings. Specifically, under the centralized supply chain structure, we demonstrate that whether the manufacturer can increase the direct price depends on the relationship between the positive degree of informativeness of online reviews and consumers' acceptance of the Internet channel, but the retailer has to lower the retail price with online reviews. By contrast, under the decentralized supply chain structure, all prices can be higher or lower, depending not only on consumers' acceptance of the Internet channel but also on the weight on online reviews. Second, the demand in the retail channel is always hurt by online reviews under the centralized channel but is not affected under the decentralized channel. Differently, positive online reviews always increase the demand in the Internet channel under the centralized channel but do not always expand the demand under the decentralized channel. Third, we demonstrate that, under the decentralized channel, the manufacturer has the chance to benefit from online reviews but the retailer is always harmed. In addition, under the two channel settings, the manufacturer gains more profit

only when the information revealed by online reviews is sufficiently favorable.

The rest of this chapter is organized as follows. In section 2.2, we lay out the model. Section 2.4 and section 2.4 discuss the main results of the effect of OCRs on a dual channel supply chain. Section 2.5 gives some numerical examples and conclusions are presented in section 2.6.

2.2 Model

Consider a dual channel supply chain with a manufacturer and a retailer. The manufacturer distributes a single product through both a retail channel and an Internet channel. It is reasonable to assume that consumers tend to search the product online before they go to the retail channel when the product is available in both channels. As mentioned above, considering the virtual descriptions of the product in the Internet channel, we further assume that consumers have a lower acceptance of the Internet channel than the retail channel. Mathematically, consumers can only achieve the quality of λq $(0 < \lambda < 1)$ in the Internet channel, where q is the valuation that consumers can derive in the retail channel and λ represents the acceptance of the Internet channel. Kacen et al. (2013) and Luo and Sun (2016) both give empirical studies to show that for many products, such as books, shoes, jewelries, apparels and consumer electronics, consumers have a lower "willingness to pay" in the Internet channel than in the retail channel. Therefore, the model in this chapter is developed for those experience products. For one consumer, the net utility in the retail channel and in the Internet channel can be characterized as $U_r^0 = q - p_r$ and $U_m^0 = \lambda q - p_m$, where p_r and p_m denote the sell price in the retail channel (the retail price) and the sell price in the Internet channel (the direct price). The consumer would be indifferent between the two channels if and only if $q - p_r = \lambda q - p_m$. In other words, the consumers whose valuations satisfy $q - p_r \geq \lambda q - p_m$ and $q - p_r \geq 0$ would buy the product from the retail channel while the consumers whose valuations satisfy $q - p_r < \lambda q - p_m$

and $\lambda q - p_m \geq 0$ would prefer the Internet channel. We employ D_r^0 and D_m^0 to represent the demand in the retail channel and in the Internet channel without the effect of online reviews. Thus, the two channels' demand functions can be characterized as

$$D_r^0 = 1 - \frac{p_r - p_m}{1 - \lambda}, \tag{2.1}$$

$$D_m^0 = \frac{\lambda p_r - p_m}{\lambda(1 - \lambda)}. \tag{2.2}$$

The above equations are consistent with the demand functions of Chiang et al. (2003) and such linear demand model also have been widely used and proved in previous studies(Dumrongsiri et al. 2008, Chen et al. 2017a). Differently, to easily derive the impacts of online consumer reviews and for brevity, we only derive the case where the demand in both channels is nonnegative. That is, we have the following inequality constraint: $p_m \leq \lambda p_r$.

As mentioned above, we assume that consumers are imperfectly informed before purchase, especially in the Internet channel. The manufacturer has the opportunity to provide online reviews to reduce the product uncertainty. In order to examine the effect of online reviews on the pricing decisions and profits of the channel players, we treat the state without online reviews as the benchmark and only investigate the steady state when online reviews have already accumulated. It is worth noting that we assume that all consumers can access to the same realization of a signal from online reviews and they incorporate this information into their valuations. In other words, our baseline model does not consider those traditional consumers who are loyal to the retail channel or those consumers who may do showrooming before purchase products through the Internet channel (Jing 2018). This point helps us to focus on the impacts of online reviews on the performance of channel members. Mathematically, we denote q_0 $(-1 \leq q_0 \leq 1)$ as the common belief reflected by online reviews. Specifically, if the consumer perceives a positive review signal, there exists $q_0 > 0$, and vice versa. In addition, online reviews

provide more information about the product properties that can only be reached after consumption; thus, online reviews affect not only the evaluation in the Internet channel, but also affect the valuation in the retail channel. Refer to the method of minimum variance estimation used by Kwark et al. (2014), consumer's expected posterior beliefs regarding the perceived quality in the Internet channel and in the retail channel become $(1-r)\lambda q + rq_0$ and $(1-r)q + rq_0$, respectively, where $r(0 < r < 1)$ refers to the weight of online reviews on the evaluation of the product. A larger r means that the precision of the product review information is higher, and thus consumers are more willing to adjust their quality assessment based on online reviews. The consumer utility with online reviews then can be characterized as $U_r^R = (1-r)q + rq_0 - p_r$ and $U_m^R = (1-r)\lambda q + rq_0 - p_m$. Accordingly, the consumer with perceived quality $\widetilde{q}^R = \frac{p_r - p_m}{(1-\lambda)(1-r)}$ is indifferent between the two channels. Consumers whose valuations satisfy $U_r^R \geq 0$ and $q \geq \widetilde{q}^R$ would buy the product from the retail channel while consumers with valuations satisfy $U_m^R \geq 0$ and $q < \widetilde{q}^R$ would buy the product from the Internet channel. Thus, the demand in the retail channel (D_r^R) and the demand in the Internet channel (D_m^R) with online reviews can be obtained as follows.

$$D_r^R = 1 - \frac{p_r - p_m}{(1-\lambda)(1-r)}, \tag{2.3}$$

$$D_m^R = \frac{\lambda p_r - p_m + (1-\lambda) r q_0}{\lambda(1-\lambda)(1-r)}. \tag{2.4}$$

Also, to ensure the nonnegative demand in both channels, we assume that $\frac{p_m - (1-\lambda) r q_0}{\lambda} \leq p_r \leq p_m + (1-\lambda)(1-r)$.

Next, we employ the two channel structures: the centralized structure and the decentralized structure. Under the centralized case, the manufacturer and the retailer act as a system to maximize the total profit of the supply chain, and under the decentralized case, the manufacturer and the retailer make their own decisions

to maximize their profits. With the benchmark case of without online reviews, we focus on the impacts of online reviews on the pricing decisions and profits of the manufacturer and the retailer under these two channel structures. To ensure the profit expressions behave well and the validity of the solutions, we assume that parameters used in this chapter satisfy the following constraints: (i) $\frac{c_m}{c_r} \leq \lambda \leq \frac{1-c_r}{1-c_m}$; (ii) $c_m \leq r \leq \min\{1-\frac{c_r-c_m}{1-\lambda}, 1-\frac{2c_r}{\lambda}\}$; (iii) $q_0 \geq \max\{-\frac{c_r\lambda-c_m}{r-r\lambda}, -\frac{\lambda-r\lambda-2c_r}{2r}\}$.

Note that c_r and c_m are marginal costs incurred by the manufacturer in the retail channel and in the Internet channel. Following Chiang et al. (2003), we assume that $0 < c_m < c_r < 1$. In addition, to avoid the triviality and to ensure the validity of the conditions, we assume that c_m and c_r are small enough and $2c_r^2 < c_m(1-c_m)$ holds. The conditions above indicate some limitations of our models. First, condition (i) means that consumers' acceptance of the Internet channel should not be too low or too high; this assumption announces that our model is more appropriate for those consumer experience products which need to be inspected physically before purchase. As mentioned above, the survey of Luo and Sun (2016) reveals that for a variety of products (such as apparel, consumer electronics, jewelry, and books), consumers' willingness-to-pay ranges from 70.46% to 87.17%. Condition (ii) indicates that online reviews may affect consumers' assessment of the product quality but cannot dominate their decision-making process. Condition (iii) is presented to ensure the nonnegativity of the profits of the manufacturer and the retailer under the two channel structures. In other words, online reviews cannot be too negative, otherwise the players would suffer a lot and thus there is no necessity to discuss the impacts of online reviews.

2.3 The centralized supply chain structure

In this section, we consider the centralized case, i.e., both players act as a system to maximize the total profit of the supply chain. Specifically, we can formulate

the channel profit (π_v) as

$$\pi_v = (p_r - c_r)D_r + (p_m - c_m)D_m, \tag{2.5}$$

in which $(D_r, D_m) \in \{(D_r^0, D_m^0), (D_r^R, D_m^R)\}$ with $D_r = D_r^0$ and $D_m = D_m^0$ for the scenario without online reviews and $D_r = D_r^R$ and $D_m = D_m^R$ for the scenario with online reviews; p_r and p_m denote retail price and direct price. To better understand the effects of online reviews on the behaviors of the manufacturer and the retailer, we treat the scenario without online reviews as the benchmark. We first give the optimal solutions of the centralized structure without and with online reviews in Table 2.1.

Table 2.1: Optimal solutions under the centralized supply chain

	Without online reviews	With online reviews
p_m	$\frac{\lambda+c_m}{2}$	$\frac{rq_0+\lambda-r\lambda+c_m}{2}$
p_r	$\frac{1+c_r}{2}$	$\frac{rq_0+1-r+c_r}{2}$
D_m	$\frac{\lambda c_r-c_m}{2\lambda(1-\lambda)}$	$\frac{(1-\lambda)rq_0+c_r\lambda-c_m}{2\lambda(1-\lambda)(1-r)}$
D_r	$\frac{1}{2}-\frac{c_r-c_m}{2(1-\lambda)}$	$\frac{1}{2}-\frac{c_r-c_m}{2(1-\lambda)(1-r)}$
π_v	$\frac{(1-c_r)^2}{4}+\frac{(c_r-c_m)^2}{4(1-\lambda)}+\frac{c_m^2-\lambda c_r^2}{4\lambda}$	$\frac{r^2}{4(1-r)\lambda}q_0^2+\frac{r(\lambda-r\lambda-c_m)}{2(1-r)\lambda}q_0+\frac{1-r-2c_r}{4}+\frac{c_r^2\lambda+c_m^2-2c_mc_r\lambda}{4\lambda(1-\lambda)(1-r)}$

Proof. Table 2.1 reports the optimal results of the benchmark (without online reviews) in the centralized structure; the results are the same as the specific results in the study of Chiang et al. (2003) (i.e., third column in Table 3). Therefore, we only give the proof of the situation with online reviews.

Substituting Equations (2.3) and (2.4) into Equation (2.5) and then differentiating profit function with respect p_r and p_m, we obtain

$$\frac{\partial^2\pi}{\partial p_r^2} = -\frac{2}{(1-\lambda)(1-r)} < 0, \quad \frac{\partial^2\pi}{\partial p_m^2} = -\frac{2}{\lambda(1-\lambda)(1-r)} < 0,$$
$$\begin{vmatrix} \frac{\partial^2\pi}{\partial p_r^2} & \frac{\partial^2\pi}{\partial p_r p_m} \\ \frac{\partial^2\pi}{\partial p_m p_r} & \frac{\partial^2\pi}{\partial p_m^2} \end{vmatrix} = \frac{4}{\lambda(1-\lambda)(1-r)^2} > 0.$$

It can be shown that the Hessian matrix is negative definite, then the profit function π_v is jointly concave in (p_r, p_m). By solving the first-order conditions of Equations (2.5) for p_r and p_m, we have the following results:

$$p_m^{R*} = \frac{rq_0 + \lambda - r\lambda + c_m}{2},\ p_r^{R*} = \frac{rq_0 + 1 - r + c_r}{2} \tag{2.6}$$

Substituting (2.6) in Equations (2.3), (2.4), and (2.5), we get the results in Table 2.1. □

Proposition 2.1. *Under a centralized supply chain with online reviews:*

(1) The direct price in the Internet channel is higher (i.e., $p_m^R \geq p_m^0$) if and only if $q_0 \geq \lambda$, whereas the retail price is always lower (i.e., $p_r^R < p_r^0$).

(2) The demand in the Internet channel is higher (i.e., $D_m^R \geq D_m^0$) if and only if $q_0 \geq -\frac{c_r\lambda - c_m}{1-\lambda}$, whereas the demand in the retail channel is always lower (i.e., $D_r^R < D_r^0$).

(3) The profit of the whole channel is higher if and only if $q_0 \geq q_1$, where

$$q_1 = \frac{\lambda r + c_m - \lambda}{r} + \sqrt{\frac{\lambda(1-\lambda)(1-r)}{r} + \frac{(\lambda - c_m)^2(1-r)}{r^2} - \frac{\lambda(c_r - c_m)^2}{r(1-\lambda)}},$$

and q_1 decreases with r.

Proof. From Table 2.1, we get optimal results of prices, demands and profits without and with online reviews. First, subtracting p_m^0 from p_m^R and p_r^0 from p_r^R, we obtain

$$p_m^R - p_m^0 = \frac{rq_0 + \lambda - r\lambda + c_m}{2} - \frac{\lambda + c_m}{2} = \frac{r(q_0 - \lambda)}{2},$$
$$p_r^R - p_r^0 = \frac{rq_0 + 1 - r + c_r}{2} - \frac{1 + c_r}{2} = \frac{r(q_0 - 1)}{2}.$$

Thus, we have $p_m^R > p_m^0$ if and only if $q_0 > \lambda$, while the retail price with online reviews is always lower than the price without online reviews. Similarly,

$$D_m^R - D_m^0 = \frac{(1-\lambda)rq_0 + c_r\lambda - c_m}{2\lambda(1-\lambda)(1-r)} - \frac{\lambda c_r - c_m}{2\lambda(1-\lambda)} = \frac{r((1-\lambda)q_0 + c_r\lambda - c_m)}{2\lambda(1-\lambda)(1-r)},$$
$$D_r^R - D_r^0 = \frac{1}{2} - \frac{c_r - c_m}{2(1-\lambda)(1-r)} - \frac{1}{2} + \frac{c_r - c_m}{2(1-\lambda)} = \frac{r(c_m - c_r)}{(1-r)(1-\lambda)}.$$

Thus, we have $D_m^R > D_m^0$ if and only if $q_0 > -\frac{\lambda c_r - c_m}{1-\lambda}$, while the demand with online reviews is always lower than without online reviews. Similarly, for profits in the two channels, we have

$$\pi_v^R - \pi_v^0 = \frac{r^2}{4(1-r)\lambda} q_0^2 + \frac{r(\lambda - r\lambda - c_m)}{2(1-r)\lambda} q_0 + \frac{r(^2_r + c_m^2 - 2\lambda c_r c_m)}{4\lambda(1-\lambda)(1-r)} - \frac{r}{4}.$$

When $q_0 \geq -\frac{\lambda c_r - c_m}{r(1-\lambda)}$, we have a unique threshold value q_1; if $q_0 \geq q_1$, then $\pi_v^R \geq \pi_v^0$; otherwise, $\pi_v^R < \pi_v^0$, where $q_1 = \frac{\lambda r + c_m - \lambda}{r} + \sqrt{\frac{\lambda(1-\lambda)(1-r)}{r} + \frac{(\lambda - c_m)^2(1-r)}{r^2} - \frac{\lambda(c_r - c_m)^2}{r(1-\lambda)}}$.

We then examine the impacts of r on q. Let $q_1 = f_1(r) + \sqrt{f_2(r)}$, where $f_1(r) = \frac{\lambda r + c_m - \lambda}{r}$, $f_2(r) = \frac{\lambda(1-\lambda)(1-r)}{r} + \frac{(\lambda - c_m)^2(1-r)}{r^2} - \frac{\lambda(c_r - c_m)^2}{r(1-\lambda)}$. Then, we have $\frac{\partial f_1(r)}{\partial r} = \frac{\lambda - c_m}{r^2}$, $\frac{\partial \sqrt{f_2(r)}}{\partial r} = -\frac{1}{2r}\left(\frac{\lambda(1-\lambda) + \frac{(\lambda - c_m)^2}{r^2} + f_2(r)}{\sqrt{f_2(r)}}\right) = -\frac{1}{2r}\left(\frac{\lambda(1-\lambda) + \frac{(\lambda - c_m)^2}{r^2}}{\sqrt{f_2(r)}} + \sqrt{f_2(r)}\right) \leq -\frac{1}{2r}\left(2\sqrt{\lambda(1-\lambda) + \frac{(\lambda - c_m)^2}{r^2}}\right) \leq -\frac{\lambda - c_m}{r^2}$. Therefore, we have $\frac{\partial q_1}{\partial r} < 0$, which means q_1 decreases with r. □

Proposition 2.1 indicates that under the centralized channel structure, online reviews may not increase the direct price but always lower the retail price. The intuition is that online reviews have two impacts on consumers' valuation of the product. The first aspect is to homogenize consumers' perceived quality difference between the two channels, from $(1-\lambda)q$ to $(1-r)(1-\lambda)q$. Such effect makes consumers more price sensitive, which reduces the price difference in the two channels. The second aspect is to reduce the uncertainty of consumers' quality perception. Specifically, if the degree of the informativeness of online reviews is negative and less than some degree (i.e., $q < -\frac{c_r\lambda - c_m}{1-\lambda}$), online reviews may reduce consumers' utilities in both channels, driving the manufacturer and the retailer to cut the prices. In this case, the total market share is also reduced because of the negative information of online reviews. Proposition 2.1 then demonstrates that the demand in the Internet channel is likely to increase even with the negative online reviews (i.e., $q_0 > -\frac{c_r\lambda - c_m}{1-\lambda}$). However, negative online reviews always hurt the whole supply chain. Only when the positive degree of online reviews increases to some extent can the whole supply chain benefit from online reviews. For detail,

if $q_1 \leq q_0 < \lambda$, although the optimal prices in both channels are still lower with online reviews, the increment in the demand of the Internet channel can offset the loss in the retail channel, which makes the whole channel profitable. Further, if online reviews are quite favorable ($q_0 > \lambda$), it is quite safe for the manufacturer to set a higher direct price because of the obvious positive effect of online reviews.

Moreover, we find that under the centralized channel structure, online reviews always hurt the demand in the retail channel. The intuition is as follows. As analyzed before, in presence of online reviews, the demand in the retail channel changes from $(1 - \frac{p_r^0 - p_m^0}{1-\lambda})$ to $(1 - \frac{p_r^R - p_m^R}{(1-\lambda)(1-r)})$. In other words, the weight of online reviews on consumers' valuation and the reduced price difference work jointly to affect the demand in the retail channel. Besides, it is easy to verify that $(p_r^{R*} - p_m^{R*})/(1-r)$ is always larger than $(p_r^{0*} - p_m^{0*})$, which results in the reduced demand in the retail channel.

In addition, we examine the effects of parameter r on the profit threshold q_1 and find that the threshold value q_1 decreases with r (The proof is given in the Appendix). Figure 2.1 illustrates the relationship clearly. This means that the whole supply chain is easier to benefit from online reviews if consumers put a higher weight on online reviews. In this case, online reviews play a more significant role in affecting their valuation toward the product. Thus, even though the degree of positive online reviews is not very obvious, a higher weight on online reviews can offset the lower positive informativeness of online reviews, which benefits the whole supply chain.

2.4 The decentralized supply chain structure

In this section, we consider the decentralized structure where the manufacturer and the retailer make their own decisions to maximize their profits. With the demand functions in section 3, we can formulate the retailer's profit (π_r) and the

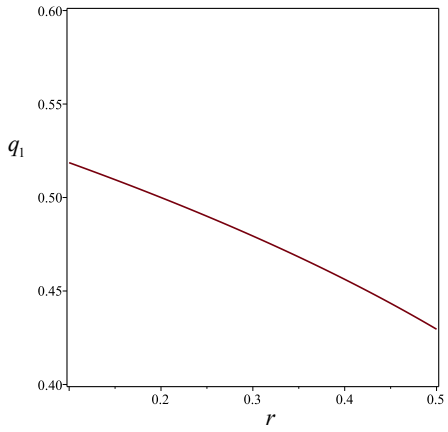


Figure 2.1: Impacts of r on q_1 ($c_m = 0.1, c_r = 0.2, \lambda = 0.8$)

manufacturer's profit (π_m) as follows.

$$\pi_r = (p_r - w)D_r, \tag{2.7}$$

$$\pi_m = (w - c_r)D_r + (p_m - c_m)D_m, \tag{2.8}$$

We analyze the Stackelberg competition model with backward induction and the sequence is as follows. In the first stage, the manufacturer decides the wholesale price (w) in the retail channel and the direct price (p_m) in the Internet channel. In the second stage, the independent retailer is presented as the follower to determine the retail price (p_r) to maximize its own profit, conditional on the wholesale price (w) and the direct price (p_m). Noted that the wholesale price should not be higher than the price in the Internet channel (i.e.,$w \leq p_m$); otherwise, the retailer may buy the product from the Internet channel. We give the equilibrium outcomes in the decentralized supply chain in Table 2.2.

Proof. Table 2.2 first gives the equilibrium results of the benchmark (without online reviews), which are the same as the specific scenario in the study of Chiang et al. (2003) (equilibrium results in Region 1). Thus, we only give the proof of the outcomes with online reviews.

By the backward induction, we first solve the retailer's optimization problem.

Table 2.2: Equilibrium outcomes under the decentralized supply chain

	Without online reviews	With online reviews	
		$q_0 < \frac{c_m}{r}$	$\frac{c_m}{r} < q_0 < 1$
w	$\frac{\lambda}{2}$	$\frac{2rq_0+(1-r)\lambda}{2}$	$\frac{rq_0+\lambda-r\lambda+c_m}{2}$
p_m	$\frac{\lambda}{2}$	$\frac{2rq_0+(1-r)\lambda}{2}$	$\frac{rq_0+\lambda-r\lambda+c_m}{2}$
p_r	$\frac{1}{2}$	$\frac{2rq_0+(1-r)}{2}$	$\frac{rq_0+1-r+c_m}{2}$
D_m	0	0	$\frac{rq_0-c_m}{2(1-r)\lambda}$
D_r	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
π_m	$\frac{\lambda-2c_r}{4}$	$\frac{rq_0}{2}+\frac{\lambda(1-r)-2c_r}{4}$	$\frac{r^2{q_0}^2}{4(1-r)\lambda}+\frac{(\lambda-r\lambda-c_m)rq_0}{2\lambda(1-r)}+\frac{(1-r)\lambda-2c_r}{4}+\frac{c_m^2}{4(1-r)\lambda}$
π_r	$\frac{1-\lambda}{4}$	$\frac{(1-\lambda)(1-r)}{4}$	$\frac{(1-\lambda)(1-r)}{4}$

Substituting Equation (2.3) into Equation (2.7), the profit of the retailer is maximized as follows:

$$\max_{p_r} \ \pi_r = (p_r - w)(1 - \frac{p_r - p_m}{(1-\lambda)(1-r)}), \tag{2.9}$$

By solving the first condition of Equation (2.9) for p_r, we obtain the response function for the retailer:

$$p_r^* = \frac{p_m + w + (1-r)(1-\lambda)}{2} \tag{2.10}$$

Substituting Equation (2.10) in (2.3), (2.4) and then substituting the two demand functions in the profit function of the manufacturer (Equation (2.8)), we rewrite the manufacturer's decision problem as follows:

[P1]

$$\begin{aligned}\max_{p_m,w} \ \pi_m = (w-c_r)&\left(\frac{1}{2}+\frac{p_m-w}{2(1-r)(1-\lambda)}\right)\\ &+(p_m-c_m)\left(\frac{(\lambda-2)p_m+\lambda w}{2\lambda(1-\lambda)(1-r)}+\frac{\lambda-r\lambda+2rq_0}{2(1-r)\lambda}\right)\end{aligned} \tag{2.11}$$

subject to

$$w \leq p_m, \tag{2.12}$$

$$\frac{p_m-(1-\lambda)rq_0}{\lambda} \leq \frac{p_m+w+(1-r)(1-\lambda)}{2}. \tag{2.13}$$

It should be noted that condition (Equation (2.13)) is to ensure that the demand in the Internet channel is nonnegative. We then solve [P1] by Lagrangian dual approach. The Lagrangian dual problem is to minimize $L_1(p_m, w, \theta_1, \theta_2)$ over $\theta_1 \leq 0$ and $\theta_2 \leq 0$, where

$$L_1(p_m, w, \theta) = sup\{\pi_m + \theta_1(w - p_m) + \theta_2(\frac{p_m-(1-\lambda)rq_0}{\lambda} - \frac{p_m+w+(1-r)(1-\lambda)}{2})\}. \tag{2.14}$$

Calculating the first-order partial derivatives of $L_1(p_m, w, \theta_1, \theta_2)$ with respect to p_m and w, and solving the corresponding equations to zero, we have the following results:

$$\begin{aligned} p_m &= \frac{(1-r)(1-\lambda)\theta_2+rq_0+c_m+\lambda-r\lambda}{2}, \\ w &= (1-\lambda)(1-r)\theta_1+\frac{rq_0+c_r+1-r}{2}. \end{aligned} \tag{2.15}$$

Substituting them into $L_1(p_m, w, \theta_1, \theta_2)$ and solving the first-order condition with respect to θ_1 and θ_2, it follows that

$$\begin{aligned} \theta_1 &= -\frac{(1-\lambda)(1-r)+c_r-rq_0}{2(1-\lambda)(1-r)}, \\ \theta_2 &= -\frac{c_m-rq_0}{2(1-\lambda)(1-r)}, \end{aligned} \tag{2.16}$$

To ensure θ_1 and θ_2 are negative, we have $q_0 < \frac{c_m}{r}$. Then, substituting Equation (2.16) into Equation (2.15) we get the only solution as follows.

$$p_m^R = w^R = \frac{2rq_0+\lambda-r\lambda}{2}.$$

Thus, other results in the case of $q_0 < \frac{c_m}{r}$ can be easily calculated.

To guarantee the non-triviality of the solutions, we only consider the cases when the profits of the manufacturer and the retailer are nonnegative. Therefore, under this case, by solving $\pi_m^R = \frac{rq_0}{2} + \frac{\lambda(1-r)-2c_r}{4} \geq 0$, we have $q_0 \geq -\frac{\lambda-r\lambda+2c_r}{2r}$. Next, we consider the situation of $\frac{c_m}{r} \leq q_0 \leq 1$. In this situation, condition (2.13) is automatically satisfied. We rewrite the Lagrangian dual problem $L_2(p_m, w, \theta_3)$

over $\theta_3 \leq 0$, where

$$L_2(p_m, w, \theta) = sup\{\pi_m + \theta_3(w - p_m)\}. \tag{2.17}$$

Similarly, calculating the first-order partial derivatives of $L_2(p_m, w, \theta_3)$ with respect to p_m and w, and solving the corresponding equations to zero, we have the following results:

$$p_m = \frac{rq_0 + c_m + \lambda - r\lambda}{2},\ w = (1-\lambda)(1-r)\theta_3 + \frac{rq_0 + c_r + 1 - r}{2}. \tag{2.18}$$

Substituting Equation (2.18) into $L_2(p_m, w, \theta_3)$ and solving the first-order condition with respect to θ_3, it follows that

$$\theta_3 = -\frac{(1-\lambda)(1-r) + c_r - c_m}{2(1-\lambda)(1-r)}. \tag{2.19}$$

It can be easily verified that $\theta_3 < 0$. Consequently, the problem has the following solutions:

$$p_m^R = w^R = \frac{rq_0 + \lambda - r\lambda + c_m}{2}.$$

Thus, other results in the case of $\frac{c_m}{r} \leq q_0 \leq 1$ can be easily calculated. □

The equilibrium outcomes of Table 2.2 indicate that the manufacturer's optimal pricing decision without online reviews is $p_m^* = w^* = \frac{\lambda}{2}$. In the presence of online reviews, we find that the equilibrium wholesale price and the direct price are also equal. Moreover, it is easy to derive the retailer's best response of the retail price without online reviews is $p_r^* = (p_m + w + 1 - \lambda)/2$ while the best response of the retail price with online reviews is $p_r^{R*} = (p_m + w + (1-\lambda)(1-r))/2$. That is to say, the retailer would raise the retail price by an equivalent amount if the manufacturer increases the direct price p_m and wholesale price w by the same amount. We then examine the effect of online reviews on the pricing and the performances of the manufacturer and the retailer and obtain the following propositions.

Proposition 2.2. *Under a decentralized supply chain with online reviews, the direct price and the wholesale price are higher (i.e., $p_m^R \geq p_m$ and $w^R \geq w$) if and only if $q_0 \geq q_2$; the retail price is higher (i.e., $p_r^R \geq p_r$) if and only if $q_0 \geq q_3$, where*

$$q_2 = \begin{cases} \frac{\lambda}{2}, & r < \frac{2c_m}{\lambda} \\ \lambda - \frac{c_m}{r}, & otherwise \end{cases}, \quad q_3 = \begin{cases} \frac{1}{2}, & r < 2c_m \\ 1 - \frac{c_m}{r}, & otherwise \end{cases}.$$

When $r < \frac{2c_m}{\lambda}$, q_2 is independent on r; otherwise, q_2 increases with r; when $r < 2c_m$, q_3 is independent on r; otherwise, q_3 increases with r. In addition, q_3 is always larger than q_2.

Proof. Using the results in Table 2.2, we have

$$p_m^0 = \frac{\lambda}{2}, \quad p_m^R = \begin{cases} \frac{2rq_0+(1-r)\lambda}{2}, & q_0 < \frac{c_m}{r} \\ \frac{rq_0+\lambda-r\lambda+c_m}{2}, & otherwise \end{cases}$$

It is easy to verify that when $q_0 = \frac{c_m}{r}$, $p_m^R = \frac{2c_m+\lambda-r\lambda}{2}$ holds. Then we have the following cases:

(1) If $\frac{\lambda}{2} < \frac{2c_m+\lambda-r\lambda}{2}$, we have $\Delta p_m = \frac{2rq_0+(1-r)\lambda}{2} - \frac{\lambda}{2} = \frac{r(2q_0-\lambda)}{2}$. Therefore, in this case, when $q_0 \geq \frac{\lambda}{2}$, $p_m^R \geq p_m^0$.

(2) If $\frac{\lambda}{2} \geq \frac{2c_m+\lambda-r\lambda}{2}$, we have $\Delta p_m = \frac{rq_0+(1-r)\lambda+c_m}{2} - \frac{\lambda}{2} = \frac{rq_0+c_m-r\lambda}{2}$. Therefore, in this case, when $q_0 \geq \lambda - \frac{c_m}{r}$, $p_m^R \geq p_m$. With the same method, we can derive the relationship between p_r^R and p_r, thus, Proposition 2.2 holds. □

Proposition 2.2 shows that, in the presence of online reviews, both the direct price and the retail price can be higher or lower. It is easy to verify that q_2 always increases with λ, that is, the lower the consumers' acceptance of the Internet channel, the higher the probability that the manufacturer can set a higher direct price. By contrast, q_3 is independent on λ, which means the impacts of online reviews on the pricing strategy of the retailer have no relationship with consumers' acceptance of the Internet. Moreover, when r excesses some degree, both q_2 and q_3 are increasing in r. This is because that the weight of online reviews plays a

dominant role in reducing the quality difference in the two channels and a higher r makes consumers more price sensitive. In this case, only when the information provided by online reviews is sufficiently positive, can the manufacturer and the retailer raise the direct price and the retail price. Further, we derive the impacts of online reviews on the profits of both players and give more explanations.

Proposition 2.3. *Under a decentralized supply chain, the profit of the manufacturer is higher with online reviews (i.e., $\pi_m^R \geq \pi_m$) if and only if $q_0 \geq q_4$, while the profit of the retailer is always lower with online reviews, where*

$$q_4 = \begin{cases} \frac{\lambda}{2}, & r < \frac{2c_m}{\lambda} \\ \frac{r\lambda - \lambda + c_m + \sqrt{\lambda(1-r)(\lambda - 2c_m)}}{r}, & otherwise \end{cases}.$$

When $r < \frac{2c_m}{\lambda}$, q_4 is independent on r; otherwise, q_4 decreases with r.

Proof. Using the results in Table 2.2, we have

$$\begin{aligned} \pi_m^0 &= \frac{\lambda - 2c_r}{4}, \quad \pi_r^0 = \frac{1-\lambda}{4}, \\ \pi_m^R &= \begin{cases} \frac{rq_0}{2} + \frac{\lambda(1-r) - 2c_r}{4}, & q_0 < \frac{c_m}{r}, \\ \frac{r^2 {q_0}^2}{4(1-r)\lambda} + \frac{(\lambda - r\lambda - c_m) r q_0}{2\lambda(1-r)} + \frac{(1-r)\lambda - 2c_r}{4} + \frac{c_m^2}{4(1-r)\lambda}, & otherwise \end{cases}, \\ \pi_r^R &= \frac{(1-\lambda)(1-r)}{4}. \end{aligned}$$

Similar to the proof of Proposition 2.2, it is easy to verify that when $q_0 = \frac{c_m}{r}$, we have $\pi_m^R = \frac{\lambda - r\lambda + 2c_m - 2c_r}{4}$. Then we have the following cases:

(1) If $\frac{\lambda - 2c_r}{4} < \frac{\lambda - r\lambda + 2c_m - 2c_r}{4}$, we have $\Delta\pi_{m1} = \frac{rq_0}{2} + \frac{\lambda(1-r) - 2c_r}{4} - \frac{\lambda - 2c_r}{4}$. Therefore, in this case, when $q_0 \geq \frac{\lambda}{2}$, $\pi_m^R \geq \pi_m^0$.

(2) If $\frac{\lambda - 2c_r}{4} \geq \frac{\lambda - r\lambda + 2c_m - 2c_r}{4}$, we have $\Delta\pi_{m2} = \frac{r^2 {q_0}^2}{4(1-r)\lambda} + \frac{(\lambda - r\lambda - c_m) r q_0}{2\lambda(1-r)} + \frac{(1-r)\lambda - 2c_r}{4} + \frac{c_m^2}{4(1-r)\lambda} - \frac{\lambda - 2c_r}{4}$, from which we obtain $\frac{\partial \Delta\pi_{m2}}{\partial q_0} = \frac{r(rq_0 + \lambda - r\lambda - c_m)}{2(1-r)\lambda}$. It is easy to verify that when $q_0 \geq \frac{c_m}{r}$, $\frac{\partial \Delta\pi_{m2}}{\partial q_0} > 0$. That is, $\Delta\pi_{m2}$ increases in q_0. By solving $\Delta\pi_{m2} \geq 0$, we have $q_0 \geq \frac{r\lambda - \lambda + c_m + \sqrt{\lambda(1-r)(\lambda - 2c_m)}}{r}$. For retail price, we have $\Delta\pi_r = \frac{(1-\lambda)(1-r)}{4} - \frac{1-\lambda}{4} < 0$. Then, Proposition 2.3 holds.

We next examine the impacts of r on q_2, q_3 and q_4.

It is easy to verify that if $r < \frac{2c_m}{\lambda}$, q_2 is independent on r. If $r > \frac{2c_m}{\lambda}$, we have $\frac{\partial q_2}{\partial r} = \frac{c_m}{r^2} > 0$, which means q_2 increases with r. Similarly, it is easy to verify that q_3 is independent on r if $r < 2c_m$ and q_3 is increasing with r in other cases.

Similarly, it is noted that when $r < \frac{2c_m}{\lambda}$, q_4 is independent on r. Thus, we concentrate on the case when $r \geq \frac{2c_m}{\lambda}$. That is, $q_4 = \frac{r\lambda-\lambda+c_m+\sqrt{\lambda(1-r)(\lambda-2c_m)}}{r}$. Then we have $\frac{\partial q_4}{\partial r} = \frac{\lambda-c_m}{r^2} - \frac{\lambda(2-r)(\lambda-2c_m)}{2r^2\sqrt{\lambda(1-r)(\lambda-2c_m)}}$. By solving $\frac{\partial q_4}{\partial r} = 0$, we obtain $r = \frac{2c_m}{\lambda}$. When $r > \frac{2c_m}{\lambda}$, we have $\frac{\partial q_4}{\partial r} < 0$, which indicates that q_4 is decreasing in r. □

Proposition 2.3 demonstrates that online reviews do not always favor the manufacturer but always hurt the retailer under the decentralized setting. To better understand the relationship of the threshold values above, we present the comparison results through numerical examples (see Figure 2.2). Specifically, when the weight on online reviews is relatively small ($r < \frac{2c_m}{\lambda}$), we have $q_4 = q_2 < q_3$. In this situation, when $q_0 \geq q_4$, although the online reviews do not affect the demand in both channels, the profit of the manufacturer can be improved because of the increased wholesale price and the increased direct price (in region A_1 and A_2). When the weight on online reviews is relatively large ($r \geq \frac{2c_m}{\lambda}$), q_4 decreases with r but q_2 increases with r (The proof is given in the Appendix). Therefore, the following relationship holds: $q_4 < q_2 < q_3$. In this case, if $q_4 \leq q_0 < q_2$ (in region B_3), the signal revealed by online reviews is not favorable enough; the optimal strategies for the manufacturer and the retailer are to reduce all prices, which lead to the higher demand in the Internet channel. Therefore, the manufacturer is profitable because the increment of the demand in the Internet channel can offset the decrease in the direct price and the wholesale price. Further, when online reviews are highly favorable ($q_0 \geq q_2$), the manufacturer can enjoy the positive impact of online reviews to a great extent. The intuition is as follows. In the presence of obvious positive online reviews, more consumers are willing to purchase the product from the Internet channel. In this scenario, online reviews reduce the perceived

quality difference between the two channels considerably and improve consumers' valuation towards the product. Thus, in the Internet channel, the manufacturer is better off because of the higher direct price as well as the increased demand. In the retail channel, it is safe for the manufacturer to set a higher wholesale price, leading to a higher profit.

By contrast, although the retailer has the chance to increase the retail price, online reviews may still hurt the retailer by reducing the marginal profit of the retailer. It is interesting to find that the profit of the retailer is not affected by q_0 under the decentralized channel. The reasons may be as follows. As analyzed before, with online reviews, the best response of retail price becomes $p_r^{R*} = (p_m + w + (1-\lambda)(1-r))/2$,which only have relationship with r. Besides, under this channel setting, the retailer has more incentive to keep the demand in the retail channel. Therefore, the profit of the retailer is independent of q_0.

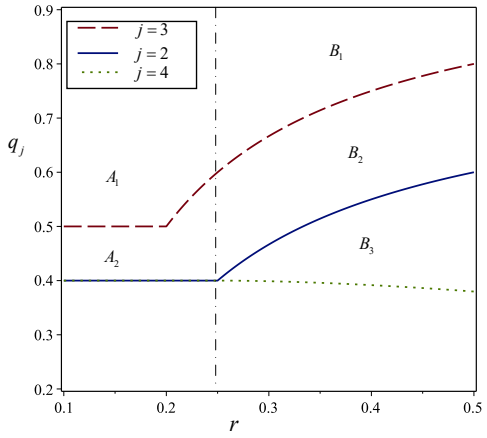


Figure 2.2: Impacts of r on q_2, q_3 and q_4 ($c_m = 0.1, c_r = 0.2, \lambda = 0.8$)

As analyzed before, under the decentralized channel structure, online reviews may increase the profit of the manufacturer but the profit of the retailer always decreases. We are interested to derive the condition under which online reviews can improve the profit of the supply chain under the decentralized setting. In other words, is it possible that the increment of the manufacturer's profit can offset the loss of the retailer's profit?

Proposition 2.4. *Under the decentralized channel setting, the total profit of the supply chain is higher with online reviews than without if and only if* $q_0 > q_5$, *where*

$$q_5 = \begin{cases} \frac{1}{2}, & r < 2c_m \\ \frac{r\lambda-\lambda+c_m+\sqrt{\lambda(1-r)(\lambda+r-\lambda r-2c_m)}}{r}, & otherwise \end{cases}.$$

When $r < 2c_m$, q_5 *is independent on* r; *otherwise,* q_5 *decreases with* r.

Proof. According to the proof of Proposition 2.3, it is easy to give the total profit of the decentralized channel without online reviews (π^0) and without online reviews (π^R). Mathematically,

$$\pi^0 = \frac{\lambda - 2c_r}{4} + \frac{1-\lambda}{4} = \frac{c_r}{2},$$
$$\pi^R = \begin{cases} \frac{rq_0}{2} + \frac{\lambda(1-r)-2c_r}{4} + \frac{(1-\lambda)(1-r)}{4}, & q_0 < \frac{c_m}{r} \\ \frac{r^2{q_0}^2}{4(1-r)\lambda} + \frac{(\lambda-r\lambda-c_m)rq_0}{2\lambda(1-r)} + \frac{(1-r)\lambda-2c_r}{4} + \frac{c_m^2}{4(1-r)\lambda} + \frac{(1-\lambda)(1-r)}{4}, & otherwise \end{cases},$$

With the same method in the proof of Proposition 2.3, we have $\pi^R \geq \pi^0$ if and only if $q_0 \geq q_5$, where

$$q_5 = \begin{cases} \frac{1}{2}, & r < 2c_m \\ \frac{r\lambda-\lambda+c_m+\sqrt{\lambda(1-r)(\lambda+r-\lambda r-2c_m)}}{r}, & r \geq 2c_m \end{cases}$$

In addition, we examine the impacts of r on q_5. It is easy to verify that if $r < 2c_m$, q_5 is independent on r. We concentrate on the case when $r \geq 2c_m$. That is, $q_5 = \frac{r\lambda-\lambda+c_m+\sqrt{\lambda(1-r)(\lambda+r-\lambda r-2c_m)}}{r}$. Then we have $\frac{\partial q_5}{\partial r} = \frac{\lambda-c_m}{r^2} - \frac{\lambda(r+2\lambda-2\lambda r+2c_m r-4c_m)}{2r^2\sqrt{\lambda(1-r)(\lambda+r-\lambda r-2c_m)}}$. By solving $\frac{\partial q_5}{\partial r} = 0$, we have $r = 2c_m$. When $r > 2c_m$, we have $\frac{\partial q_5}{\partial r} < 0$, which indicates that q_5 is also decreasing with r. Thus, Proposition 2.4 holds. □

When the supply chain is decentralized, Proposition 2.4 illustrates that when the information revealed by online reviews is quite positive, the increase in the manufacturer's profit can offset the decrease of the retailer's profit. In other words, online reviews can improve the efficiency of the supply chain. In fact, under the decentralized setting, the profit of the retailer is independent on q_0 but decreases

with r. Differently, when r excesses to some degree, q_5 decreases with r (The proof is given in the Appendix). Figure 2.3 explicitly illustrates the impacts of r on q_5. That is, the greater the weight on online reviews, the higher the probability that the manufacturer can benefit from online reviews. Therefore, in order to ensure the retailer's participation, one possible cooperation mechanism is to keep the profit of the retailer the same as the case without online reviews. Proposition 2.4 indicates that it is possible for the manufacturer to improve the efficiency of the decentralized channel without hurting the retailer.

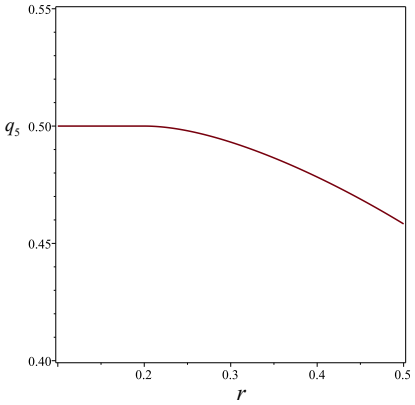


Figure 2.3: Impacts of r on q_5 ($c_m = 0.1, c_r = 0.2, \lambda = 0.8$)

Next, to reflect the effects of online reviews on the channel efficiency under different channel settings, we compare the threshold value q_1 and q_5 and summarize the comparison results below.

Proposition 2.5. *The decentralized supply chain is easier to benefit from online reviews than centralized supply chain when $r < r_1$, where*

$$r_1 = \begin{cases} \frac{4(c_m - c_m\lambda - {c_m}^2 - {c_r}^2\lambda + 2c_m c_r\lambda)}{1-\lambda}, & \lambda \geq \frac{(1-2c_m)c_m}{2{c_r}^2 + c_m - 4c_m c_r} \\ \frac{(1-\lambda){c_m}^2}{{c_m}^2 + {c_r}^2\lambda - 2c_m c_r\lambda}, & otherwise \end{cases}.$$

Proof. From Proposition 2.1 and Proposition 2.4, we have the threshold value q_1 and q_5, where

$$q_1 = \frac{\lambda r + c_m - \lambda}{r} + \sqrt{\frac{\lambda(1-\lambda)(1-r)(\lambda + r - \lambda r - 2c_m) + c_m^2(1-r-\lambda) - c_r\lambda r(c_r - 2c_m)}{(1-\lambda)r^2}},$$

$$q_5 = \begin{cases} \frac{1}{2}, & r < 2c_m \\ \frac{r\lambda - \lambda + c_m + \sqrt{\lambda(1-r)(\lambda + r - \lambda r - 2c_m)}}{r}, & r \geq 2c_m. \end{cases}$$

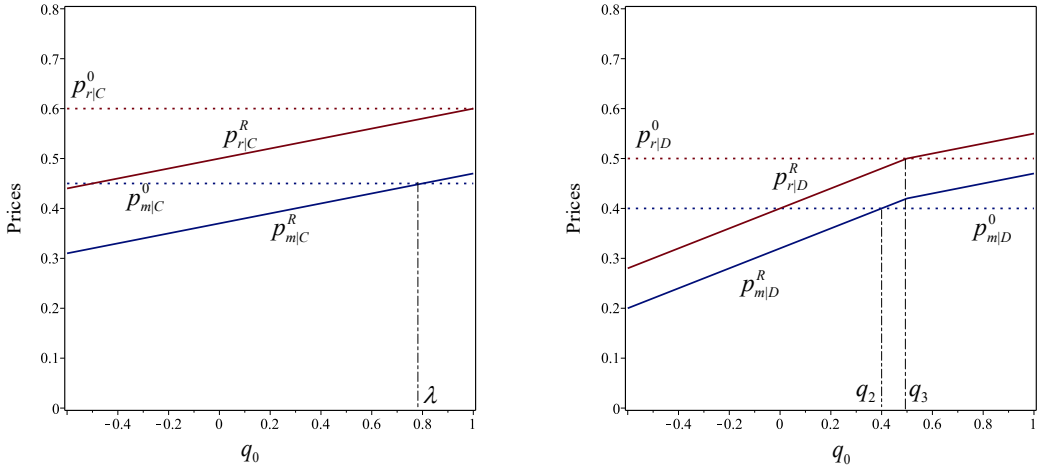
We let $\delta_1 = q_1 - \frac{1}{2}$, $\delta_2 = q_1 - \frac{r\lambda-\lambda+c_m+\sqrt{\lambda(1-r)(\lambda+r-\lambda r-2c_m)}}{r}$. First, by solving $\delta_1 > 0$, we have $r < \frac{4(c_m-c_m\lambda-{c_m}^2-{c_r}^2\lambda+2c_mc_r\lambda)}{1-\lambda}$. It is noted that this condition holds only when $\frac{4(c_m-c_m\lambda-{c_m}^2-{c_r}^2\lambda+2c_mc_r\lambda)}{1-\lambda} < 2c_m$, which equals to $\lambda \geq \frac{(1-2c_m)c_m}{2{c_r}^2+c_m-4c_mc_r}$. Then, if $\lambda < \frac{(1-2c_m)c_m}{2{c_r}^2+c_m-4c_mc_r}$, by solving $\delta_2 > 0$, we have $r < \frac{(1-\lambda){c_m}^2}{{c_m}^2+{c_r}^2\lambda-2c_mc_r\lambda}$. Then, Proposition 2.5 holds. □

Proposition 2.5 demonstrates that the decentralized channel has a higher probability to benefit from online reviews than centralized channel only when the weight on online reviews is extremely small. As mentioned before, under the centralized case, online reviews always hurt the retail channel (lowering the retail price and the demand of the retail channel). Therefore, when r is quite small, the information revealed by online reviews should be sufficiently positive such that the increase of the demand can make the whole channel profitable. In other words, when r is extremely small, the manufacturer under the centralized channel should take more effort to encourage consumers to give highly favorable reviews. When r increases to some degree, we show that the decentralized channel requires a relatively higher positive signal to ensure the profitability from online reviews. The intuition is as follows. Under the decentralized channel, the retailer will more aggressively cut the retail price to keep the demand in the retail channel and the higher the r, the lower the profit of the retailer. Therefore, the decentralized supply chain may need a higher degree of positive review information to improve the efficiency of the channel.

2.5 Numerical examples

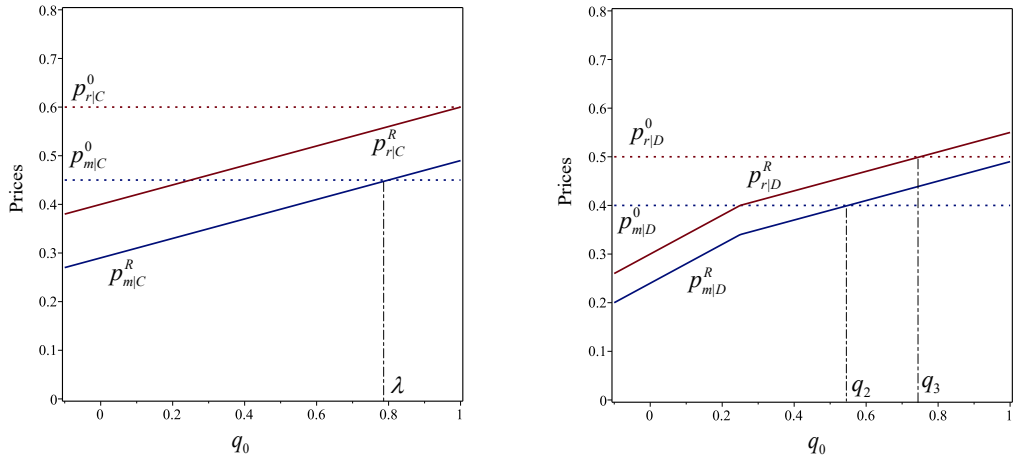
In this section, we represent numerical examples to illustrate the theoretical results and analyze the effect of the parameters on the decision variables. For convenience, we let $c_m = 0.1$ and $c_r = 0.2$. The parameters λ and r satisfy the constraint conditions stated in the sections above. We use subscript C and D to represent

the decision variables under the centralized channel and under the decentralized channel, respectively. In specific, $p^0_{r|C}$ ($p^R_{r|C}$) and $p^0_{m|C}$($p^R_{m|C}$) indicate the retail price and the direct price without (with) online reviews under the centralized structure, $p^0_{r|D}$ ($p^R_{r|D}$) and $p^0_{m|D}$($p^R_{m|D}$) indicate the retail price and the direct price without (with) online reviews under the decentralized structure, and π^0_C (π^R_C) and π^0_D (π^R_D) denote the channel profits without (with) online reviews under the two channel structures. The results are summarized in Figure 2.4-2.7.



(a) Under the centralized channel (b) Under the decentralized channel

Figure 2.4: Impacts of online reviews on prices under different channel structures ($\lambda = 0.8, r = 0.2$)



(a) Under the centralized channel (b) Under the decentralized channel

Figure 2.5: Impacts of online reviews on prices under different channel structures ($\lambda = 0.8, r = 0.4$)

Figure 2.4 and Figure 2.5 explore the effects of online reviews on the pricing decisions of the manufacturer and the retailer under the centralized channel

and under the decentralized channel. First, as shown in Figure 2.4(a) and Figure 2.4(b), online reviews play different roles in affecting the pricing decisions of the manufacturer and the retailer under different channel settings. Online reviews always lower the retail price under the centralized channel but may increase the retail price under the decentralized channel. Differently, the direct price under the two settings can be higher or lower with online reviews, but under the decentralized channel, the manufacturer has a higher probability to charge a higher direct price. More interestingly, from the two figures of Figure 2.4, we find that in the presence of online reviews, it is possible for the manufacturers under the centralized channel and under the decentralized channel to set identical direct prices (when $q_0 \geq \frac{c_m}{r}$).

Second, Figure 2.4(a) and Figure 2.5(a) (Figure 2.4(b) and Figure 2.5(b)) show that online reviews always reduce the price difference between the two channels, no matter what the channel structure is. Besides, when consumers put a higher weight on online reviews (a larger r), the price competition between the two channels would be more intense. Additionally, under the centralized channel structure, whether the manufacturer can raise the direct price has no relationship with r. By contrast, under the decentralized channel structure, if r is relatively large, the manufacturer can charge a higher direct price only when the information revealed by online reviews is sufficiently favorable.

Figure 2.6 and Figure 2.7 show the impacts of online reviews on the profits of the centralized supply chain and the decentralized supply chain, which corresponds to the results of Proposition 2.5. Specifically, Figure 2.6 shows the scenario when consumers already have an extremely high acceptance of the Internet channel. Accordingly, the range of the weight on online reviews would be small. In this case, the decentralized channel is easier to benefit from online reviews if r is extremely small. Figure 2.7 corresponds to the situation when λ is not very high. It is noted that in this situation, the profit difference between the two channel

structures decreases, which means the double-marginalization problem is softened. More importantly, these figures illustrate that the effects of online reviews on the total profits of the channel under different settings are quite similar. That is, the channel is more likely to be affected by online reviews if r is higher. In other words, when consumers give a high weight on online reviews, the supply chain would be profitable if the information revealed by online reviews is sufficiently positive. However, if online reviews do not provide a sufficiently positive signal of the product, the supply chain would suffer a lot.

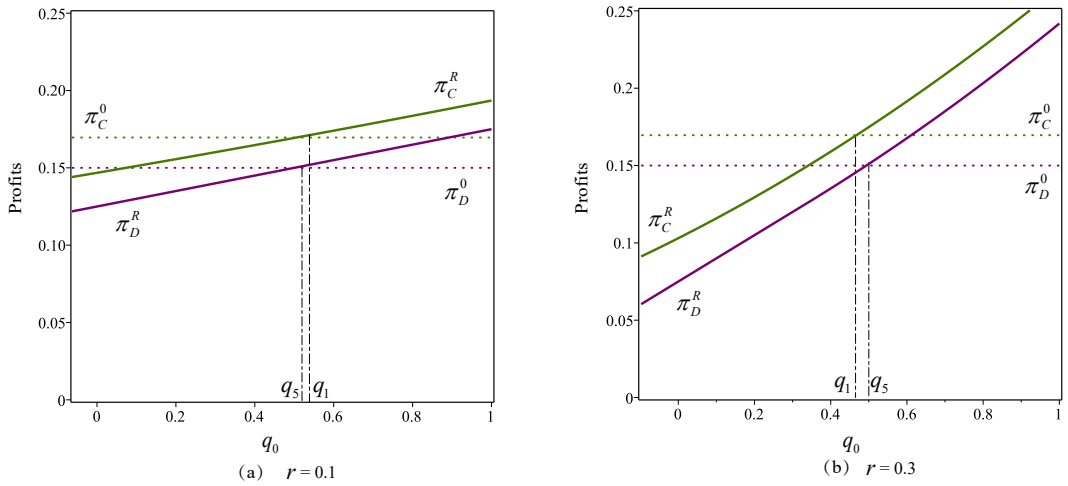


Figure 2.6: Impacts of online reviews on channel profits ($\lambda = 0.85$)

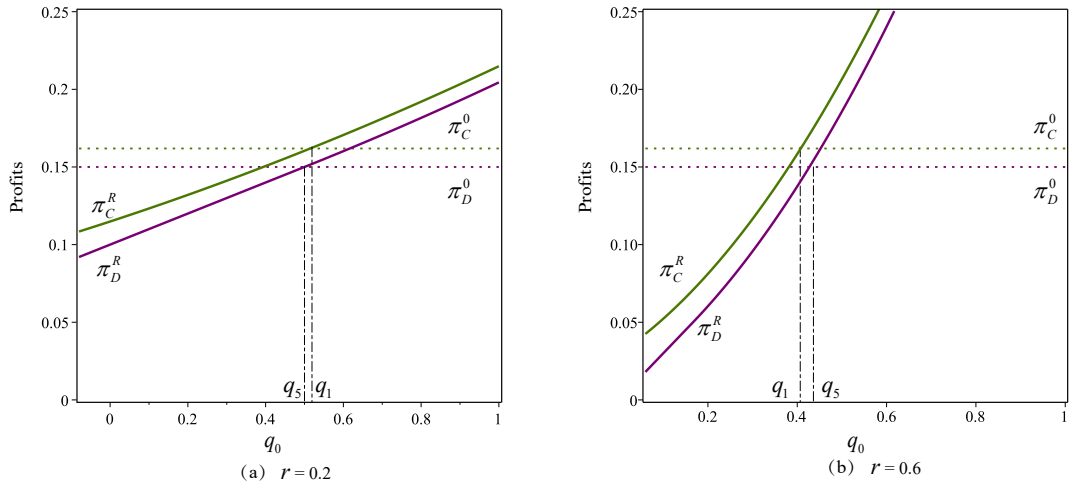


Figure 2.7: Impacts of online reviews on channel profits ($\lambda = 0.7$)

2.6 Conclusions

This chapter investigates a dual supply chain in which the manufacturer sells a single product through a retail channel and an Internet channel. By an analytical modeling framework, we examine the impacts of online reviews on pricing strategies and profits of the manufacturer and the retailer, under the centralized channel structure and decentralized channel structure. Some insights are found.

We show that online reviews influence the pricing decisions of the manufacturer and the retailer differently under different channel settings. Under the centralized channel structure, whether the manufacturer can charge a higher direct price depends on the relationship between the degree of informativeness of online reviews and consumers' acceptance of the Internet channel, whereas the retailer has to reduce the retail price with online reviews. Differently, all prices can be higher or lower with online reviews under the decentralized channel, and the manufacturer under the decentralized channel has a higher probability to raise the direct price than under the centralized channel. Besides, under the centralized channel setting, the demand of the Internet channel is likely to increase even with negative online reviews but the demand of the retail channel is always lower with online reviews. In contrast, online reviews only affect the demand of the Internet channel but do not influence the demand of the retail channel under the decentralized setting.

Our results generate some managerial implications, not only for the manufacturer but also for the retailer. First, for the manufacturer, it is beneficial to host a review system only when the information revealed by online reviews is favorable enough. It is worthwhile to noted that, although the profit thresholds under different channel settings are different, they both decrease with the weight on online reviews. That means, the manufacturer should not consider the impacts of online reviews in isolation. It is necessary for the manufacturer to devote more efforts to improve the consumers' weight on online reviews in their purchase process and

to ensure a sufficient level of positive review informativeness. For instance, the manufacturer can encourage consumers to post the reviews regarding to the product information to increase the precision of online reviews, or market the product to the proper consumer segments who are less skillful to access the product by themselves and thus are more likely to be influenced by online reviews. Second, it is also crucial for the retailer to understand the implications of online reviews on the retail channel. If the channel is centralized, it is safe for the retailer to welcome online reviews because she gains from the additional profit of the whole channel. But if the retailer is under the decentralized channel, cooperation mechanism is necessary to ensure that the profit of the retailer would not be harmed by online reviews.

Chapter 3

Implications of online review on two competing manufacturers and a common retailer

3.1 Introduction

In practice, it is common for a single retailer to sell vertically differential products from competing manufacturers. For instance, in the smartphone market, Amazon.com provides cell phones with different brands. Consider two products that are more vertical differentiated: *Samsung Galaxy S20* and *Huawei P30 Pro*. On the one hand, *Samsung Galaxy S20* has better performances in some vertical attributes, such as RAM, CPU and Camera, which are related with its higher price. We treat this aspect as quality dimension. It is easy to understand that, for this dimension, consumers all prefer high quality than low quality. One the other hand, these two products also have some horizontal differences (e.g., color and screen appearance), and for the horizontal dimension, different consumers may have different preferences.

Not surprise, product differentiation and pricing problem have been explored by many researchers. Most of them study vertical differentiation (Moorthy 1988, Rosenkranz 1995, Rhee 1996, Greenstein and Ramey 1998, Liu and Serfes 2005) or horizontal differentiation (Hotelling 1990, Hendel and De Figueiredo 1997, Tyagi

2000), separately. Some studies also consider both horizontal and vertical differentiation at the same time (Iyer 1998, Bohlmann et al. 2002, Xiao et al. 2014b). We differ from this line of research by incorporating the product differentiation problem in a channel setting with competing manufacturers and a common retailer. This channel structure also gains increasing attentions from the literature. To illustrate, Choi (1991) derives three noncooperative games and considers different power structures to study the pricing issue between two manufacturers and a common retailer. The findings highlight the significance of the demand function on the profitability of channel members. The study of Lee and Staelin (1997) also involves such channel setting and investigates the impact of different strategic pricing decisions (i.e., price leadership and product line pricing) on channel members. Recently, Cachon and Kök (2010) focus on the contract negotiations between two competing manufacturers and a retailer by comparing three types of contracts: wholesale-price contract, quantity-discount contract and two-part tariff contract.

As an extension of this stream, we still differ from the aforementioned work by unraveling the impact of online reviews on the pricing decisions and profit performances of channel members. As mentioned above, we assume that the products are differentiated in two dimensions. In the vertical dimension, in consistent with Chambers et al. (2006) and Chen et al. (2017a), we use "product quality" to indicate a combination of attributes with "more-is-better" property. Consumers always prefer the product with a higher quality in the vertical dimension. In the horizontal dimension, we claim that consumers are heterogeneous, which means that different consumers have different needs.

In consistent with Kwark et al. (2014) and Liu et al. (2017) , we assume online reviews can reduce consumers' uncertainty about the product quality. On the one hand, consumers can perceive the true quality difference between the two products with online reviews. On the other hand, consumers would have a better knowledge

about which product fits them better. Additionally, we propose a two-period theoretic framework to derive the implication of online reviews. That is, we allow the retailer to adjust prices of the two products before and after online reviews are available. In specific, consumers in the first period make purchase decisions based on the product prices and expectations about the product qualities. After the purchase, they leave the truthful online reviews. With these reviews, consumers in the second period can learn the true product quality difference and their preference uncertainty can be reduced as well. Overall, we attempt to investigate the impacts of online reviews on the demand, equilibrium prices and profits of the competing manufacturers and the retailer.

The major findings are as follows. First, we show that whether the retailer should enlarge or reduce the price difference in the second period largely depends on the product quality difference. It is possible for the retailer to charge higher prices for both products in the presence of online reviews, which inevitably make consumers buy products with higher prices. Second, our results indicate that online reviews may not favor high-quality manufacturer or hurt low-quality manufacturer. When the two products have moderate quality difference, online reviews play positive roles for both manufacturers, leading to higher wholesale prices and higher profits. Third, the larger the quality difference of the two products, the higher the probability that the retailer can be better off. Moreover, it is not judicious for the retailer to encourage consumers to give more informative online reviews because highly accurate information actually reduces the competition in the upstream, which benefits the manufacturers but harms the retailer.

The remainder of this chapter is organized as follows. In section 3.2, we describe the problem, give the necessary assumptions and notations and lay out the basic mathematical models. Section 3.3 develops the properties and corollaries of the underlying problem and discusses the main results. Conclusions are drawn in 3.4.

3.2 Model

We consider a supply chain with two competing manufacturers and one common retailer. The two manufacturers, A and B, produce partially substitutable products. On the one hand, these two products are vertically differentiated, which means that they have different quality levels. In this dimension, consumers agree on the relative value of different products. Without loss of the generality, we assume that the quality of product A (produced by manufacturer A) is higher than the quality of product B (produced by manufacturer B) and the actual quality difference is q, which is known to the retailer and manufacturers but unknown to consumers. On the other hand, these two products are horizontally differentiated. To capture the horizontal difference, we assume that product A and product B are located at positions 0 and 1 of a line of length 1. Regular consumers are uniformly distributed along the line, and the distance from the consumer to the product captures the degree of the misfit.

As mentioned before, the retailer faces new consumers in two distinct periods. In the first period, consumers make purchase decision based on their expectations about the quality difference and the misfit cost of the two products. After purchasing the product, the first-period consumers can learn the true product quality difference and tend to reveal it by posting online reviews. As a result, consumers in the second period would make purchase decisions based on the information revealed by online reviews.

3.2.1 Consumers

We consider two types of consumers, loyal consumers and regular consumers. Loyal consumers only purchase the product they are loyal to and have a certain valuation towards the product. For example, loyal consumers for *Huawei* only buy the smart phone produced by *Huawei*, and they will buy the product as long as the sell price

is acceptable. That is, the purchase decision of loyal consumers only depends on the price of the product. In consistent with Kwark et al. (2014), we present the demand for product i in period j is

$$D_{il}^{(j)} = \eta - \alpha p_i^{(j)}, \tag{3.1}$$

in which D_{il}^{j} is the demand of loyal consumers for product i in period j ($i = A, B$ and $j = 1, 2$), η means the potential size of loyal consumers for each product, α indicates the price sensitivity of the loyal consumers, and $p_i^{(j)}$ is the price of product i in period j.

We pay more attention to the regular consumers, who would compare the two products in both vertical dimension and horizontal dimension. For the regular consumers, we follow the assumption of Liu et al. (2017). In each period, the retailer has a unit mass of regular consumers. On the one hand, they have a prior belief of the product quality difference (m), which may depend on product information provided by the retailer. On the other hand, their horizontal preference is uniformly distributed over [0,1] and each regular consumer buys one unit of product. Recall that we assume product A is located at 0 and product B is located at 1, for the consumer who located at y, the misfit cost between the consumer and product A is yt and the misfit cost between the consumer and product B is $(1 - y)t$, where t indicates the unit misfit cost. Thus, when there is no online reviews, the expected utility difference between the two products for a regular consumer in period j can be formulated as

$$U^{(j)} = m + (\frac{1}{2} - y)t - (p_A^{(j)} - p_B^{(j)}), \tag{3.2}$$

Therefore, in the absence of online reviews, the demand functions of regular consumers in each period ($D_{ir}^{(j)}, i = A, B$ and$j = 1, 2$):

$$D_{Ar}^{(j)} = \frac{1}{2} + \frac{m - (p_A - p_B)}{t}, \quad D_{Br}^{(j)} = \frac{1}{2} - \frac{m - (p_A - p_B)}{t} \tag{3.3}$$

Combining Equation (3.3) and the demand function of loyal consumers (Equa-

tion (3.1)), we can get the demand functions of the two products in each period without online reviews as follows.

$$\begin{aligned} D_A^{(j)} &= \frac{1}{2} + \eta + \frac{m}{t} - (\frac{1}{t} + \alpha)p_A^{(j)} + \frac{1}{t}p_B^{(j)} \\ D_B^{(j)} &= \frac{1}{2} + \eta - \frac{m}{t} - (\frac{1}{t} + \alpha)p_B^{(j)} + \frac{1}{t}p_A^{(j)} \end{aligned} \tag{3.4}$$

Next, we turn to the case with online reviews. We assume that online reviews are generated by the first-period consumers and only affect regular consumers in period 2. In detail, for consumers in period 1, the utility difference is as same as Equation (3.2). We focus on the impact of online reviews on the utility of regular consumers in period 2. We make the following basic assumptions. On the one hand, online reviews can reveal the true difference of the two products. Thus, regular consumers would update their belief about the quality difference from m to $\theta m + (1-\theta)q$, where $(1-\theta)$ indicates the weight of online reviews on consumers' valuation of the products. On the other hand, regular consumers in period 2 would be more certain about their locations. Mathematically, we follow Liu et al. (2017) and assume that the probability of a regular consumer's belief about locating at point y would change from $1/2$ to $(1+\lambda)/2$, where λ measures the informativeness of online reviews. Based on the analysis before, for a regular consumer, the utility difference between the two products in period 2 with online reviews can be expressed as

$$\hat{U}^{(2)} = \theta m + (1-\theta)q + \frac{(1+\lambda)(1-2y)}{2}t - (p_A^{(2)} - p_B^{(2)}), \tag{3.5}$$

where $\hat{U}^{(2)}$ is regular consumers' utility difference in period 2 with online reviews.

It is straightforward to give the demand functions in period 1, which is the same as Equation (3.4). In period 2, as analyzed before, consumers update their valuation based on online reviews. Thus, with the utility function (Equation (3.5)),

we character the demand functions of regular consumers in period 2 as follows.

$$\begin{aligned}\hat{D}_{Ar}^{(2)} &= \frac{1}{2} + \frac{\theta m + (1-\theta)q - (p_A^{(2)} - p_B^{(2)})}{(1+\lambda)t}, \\ \hat{D}_{Br}^{(2)} &= \frac{1}{2} - \frac{\theta m + (1-\theta)q - (p_A^{(2)} - p_B^{(2)})}{(1+\lambda)t}.\end{aligned} \tag{3.6}$$

Similarly, combined with the demand functions of loyal consumers, the demands of the two products in period 2 can be obtained as:

$$\begin{aligned}\hat{D}_A^{(2)} &= \frac{1}{2} + \eta + \frac{\theta m + (1-\theta)q}{(1+\lambda)t} - \left(\frac{1}{(1+\lambda)t} + \alpha\right) p_A^{(2)} + \frac{1}{(1+\lambda)t} p_B^{(2)} \\ \hat{D}_B^{(2)} &= \frac{1}{2} + \eta - \frac{\theta m + (1-\theta)q}{(1+\lambda)t} - \left(\frac{1}{(1+\lambda)t} + \alpha\right) p_B^{(2)} + \frac{1}{(1+\lambda)t} p_A^{(2)}\end{aligned} \tag{3.7}$$

3.2.2 Game structure

In the absence of online reviews, the sequences of the game in the two periods are the same and are as follows. First, both manufacturers set wholesale prices (w_A and w_B) simultaneously. Second, the retailer is presented as the follower to determine the retail prices (p_A and p_B) to maximize its own profit, conditional on the wholesale prices.

In the presence of online reviews, the sequence of the game is as follows. At the beginning of period 1, both manufacturers decide wholesale prices ($\hat{w}_A$ and $\hat{w}_B$) simultaneously and then the retailer sets the prices of the two products in period 1 ($\hat{p}_A^{(1)}$ and $\hat{p}_B^{(1)}$) to maximize its profit in period 1, conditional on the wholesale prices. Next, at the beginning of period 2, the retailer sets the prices of the products in period 2 ($\hat{p}_A^{(2)}$ and $\hat{p}_B^{(2)}$) to maximize the total profit of two periods, conditional on the wholesale prices and retail prices in period 1.

Table 3.1 gives the main notations in this chapter.

Table 3.1: Notations and Explanations for Variables and Distributions

Notation	Explanation
i	Index for products/manufacturers, $i = A, B$
j	Index for period, $j = 1, 2$
m	Consumers' prior belief of the quality difference without online reviews
q	The actual quality difference between the two products
t	The misfit cost per unit distance
y	The location of regular consumers, $y \in [0, 1]$
η	Size of potential demand from loyal consumers of the two products
α	Price sensitivity of loyal consumers
λ	The informativeness of online reviews
θ	The weight of consumers' own assessment of product quality difference
p_i	The price of product i in each period without online reviews
$\hat{p}_i^{(j)}$	The price of product i in period j with online reviews
D_i	The demand of product i in each period without online reviews
$\hat{D}_i^{(j)}$	The demand of product i in period j with online reviews
π_i	The profit of manufacturer i in each period without online reviews
π_R	The profit of the retailer in each period without online reviews
$\hat{\pi}_i^{(j)}$	The profit of manufacturer i in period j with online reviews
$\hat{\pi}_R^{(j)}$	The profit of the retailer in period j with online reviews
$*$	The asterisk indicates the equilibrium result
$\hat{}$	The hat $\hat{}$ over a variable indicates the scenario with online reviews

3.3 Analysis

We first analyze the benchmark case without online reviews. Based on the timing of the game discussed in subsection 3.2.2, we first derive the pricing decisions of the retailer. That is, the retailer determines the retail prices (p_A and p_B) to maximize its own profit (π_R), conditional on the wholesale prices of the two manufacturers. We have

$$\max_{p_A, p_B} \pi_R = (p_A - w_A)D_A + (p_B - w_B)D_B. \tag{3.8}$$

By the first-order conditions, we get the optimal retail prices, which are functions of wholesale prices (w_A and w_B). Then anticipating the retail prices (p_A and p_B) in response to the wholesale prices, the manufacturer i ($i = A, B$) maximizes its profit (π_i) by setting the optimal wholesale price, that is,

$$\max_{w_i} \pi_i = w_i D_i, \quad i = A, B. \tag{3.9}$$

Thus, the equilibrium prices, the demand and profits of the manufacturers and the retailer in each period in the absence of online reviews are given by Lemma 3.1.

Lemma 3.1. *In the absence of online reviews, the equilibrium wholesale prices, retail prices, demand, and profits of the manufacturers and the retailer in each period are as follows.*

$$
\begin{aligned}
D_A &= \frac{(1+\alpha t)H}{2(1+2\alpha t)} + \frac{m(1+\alpha t)}{2t(3+2\alpha t)}, \quad D_B = \frac{(1+\alpha t)H}{2(1+2\alpha t)} - \frac{m(1+\alpha t)}{2t(3+2\alpha t)}, \\
w_A &= \frac{Ht}{1+2\alpha t} + \frac{m}{3+2\alpha t}, \quad w_B = \frac{Ht}{1+2\alpha t} - \frac{m}{3+2\alpha t}, \\
p_A &= \frac{(1+3\alpha t)H}{2\alpha(1+2\alpha t)} + \frac{m(5+3\alpha t)}{2(2+\alpha t)(3+2\alpha t)}, \\
p_B &= \frac{(1+3\alpha t)H}{2\alpha(1+2\alpha t)} - \frac{m(5+3\alpha t)}{2(2+\alpha t)(3+2\alpha t)}, \\
\pi_A &= \frac{((3+2\alpha t)tH + (1+2\alpha t)m)^2(1+\alpha t)}{8t(1+2\alpha t)^2(3+2\alpha t)^2}, \\
\pi_B &= \frac{((3+2\alpha t)tH - (1+2\alpha t)m)^2(1+\alpha t)}{8t(1+2\alpha t)^2(3+2\alpha t)^2}, \\
\pi_R &= \frac{(1+\alpha t)^2H^2}{2\alpha(1+2\alpha t)^2} + \frac{(1+\alpha t)^2m^2}{2t(2+\alpha t)(3+2\alpha t)^2},
\end{aligned}
$$

where $H = \eta + \frac{1}{2}$.

To avoid trivial cases and to ensure the market sizes of loyal consumers and regular consumers are always positive, we have the following conditions: $0 < m < \overline{m}$, where $\overline{m} = \frac{(3+2\alpha t)(2+\alpha t)t}{2(1+4\alpha t+2\alpha^2t^2)}$.

Proof. Let $H = \frac{1}{2} + \eta$. With the demand function of Equation (3.4), we can reformulate the retailer's profit (π_R) as

$$
\begin{aligned}
\pi_R = (p_A - w_A)\left(H + \frac{m}{t} - (\frac{1}{t}+\alpha)p_A + \frac{1}{t}p_B\right) \\
+ (p_B - w_B)\left(H - \frac{m}{t} - (\frac{1}{t}+\alpha)p_B + \frac{1}{t}p_A\right).
\end{aligned} \tag{3.10}
$$

By solving the first-order conditions of Equation (3.10) for p_A and p_B, we have the following results

$$
\begin{aligned}
p_A &= \frac{H}{2\alpha} + \frac{m}{2(2+\alpha t)} + \frac{w_A}{2}, \\
p_B &= \frac{H}{2\alpha} - \frac{m}{2(2+\alpha t)} + \frac{w_B}{2}.
\end{aligned} \tag{3.11}
$$

Substituting Equation (3.11) into demand functions of Equation (3.4), we rewrite

the manufacturers' profits as

$$\begin{aligned}\pi_A &= w_A\left(\frac{H}{2}+\frac{m}{2t}-\frac{(1+\alpha t)w_A}{2t}+\frac{w_B}{2t}\right),\\ \pi_B &= w_B\left(\frac{H}{2}-\frac{m}{2t}+\frac{w_A}{2t}-\frac{(1+\alpha t)w_B}{2t}\right).\end{aligned} \tag{3.12}$$

By solving the first-order condition of π_A for p_A and the first-order condition of π_B for p_B, we obtain

$$\begin{aligned}w_A &= \frac{Ht}{1+2\alpha t}+\frac{m}{3+2\alpha t},\\ w_B &= \frac{Ht}{1+2\alpha t}-\frac{m}{3+2\alpha t}.\end{aligned} \tag{3.13}$$

Substituting the above wholesale prices into Equations (3.11), we obtain the optimal retail prices as follows

$$\begin{aligned}p_A &= \frac{(1+3\alpha t)H}{2\alpha(1+2\alpha t)}+\frac{(5+3\alpha t)m}{2(2+\alpha t)(3+2\alpha t)},\\ p_B &= \frac{(1+3\alpha t)H}{2\alpha(1+2\alpha t)}-\frac{(5+3\alpha t)m}{2(2+\alpha t)(3+2\alpha t)}.\end{aligned} \tag{3.14}$$

Also, substituting the above optimal retail prices into demand function of Equation (3.4), we obtain

$$\begin{aligned}D_A &= \frac{(1+\alpha t)H}{2(1+2\alpha t)}+\frac{m(1+\alpha t)}{2t(3+2\alpha t)},\\ D_B &= \frac{(1+\alpha t)H}{2(1+2\alpha t)}-\frac{m(1+\alpha t)}{2t(3+2\alpha t)}.\end{aligned} \tag{3.15}$$

With the above equilibrium demands, wholesale prices and retail prices, we obtain equilibrium profits in Lemma 3.1.

In addition, to avoid trivial cases, we assume that the market potential sizes of the loyal consumers and regular consumers are positive. Recall that $D_{Al} = \eta-\alpha p_A, D_{Bl} = \eta-\alpha p_B$, $\mathrm{D}_{Ar} = \frac{1}{2}+\frac{m-(p_A-p_B)}{t}$, and $D_{Br} = \frac{1}{2}-\frac{m-(p_A-p_B)}{t}$. We only need to ensure $D_{Al}>0$ and $D_{Br}>0$. In addition, in order to focus our attention on the impacts of online reviews on regular consumers, we only derive the condition when $D_{Br}>0$, which requires that D_{Al} is always positive (i.e., η is large enough). Mathematically, substituting the equilibrium prices into D_{Al} and D_{Br} and solving and $D_{Br}>0$ and $D_{Al}>0$, we have $m<\overline{m}$, where $\overline{m} = m\frac{(3+2\alpha t)(2+\alpha t)t}{2(1+4\alpha t+2\alpha^2t^2)}$. □

We next consider the scenario with online reviews. According to game sequence in subsection 3.2.2, in stage 3 of this case, the retailer determines the retail prices in period 2 ($\hat{p}_A^{(2)}$ and $\hat{p}_B^{(2)}$) to maximize its profit in period 2 ($\hat{\pi}_R^{(2)}$), conditional on the wholesale prices of the two manufacturers; that is

$$\max_{\hat{p}_A^{(2)},\hat{p}_B^{(2)}} \hat{\pi}_R^{(2)} = (\hat{p}_A^{(2)} - \hat{w}_A)\hat{D}_A^{(2)} + (\hat{p}_B^{(2)} - \hat{w}_B)\hat{D}_B^{(2)}. \tag{3.16}$$

By the first-order conditions, we get the optimal retail prices in period 2, which are functions of wholesale prices ($\hat{w}_A$ and $\hat{w}_B$). Then, in stage 2, the retailer maximizes its total profit by setting the retail price in period 1; that is

$$\max_{\hat{p}_A^{(1)},\hat{p}_B^{(1)}} \hat{\pi}_R = (\hat{p}_A^{(1)} - \hat{w}_A)\hat{D}_A^{(1)} + (\hat{p}_B^{(1)} - \hat{w}_B)\hat{D}_B^{(1)} + \hat{\pi}_R^{(2)}. \tag{3.17}$$

Next, by anticipating the retail price $p_i^{(j)}$ ($i = A, B$ and $j = 1, 2$) in response to the wholesale prices, manufacturer i ($i = A, B$) maximizes its profit ($\hat{\pi}_i$) and gets the optimal wholesale price, that is,

$$\max_{\hat{w}_i} \hat{\pi}_i = \hat{w}_i(\hat{D}_i^{(1)} + \hat{D}_i^{(2)}), \quad i = A, B. \tag{3.18}$$

Thus, the equilibrium prices, the demand and profits of the manufacturers and the retailer in each period with online reviews are given by Lemma 3.2.

Lemma 3.2. *In the presence of online reviews, the equilibrium wholesale prices, retail prices, demand, and profits of the manufacturers and the retailer in each*

period are as follows.

$$\hat{D}_A^{(1)} = \frac{(1+\Lambda+2\Lambda\alpha t)H}{2(1+\Lambda+4\Lambda\alpha t)} + \frac{(3+\Lambda+3\Lambda\alpha t)m-(2+\alpha t)\mu}{2(3+3\Lambda+4\Lambda\alpha t)t},$$

$$\hat{D}_B^{(1)} = \frac{(1+\Lambda+2\Lambda\alpha t)H}{2(1+\Lambda+4\Lambda\alpha t)} - \frac{(3+\Lambda+3\Lambda\alpha t)m-(2+\alpha t)\mu}{2(3+3\Lambda+4\Lambda\alpha t)t},$$

$$\hat{D}_A^{(2)} = \frac{(1+\Lambda+2\Lambda\alpha t)H}{2(1+\Lambda+4\Lambda\alpha t)} + \frac{(2+\Lambda\alpha t)\Lambda m-(1+3\Lambda+3\Lambda\alpha t)\mu}{2(3+3\Lambda+4\Lambda\alpha t)\Lambda t},$$

$$\hat{D}_B^{(2)} = \frac{(1+\Lambda+2\Lambda\alpha t)H}{2(1+\Lambda+4\Lambda\alpha t)} - \frac{(2+\Lambda\alpha t)\Lambda m-(1+3\Lambda+3\Lambda\alpha t)\mu}{2(3+3\Lambda+4\Lambda\alpha t)\Lambda t},$$

$$\hat{w}_A = \frac{2H\Lambda t}{1+\Lambda+4\Lambda\alpha t} + \frac{\Lambda m+\mu}{3+3\Lambda+4\Lambda\alpha t},$$

$$\hat{w}_B = \frac{2H\Lambda t}{1+\Lambda+4\Lambda\alpha t} - \frac{\Lambda m+\mu}{3+3\Lambda+4\Lambda\alpha t},$$

$$\hat{p}_A^{(1)} = \frac{(1+\Lambda+6\Lambda\alpha t)H}{2(1+\Lambda+4\Lambda\alpha t)\alpha} + \frac{(3+5\Lambda+5\Lambda\alpha t)m+(2+\alpha t)\mu}{2(3+3\Lambda+4\Lambda\alpha t)(2+\alpha t)},$$

$$\hat{p}_A^{(2)} = \frac{(1+\Lambda+6\Lambda\alpha t)H}{2(1+\Lambda+4\Lambda\alpha t)\alpha} + \frac{(2+\Lambda\alpha t)\Lambda m+(5+3\Lambda+5\Lambda\alpha t)\mu}{2(3+3\Lambda+4\Lambda\alpha t)(2+\alpha t)},$$

$$\hat{p}_B^{(1)} = \frac{(1+\Lambda+6\Lambda\alpha t)H}{2(1+\Lambda+4\Lambda\alpha t)\alpha} - \frac{(3+5\Lambda+5\Lambda\alpha t)m+(2+\alpha t)\mu}{2(3+3\Lambda+4\Lambda\alpha t)(2+\alpha t)}$$

$$\hat{p}_B^{(2)} = \frac{(1+\Lambda+6\Lambda\alpha t)H}{2(1+\Lambda+4\Lambda\alpha t)\alpha} - \frac{(2+\Lambda\alpha t)\Lambda m+(5+3\Lambda+5\Lambda\alpha t)\mu}{2(3+3\Lambda+4\Lambda\alpha t)(2+\alpha t)},$$

$$\hat{\pi}_A = \frac{(1+\Lambda+2\Lambda\alpha t)\big(2(3+3\Lambda+4\Lambda\alpha t)\Lambda tH+(1+\Lambda+4\Lambda\alpha t)(\Lambda m+\mu)\big)^2}{(1+\Lambda+4\Lambda\alpha t)^2(3+3\Lambda+4\Lambda\alpha t)^2\Lambda t},$$

$$\hat{\pi}_B = \frac{(1+\Lambda+2\Lambda\alpha t)\big(2(3+3\Lambda+4\Lambda\alpha t)\Lambda tH-(1+\Lambda+4\Lambda\alpha t)(\Lambda m+\mu)\big)^2}{(1+\Lambda+4\Lambda\alpha t)^2(3+3\Lambda+4\Lambda\alpha t)^2\Lambda t},$$

$$\hat{\pi}_R^{(1)} = \frac{(1+\Lambda+2\Lambda\alpha t)^2H^2}{2(1+\Lambda+4\Lambda\alpha t)^2\alpha} + \frac{\big((3+\Lambda+3\Lambda\alpha t)m-(2+\alpha t)\mu\big)^2}{2t(2+\alpha t)(3+3\Lambda+4\Lambda\alpha t)^2},$$

$$\hat{\pi}_R^{(2)} = \frac{(1+\Lambda+2\Lambda\alpha t)^2H^2}{2(1+\Lambda+4\Lambda\alpha t)^2\alpha} + \frac{\big(\Lambda(2+\Lambda\alpha t)m-(1+3\Lambda+3\Lambda\alpha t)\mu\big)^2}{2\Lambda t(2+\Lambda\alpha t)(3+3\Lambda+4\Lambda\alpha t)^2},$$

$$\hat{\pi}_R = \hat{\pi}_R^{(1)} + \hat{\pi}_R^{(2)},$$

where $\mu = \theta m + (1-\theta)q$, $\Lambda = 1+\lambda$.

Similarly, we add the following conditions: $\max\{0, q_0\} < q < \overline{q}$, where $q_0 = \frac{\mu_0-\theta m}{1-\theta}$, $\overline{q} = \frac{\overline{\mu}-\theta m}{1-\theta}$, $\overline{\mu} = \frac{\Lambda(2+\Lambda\alpha t)(4\Lambda\alpha t^2+3\Lambda t+3t+2m)}{2(4\Lambda^2\alpha^2t^2+3\Lambda^2\alpha t+6\Lambda\alpha t+3\Lambda+1)}$, and $\mu_0 = \frac{(4\Lambda\alpha^2t^2+6\Lambda\alpha t+3\alpha t+\Lambda+3)m}{2+\alpha t} - \frac{(4\Lambda\alpha t+3\Lambda+3)t}{2}$.

Proof. We first consider the second-period equilibrium prices. In the second period, as mentioned above, the demand function is presented in Equation (3.7). We denote $\mu = \theta m + (1-\theta)q, \Lambda \equiv 1+\lambda$. Thus, we can reformulate the retailer's

second-period profit $\pi_R^{(2)}$ as

$$\begin{aligned}\pi_R^{(2)} = (p_A^{(2)} - w_A)\left(H + \frac{\mu}{\Lambda t} - (\frac{1}{\Lambda t} + \alpha)p_A^{(2)} + \frac{1}{\Lambda t}p_B^{(2)}\right) \\ + (p_B^{(2)} - w_B)\left(H - \frac{\mu}{\Lambda t} - (\frac{1}{\Lambda t} + \alpha)p_B^{(2)} + \frac{1}{\Lambda t}p_A^{(2)}\right).\end{aligned} \tag{3.19}$$

Similarly, taking the first-order derivative with respect to $p_A^{(2)}$ and $p_B^{(2)}$ and solving equations $\partial\pi_R^{(2)}/\partial p_A^{(2)} = 0$ and $\partial\pi_R^{(2)}/\partial p_B^{(2)} = 0$, we get the equilibrium second-period prices:

$$\begin{aligned}p_A^{(2)} &= \frac{H}{2\alpha} + \frac{\mu}{2(2+\Lambda\alpha t)} + \frac{w_A}{2}, \\ p_B^{(2)} &= \frac{H}{2\alpha} - \frac{\mu}{2(2+\Lambda\alpha t)} + \frac{w_B}{2}.\end{aligned} \tag{3.20}$$

Substituting the above equations into demand functions of Equation (3.7), we can rewrite the retailer's second-period profit as

$$\begin{aligned}\pi_R^{(2)} = &\left(\frac{H}{2\alpha} + \frac{\mu}{2(2+\Lambda\alpha t)} - \frac{1}{2}w_A\right)\left(\frac{H}{2} + \frac{\mu}{2\Lambda t} - \frac{1}{2}(\frac{1}{\Lambda t} + \alpha)w_A + \frac{1}{2\Lambda t}w_B\right) \\ &+ \left(\frac{H}{2\alpha} - \frac{\mu}{2(2+\Lambda\alpha t)} - \frac{1}{2}w_B\right)\left(\frac{H}{2} - \frac{\mu}{2\Lambda t} + \frac{1}{2\Lambda t}w_A - \frac{1}{2}(\frac{1}{\Lambda t} + \alpha)w_B\right)\end{aligned} \tag{3.21}$$

Next, consider the first-period equilibrium prices. In period 1, recall that the demand functions are presented as Equation (3.4). And the retailer's first-period profit is $\pi_R^{(1)} = (p_A^{(1)} - w_A)D_A^{(1)} + (p_B^{(1)} - w_B)D_B^{(1)}$. Thus, the total profit of the retailer is $\pi_R = \pi_R^{(1)} + \pi_R^{(2)}$.

Similarly, taking the first-order derivative with respect to $p_A^{(1)}$ and $p_B^{(1)}$ and solving equations $\partial\hat{\pi}_R/\partial p_A^{(1)} = 0$ and $\partial\hat{\pi}_R/\partial p_B^{(1)} = 0$, we get the equilibrium first-period prices are

$$\begin{aligned}p_A^{(1)} &= \frac{H}{2\alpha} + \frac{m}{2(2+\alpha t)} + \frac{w_A}{2}, \\ p_B^{(1)} &= \frac{H}{2\alpha} - \frac{m}{2(2+\alpha t)} + \frac{w_B}{2}\end{aligned} \tag{3.22}$$

Then, the demand of the product in period 1 ($D_A^{(1)}$ and $D_B^{(2)}$) can be obtained easily. Combining the demand functions in period 2, we reformulate the demands of the two products in the two periods as

$$\begin{aligned}D_A &= \frac{\Lambda t H + \Lambda m + \mu}{2\Lambda t} - \frac{1 + \Lambda + 2\Lambda\alpha t}{2\Lambda t}w_A + \frac{1+\Lambda}{2\Lambda t}w_B, \\ D_B &= \frac{\Lambda t H - \Lambda m - \mu}{2\Lambda t} - \frac{1 + \Lambda + 2\Lambda\alpha t}{2\Lambda t}w_B + \frac{1+\Lambda}{2\Lambda t}w_A.\end{aligned}$$

Then, the profits of manufacturers are

$$\pi_A = w_A\left(\frac{\Lambda tH+\Lambda m+\mu}{2\Lambda t}-\frac{1+\Lambda+2\Lambda\alpha t}{2\Lambda t}w_A+\frac{1+\Lambda}{2\Lambda t}w_B\right),$$
$$\pi_B = w_B\left(\frac{\Lambda tH-\Lambda m-\mu}{2\Lambda t}-\frac{1+\Lambda+2\Lambda\alpha t}{2\Lambda t}w_B+\frac{1+\Lambda}{2\Lambda t}w_A\right).$$

Taking the first-order derivative with respect to w_A and w_B and solving equations $\partial\pi_A/\partial w_A = 0$ and $\partial\pi_B/\partial w_B = 0$ simultaneously, we get the equilibrium wholesale prices

$$\hat{w}_A = \frac{2H\Lambda t}{1+\Lambda+4\Lambda\alpha t}+\frac{\Lambda m+\mu}{3+3\Lambda+4\Lambda\alpha t},$$
$$\hat{w}_B = \frac{2H\Lambda t}{1+\Lambda+4\Lambda\alpha t}-\frac{\Lambda m+\mu}{3+3\Lambda+4\Lambda\alpha t}.$$

Accordingly, other results in Lemma 3.2 can be obtained.

With the same method, we derive the condition when the market sizes of the two consumer segments are positive. By solving $\hat{D}^j_{Al} > 0$ and $\hat{D}^j_{Br} > 0$ $(j = 1, 2)$, we get the following condition: $\max\{0, \mu_0\} < \mu < \overline{\mu}$, where $\overline{\mu} = \frac{\Lambda(2+\Lambda\alpha t)(4\Lambda\alpha t^2+3\Lambda t+3t+2m)}{2(4\Lambda^2\alpha^2t^2+3\Lambda^2\alpha t+6\Lambda\alpha t+3\Lambda+1)}$, $\mu_0 = \frac{(4\Lambda\alpha^2t^2+6\Lambda\alpha t+3\alpha t+\Lambda+3)m}{2+\alpha t}-\frac{(4\Lambda\alpha t+3\Lambda+3)t}{2}$. Accordingly, we have $max\{0, q_0\} < q < \overline{q}$, where $\overline{q} = \frac{\overline{\mu}-\theta m}{1-\theta}$ and $q_0 = \frac{\mu_0-\theta m}{1-\theta}$. □

With the lemmas above, we first discuss the impacts of online reviews on the pricing decisions of the retailer in the two periods.

Proposition 3.1. *In the presence of online reviews,*

(1) Product A's retail price in period 2 is higher than its price in period 1 (i.e., $\hat{p}^{(2)}_A > \hat{p}^{(1)}_A$) while product B's retail price in period 2 is lower than its price in period 1 (i.e., $\hat{p}^{(2)}_B < \hat{p}^{(1)}_B$) if and only if $q > q_1$.

(2) The price difference in period 2 is larger than price difference in period 1 if and only if $q > q_1$, where $q_1 = m\left(1+\frac{\lambda\alpha t}{(2+\alpha t)(1-\theta)}\right)$.

Proof. From Lemma 3.2, we have the equilibrium prices in the two periods for the scenario with online reviews. We first compare the prices of product A. We notice that $\hat{p}^{(2)}_A > \hat{p}^{(1)}_A$ if and only if $\hat{p}^{(2)}_A - \hat{p}^{(1)}_A = \frac{\mu}{2(2+\Lambda\alpha t)} - \frac{m}{2(2+\alpha t)} > 0$. Solving

this inequality, we have $\mu > \mu_1 = \frac{(2+\Lambda\alpha t)m}{\alpha t+2}$. Accordingly, we have $q < q_1 = \frac{\mu_1-\theta m}{1-\theta}$. Similarly, when $q > q_1$, we have $\hat{p}_B^{(2)} < \hat{p}_B^{(1)}$. Besides, we have $(\hat{p}_A^{(2)} - \hat{p}_B^{(2)}) - (\hat{p}_A^{(1)} - \hat{p}_B^{(1)}) = \frac{\mu}{(2+\Lambda\alpha t)} - \frac{m}{(2+\alpha t)}$. Thus, it is easy to find that the price difference in period 2 is larger than the price difference in period 1 if and only if $q > q_1$. Then, Proposition 3.1 holds. □

Proposition 3.1 shows that, in the presence of online reviews, whether the retailer should reduce or enlarge the price difference of the two products in period 2 depends on the quality difference of the two products reflected by online reviews. Specifically, if the quality difference inferred from online reviews is relatively large, the retailer can raise the price of product A but have to lower the price of product B. In other words, online reviews enlarge the price difference of the two products in the second period when the two products have a relative obvious quality difference. It is noted q_1 is always greater than m, which means that it is possible for the retailer to increase the price difference only when consumers underestimate the quality difference, and the lower the m, the higher the probability that the retailer can make the two products more price differentiated. We give clear description in Figure 3.1. For instance, if consumers' prior belief (m) is relatively large ($m = 1$), the retailer can set a higher price difference in period 2 only when q is also relatively large ($q > 1$). It can also be seen that the first-period price difference is more easily affected by consumers' prior belief on product quality difference (m).

Corollary 3.1. *In the presence of online reviews, the price difference of the products in period 1 decreases with λ if and only if $q > max\{q_2, 0\}$; the price difference of the products in period 2 decreases with λ if and only if $q > max\{q_3, 0\}$, where $q_2 = (\frac{3}{3+4\alpha t} - \theta)\frac{m}{1-\theta}$, and $q_3 = (\frac{3(2+\alpha t(1+\lambda))^2}{(20\alpha^3t^3+27\alpha^2t^2+9\alpha t)(1+\lambda)^2+(40\alpha^2t^2+30\alpha t)(1+\lambda)+25\alpha t+12} - \theta)\frac{m}{1-\theta}$.*

Proof. From Lemma 3.2, we have $\hat{p}_A^{(1)} - \hat{p}_B^{(1)} = \frac{(3+5\Lambda+5\Lambda\alpha t)m+(2+\alpha t)\mu}{(3+3\Lambda+4\Lambda\alpha t)(2+\alpha t)}$. Recall that $\Lambda = 1 + \lambda$. Then, by solving $\partial(\hat{p}_A^{(1)} - \hat{p}_B^{(1)})/\partial\lambda = 0$, we get the threshold value $q_2 = (\frac{3}{3+4\alpha t} - \theta)\frac{m}{1-\theta}$. It is easy to verify that when $q > q_2$, $\partial(\hat{p}_A^{(1)} - \hat{p}_B^{(1)})/\partial\lambda < 0$.

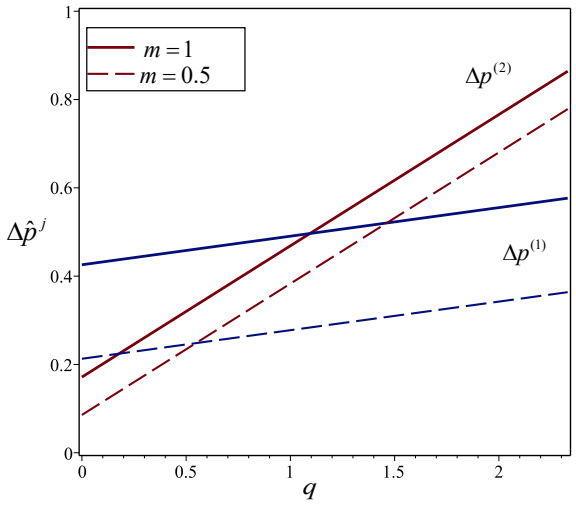


Figure 3.1: Impacts of online reviews on the price differences in the two periods $(\eta = 4, \alpha = 0.6, t = 2, \lambda = 0.2, \theta = 0.2)$

The impacts of λ on price differences of the products in period 2 can be obtained with the same logic. Thus, Corollary 3.1 holds. □

It is easy to verify that $q_2 > q_3$. Corollary 3.1 indicates that the impact of the informativeness of online reviews on setting price difference also has relationship with product quality difference. More specifically, if the two products have extremely small quality difference $(0 < q < q_3)$, more information online reviews provide, more likely the retailer can enlarge the price difference of the two products in each period. If q is relatively large $(q > q_2)$, the price difference in each period decreases with λ, which means that online reviews with more accurate information would would intensify the price competition of the two products.

Corollary 3.2. *In the presence of online reviews, product A's demand in period 2 is higher than its demand in period 1 if and only if $q > q_4$; while product B's demand in period 2 is lower than its demand in period 1 if and only if $q > q_4$, where* $q_4 = m\left(-\frac{\theta}{1-\theta} + \frac{(1+\lambda)(6+\lambda+4\alpha t+4\alpha\lambda t)}{(1-\theta)(6+5\lambda+4\alpha t+4\alpha\lambda t)}\right)$.

Proof. From Lemma 3.2, we have $\hat{D}_A^{(2)} - \hat{D}_A^{(1)} = \frac{(1+5\Lambda+4\Lambda\alpha t)(\theta m+(1-\theta)q)-(5+\Lambda+4\Lambda\alpha t)\Lambda m}{2(3+3\Lambda+4\Lambda\alpha t)\Lambda t}$. By solving $\hat{D}_A^{(2)} - \hat{D}_A^{(1)} > 0$, we get $q > q_4$. The relationship of $\hat{D}_B^{(2)}$ and $\hat{D}_B^{(1)}$ can be obtained with the same method. □

With simple comparison, we have $q_1 < q_4$. Combining Proposition 3.1 and Corollary 3.2, we find that if the quality difference between the two products is relatively obvious ($q > q_4$), although the retailer raises product A's price and reduces product B's price in period 2, quality difference plays a dominant role in affecting consumers' utilities and the obvious quality advantage of product A can offset the enlarged price difference between the two products, which makes some consumers shift from product B to product A.

To understand the impact of online reviews on pricing decisions of the manufacturers and the retailer, we compare the equilibrium results without and with online reviews.

Proposition 3.2. *When there exists online reviews, compared with the case without online reviews,*

(1) The wholesale price of product A is higher (i.e., $\hat{w}_A > w_A$) if and only if $q > max\{0, q_5\}$, where $q_5 = m\left(1 + \frac{2(\Lambda-1)\alpha t}{(1-\theta)(3+2\alpha t)}\right) - \frac{(\Lambda-1)(3+3\Lambda+4\alpha\Lambda t)tH}{2(1-\theta)(1+2\alpha t)(1+\Lambda+4\alpha\Lambda t)}$.

(2) The wholesale price of product B is higher (i.e., $\hat{w}_B > w_B$) if and only if $q < min\{\overline{q}, q_6\}$, where $q_6 = m\left(1 + \frac{2(\Lambda-1)\alpha t}{(1-\theta)(3+2\alpha t)}\right) + \frac{(\Lambda-1)(3+3\Lambda+4\alpha\Lambda t)tH}{2(1-\theta)(1+2\alpha t)(1+\Lambda+4\alpha\Lambda t)}$.

(3) The retail price of product A in period 1 is higher (i.e., $\hat{p}_A^{(1)} > p_A$) if and only if $q > max\{0, q_5\}$; the retail price of product A in period 2 is higher (i.e., $\hat{p}_A^{(2)} > p_A$) if and only if $q > max\{0, q_7\}$, where $q_7 = \frac{m(2+\Lambda\alpha t)(10\Lambda\alpha^2t^2+22\Lambda\alpha t+9\alpha t+9\Lambda+24)}{(1-\theta)(2+\alpha t)(3+2\alpha t)(5+3\Lambda+5\Lambda\alpha t)} - \frac{m\theta}{1-\theta} - \frac{(\Lambda-1)(2+\Lambda\alpha t)(4+3\Lambda+4\Lambda\alpha t)tH}{(1-\theta)(1+2\alpha t)(1+\Lambda+4\Lambda\alpha t)(5+3\Lambda+5\Lambda\alpha t)}$.

(4) The retail price of product B in period 1 is higher (i.e., $\hat{p}_B^{(1)} > p_B$) if and only if $q < min\{\overline{q}, q_6\}$; the retail price of product B in period 2 is higher (i.e., $\hat{p}_B^{(2)} > p_B$) if and only if $q < min\{\overline{q}, q_8\}$, where $q_8 = \frac{m(2+\Lambda\alpha t)(10\Lambda\alpha^2t^2+22\Lambda\alpha t+9\alpha t+9\Lambda+24)}{(1-\theta)(2+\alpha t)(3+2\alpha t)(5+3\Lambda+5\Lambda\alpha t)} - \frac{m\theta}{1-\theta} + \frac{(\Lambda-1)(2+\Lambda\alpha t)(4+3\Lambda+4\Lambda\alpha t)tH}{(1-\theta)(1+2\alpha t)(1+\Lambda+4\Lambda\alpha t)(5+3\Lambda+5\Lambda\alpha t)}$.

Proof. We first derive the condition under which manufacturer A charger a higher wholesale price with online reviews (i.e., $\hat{w}_A > w_A$). From the results in Lemma 3.1

and Lemma 3.2, we notice that $\hat{w}_A > w_A$ if and only if $\hat{w}_A - w_A = \frac{\theta m+(1-\theta)q}{3+3\Lambda+4\Lambda\alpha t} - \frac{(3+2\Lambda\alpha t)m}{(3+3\Lambda+4\Lambda\alpha t)(3+2\alpha t)} + \frac{(\Lambda-1)tH}{(1+\Lambda+4\Lambda\alpha t)(1+2\alpha t)} > 0$. Solving this inequality, we have $q > q_5 = m\left(1+\frac{2(\Lambda-1)\alpha t}{(1-\theta)(3+2\alpha t)}\right) - \frac{(\Lambda-1)(3+3\Lambda+4\alpha\Lambda t)tH}{2(1-\theta)(1+2\alpha t)(1+\Lambda+4\alpha\Lambda t)}$. We verify that q_3 is always smaller than $\overline{q}$, but it can be greater or smaller than 0.

Similarly, it is easy to obtain $\hat{w}_B - w_B = -\frac{\theta m+(1-\theta)q}{3+3\Lambda+4\Lambda\alpha t} + \frac{(3+2\Lambda\alpha t)m}{(3+3\Lambda+4\Lambda\alpha t)(3+2\alpha t)} + \frac{(\Lambda-1)tH}{(1+\Lambda+4\Lambda\alpha t)(1+2\alpha t)} > 0$, from which we have $q < q_6$, where $q_6 = m\left(1+\frac{2(\Lambda-1)\alpha t}{(1-\theta)(3+2\alpha t)}\right) + \frac{(\Lambda-1)(3+3\Lambda+4\alpha\Lambda t)tH}{2(1-\theta)(1+2\alpha t)(1+\Lambda+4\alpha\Lambda t)}$. With the same method, we can get other results in Proposition 3.2. □

Noted that $q_5 < q_7 < q_1 < q_8 < q_6$. Proposition 3.2 first indicates that online reviews affect the pricing decisions in the upstream. For manufacturer A, when the quality difference exceeds some degree ($q > \max\{0, q_5\}$), online reviews would reflect the quality advantage of product A. In this case, it is possible for manufacturer A to charge a higher wholesale price. Besides, manufacturer B also has some space to improve the wholesale price of product B as long as the quality difference is not very large ($q < \min\{q_6, \overline{q}\}$). In other words, online reviews may reduce the pricing competition in the upstream and allow both manufacturers to charge higher wholesale prices at the same time. Moreover, Proposition 3.2 reveals that in the presence of online reviews, the retail prices of the two products in the two periods can be higher or lower, depending on the quality difference of the two products.

Corollary 3.3. *In the presence of online reviews, all prices are higher with online reviews and consumers are worse off with online reviews when* $max\{0, q_7\} < q < min\{q_8, \overline{q}\}$.

Proof. From Proposition 3.2, it is easy to find that when $q > \min\{0, q_7\}$, we have $\hat{p}_A^{(1)} > p_A$ and $\hat{p}_A^{(2)} > p_A$. Besides, when $q < min\{\overline{q}, q_8\}$, we have $\hat{p}_B^{(1)} > p_B$ and $\hat{p}_B^{(2)} > p_B$. Therefore, when $\max\{0, q_7\} < q < \min\{q_8, \overline{q}\}$, all prices with online reviews are higher than without online reviews. □

Intuitively, consumers may benefit from online reviews because that online reviews provide more information for consumers to reduce the uncertainty of product quality and learn the true quality difference of the products. However, Corollary 3.3 indicates that this may not always be true. In other words, consumers may be worse off because that when $\max\{0, q_7\} < q < \min\{q_8, \overline{q}\}$, because all prices are higher with online reviews in this interval. Moreover, $(q_8 - q_7)$ increases with λ, which means that under this scenario, more information actually makes consumers pay higher prices for each product. This finding is also consistent with the study of Jiang and Yang (2019). The reason is that more informative online reviews actually soften the competition between the manufacturers, which leads to the higher wholesale prices and the higher profits of manufacturers. With the increased wholesale prices, the retailer has to raise the retail prices as well, which inevitably make consumers pay higher prices for the products.

In the next, we turn to the impact of online reviews on the profits of the retailer and the manufacturers.

Proposition 3.3. *In the presence of online reviews, compared with the case without online reviews, the manufacturers and the retailer are not always better off or worse off. Specifically,*

(1) The profit of manufacturer A is higher (i.e., $\hat{\pi}_A > \pi_A$) if and only if $q > max\{0, Q_1\}$, where $Q_1 = \frac{m}{1-\theta}\left(\frac{(3+3\Lambda+4\Lambda\alpha t)\sqrt{\gamma_1}}{3+2\alpha t} - \Lambda - \theta\right) + \frac{tH}{1-\theta}\left(\frac{(3+3\Lambda+4\Lambda\alpha t)\sqrt{\gamma_1}}{1+2\alpha t} - \frac{2(3+3\Lambda+4\Lambda\alpha t)\Lambda}{1+\Lambda+4\Lambda\alpha t}\right)$.

(2) The profit of manufacturer B is higher (i.e., $\hat{\pi}_B > \pi_B$) if and only if $q < min\{\overline{q}, Q_2\}$, where $Q_2 = \frac{m}{1-\theta}\left(\frac{(3+3\Lambda+4\Lambda\alpha t)\sqrt{\gamma_1}}{3+2\alpha t} - \Lambda - \theta\right) - \frac{tH}{1-\theta}\left(\frac{(3+3\Lambda+4\Lambda\alpha t)\sqrt{\gamma_1}}{1+2\alpha t} - \frac{2(3+3\Lambda+4\Lambda\alpha t)\Lambda}{1+\Lambda+4\Lambda\alpha t}\right)$.

(3) The profit of the retailer is lower with online reviews (i.e., $\hat{\pi}_A > \pi_A$) if $q < min\{Q_3, \overline{q}\}$, where $Q_3 = \frac{m}{1-\theta}\left(-\theta + \frac{2\gamma_3}{\gamma_2}\right) + \frac{1}{1-\theta}\sqrt{\frac{2(1+\alpha t)^2 m^2}{t(2+\alpha t)(3+2\alpha t)^2\gamma_2} - \frac{(\Lambda\gamma_2+2\gamma_3)((2+\Lambda\alpha t)\gamma_2 - 2(2+\alpha t)\gamma_3)m^2}{(2+\alpha t)\gamma_2^2} + \frac{2\gamma_4 H^2}{\gamma_2}}$.

Here, $\gamma_1 = \frac{2\Lambda(1+\alpha t)}{1+\Lambda+2\Lambda\alpha t}$, $\gamma_2 = \frac{10\Lambda^2\alpha^2t^2+20\Lambda^2\alpha t+8\Lambda\alpha t+9\Lambda^2+10\Lambda+1}{\Lambda t(2+\Lambda\alpha t)(3+3\Lambda+4\Lambda\alpha t)^2}$, $\gamma_3 = \frac{2+2\Lambda+3\Lambda\alpha t}{t(3+3\Lambda+4\Lambda\alpha t)^2}$, $\gamma_4 = \frac{(\Lambda-1)t(8\Lambda\alpha^2t^2+9\Lambda\alpha t+3\alpha t+2\Lambda+2)}{(1+2\alpha t)^2(1+\Lambda+4\Lambda\alpha t)^2}$.

Proof. From Lemma 3.1 and Lemma 3.2, we first compare the profits of manufacturer A. Specifically, we have $\Delta\pi_A = \hat{\pi}_A - 2\pi_A = \frac{(1+\Lambda+2\Lambda\alpha t)\left(2(3+3\Lambda+4\Lambda\alpha t)\Lambda tH+(1+\Lambda+4\Lambda\alpha t)(\Lambda m+\mu)\right)^2}{(1+\Lambda+4\Lambda\alpha t)^2(3+3\Lambda+4\Lambda\alpha t)^2\Lambda t} - \frac{((3+2\alpha t)tH+(1+2\alpha t)m)^2(1+\alpha t)}{8t(1+2\alpha t)^2(3+2\alpha t)^2}$. We notice that Δ_{π_A} is increasing with μ because $\frac{\partial\Delta_{\pi_A}}{\partial\mu} = \frac{\left(2(3+3\Lambda+4\Lambda\alpha t)\Lambda tH+(1+\Lambda+4\Lambda\alpha t)(\Lambda m+\mu)\right)(1+\Lambda+2\Lambda\alpha t)}{(1+\Lambda+4\Lambda\alpha t)(3+3\Lambda+4\Lambda\alpha t)^2\Lambda t} > 0$, which means $\Delta\pi_A$ is increasing with q.

Then, by solving $\Delta\pi_A = 0$, we have the unique threshold value $M_1 = \left(\frac{(3+3\Lambda+4\Lambda\alpha t)\gamma_1}{3+2\alpha t}-\Lambda\right)m+\left(\frac{(3+3\Lambda+4\Lambda\alpha t)\gamma_1}{1+2\alpha t}-\frac{2(3+3\Lambda+4\Lambda\alpha t)\Lambda}{1+\Lambda+4\Lambda\alpha t}\right)tH$, where $\gamma_1 = \sqrt{\frac{2\Lambda(1+\alpha t)}{1+\Lambda+2\Lambda\alpha t}}$. Accordingly, $Q_1 = \frac{M_1-\theta m}{1-\theta}$. We verified that Q_1 is always smaller than $\overline{q}$ but we are not sure whether it is greater or smaller than 0. Next, for manufacturer B, we have $\Delta\pi_B = \hat{\pi}_B - 2\pi_B = \frac{(1+\Lambda+2\Lambda\alpha t)\left(2(3+3\Lambda+4\Lambda\alpha t)\Lambda tH-(1+\Lambda+4\Lambda\alpha t)(\Lambda m+\mu)\right)^2}{(1+\Lambda+4\Lambda\alpha t)^2(3+3\Lambda+4\Lambda\alpha t)^2\Lambda t} - \frac{((3+2\alpha t)tH-(1+2\alpha t)m)^2(1+\alpha t)}{8t(1+2\alpha t)^2(3+2\alpha t)^2}$. We notice that $\Delta\pi_B$ is decreasing with μ because $\frac{\partial\Delta_{\pi_B}}{\partial\mu} = -\frac{\left(2(3+3\Lambda+4\Lambda\alpha t)\Lambda tH-(1+\Lambda+4\Lambda\alpha t)(\Lambda m+\mu)\right)(1+\Lambda+2\Lambda\alpha t)}{(1+\Lambda+4\Lambda\alpha t)(3+3\Lambda+4\Lambda\alpha t)^2\Lambda t} < 0$, which means Δ_{π_B} is decreasing with q. Then, by solving $\Delta_{\pi_B} = 0$, we have the unique threshold value $M_2 = \left(\frac{(3+3\Lambda+4\Lambda\alpha t)\gamma_1}{3+2\alpha t}-\Lambda\right)m-\left(\frac{(3+3\Lambda+4\Lambda\alpha t)\gamma_1}{1+2\alpha t}-\frac{2(3+3\Lambda+4\Lambda\alpha t)\Lambda}{1+\Lambda+4\Lambda\alpha t}\right)tH$, where $\gamma_1 = \sqrt{\frac{2\Lambda(1+\alpha t)}{1+\Lambda+2\Lambda\alpha t}}$. Accordingly, $Q_2 = \frac{M_2-\theta m}{1-\theta}$. We verify that $Q_2 > 0$ but we are not sure whether it is greater or smaller than $\overline{q}$.

In the next, we compare the profits of the retailer with and without online reviews. In specific, we have $\Delta\pi_R = \hat{\pi}_R^{(1)} + \hat{\pi}_R^{(2)} - 2\pi_R = \frac{(1+\Lambda+2\Lambda\alpha t)^2H^2}{(1+\Lambda+4\Lambda\alpha t)^2\alpha} + \frac{\left((3+\Lambda+3\Lambda\alpha t)m-(2+\alpha t)\mu\right)^2}{2t(2+\alpha t)(3+3\Lambda+4\Lambda\alpha t)^2} + \frac{\left(\Lambda(2+\Lambda\alpha t)m-(1+3\Lambda+3\Lambda\alpha t)\mu\right)^2}{2\Lambda t(2+\Lambda\alpha t)(3+3\Lambda+4\Lambda\alpha t)^2} - \frac{(1+\alpha t)^2H^2}{\alpha(1+2\alpha t)^2} - \frac{(1+\alpha t)^2m^2}{t(2+\alpha t)(3+2\alpha t)^2}$. We rewrite $\Delta\pi_R$ as $\Delta\pi_R = Aq^2 + Bq + C(m)$, where $A = \frac{(1-\theta)^2\gamma_2}{2}$, $B = (1-\theta)(\theta\gamma_2-2\gamma_3)m$, $C(m) = \left((\theta^2+\frac{\Lambda(2+\Lambda\alpha t)}{2+\alpha t})\frac{\gamma_2}{2} - 2(\theta+\frac{\Lambda-1}{2+\alpha t})\gamma_3 - \frac{(1+\alpha t)^2}{(2+\alpha t)(3+2\alpha t)^2t}\right)m^2 - \gamma_4H^2$, $\gamma_2 = \frac{10\Lambda^2\alpha^2t^2+20\Lambda^2\alpha t+8\Lambda\alpha t+9\Lambda^2+10\Lambda+1}{\Lambda t(2+\Lambda\alpha t)(3+3\Lambda+4\Lambda\alpha t)^2}$, $\gamma_3 = \frac{2+2\Lambda+3\Lambda\alpha t}{t(3+3\Lambda+4\Lambda\alpha t)^2}$, $\gamma_4 = \frac{(\Lambda-1)t(8\Lambda\alpha^2t^2+9\Lambda\alpha t+3\alpha t+2\Lambda+2)}{(1+2\alpha t)^2(1+\Lambda+4\Lambda\alpha t)^2}$.

With the conditions analyzed before, we find that $C(m)$ is always negative.

Moreover, we verify that $B^2 - 4AC > 0$ and $-\frac{B}{2A} > 0$, which means when $q > 0$, there have a unique root Q_3 that to ensure that $\Delta_{\pi_R} > 0$. Mathematically, $Q_3 = \frac{1}{1-\theta}\left((-\theta + \frac{2\gamma_3}{\gamma_2})m + \sqrt{\frac{2(1+\alpha t)^2 m^2}{t(2+\alpha t)(3+2\alpha t)^2\gamma_2} - \frac{(\Lambda\gamma_2+2\gamma_3)((2+\Lambda\alpha t)\gamma_2-2(2+\alpha t)\gamma_3)m^2}{(2+\alpha t)\gamma_2^2} + \frac{2\gamma_4 H^2}{\gamma_2}}\right)$.

□

Moreover, we verify that $Q_1 < Q_2 < Q_3$. Proposition 3.3 first shows that online reviews may not always favor manufacturer A or hurt manufacturer B. In specific, manufacturer A is better off when the quality difference is relatively large ($q > \max\{0, Q_1\}$). As analyzed before, in this scenario, online reviews show the quality advantage of product A in the second period and thus manufacturer A has a higher incentive to raise the wholesale price, leading to a higher profit of manufacturer A. Besides, larger quality difference between the two products makes the positive effect for manufacturer A more significant. That means manufacturer A has a higher probability to charge a higher price and gain more profit. Counter intuitively, manufacturer B also has the chance to benefit from online reviews (when $q < \min\{\overline{q}, Q_2\}$), and the narrower the quality gap between the two product, the more likely manufacturer B has a profit advantage.

More interestingly, Proposition 3.3 indicates that it is likely for the competing manufacturers to benefit from online reviews at the same time. In other words, when the quality difference is moderate ($\max\{0, Q_1\} < q < \min\{\overline{q}, Q_2\}$), online reviews can ease the competition in the upstream. In this situation, manufacturer A mainly benefits from its quality advantage; manufacturer B is safe to increase its wholesale price to some degree because the addition of online reviews plays a dominant role in reducing consumers' location uncertainty. That is, under this scenario, online reviews reduce the price competition in the upstream. Hence, the reduced competition in the upstream increases their wholesale prices as well as their profits. Moreover, $Q_2 - Q_1$ is always increasing with λ. That is, more informative online reviews are beneficial to both manufacturers. Proposition 3.3 further indicates that the retailer can be better off or be harmed in the presence

of online reviews. To better understand the scenario under which the retailer can benefit from online reviews, we derive the condition when $Q_3 < \overline{q}$.

Corollary 3.4. *In the presence of online reviews, the retailer gains more profit from online reviews if and only if* $0 < \lambda < min\{\lambda_1, 1\}, 0 < m < m_1$ *and* $q > Q_3$.

Proof. We derive the condition under which $Q_3 < \overline{q}$. We let $\gamma_5 = \frac{\Lambda(2+\Lambda\alpha t)}{4\Lambda^2\alpha^2t^2+3\Lambda^2\alpha t+6\Lambda\alpha t+3\Lambda+1}$. Therefore, we have $\delta_1 = \overline{q} - Q_3 = \overline{q} = \frac{1}{1-\theta}\left((-\theta+\gamma_5)m + \frac{1}{2}t\gamma_5(3+3\Lambda+4\Lambda\alpha t)\right) - Q_3$. We verify that $\partial\delta_1(m)/\partial m < 0$, which means δ_1 is decreasing in m. Besides, when $m = \overline{m}$, we have $\delta_1(0) < 0$. Therefore, to ensure the possibility of $\delta_1(m) > 0$, we need to ensure $\delta_1(0) > 0$. We let $f(\lambda) = \delta_1(0) = \frac{1}{2}t\gamma_5(3+3(1+\lambda)+4(1+\Lambda)\alpha t) - \sqrt{\frac{2\gamma_4}{\gamma_2}}$. It is easy to verify that $f(\lambda)$ decreases with λ and $f(0) > 0$. Therefore, there always exists λ_1, when $0 < \lambda < \min\{\lambda_1, 1\}$, we have $f(\lambda) > 0$. Further, under this scenario, there exists m_1, when $0 < m < m_1$ and $q > Q_3$, we have $\Delta\pi_R > 0$. □

Because of the complexity of the expression of m_1 and λ_1, we do not give the mathematical expression here. Rather, we use Figure 3.2 to illustrate the impacts of online reviews on the retailer by considering different parameters. It is easy to find that only when λ is smaller than some threshold and m is also quite small (consumers tend to believe the quality difference is extremely small but online reviews show significant quality difference), online reviews may play a positive effect on the retailer. In this scenario, the retailer can increase the retail price of product A in both periods. Although a higher first-period retail price of product A may result in the reduced demand in the first period, the dominated quality advantage of product A would attract more consumers in the second period even if the second-period price of product A is quite high. Therefore, when the quality difference is extreme obvious, the gain in period 2 can outweigh the loss in period 1.

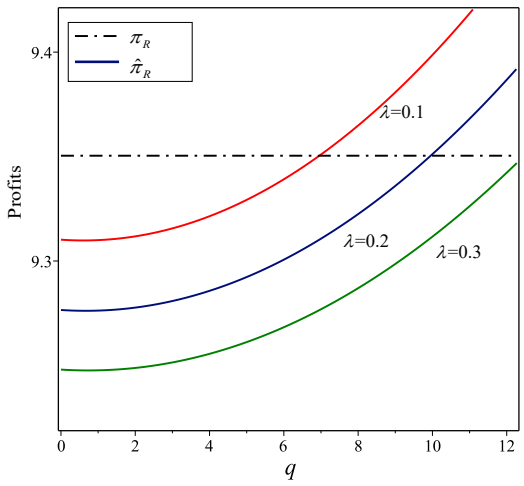


Figure 3.2: Impacts of online reviews on the retailer's profit
($\eta = 4, \alpha = 0.6, t = 15, m = 1, \theta = 0.2$)

3.4 Conclusions

This chapter investigates the influence of online reviews in a channel structure in which two competing manufacturers sell differentiated products through a retailer. By a two-period analytical model, we show that online reviews play important roles in affecting the pricing decisions and profitability of the manufacturers and the retailer. We highlight some insights in the following.

First, we show that in the presence of online reviews, the retailer should adjust the prices of the products in the second period, which can be lower or higher, depending on the quality difference of the two products. The larger the quality difference, the higher the probability that the retailer can increase the price difference in the second period. Moreover, we find that consumers may have to pay higher prices in the presence of online reviews, especially with online reviews with a higher informativeness. This is because when the quality difference reflected by online reviews is not very significant, an increase of the informativeness plays more important roles in reducing the price competition between the manufacturers, which leads to the increase of the wholesale prices of both products. To react to the higher wholesale prices, the retailer would also raise both products' retail prices. We further show that the impact of the informativeness of online reviews

also has a relationship with the quality difference of the two products.

Second, our results indicate that online reviews affect the pricing decisions of the competing manufacturers. In specific, online reviews may intensify or ease the pricing competition in the upstream. Interestingly, the competing manufacturers have the chance to be better off simultaneously. That is, when the two products have a moderate quality difference, online reviews play positive roles for both manufacturers, leading to the higher wholesale prices and the higher profits. Moreover, the higher informativeness of online reviews, the more likely that they can gain more profits at the same time.

Third, we show that compared to the manufacturers, the retailer is less likely to benefit from online reviews. In fact, only when online reviews reveal significantly obvious quality difference relative to consumers' prior beliefs, can the retailer gain more profits from online reviews. In addition, contrary to the popular belief, more informative online reviews tend to harm the profitability of the retailer.

Overall, our study adds the impact of online reviews into the literature stream of channel competition and especially fits to a setting that competing manufacturers and the retailer can adjust their prices dynamically. We demonstrate that it is critical for the manufacturers to gain a deeper understanding of impacts of online reviews (the average and the informativeness) on the pricing decisions and the profitability. So, they can strategically react to different scenarios. From the retailer's perspective, our results suggest that the impact of online reviews is associated with the degree of product quality differentiation. The retailer is more likely to benefit from online reviews if online reviews show obvious quality difference but consumers' prior beliefs indicate a limited quality difference. Moreover, the retailer may be harmed by more informative online reviews. These results give some enlightenment for the retailer to design the review platform. For instance, it is better for the retailer to take the quality difference into consideration, and it is not always wise for the retailer to encourage consumers to give more informative

reviews to show their preferences.

Chapter 4

Promotions of online reviews from a channel perspective

4.1 Introduction

It is widely acknowledged that consumers today heavily rely on online reviews to make purchasing decisions (Sen and Lerman 2007, Park and Kim 2008, Schlosser 2011). Recognizing the widespread influence of online reviews, firms increasingly adjust their marketing strategy to response to this powerful information, and tend to investigate the factors that drive consumers' communication in terms of online reviews. For example, Resnick et al. (2000) support the idea that the informativeness of online reviews may be affected by some self-interested factors. Similarly, numerous evidences suggest that consumers' motivation of posting online reviews can be affected by high level of satisfaction or trust (Anderson and Sullivan 1993, Maxham III and Netemeyer 2002, Gvili and Levy 2016, Kim et al. 2009, Oliver 1980). Differently, Hennig-Thurau et al. (2004) and Wang et al. (2009) show that incentives play important roles in consumers' decision of giving online reviews. Picazo-Vela et al. (2010) indicate that the consumers' intention of generating online reviews has relationship with the perceived pressure, the degree of push that consumers perceived, such as follow-up invitation and calls. Some other scholars illustrate that consumers' conversation behaviors are affected by the linguistic

style of customer reviews (Chaiken and Maheswaran 1994, Ireland and Pennebaker 2010, Menon and Blount 2003).

With the fact that online environment has a nature of anonymity (Dellarocas 2003, Goldsmith and Horowitz 2006, Ku et al. 2012) and consumers' engagement of posting online reviews is likely to be affected, a growing number of firms pay attention to the manipulations or the promotions of online reviews, by different forms. For example, many retailers in Taobao.com or Jingdong.com offer financial incentives, rewards or coupons to the consumers to encourage them to give positive online reviews. Besides, providing a high service quality and building a good reputation may also be treated as one form of promotion strategies to improve consumers' intention of giving favorable reviews (Lacey 2012, Melián-González et al. 2013, Yacouel and Fleischer 2012). Moreover, taking a more extreme form, some firms even post fake reviews on their websites to boost positive reviews. A famous incident in 2004 was that Amazon.com' Canadian site once revealed that a lot of book reviews were written by books' publishers (Harmon 2004). Coincidentally, in 2011, the New York Times revealed that firms on an Amazons-owned crowed sourcing marketplace hired workers to post fake 5-star Yelp reviews, as little as 25 cents per view (Segal 2011).

Promotions or manipulations of online reviews, therefore, inevitably have received increasing attentions from academic researchers. Numerous research shows that this phenomenon is a growing practice in different areas, such as book (Northrup 2009), music (Mayzlin 2006) and tourism market(Gössling et al. 2018). Some researchers empirically examine the impacts of manipulations on consumers' purchase decisions (Burtch et al. 2018, Hu et al. 2012, Luca and Zervas 2016). Others also explore how manipulations affect firms' strategies. For example, Dellarocas (2006) points out that strategic manipulations of online reviews may increase the information value of reviews to consumers under some conditions. Ryu and Feick (2007) indicate that reward programs influence the referral likelihood and

suggest that firms should pay attention to the design of reward program. Aral and Walker (2011) conduct a large scale field experiment to show that viral features can lead to identifiable peer influence. Mayzlin et al. (2014) empirically examine the effect of promotional reviews by comparing online reviews on Expedia.com and TripAdvisor.com. Recently, Burtch et al. (2018) show that offering financial incentives can stimulate consumers to give more favorable reviews. They find that businesses with low reputations are more likely to manipulate reviews.

It is noted that most previous studies above are empirical and focus on single-vendor scenario. In practice, a lot of products are delivered through a distribution channel with one manufacturer and one retailer. Therefore, the interaction between the manufacturer and the retailer plays a significant role in supply chain management. In fact, we are inspired by the literature considering cooperative advertising and pricing problem in a distribution channel. In recent years, cooperative advertising has been treated as a powerful strategy in marketing channels in which one party undertake a certain fraction of advertising expenditure for its partner. Such practice has been widely addressed by researchers (Karray and Zaccour 2006, Xie and Ai 2006, Szmerekovsky and Zhang 2009, Yan 2010, Karray 2015, 2013, Yan et al. 2016, Ahmadi-Javid and Hoseinpour 2018). We go beyond these studies by considering cooperative promotions of online reviews in a distribution channel consisting one manufacturer and one retailer. We seek to understand whether the promotion of reviews is always wise for the retailer and whether the manufacturer can be better off with this strategy.

In this chapter, we offer theoretical analysis of the implications of promotions from a channel perspective. It is worth noting that, in order to avoid some business ethics, we assume that promotions of online reviews referred here are some reasonable strategies that increase consumers' positive feedback in exchange for payment. In other words, we do not consider some strategies like posting fake reviews or deleting negative reviews. In particular, we consider a supply chain with

a manufacturer and a retailer; the manufacturer sells the product to the retailer and the retailer distributes the product to end consumers. Two channel structures, the centralized channel and decentralized channel, are analyzed. We assume that online reviews are presented to enable consumers to estimate their valuations of the product. In particular, two metrics of online reviews are considered: average rating of reviews and the variance of reviews. The average rating measures consumers' average assessment of the product value, while the variance captures the inconsistency among reviews (i.e., how much consumers differ in their preferences) (Moe and Trusov 2011, Sun 2012). For example, a product with the average rating of 3 out 5 may be accomplished by either low-variance reviews (e.g., all consumers rate 3 out 5) or a high-variance reviews (e.g., half of consumers rate 1 out 5 and the other half rate 5 out 5). Following Dellarocas (2006), we assume that the retailer can take some promotion strategies to improve the average rating in a reasonable range, at a cost. This is because the average rating tends to indicate the favorability of the product. It is also well documented that consumers prefer products with high average ratings (Sen and Lerman 2007, Vermeulen and Seegers 2009, Purnawirawan et al. 2015, Nieto-García et al. 2017, De Pelsmacker et al. 2018). For example, Anderson and Magruder (2012) show that even a half-star difference of the average rating can influence the product sales dramatically. However, it is worth highlighting that, in the process of promoting the average rating, the variance may be changed as well, which can be higher or lower. In particular, the variance may decrease if the retailer targets consumers who give extremely low rate but increase if the retailer targets the consumers who give moderate rates. Therefore, it is necessary to take the impacts of the variance when the retailer and the manufacturer invest in the promotions of the average of reviews.

We present the following findings. First, when promotions of online reviews lead to a reduction of variance, the demand of the product can be improved, no matter which channel structure is taken. However, a greater variance may impair the demand although promotions can lead to a more favorable average

rating. It is interesting to find that the impact of promotions of reviews on the demand of the centralized channel is easier to be affected by the product quality. Second, the retailer can charge a higher retail price under the two channels if the variance increases or decreases slightly; otherwise, whether the retailer should set a higher or lower price depends on the product quality. Third, our results indicate that it is not always necessary for the retailer to engage in promotions of online reviews since that the retailer can be hurt by the promotion strategy under some scenarios. More specifically, it is better for the retailer selling relative low-quality product to ensure a higher variance in the process of review promotions. Differently, for the retailer who carries a relatively high-quality product, too high variance may undermine the efficiency of promotions of online reviews. Contrary to the conventional wisdom, we demonstrate that it is possible for consumers, the retailer and the manufacturer to enjoy the positive impact of promotions of online reviews simultaneously. Last but not least, we show that under the decentralized channel, the manufacturer has a higher probability to benefit from the promotions than the retailer. Moreover, the manufacturer under the decentralized channel is more likely to be better off than the manufacturer under the centralized channel. Differently, the retailer under the centralized setting is more safe to engage in promotions of online reviews that the retailer under the decentralized setting.

This chapter proceeds as follows. We propose the basic models in section 4.2. Section 4.3 and section 4.4 analyze the implications of promotions of online reviews under the centralized and decentralized channel structures, respectively. Section 4.5 compares some results under the two channel structures. We conclude with some managerial implications in section 4.6.

4.2 Model

Consider a manufacturer-retailer supply chain where the manufacturer sells one product to the retailer at a unit wholesale price w and the retailer distributes the

product to end consumers at a unit retail price p. Following Dellarocas (2006) and Sun (2012), we assume that the product has two components: a vertical component (quality) and a horizontal component. In specific, the quality captures the attribute of the product whose valuation is identical among consumers and a higher quality always means a higher willingness-to-pay of consumers. For example, consumers all prefer the digital camera with a better durability. A horizontal component reveals the inconsistency of the reviews. For instance, consumers may want different colors when they purchase smart phones or clothes.

In consistent with Li (2017), we make a basic assumption that consumers tend to believe that the average rating of online reviews represents the true product quality q while the review variance indicates the inconsistency of online reviews. We use q_i to indicate the value of product to consumer i, and thus q_i follows a uniform distribution $[q-a, q+a]$, where a captures the review variance. Thus, the utility of consumer i is $q_i - p$, where p is the price of the product. Then, we can characterize the demand function as follows:

$$D = \frac{q + a - p}{2a} \tag{4.1}$$

4.2.1 Promotions of online reviews

Following Dellarocas (2006), we focus on promotions of online reviews because of the anonymity of reviews. Without loss of generality, we assume that the retailer can encourage consumers to give more positive reviews, at some costs. For example, the retailer can give some rewards or rebates to consumers. It is noted that we restrict the range of review promotions, which means that the retailer only affects a small scope of consumers in a reasonable and acceptable range. Mathematically, we assume that the retailer can increase consumers' perception of product quality by increasing the average rating of online reviews from q to $q + \eta$ at total cost $\frac{c}{2}\eta^2$, where c captures the cost efficiency of promotions of online reviews. Besides, the promotions of average rating would also change the

variation of online reviews from a to b. Therefore, with the promotions of online reviews, consumers' perceived quality of the product follows a uniform distribution $[q+\eta-b, q+\eta+b]$. Then, the demand function with promotions of online reviews can be obtained as

$$D^M = \frac{q+\eta+b-p}{2b} \tag{4.2}$$

Further, in consistent with Li (2017), we assume that the market is not fully covered, with or without promotions, and the promotions of the average rating are restricted in a moderate range. Thus, for convenience, we have $0 < q < 1, 0 < \eta < 1, a \geq 2$ and $b \geq 2$.

4.3 Promotions under the centralized supply structure

In this section, we consider the channel integration, that is, the manufacturer and the retailer act as a system to maximize the joint channel profit. To better understand the impact of promotions of online reviews, we treat the case without promotions of reviews as the benchmark. In this scenario, the manufacturer and the retailer set the retail price (p_c) to maximize the channel profit (π_c). For simplicity, we assume the marginal cost for each demand is zero.

Then we consider the case with promotions of online reviews. In specific, in the presence of the promotions, the channel should decide the retail price p_c^M and the degree of manipulation η at the same time to maximize the channel profit π_c^M. Hence, with the above demand functions (Equation (4.1) and Equation (4.2)), we can formulate the profit without manipulation π_c and with manipulation π_c^M as follows, respectively.

$$\pi_c(p_c) = \frac{(q+a-p_c)p_c}{2a} \tag{4.3}$$

$$\pi_c^M(p_c^M, \eta_c) = \frac{(q+\eta_c+b-p_c^M)p_c^M}{2b} - \frac{c\eta_c^2}{2} \tag{4.4}$$

We first give the equilibrium results without and with promotions in the centralized structure in the following lemmas.

Lemma 4.1. *The equilibrium retail price, the demand, the channel profit without promotions of online reviews in the centralized structure are as follows.*

$$p_c = \frac{q+a}{2}, \quad D_c = \frac{q+a}{4a}, \quad \pi_c = \frac{(q+a)^2}{8a}.$$

Lemma 4.2. *The equilibrium retail price, the demand, the channel profit with promotions of online reviews in the centralized structure are as follows.*

$$\eta_c = \frac{q+b}{4bc-1}, \quad p_c^M = \frac{2(q+b)bc}{4bc-1}, \quad D_c^M = \frac{(q+b)c}{4bc-1}, \quad \pi_c^M = \frac{(q+b)^2 c}{2(4bc-1)}.$$

Proof. Lemma 4.1 presents the equilibrium results of the benchmark without review promotions. Recall that the profit function in the centralized channel is presented as Equation (4.3). By solving the first-order conditions of Equation (4.3) for p_c, we obtain the equilibrium price $p_c = \frac{q+a}{2}$. Substituting it into the demand function (Equation (4.1)) and the profit function (Equation (4.3), we get the results in Lemma 4.1.

With the same method, we derive the results with promotions of online reviews. Recall that the profit function with promotions of online reviews in the centralized channel is presented as Equation(4.4). By solving the first-order condition of Equations (4.4) for p_c^M and η_c, we obtain the equilibrium price $p_c^M = \frac{2(q+b)bc}{4bc-1}$ and the promotion level of average rating $\eta_c = \frac{q+b}{4bc-1}$. Substituting them into the demand function (Equations (4.2)) and the profit function (Equation (4.4)), we obtain the results in Lemma 4.2. Here, to ensure that $0 < \eta < 1$ always holds and to keep the analysis simple without affecting the key findings, we impose the condition of $c > \frac{1}{2}$ throughout this chapter. □

By comparing the equilibrium results in Lemma 4.1 and Lemma 4.2, we derive the influence of promotions of online reviews under the centralized structure.

Proposition 4.1. *Under the centralized structure,*

(1) The retail price with promotions of online reviews is lower than without (i.e., $p_c^M < p_c$) if and only if $c > max\{1/2, c_{c1}\}$, $b < b_{c1}$ and $q < min\{1, q_{c1}\}$; in other cases, $p_c^M \geq p_c$.

(2) The demand with promotions of online reviews is higher than without (i.e., $D_c^M > D_c$) if $b < b_{c2}$, or if $b > b_{c2}$ and $q < q_{c2}$.

$$c_{c1} = \frac{a}{8(a-2)}, \quad b_{c1} = \frac{a}{2} + \frac{1}{2}\sqrt{a^2 - \frac{a}{c}}, \quad b_{c2} = a + \frac{a+1}{4c},$$
$$q_{c1} = -4b^2c + 4abc - a, \quad q_{c2} = \frac{a}{4(b-a)c - 1}$$

Proof. From Lemma 4.1 and lemma 4.2, we have

$$\Delta p_c = p_c^M - p_c = \frac{2(q+b)bc}{4bc-1} - \frac{q+a}{2} = \frac{q}{2(4bc-1)} + \frac{4cb^2 - 4acb + a}{2(4bc-1)} \tag{4.5}$$

Equation (4.5) shows that Δp_c is always increasing in q since that $\frac{1}{2(4bc-1)} > 0$. In fact, when $\frac{4cb^2-4acb+a}{2(4bc-1)} \geq 0$ (i.e., $b \geq b_{c1} = \frac{a}{2} + \frac{1}{2}\sqrt{a^2 - \frac{a}{c}}$), we have $\Delta p_c \geq 0$. Then we derive the case when $b < b_{c1}$. By solving $\Delta p_c = 0$, we get the threshold value $q_{c1} = -4b^2c + 4abc - a$; when $q > q_{c1}$, $\Delta p_c > 0$.

Next, we turn to the comparison of the demand without and with the promotions of online reviews. It is easy to get

$$\Delta D_c = D_c^M - D_c = \frac{(q+b)c}{4bc-1} - \frac{q+a}{4a} = \frac{(1+4ac-4bc)q}{4(4bc-1)a} + \frac{1}{4(4bc-1)} \tag{4.6}$$

From Equation (4.6), it is easy to check that when $\frac{1+4ac-4bc}{4(4bc-1)a} > 0$ or when $\frac{(1+4ac-4bc)}{4(4bc-1)a} + \frac{1}{4(4bc-1)} > 0$, $\Delta D_c > 0$ always holds. That is, when $b < b_{c2} = a + \frac{a+1}{4c}$, we have $\Delta D_c > 0$. Then we turn to the case when $b > b_{c2}$, and we find that ΔD_c is decreasing in q in this case. Solving $\Delta D_c > 0$ with respect q, we have $q < q_{c2} = \frac{a}{4(b-a)c-1}$. Therefore, Proposition 4.1 holds. □

With simple comparison, we have $b_{c1} < a < b_{c2}$. Proposition 4.1 first shows that if promotions of online reviews are accomplished by an increase of the variance, the retailer can charge a higher price with promotions of online reviews. However, if the variance reduces significantly, whether the retailer can set a higher

price or a lower price depends on the degree of the quality of product. In specific, if the quality of the product is quite low, the obviously low variance may undermine consumers' valuations of the product, despite of the fact that promotions of online reviews increase the average rating to some extent. In this case, the retailer has to cut the retail price to enlarge the demand of the product.

Proposition 4.1 then indicates that if promotions of online reviews lead to a significant increase of the variance, the promotion strategy may damage the demand of the product. This is because the variance of reviews reveals more information about the consumers' own preference, thus a high variance means a higher inconsistency of the reviews. Consumers may face a higher uncertainty about whether the product matches their needs or preferences. Put differently, for the product with a relatively high quality, increasing the average rating and the variance at the same time may cut the demand of the product. In fact, it is better for the retailer selling a relatively low-quality product to set a higher variance in the process of manipulations. This result is consistent with the study of West and Broniarczyk (1998); they find that a higher variance increases the purchase likelihood if and only if the average rating is below an aspiration level. We then deploy the impacts of promotions on the profitability of the whole supply chain and give further explanations.

Proposition 4.2. *Under the centralized structure,*

(1) When $b \geq max\{2, b_{c1}\}$*, the whole supply chain is better off with promotions of online reviews, but the promotion efficiency decreases with the product quality if and only if* $b \geq b_{c2}$ *and* $q \geq q_{c2}$*.*

(2) When $c > max\{1/2, c_{c1}\}$*,* $b < b_{c1}$*, the whole supply chain is hurt by promotions of online reviews if and only if* $q < min\{1, q_{c3}\}$*, where*

$$q_{c3} = \frac{-a + 2(a-b)\sqrt{ac(4bc-1)}}{4c(a-b)+1}.$$

Proof. From Lemma 4.1 and Lemma 4.2, we have

$$\Delta\pi_c = \pi_c^M - \pi_c = \frac{-4bc+4ac+1}{8a(4bc-1)}q^2 + \frac{1}{4(4bc-1)}q + \frac{4cb^2-4acb+a}{8(4bc-1)} \tag{4.7}$$

The first-order condition of Equation (4.7) is $\frac{\partial\Delta\pi_c}{\partial q} = \frac{-4bc+4ac+1}{4a(4bc-1)}q + \frac{1}{4(4bc-1)}$. By solving $\frac{\partial\Delta\pi_c}{\partial q} = 0$, we get the threshold value $q_{c2} = \frac{a}{4(b-a)c-1}$. There may be two cases:

(1) When $0 < q_{c2} < 1$, $\Delta\pi_m$ is nonmonotonic in the quality interval [0,1]. Solving $0 < q_{c2} < 1$, we have $b > b_{c2} = a + \frac{a+1}{4c}$. Therefore, when $b > b_{c2}$ and $q > q_{c2}$, $\frac{\partial\Delta\pi_c}{\partial q} < 0$. Then let $q = 1$, we examine the value of $\Delta\pi_c$. Mathematically, we have $\Delta\pi_c(q=1) = \frac{4acb^2-(4ca^2+4c)+a^2+4ac+2a+1}{8(4bc-1)}$. It is easy to prove that $\frac{\partial\Delta\pi_c(q=1)}{\partial b} = \frac{(b+1)(2cb-2c-1)}{(4bc-1)^2} > 0$. That is, $\Delta\pi_c(q=1)$ increases with b. Substituting $b = b_{c2}$ into $\Delta\pi_c(q=1)$, we have $\Delta\pi_c(q=1, b=b_{c2}) = \frac{(a+1)^2}{32ac} > 0$. Therefore, when $b > b_{c2}$ and $q > q_{c2}$, we have $\frac{\partial\Delta\pi_c}{\partial q} < 0$ and $\Delta\pi_c > 0$. When $b > b_{c2}$ and $q < q_{c2}$, $\frac{\partial\Delta\pi_c}{\partial q} > 0$ and $\Delta\pi_c > 0$.

(2) When $q_{c2} \leq 0$ or $q_{c2} \geq 1$, which requires $b \leq b_{c2}$, $\Delta\pi_c$ is monotonic increasing in the quality interval [0,1]. In fact, when $\frac{-4bc+4ac+1}{4a(4bc-1)} > 0$, it is straightforward to have $\Delta\pi_c > 0$. Put differently, when $b > b_{c1} = \frac{a}{2} + \frac{1}{2}\sqrt{a^2 - \frac{a}{c}}$, we have $\Delta\pi_c > 0$. Since we make the global assumption of $b > 2$, we further derive the condition when $b_{c1} > 2$, which obtains $c > c_{c1} = \frac{a}{8(a-2)}$. Correspondingly, when $c > c_{c1}$, $b_{c1} > 2$, by solving $\Delta\pi_c = 0$, we can get the threshold value $q_{c3} = \frac{-a+2(a-b)\sqrt{ac(4bc-1)}}{4c(a-b)+1}$. When $a > a_{c1}, b < b_{c1}$ and $q < q_{c3}$, we have $\Delta\pi_c < 0$. Combining the analysis above, we get the results in Proposition 4.2. □

Proposition 4.2 indicates that promotions of online reviews may benefit or hurt the channel profit. We plot Figure 4.1 to illustrate the corresponding results clearly. Specifically, as Figure 4.1(a) shows, when promotions of online reviews lead to a significant decrease in the variance (i.e., $b < b_{c1}$), the supply chain may be worse off if the product quality is not high enough ($q < q_{c3}$). In this case, as mentioned above, a low variance actually undermine consumers' willingness to pay,

which makes the retailer cut the retail price. In contrast, if the variance increases obviously (Figure 4.1(c)), the increment of the profit decreases with the product quality if the product quality is relatively high ($q > q_{c2}$). The reason is that online reviews with a favorable average rating and a high variance may damage the demand of product, which results in a low efficiency of review promotions. An interesting finding is that, in the presence of the promotions, it is possible for the supply chain and customers to realize a win-win. In specific, when $c > c_{c1}, b < b_{c1}$ and $q_{c3} < q < \min\{1, q_{c1}\}$, the optimal pricing decision for the retailer is to cut price to some level, which would increase the demand of product and thus benefit the supply chain.

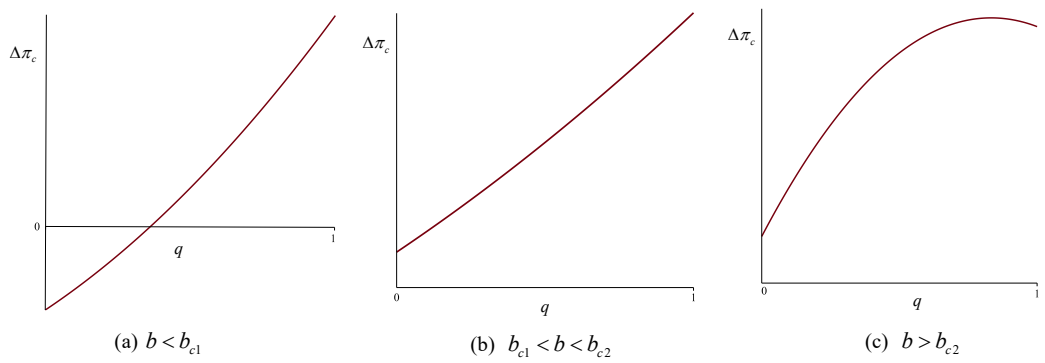


Figure 4.1: Impacts of b and q on the channel profit under centralized channel ($c = 1, a = 2.5$)

4.4 Promotions of online reviews under the decentralized supply structure

In this section, we consider the decentralized channel structure, that is, the manufacturer and the retailer aim to maximize their own profits. In the absence of promotions of online reviews, the game sequence is as follows. The manufacturer first decides the wholesale price w to maximize its profit π_m, and the retailer then determines the retail price p_d to maximize its profit π_r, given the wholesale price w. Thus, manufacturer's profit and retailer's profit without promotions of online

reviews can be formulated as follows:

$$\begin{aligned} \pi_m(w) &= w\frac{q+a-p_d}{2a}, \\ \pi_r(r) &= (p_d-w)\frac{q+a-p_d}{2a}. \end{aligned} \tag{4.8}$$

Then, in the presence of promotions of online reviews, we follow Lu et al. (2019) and assume that the manufacturer provides a subsidy proportion λ and the retailer decides the degree of promotion η_d. The game sequence is as follows. The manufacturer first decides the wholesale price w and the subsidy proportion λ to maximize its profit π_m^M , and then the retailer is presented as the follower to decide the retail price p_d^M and the degree of promotion η_d to maximize its profit π_r^M. We give the corresponding profit functions of the manufacturer and the retailer as follows:

$$\begin{aligned} \pi_m^M(w^M,\lambda) &= w^M\frac{q+\eta_d+b-p_d^M}{2b} - \frac{c}{2}\lambda\eta_d^2, \\ \pi_r^M(p_d^M,\eta_d) &= (p_d^M-w^M)\frac{q+\eta_d+b-p_d^M}{2b} - \frac{c}{2}(1-\lambda)\eta_d^2 \end{aligned} \tag{4.9}$$

We next give the equilibrium outcomes in the decentralized supply chain without and with promotions of online reviews in the following lemmas.

Lemma 4.3. *The equilibrium wholesale price, retail price, the demand, the profits of the manufacturer and the retailer without promotions of online reviews in the decentralized structure are as follows.*

$$\begin{aligned} w &= \frac{q+a}{2}, \quad p_d = \frac{3(q+a)}{4}, \quad D_d = \frac{q+a}{8a}, \\ \pi_m &= \frac{(q+a)^2}{16a}, \quad \pi_r = \frac{(q+a)^2}{32a}. \end{aligned}$$

Lemma 4.4. *The equilibrium wholesale price, retail price, the demand, the profits of the manufacturer and the retailer with promotions of online reviews in the decentralized structure are as follows.*

$$\begin{aligned} \eta_d &= \frac{6(q+b)}{32bc-9}, \quad \lambda = \frac{1}{3}, \\ w^M &= \frac{(q+b)(16bc-3)}{32bc-9}, \quad p_d^M = \frac{3(q+b)(8bc-1)}{32bc-9}, D_d^M = \frac{4c(q+b)}{32bc-9}, \\ \pi_m^M &= \frac{2c(q+b)^2}{32bc-9}, \quad \pi_r^M = \frac{4c(8bc-3)(q+b)^2}{(32bc-9)^2}. \end{aligned}$$

Proof. Lemma 4.3 presents the equilibrium results of the benchmark without review promotions under the decentralized channel setting. We solve the equilibrium by the backward induction. Recall that the demand function without the promotions is $D_d = \frac{q+a-p_d}{2a}$. The retailer's decision problem is as follows

$$\max_{p_d} \ \pi_r = (p_d - w)\frac{q+a-p_d}{2a} \tag{4.10}$$

By solving the first condition of Equation (4.10) for p_d, we obtain the response function for the retailer

$$p_d = \frac{q+a+w}{2} \tag{4.11}$$

Substituting Equation (4.11) into the demand function, and then we can rewrite the decision problem of the manufacturer as

$$\max_{w} \ \pi_m = wD_d = w\frac{q+a-w}{4a} \tag{4.12}$$

Solving the first condition of Equation (4.12) for w, we get $w^* = \frac{q+a}{2}$. Then, substituting it into Equation (4.11) and the demand function. We can obtain the outcomes in Lemma 4.3.

With the same logic, we derive the results with promotions of online reviews under the decentralized channel. Noted that in the presence of the promotions, $D_d^M = \frac{q+\eta+b-p_d^M}{2b}$. We also rewrite the retailer's problem as

$$\max_{p_d^M, \eta_d} \ \pi_r^M = (p_d^M - w^M)\frac{q+a-p_d^M}{2a} - \frac{c}{2}(1-\lambda)\eta_d^2 \tag{4.13}$$

Calculating the first-order partial derivatives of Equation (4.13) with respect p_d^M and η_d, and solving the corresponding equations to zero, we obtain the following results

$$\begin{aligned} \eta_d &= \frac{w^M - q - b}{4bc\lambda - 4bc + 1}, \\ p_d^M &= \frac{(2bc\lambda - 2bc + 1)w^M + 2bc(\lambda - 1)(b+q)}{4bc\lambda - 4bc + 1}. \end{aligned} \tag{4.14}$$

Substituting Equation (4.14) into the demand function, and substituting the corresponding demand into the manufacturer's profit function, we can rewrite the decision problem of the manufacturer as follows

$$\max_{w^M, \lambda} \ \pi_m^M = \frac{(1-\lambda)(w^M - q - b)cw^M}{4bc\lambda - 4bc + 1} - \frac{(w^M - q - b)^2 c\lambda}{2(4bc\lambda - 4bc + 1)^2} \tag{4.15}$$

Calculating the first-order partial derivatives of Equation (4.15) with respect w^M and λ, and solving the corresponding equations to zero, we obtain the following results:

$$\lambda = \frac{1}{3}, \quad w^M = \frac{(q+b)(16bc-3)}{32bc-9}. \tag{4.16}$$

Then, substituting Equation (4.16) into Equations (4.15), (4.14) and (4.13), we can easily obtain the outcomes in Lemma 4.4. □

It is interesting to find that the sharing rates of the manufacturer and the retailer are constants and do not vary with the degree of the review promotions. The reason may be as follows. The manufacturer's marginal profit is independent of λ while the retailer's marginal profit is increasing in λ. Therefore, it is possible for the manufacturer to give a constant participation rate to ensure that the retailer is willing to take the promotion strategy. Moreover, the retailer tends to share more costs than the manufacturer if taking the promotion strategy. With the results above, we next examine the impacts of promotion on the pricing decisions and on the performances of the manufacturer and the retailer.

Proposition 4.3. *Under the decentralized structure,*

(1) The wholesale price with promotions of online reviews is lower than without (i.e., $w^M < w$) if and only if $c > max\{1/2, c_{d1}\}$, $b < b_{d1}$ and $q < min\{1, q_{d1}\}$; in other cases, $w^M \geq w$.

(2) The retail price with promotions of online reviews is lower than without (i.e., $p_d^M < p_d$) if and only if $c > max\{1/2, c_{d2}\}$, $b < b_{d2}$ and $q < min\{1, q_{d2}\}$; in other cases, $p_d^M \geq p_d$.

(3) The demand with promotions of online reviews is higher than without (i.e.,

$D_d^M > D_d$) *if* $b < b_{d3}$ *or if* $b > b_{d3}$ *and* $q < q_{d3}$, *where,*

$$
\begin{aligned}
c_{d1} &= \frac{3(3a-4)}{64(a-2)}, \quad c_{d2} = \frac{(9a-8)}{64(a-2)}, \\
b_{d1} &= \frac{a}{2} + \frac{\sqrt{256a^2c^2 - 192ac + 9} + 3}{32c}, \\
b_{d2} &= \frac{a}{2} + \frac{\sqrt{64a^2c^2 - 56ac + 1} + 1}{16c}, b_{d3} = a + \frac{9(a+1)}{32c}, \\
q_{d1} &= \frac{-32cb^2 + 32acb + 6b - 9a}{3}, \\
q_{d2} &= \frac{-32cb^2 + 32acb + 4b - 9a}{5}, q_{d3} = \frac{9a}{32c(b-a) - 9}.
\end{aligned}
$$

Proof. From Lemma 4.3 and lemma 4.4, we have

$$
\Delta w = w^M - w = \frac{3q}{64bc - 18} + \frac{32cb^2 - 32acb - 6b + 9a}{2(32bc - 9)}. \tag{4.17}
$$

Equation (4.17) shows that Δw is always increasing in q since that $\frac{3}{64bc-18}$ is larger than zero. In fact, when $\frac{32cb^2 - 32acb - 6b + 9a}{2(32bc-9)} \geq 0$ (i.e.,$b \geq b_{d1} = \frac{a}{2} + \frac{\sqrt{256a^2c^2 - 192ac + 9} + 3}{32c}$), Δw is always positive. Then we derive the case when $b < b_{d1}$. By solving $\Delta w = 0$, we get the threshold value $q_{d1} = \frac{-32cb^2 + 32acb + 6b - 9a}{3}$; and when $q < q_{d1}$, $\Delta w < 0$. Therefore, result (1) of Proposition 4.3 can be obtained. Similarly, it is easy to get other results in Proposition 4.3. □

Noted that $b_{d2} < b_{d1} < a < b_{d3}$. Proposition 4.3 first indicates that in the decentralized structure, whether the retailer (the manufacturer) can set a higher or a lower retail price (wholesale price) depends on the the degree of the changed variance and the product quality. If the variance decreases too much ($b < b_{d2}$), the optimal pricing strategy for the manufacturer selling low-quality product is to lower the wholesale price. As mentioned in the situation of the centralized structure, when promotions of online reviews decrease the variance significantly, the negative impact of the obviously low variance dominates; consumers are more certain about the product's poor quality. Therefore, the manufacturer has to lower the wholesale price, which makes the retailer charge a lower price as well. For consumers, the promotions of online reviews in this cases actually play a positive effect on them.

The results then show that when promotions of online reviews increase the average rating as well as the variance, both the manufacturer and the retailer can charge a higher price, regardless of the product quality. Moreover, it is possible for the player to charge a higher price without hurting the demand (i.e., $\max\{2, b_{d1}\} < b < b_{d3}$). In this cases, promotions of online reviews increase the average rating without affecting the variance too much, and the positive effect of the favorable average rating dominate, which increases consumers' valuation toward the product. Therefore, it is safe for the retailer and the manufacturer to increase the retail price and wholesale price.

Next, we derive the impact of promotions on the profitability of the manufacturer and the retailer, and give further explanations.

Proposition 4.4. *Under the decentralized structure,*

(1) When $b \geq max\{2, b_{d4}\}$, the manufacturer is better off with promotions of online reviews, but the increment degree of the profit decreases with the product quality if and only if $b \geq b_{d3}$ and $q \geq q_{d4}$; when $c > max\{1/2, c_{d3}\}$ and $b < b_{d4}$, the manufacturer is hurt if and only if $q < min\{1, q_{d5}\}$.

(2) When $b \geq max\{2, b_{d6}\}$, the retailer is better off with promotions of online reviews, but the increment degree of the profit decreases with the product quality if and only if $b \geq b_{d5}$ and $q \geq q_{d6}$; when $c > max\{1/2, c_{d4}\}$ and

$b < b_{d6}$, the retailer is hurt if and only if $q < min\{1, q_{d7}\}$.

$$
\begin{aligned}
c_{d3} &= \frac{9a}{64(a-2)}, \quad c_{d4} = \begin{cases} \frac{1}{2} & a \geq \frac{3}{8} \\ \frac{3(3a-4+\sqrt{16-6a})}{64(a-2)} & a < \frac{3}{8} \end{cases} \\
b_{d4} &= \frac{a}{2} + \frac{\sqrt{2ac(8ac-9)}}{8c}, \\
b_{d5} &= \frac{a}{2} + \frac{3a+9+\sqrt{a(256ac^2+96ac+9a-96c-27)}}{32c}, \\
b_{d6} &= \frac{a}{3} + \frac{1}{8c} + \frac{256a^2c^2 - 240ac + 36 + X^{2/3}}{48cX^{1/3}}, \\
q_{d4} &= -\frac{9a}{32c(b-a)-9}, \quad q_{d5} = \frac{4(a-b)\sqrt{2ac(32bc-9)} - 9a}{32(a-b)+9}, \\
q_{d6} &= \frac{3a(64bc-27)}{1024b^2c^2 - 1024abc^2 + 384ac - 576bc + 81}, \\
q_{d7} &= \frac{-192abc + 81a + 8(32bc-9)(a-b)\sqrt{2ac(8bc-3)}}{1024abc^2 - 1024b^2c^2 - 384ac + 576bc - 81}.
\end{aligned}
$$

Proof. From Lemma 4.3 and lemma 4.4, we have

$$\Delta\pi_m = \pi_m^M - \pi_m = (\frac{2c}{32bc-9} - \frac{1}{16a})q^2 + (\frac{4bc}{32bc-9} - \frac{1}{8})q + \frac{2cb^2}{32bc-9} - \frac{a}{16} \quad (4.18)$$

The first-order condition of Equation (4.18) is $\frac{\partial\Delta\pi_m}{\partial q} = \frac{(-32bc+32ac+9)q}{8a(32bc-9)} + \frac{9}{256bc-72}$. By solving $\frac{\partial\Delta\pi_m}{\partial q} = 0$, we get the threshold value $q_{d4} = -\frac{9a}{32c(b-a)-9}$. There may be two cases:

(1) When $0 < q_{d4} < 1$, $\Delta\pi_m$ is nonmonotonic in the quality interval [0,1]. Solving $0 < q_{d4} < 1$, we have $b > b_{d3} = a + \frac{9(a+1)}{32c}$. Therefore, when $b > b_{d3}$ and $q > q_{d4}$, $\frac{\partial\Delta\pi_m}{\partial q} < 0$. Also, it is easy to verify that when $b > b_{d3}$, $\Delta\pi_m$ is always positive. Therefore, when $b > b_{d3}$ and $q > q_{d4}$, we have $\frac{\partial\Delta\pi_m}{\partial q} < 0$ and $\Delta\pi_m > 0$. When $b > b_{d3}$ and $q < q_{d4}$, $\frac{\partial\Delta\pi_m}{\partial q} > 0$ and $\Delta\pi_m > 0$.

(2) When $q_{d4} \leq 0$ or $q_{d4} \geq 1$, which requires $b \leq b_{d3}$, $\Delta\pi_m$ is monotonic increasing in the quality interval [0,1]. In fact, when $\frac{2cb^2}{32bc-9} - \frac{a}{16} > 0$ (i.e., $b > b_{d4} = \frac{a}{2} + \frac{\sqrt{2ac(8ac-9)}}{8c}$), it is straightforward to have $\Delta\pi_m > 0$. Considering the global assumption: $b > 2$, we derive the condition when $b_{d4} > 2$. That is, when $c > \max\{1/2, c_{d3}\}$, $b_{d4} > 2$, where $c_{d3} = \frac{9a}{64(a-2)}$. In short, if $c < c_{d3}$, $\Delta\pi_m$ is always positive. Otherwise, by solving $\Delta\pi_c = 0$, we get the threshold value

$q_{d5} = \frac{4(a-b)\sqrt{2ac(32bc-9)}-9a}{32(a-b)+9}$. Put differently, when $c > \max\{1/2, c_{d3}\}, b < b_{d4}$ and $q < q_{d5}$, we have $\Delta\pi_m < 0$. Combining the analysis above, we get result (1) of Proposition 4.4.

Since the proof of result (2) is quite similar as the proof of (1), we ignore it here and only give the expression of X: $X = 4096a^3c^3 - 5760a^2c^2 + 2214a + 216 + 162\sqrt{ac(128a^2c^2 - 183ac + 72)}$. □

With simple comparison, we have $b_{d4} < b_{d6} < b_{d2} < b_{d1} < b_{d5} < b_{d3}$. To better understand the impacts of b on the profitability of the manufacturer and the retailer, we plot Figure 4.2. Combing Proposition 4.4 and Figure 4.2, we demonstrate that the retailer and the manufacturer may not always benefit from promotions of online reviews under the decentralized channel, which is quite similar as the case under the centralized channel. In specific, if promotions of online reviews lead to an obvious reduction of the variance (i.e., $b < b_{d4}$), as shown in Figure 4.2(a), both the manufacturer and the retailer may be hurt if the quality of the product is quite low. In this case, as analyzed before, the largely low variance undermines consumers' valuation of the product, thus the manufacturer and the retailer have to cut the wholesale price and the retail price, which leads to the loss of their profits.

Second, if the promotions lead to a significant increase of the variance (i.e., $b > b_{d3}$), as shown in Figure 4.2(c), the efficiency of the manipulations may decrease if the product has a relatively high quality. In other words, the increment of profits of the manufacturer and the retailer decreases with the quality of the product. The reason is that too high variance may make the consumers doubt the high quality of the product, which damages the demand of the product.

Third, we find that when the variance do not change a lot ($b_{d6} < b < b_{d5}$), it quite safe for the manufacturer and the retailer to engage in the promotion strategy. In this cases, the increased retail price would not hurt the demand of

the product, which benefits both players. In addition, it is interesting to find that it is wise for the manufacturer to share the manipulation costs if the retailer decides to take the promotion strategy. This is because the manufacturer has a greater threshold interval to benefit from promotions of online reviews than the retailer, regardless of the product quality. Therefore, it is more important for the retailer to ensure the change of the variance in the process of promotions of online reviews. Last but not least, we illustrate that, under the decentralized channel, it is also possible for the retailer and consumers to be better off at the same time. In specific, if $0 < q_{d7} < 1$ and $q_{d7} < q < \min\{1, q_{d2}\}$, the retailer can gain more profits because of the increased demand and consumers can enjoy the lower price.

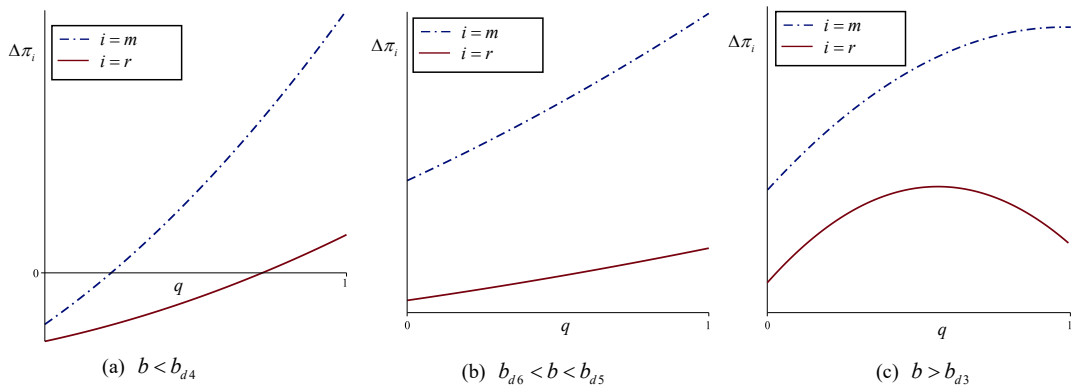


Figure 4.2: Impacts of b and q on the players' profits under the decentralized channel

$(c = 1, a = 2.5)$

4.5 Comparisons under the two channel structures

In this section, we first compare the implication of promotions of online reviews on the demand of the product, under the two channel structures.

Proposition 4.5. *When $b \leq b_{c2}$, the demands under both channels are higher with promotions of online reviews; otherwise, the demand under the centralized*

channel is more likely to be hurt by promotions of online reviews than that under the decentralized channel.

Proof. Recall that $\Delta D_c = \frac{(1+4ac-4bc)q}{4(4bc-1)a} + \frac{1}{4(4bc-1)}$ and $\Delta D_d = \frac{(9+32ac-32bc)q}{8a(32bc-9)} + \frac{9}{8(32bc-9)}$. Besides, Proposition 4.1 and Proposition 4.3 indicate that when $b < b_{c2}$, $D_c^M > D_c$ always holds, and when $b < b_{d3}$, $D_d^M > D_d$. It is easy to verify that $b_{c2} < b_{d3}$. Therefore, when $b < b_{c3}$, promotions of online reviews benefit the demands under both channels. Then, when $b_{c3} \leq b \leq b_{d3}$, $D_c^M > D_c$ holds if and only if $q < q_{c2}$, but D_d^M is always greater than D_d; when $b > b_{d3}$, $D_d^M > D_d$ holds if and only if $q < q_{d3}$ ($q_{c2} < q_{d3}$). Therefore, we summarize that when $q \geq q_{c2}$, the demand under the centralized channel is more likely to be hurt by promotions of online reviews than under the decentralized channel. Hence, Proposition 4.5 holds. □

Proposition 4.5 states that when promotions of online reviews do not lead to a relatively higher variance, this strategy plays a positive effect on the demands, regardless of the channel structure. However, when the variance increases too much, the demand under the centralized channel is more easily to be damaged by promotions of online reviews, depending on the favorability of the product quality. Therefore, the players under the centralized supply chain should decide the change range of the variance more carefully when considering the impact of the promotions on the demand of the product.

In the next, we would like to compare the influence of promotions of online reviews for the profitability of the retailer under the two channel structures. It is reasonable to assume that, under the centralized channel, the threshold value for the retailer' profitability is as same as the threshold value for the whole supply chain. For simplicity, we derive the case when the cost of promotions is not too small and get the following propositions.

Proposition 4.6. *In the presence of promotions of online reviews, when the cost of promotions is not too small ($c > max\{1/2, c_{d3}\}$), the comparisons of the re-*

tailer's profitability under the two channel structures are as follows

(1) When $b < b_{d6}$, the retailer under the centralized channel is hurt by promotions of online reviews if $q < min\{q_{c3}, 1\}$, while the retailer under the decentralized channel is hurt by promotions of online reviews if $q < min\{q_{d7}, 1\}$, where $q_{c3} < q_{d7}$.

(2) When $b_{d6} < b < b_{d5}$, the retailer always benefits from the promotions of online reviews, regardless of the channel structure.

(3) When $b > b_{d5}$, the promotion efficiency under the centralized channel decreases with the product quality if and only if $q > max\{q_{c2}, 1\}$, while the promotion efficiency under the decentralized channel decreases with the product quality if and only if $q > q_{d6}$, where $q_{d6} < q_{c2}$.

Proof. The proof is quite similar with that for Proposition 4.4, thus we omit the details here. □

From proposition 4.6, we demonstrate that the best promotion strategy for the retailer is to keep the change of the variance in a moderate range, no matter which channel structure is taken. In this case, the retailer is always better off, regardless of favorability of the product quality. If the variance decreases too much, the retailer can be better off or worse off, and it is not wise for the retailer to invest in promotions of online reviews if the product has a relatively low quality. If the variance increases too much, the promotion efficiency may decrease with the product quality. In addition, we find that the retailer under the centralized channel has a higher probability to benefit from promotions of online reviews than the retailer under the decentralized channel.

4.6 Conclusions

This chapter examines the implication of promotions of online reviews in a manufacturer-retailer channel, with an analytical modeling framework. Two channel structures are analyzed: the centralized structure and the decentralized structure. Our baseline assumption is that the retailer can take some reasonable strategies to promote or stimulate the average rating of online reviews in an acceptable range, such as providing some frills or coupons with some costs. However, promotions of the average rating may lead to the variation of the variance of online reviews, which can be higher or lower. Taking the situation without promotions of online reviews as the benchmark, we derive the impact of promotions of online reviews on the equilibrium prices, the demand and the profitability of the retailer and the manufacturer, under the centralized channel structure and under the decentralized structure, respectively.

First, our results show that, under the centralized channel structure, promotions of online reviews may not always exert positive effects on the supply chain. In specific, if promotions of online reviews reduce the variance of online reviews obviously, it is not wise for the retailer to promote the average rating if the product quality is relatively low. In this case, the lower variance in fact undermines consumers' willingness to pay. The retailer may need to cut the price to encourage the demand, which results in the loss of the profit of the channel. Contrary to conventional wisdom, it is interesting to note that in this case, if the product quality is quite high, it is possible for the channel and customers to be better off at the same time. In short, the channel benefits from the increased demand and customers can purchase the product in a lower price. In addition, if promotions of online reviews lead to a significant increase of the variance, the channel always gains more profit, but the promotion efficiency may be deceasing in the product quality. In other words, if the product has a favorable quality, the retailer should be more careful to ensure that the review variance can not be too large.

Second, we find that, under the decentralized channel structure, the manufacturer and the retailer can be worse off or better off when taking the promotion strategy. It is worth highlighting that the manufacturer has a higher probability to benefit from this strategy than the retailer. Therefore, it is wise for the manufacturer to invest in the promotions of online reviews by sharing some costs if the retailer can ensure the positive impacts of promotions of online reviews.

Third, by comparing the results under the two channel structures, we find that when the increased variance excess to some degree, the demand under both channel structures can be damaged and the demand under the centralized channel is more likely to be negatively influenced by the promotions. Another finding is that the retailer under the centralized channel has a higher probability to benefit from promotions of online reviews than the retailer under the decentralized channel.

Chapter 5

Summary and Future Research

This dissertation explores the impacts of online reviews by considering different channel perspectives. In chapter 2, we focus on a dual supply chain context in which the manufacturer sells one experience product through a retail channel and an Internet channel. By an analytical modeling framework, we examine the impacts of online reviews on pricing strategies and profit performance of the manufacturer and the retailer, under the centralized channel structure and the decentralized channel structure, respectively. The results show that online reviews affect the pricing decisions of the manufacturer and the retailer, but the influence varies with the channel setting. Besides, the offline demand under the centralized channel is inevitably damaged by online reviews, whereas offline demand is not affected under the decentralized channel. Moreover, we show that online reviews may improve or harm the profitability of the channel under the centralized channel. Differently, under the decentralized channel, the manufacturer may gain or loss with online reviews but the retailer is always hurt by online reviews.

The study of chapter 2 has the following managerial insights. As our results suggest, online reviews play a great role in the pricing interaction and profit performance of the players in a dual channel setting. Thus, for the manufacturer, devoting more efforts to ensure the highly positive review informativeness and to improve the weight of online review in consumers' decision making are quite

necessary. Moreover, the retailer can welcome online reviews if it is under the centralized channel structure but should take some cooperation strategies to ensure that it would not be harmed under the decentralized channel structure.

As we concentrate on the power of online reviews on the pricing decisions of the players in a dual channel setting, there are a few limitations in the current model set-up. First, in our model, we assume online reviews reveal the common value of the product to consumers. But in practice, online reviews may have some information bias and consumers may be heterogeneous in trusting this information. Therefore, it is interesting to propose alternative models to incorporating these aspects. Second, it would be more practical if we can incorporate those traditional customers who are only loyal to the retail channel and those consumers who may do showrooming before purchasing in the Internet channel. Third, we make the basic assumption that in the presence of online reviews, it is still profitable for the manufacturer to hold a dual channel. That is, our model does not consider the extreme case when online reviews may turn off the retail channel or the Internet channel. It may be of challenge of investigating the effects of online reviews on channel selection, and we leave this direction for future research.

Chapter 3 investigates the impacts of online reviews in a channel structure consisting two competing manufacturers selling vertically differentiated products and a common retailer. By a two-period analytical model, we present that the retailer may raise or decrease the retail prices in the second period, which depends on the quality difference of the two products. Besides, online reviews may not always intensify the pricing competition in the upstream, which means the competing manufacturers can profit from online reviews simultaneously. Compared with manufacturers, the retailer is less likely to benefit from online reviews, and highly informative online reviews may negatively influence the profitability of the retailer.

In short, the study in chapter 3 has some managerial insights for both man-

ufacturers in the upstream and for the retailer. In specific, it is significant for competing manufacturers to understand the implications of online reviews so that they can adjust their pricing decisions to different cases. More importantly, the retailer should take the quality difference into consideration when harnessing online reviews.

There are also several limitations in this study. First, our basic assumption is that the two manufacturers would not change their wholesale prices; it would be more practical to relax this assumption and investigate the case in which the manufacturers can make different wholesale prices in different stages. Second, examining the effects of online reviews on the coordination of the supply chain with multiple manufacturers and retailers is of practical interest. Third, some empirical studies are needed to verify our theoretical results.

In chapter 4, we study promotions of online reviews in a two-member supply chain with one manufacturer and one retailer. Given the importance of online reviews, it is common for retailers to take some strategies to encourage consumers to give positive feedbacks. Such promotion behavior also incurs some costs. As a member of the channel, it is necessary and meaningful for the manufacturer to take part in this strategy. Our results emphasize that the retailer should incorporate the variance of online reviews in the process of review promotions. This is because the change of variance may undermine or enhance the promotions of online reviews, regardless of the channel structure. That is to say, the strategy of promoting online reviews may hurt the manufacturer and the retailer at some scenarios. The interesting finding is that it is likely for the retailer, the manufacturer, and consumers to be better off simultaneously.

Our results also have implications for practice. In particular, it is not always necessary for retailers to take some promotional strategies to reach more favorable average rating. And they should take the product quality and the change of variance into consideration when promoting the average rating. In general, it is

more likely to be better off if they can encourage consumers give more favorable average rating while increasing the variance slightly. For the manufacturer, it is wise to support this strategy because it has a higher probability to benefit from the promotions of online reviews than the retailer.

For the topic of chapter 4, there are several promising extensions are desired. While we focus on the distribution channel with one manufacture and one retailer, it would be interesting and worthwhile to consider multiple manufacturers and retailers and consider the product competition. In addition, combining promotions of online reviews and cooperative advertising may be an intriguing next direction. Further, we assume that moderate promotions of online reviews can improve the average ratings, which is idealized. In reality, some consumers may ignore some financial incentives or react negatively by discounting online reviews; incorporating these consumer behaviors may be more challenging, and thus we leave this point for future study.

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