Original Research Article

Strategic interactions between sales formats and network effects in supply chains: The role of product quality

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Abstract: Our study uses a game-theoretic model to explore a distribution setting where a manufacturer uses wholesale and agency pricing. It focuses on the relationship between network effects and pricing decisions. Results show manufacturers often profit more with agency pricing, while platforms do better with wholesale pricing, especially with low agency costs. Both can benefit under agency pricing in certain ranges. Network effects always benefit supply chain members. Our findings may interest supply chain stakeholders.

Keywords: Network effects; Wholesale pricing; Agency pricing; Online platforms

1. Introduction

The digital economy, fueled by big data, AI, and IoT, is driving China's economic growth, industrial upgrading, and global competitiveness. Products with network externalities, like smart home devices, gain value as more consumers join the network. These devices access online resources for entertainment and convenience, analyze user data for personalized services, and enhance user experience through network effects.In today's digital world, products with network effects are common. The same-side network effect, where each consumer's utility increases with more users, is common in info-based products like software and games. Such effects are widespread . Examples include smart appliances that adapt to user preferences.[5] More usage data boosts Tesla's algorithm accuracy.

In conjunction with the question of network effects, in the present study, we undertake an analysis to address the following inquiries: 1. What is the impact of the manufacturer-platform strategic relationship on the price model decision (wholesale vs. agency)?2. How does the magnitude of the network effect affect the equilibrium decisions of the manufacturer and the platform?3. What impact does the manifestation of network effects exert on the selection of a pricing strategy, specifically comparing wholesale pricing to agency pricing?To respond to the research inquiries raised, we construct a game-theoretic model wherein a manufacturer creates a smart device targeted for marketing through an internet platform.

2. Literature review

E-tailers' strategic choices between wholesale and agency sales have attracted much academic attention in recent years. Prior studies have examined the strategic choice between wholesale and agency from various aspects such as an upstream manufacturer and a downstream retailer,[6]a competing upstream manufacturer and a downstream retailer,[6-8-9]and an upstream manufacturer and a competing downstream retailer[1] Research has been conducted.Our study incorporates network effects and explores how network effects affect model choice and also explores the effect of network effects on consumer surplus. This was not available in the previous study.

Network effects have applications in many industries and are important in many ways. The utility of some network effect products increases as the number of consumers using the product increases, and these network effect products are usually high-tech products;[4] .Our research further delves into the implications of network

effects on firms' strategic decisions, particularly focusing on their influence on various sales models and examining the specific manner in which the incorporation of network effects alters these sales models.

3. Model setup

Considering an online sales channel consisting of an online platform and a manufacturer. The manufacturer produces the product with quality level q at convex manufacturing cost $q^2/2$. The consumers have heterogeneous preference for the horizontal dimension, which is denoted by V. Moreover, V is uniformly distributed between 0 and 1. Similar to [8], all consumers have same preference on the vertical dimension. Customers buy the product with price p. Let U_i denote the utility of the customer when there is no network effect. Therefore, when a purchaser purchases the product, the utility they receive from the product is $U_i = V + q - p$.

Next, the customer's utility, who is unsure whether to purchase the goods or not, is provided by $U_i=0$. Therefore, the indifferent point is $V=p - q$. Let d_i denote the demand of customers when there is no network effect. Only when the utility of the consumer is greater than V will the consumer buy, so the demand of the consumer $d_i=1-V$.Customers' desire d_i for the goods is indicated by $d_i = 1 - p + q$. Let δ denote the intensity of network effects. According to previous research,[2-3] User groups have the capacity to create positive value through the phenomenon of network effects. Consequently, we can formulate the utility experienced by customers under the influence of these network effects: $U_S = V + q + \delta d_e - p$. Similarly, in the case of network effect, the demand is as follows: $d_e = (1 - p + q)/(1 - \delta)$.

4. Equilibrium analysis

In our subsequent analysis, we scrutinize both wholesale and agency pricing models, taking into account scenarios influenced by network effects as well as those unaffected by them.

4.1. Benchmark: Without network effect

We examine the perfect Nash equilibrium in the absence of a network effect in this subsection.

4.1.1. Benchmark: Wholesale pricing model

Within the wholesale pricing structure, the platform subsequently markets the product to consumers at a retail price designated as p.Subsequently, the profit margins for both the platform and the manufacturer are outlined as follows: $\pi_m^{NW} = wd_i - q^2/2, \pi_P^{NW} = (p - w)d_i$.

Finding the equilibrium solution for the above model, we can obtain Lemma 1.

Lemma 1 *In the case without network effect, under wholesale pricing model, the equilibrium outcomes are* $q^{NW} = 1/3, w^{NW} = 2/3, p^{NW} = 1, \pi_m^{NW} = 1/6, and\ \pi_P^{NW} = 1/9$.

From **Lemma 1**, it can be seen that in the wholesale pricing model without considering network effects, when the manufacturer's decision on quality is 1/3 and the manufacturer wholesales to the platform at a price of 2/3, the manufacturer can earn the maximum profit 1/6. The platform wholesales the product at a price of 2/3 and sells it to the consumer at a retail price 1, when it can earn the maximum profit 1/9. In such a case, the members in the supply chain reach equilibrium.

4.1.2. Benchmark: Agency pricing model

Within the framework of an agency pricing model, the manufacturer's profit π_m^{NA} and the platform's profit π_P^{NA} are provided by: $\pi_m^{NA} = (1 - \lambda)pd_i - q^2/2,\ \pi_P^{NA} = \lambda pd_i$.

Lemma 2 *In the case without network effect, under agency pricing model, the equilibrium outcomes are* $q^{NA} = (1-\lambda)/(1+\lambda), p^{NA} = 1/(1+\lambda), \pi_m^{NA} = (1-\lambda)/2(1+\lambda)\ \ and\ \pi_P^{NA} = \lambda/(1+\lambda)^2$.

In the case where the platform charges the manufacturer an agency fee of λ, the manufacturer produces a product of quality $(1 - \lambda)(1 + \lambda)$ and sells it directly to the customer at a retail price $1/(1 + \lambda)$, the manufacturer

can earn the maximum profit.To explore the specific changes brought by the agency model to the supply chain members, we draw Corollary 1.

Corollary 1 *In the agency pricing model without network effects, as the agency cost λ increases, the quality of the product q^{NA} will decreases; the retail price p^{NA} will decreases;the manufacturers' profits π_m^{NA} will also decrease;the platform' profits π_P^{NA} will increase.*

As agency fees rise, Corollary 1 implies that the product's quality as determined by the manufacturer, its retail price, and its profit all decrease. This may be attributed to the situation where, when the platform imposes a higher agency fee on the manufacturer, the manufacturer may compensate for this cost by reducing product quality, leading to a decline in both product quality and retail price. Consequently, consumer demand and manufacturer profit decrease. The platform makes more money even as it costs the manufacturer more agency fees. In scenarios with low agency fees, the platform's profit is mainly driven by the fee. Hence, an increase in the fee leads to an increase in the platform's profit. However, in situations where the agency fee is excessive, the manufacturer will raise the retail price to offset the excessive cost incurred by the agency fee; once the retail price increases, consumer demand declines, which also affects the platform's profit because of the decline in consumer demand.

4.2. Basic model: With network effect

In this subsection, we investigate the perfect Nash equilibrium under the influence of network effects.

4.2.1. Basic model: Wholesale pricing model

The more people who use the thing, the more useful it becomes. The profit margin of the manufacturer (π_m) and the platform (π_P) are determined by: $\pi_m^{IW} = wd_e - q^2/2, \pi_P^{IW} = (p-w)d_e$.

The value of d_e is related to δ. Where the value of δ is $\delta < \min\{3/4,(1+\lambda)/2\}$.Thus, the values of a and b can be divided into two regions as follows: $\Omega_1 = \{(\lambda,\delta) | 0 < \lambda < 1/2, 0 < \delta < (1+\lambda)/2\}$, $\Omega_2 = \{(\lambda,\delta) | 1/2 < \lambda < 1, 0 < \delta < 3/4\}$.

Finding the equilibrium solution for the above model, we can obtain Lemma 3.

Lemma 3 *In the network effect scenario, the equilibrium results under the wholesale pricing model are $q^{IW}=1/(3-4\delta)$, $w^{IW}=2(1-\delta)/(3-4\delta)$, $p^{IW} = 3(1-\delta)/(3-4\delta)$, $\pi_m^{IW}=1/2(3-4\delta)$ and $\pi_P^{IW} = (1-\delta)/(3-4\delta)^2$.*

By contrasting Lemma 3 with Lemma 1, it becomes evident that the equilibrium outcome of Lemma 3 is significantly influenced by the network effect δ. To delve deeper into the specific impact of variations in the network effect on the equilibrium result, we derive Corollary 2.

Corollary 2*In the case with network effect, under wholesale pricing model, as network effect δ increases, the quality of the product q^{IW}will increases; the wholesale price w^{IW} will increases;the retail price P^{IW} will increases;the manufacturers' profits π_m^{IW} will also increase;when $0 < \delta < 3/4$, as δ increases, the platform' profits π_P^{IW} will increase.*

It is clear from Corollary 2 that manufacturers always benefit from a rise in network effects. The wholesale price and the manufacturer's profit increase with the strength of the network effect. Similar to this, the platform's profitability rises in tandem with the network effect. For the primary reason, a rise in network effects might result in higher demand for the product, which in turn can attract more customers. When demand rises, the manufacturer and the platform stand to gain economically.Given the circumstances, it appears that supply chain participants benefit more from larger network effects, and that these benefits accrue over time. This indicates that businesses should try to expand the network effect as doing so can result in higher profits for the platform and the manufacturer.

4.2.2. Basic model: Agency pricing model

In the context of an agency pricing model incorporating network effects, the manufacturer's and platform's

profits are outlined as follows: $\pi_m^{IA} = (1-\lambda)pd_e - q^2/2$, $\pi_P^{IA} = \lambda pd_e$.

Lemma 4 *In the case with network effect, under agency pricing model, the equilibrium outcomes are* $q^{IA} = (1 - \lambda)/(1 - 2\delta + \lambda)$, $p^{IA} = (1 - \delta)/(1 - 2\delta + \lambda)$, $\pi_m^{IA} = (1 - \lambda) / 2(1 - 2\delta + \lambda)$ *and* $\pi_P^{IA} = \lambda(1 - \delta) / (1 - 2\delta + \lambda)^2$.

Lemma 4 is the equilibrium result derived from the agent pricing model with network effects, adding the effect of network effects to Lemma 2. To explore more specifically the effects of agency costs and network effects on the equilibrium results, we obtain Corollary 3 and Corollary 4, respectively.

Corollary 3 *In the agency pricing model with network effects, as the agency cost* λ *increases, the quality of the product* q^{IA} *will decreases; the retail price* p^{IA} *will decreases;the manufacturers' profits* π_m^{IA} *will also decrease;When* $0 < \lambda < 1$, $0 < \delta < (1 - \lambda)/2$, *the profit of the platform increases as agency cost* λ *increases.*

As can be shown from Corollary 3, an augmentation in agency fees adversely affects product quality, the manufacturer's retail pricing, and profitability within the agency pricing model that incorporates network effects. When the network effect is negligible, the platform's profit rises in tandem with the agency charge; however, when the network effect beyond a particular level, the platform's profit falls in tandem with the agency fee increase. The rationale for this is the same as that of Corollary 1, wherein an excessive agency fee causes the manufacturer to increase the retail price to offset the excessive cost incurred. However, this increases the retail price to the point where consumer demand declines, outweighing the agency fee's effect. As a result, there is a situation where the platform's profit declines as the agency fee increases. Here, the existence of network effects affects the threshold's magnitude, which is inconsistent with Corollary 1.

Corollary 4*In the case with network effect, under agency pricing model, as network effect* δ *increases, the quality of the product* q^{IA} *will increases;the retail price* P^{IA} *will increases;the manufacturers' profits* π_m^{IW} *will also increase;the profit of the platform increases with* δ *on both* Ω_1 *and* Ω_2.

The outcomes of Corollary 2 and Corollary 4 are comparable. As demonstrated by Corollary 2, a rise in network effect is invariably beneficial to the platform, the manufacturer's profit margin, the retail price set by the manufacturer, and the product quality.This case is similar to Corollary 2 in that there is a possibility that increased network effects will result in higher demand for the product, which will in turn lead to more customers and higher profits for both the platform and the manufacturer. The agency fee is added in this case, which is different from Theorem 2, but it has no bearing on the outcome that the network effect increases and enhances both the manufacturer's and the platform's profits.

5. Conclusion

This research examines an e-commerce channel with a downstream platform, upstream manufacturer, and customers, comparing wholesale and agency pricing models' equilibrium states and exploring network effects' influence. Key findings include: under the agency pricing model, higher agency costs boost platform profit but reduce manufacturer profit; network effects benefit both; without network effects, the wholesale model favors the platform (due to lower agency fees) while not benefiting the manufacturer, and agency pricing offers retailers lower prices; platforms and manufacturers can choose agency pricing with various fees even with network effects; retail prices under agency pricing aren't universally higher than wholesale, and including network effects benefits both models.

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