Advertisements on Knowledge Payment Platforms: A Game Theoretic Analysis of Pricing Strategies

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This work was supported by the National Key Research and Development Program of China under Grant 2019YFB1405201.

ABSTRACT Most knowledge payment platforms are keen to adopt a business model based on transaction revenue and advertising revenue. However, challenge with platforms has been to balance the interests of advertisers as well as their consumers. Increasing of advertising revenue, by having more advertisers may lead to higher consumers’ aversion. To address these queries, we develop a three-sided model to study the optimal pricing strategy of the knowledge payment platform. Specifically, we discuss the impact of the proportion of transaction fees charged by the platform on platform’s strategy under which the platform charges transaction fees from consumers and advertising fees from advertisers. We find that when the proportion of transaction fees charged by the platform is at a low level, the platform’s profit reaches the maximum. Once the proportion of transaction fees charged by the platform is high, which will have a negative impact on the platform’s profit although the platform adopts a strategy of increasing advertising price for advertisers. Besides, we analyze the changes of pricing strategy of knowledge payment platform under different level of network externalities. We find that with the increase of proportion of transaction fees charged by the platform and network externalities, both of the advertising price and platform’s profit are more sensitive to the proportion of transaction fees charged by the platform. On the contrary, as the degree of consumers’ aversion to advertisements increases, the platform’s profit is less sensitive to the proportion of transaction fees charged by the platform.

INDEX TERMS Advertising, knowledge payment platforms, network externalities, pricing strategies, two-sided market.

I. INTRODUCTION

With the development of mobile Internet and the upgrading of consumption pattern, the knowledge payment industry is gradually mature, and its market is expanding rapidly in China. On the one hand, the rapid development of the Internet has improved people’s ability to create knowledge, changed the way of knowledge spreading, especially promoted the development of sharing economy, which makes the selection and sharing of knowledge more convenient and becomes a driving force for the development of knowledge payment industry. On the other hand, the upgrading of consumption pattern has enhanced the demand for knowledge payment. In the process of pursuing high level self-fulfilling, rapid knowledge acquisition and efficient knowledge screening have become a common concern. Therefore, the knowledge payment has gradually formed a perfect market ecology from supply and demand. As a third party, the knowledge payment platform effectively connects consumers and knowledge providers, providing a convenient channel for knowledge sharing and acquisition.

When the scale of consumers and knowledge providers in platform reaches a certain level, it provides advertising services to advertisers. The platform has gradually formed a multilateral structure with consumers, knowledge providers and advertisers. The knowledge payment platforms,
in general, usually have a variety of revenue streams. Two main monetization approaches are (1) charging a percentage of transaction fees from consumers and (2) selling advertising spots to advertisers. In recent years, advertising revenue has grown rapidly and has become the main sources of revenue for some platforms. Zhihu is the largest Q & A knowledge payment platform in China. In 2021, the revenue of online advertising was 1.16 billion yuan, accounting for 40% of the total revenue of the whole year, becoming the largest revenue source. As the largest audio knowledge payment platform in China, Himalaya FM’s advertising revenue has increased rapidly from 0.62 billion yuan in 2019 to 1.49 billion yuan in 2021.

A. RESEARCH QUESTIONS AND CONTRIBUTIONS

The increase of advertising revenue has largely changed the business structure of knowledge payment platforms. Some platforms begin to consider how to formulate pricing strategies to optimize online advertising and content payment, which can not only ensure the growth of revenue scale, but also further optimize the revenue structure. Meanwhile, the network externality is a key consideration for managers when formulating pricing strategies for these platforms. A positive network effect, or network externality, refers to the increase of consumer utility when more consumers purchase the same product [1]. Based on the network externality, on the one hand, the increase in the number of consumers attracts more knowledge providers to join the platform, which greatly enriches consumers’ choices, and attracts more consumers to join to expand the platform’s consumer base. On the other hand, the huge consumer base attracts advertisers to place ads on the platform. However, a large number of ads in turn leads to a loss of consumers due to different degrees of aversion to ads. Therefore, the game among consumers, knowledge providers and advertisers prompts platforms to adopt the optimal pricing strategies to balance transaction revenue and advertising revenue to maximize profits.

This paper will focus on the optimal pricing strategy for knowledge payment platforms with the influence of advertisements. Our research aims to address the following research questions:

Q1: When the platform charges transaction service fees from consumers and advertising fees from advertisers at the same time, how will the proportion of transaction fees obtained by the platform affect the advertising price and platform’s profit? It will provide a managerial implications for the operation decisions of knowledge payment platform.

Q2: Whether the network externality, including intra group network externality and cross network externality will affect the pricing strategy of the platform? This question will help the platform better understand how to balance the interests of trilateral users and formulate pricing strategies in line with its development objectives.

To address these questions, we firstly provide a three-sided economic model that describes the user’s decision-making process and the platform’s own incentives to maximize profits. Then, we discuss the impact of the proportion of transaction fees charged by the platform on platform’s strategy under which the platform charges transaction fees from consumers and advertising fees from advertisers. Finally, we analyze the changes of pricing strategy of knowledge payment platform under different level of network externalities.

We shed light on several major implications from our analysis. Firstly, we take the impact of advertisers into consideration to analytically investigate the knowledge payment platform’s pricing decisions, which received limited attention in previous studies. Our model describes the impact of the proportion of transaction fees charged by the platform on advertising price and platform’s profit under which the platform charges advertising fees and proportion of transaction fees at the same time. Interestingly, we find that when the proportion of transaction fees charged by the platform is at a low level, the platform’s profit reaches the maximum. Once the proportion of transaction fees charged by the platform is high, which will have a negative impact on the platform’s profit although the platform adopts a strategy of increasing advertising price for advertisers.

Then, we investigate how different level of network externalities affect pricing strategy of the platform. The results show that with the increase of proportion of transaction fees charged by the platform and network externalities, both of the advertising price and platform’s profit are more sensitive to the proportion of transaction fees charged by the platform. On the contrary, as the degree of consumers’ aversion to advertisements increases, the platform’s profit is less sensitive to the proportion of transaction fees charged by the platform.

B. OUTLINE

The remainder of the paper is organized as follows. In the next section, we position our paper in the context of the recent literature related to online knowledge sharing, knowledge payment platforms, and online advertising. In section 3, we set our model considering a three-sided platform. In section 4, based on the model, we analyze the impact of the proportion of transaction fees charged by the platform on pricing strategy and explore the influence of network externalities. In section 5, we present our conclusions.

II. LITERATURE REVIEW

This paper is related to three streams of literature: online knowledge sharing, knowledge payment platforms, and online advertising.

A. ONLINE KNOWLEDGE SHARING

Knowledge sharing is the most crucial procedure of knowledge management [2], which can realize the economic and competition value of knowledge [3]. The development of Internet technology has largely broken through the time and space boundary of knowledge sharing. People can share and obtain knowledge on the knowledge sharing platform anytime and anywhere. Scholars majorly focus on the motivation
and the influencing factors of knowledge sharing behavior, including individual cognition [4], [5], interpersonal interaction [6], [7], and organizational context. Nov et al. [8] study people’s motivation to share knowledge from the perspective of social capital theory. They conclude that the structural dimension of social capital, followed by motivation to benefit the public, to be the strongest predictors of contribution, whereas self-motivation and cognitive dimension have least predicting power. Through the lens of organizational citizenship behavior (OCB), Yu and Chu [9] explore the factors that facilitate voluntary knowledge sharing in a virtual community. They suggest that effective leader–member exchange relationships, the attractiveness of the group to individuals, and affection similarity are important in establishing a virtual environment within which voluntary contributions could be promoted effectively.

Online knowledge sharing enriches the ways of knowledge acquisition and communication, making everyone becomes a contributor and recipient of knowledge. However, the quality of knowledge and the sustainability of platform have become problems, which gradually cannot meet the needs of people to obtain knowledge quickly. At the same time, with the upgrading of people’s consumption structure, the payment for knowledge content has become a universal consensus for people to obtain knowledge efficiently.

B. KNOWLEDGE PAYMENT PLATFORMS

The concept of knowledge payment is developed from knowledge sharing and content payment. It has the core connotation of knowledge sharing, and is presented in the form of payment [10], [11]. Some scholars focus on the motivation of knowledge payment platforms [12], [13]. Chen et al. [14] believes that the sustainability of knowledge contribution has become a problem due to the non-economic characteristics of non-commercial knowledge sharing platforms. Therefore, it is particularly important for knowledge payment platforms to encourage providers to provide high-quality knowledge to consumers based on payment. Some scholars also believe that it is an inevitable trend to meet the demand of consumers by providing paid knowledge services, which enables experts in different fields to trade their high-quality knowledge with money and helps consumers to access high-quality external resources based on online payment, such as Himalaya FM and Zhihu [15], [16], [17].

The pricing of knowledge payment platforms has also been studied in recent years. Some scholars focus their research on the factors affecting the pricing of the platforms, including internal factors [18], [19], [20], [21], external factors [22] and perception factors [23]. Zhang et al. [24] refines consumers according to their level of professional knowledge and analyzes the relationship between price and consumer satisfaction.

However, with the maturity of knowledge payment platforms, the structure and revenue model have also changed greatly. As one of the main revenue sources of platforms, advertising revenue has a great impact on platforms’ pricing strategies, which has been ignored in previous studies. In our study, we consider the impact of the increase of advertising revenue on the transaction fees and profits charged by the platform, which may help the platform formulate the optimal pricing strategy.

C. ONLINE ADVERTISING

With the popularity of online consumption, more and more advertisers shift their business focus to online advertising. The expansion of Internet-based advertising is transforming the advertising business by providing more efficient methods of matching advertisers and consumers [25]. The pricing of online advertising has also been studied [26], [27]. There are multiple pricing models available but the most common ones are:

- **Cost Per Thousand Impressions (CPM).** In the early days, online advertisers and publishers had simply used this model, standard to traditional media advertising, and advertisers paid according to the number of times their advertisement got delivered to consumers [28].
- **Cost Per Click (CPC).** This is one of the most popular pricing models for online advertising. In this model, the publisher pays only for click-through (click hereafter)-when a visitor clicks on an advertisement (ad hereafter) [29].
- **Cost Per Action (CPA).** With the CPA model, the advertiser only pays for those impressions that lead to a conversion or goal (a purchase, a sign-up, a follower) [30].
- **Real-Time Bidding (RTB).** In RTB, publishers (such as websites and mobile apps) sell the individual advertisement impressions via hosting real-time auctions, and advertisers are allowed to evaluate and bid for each impression [31].

Recently, the research on online advertising mainly focuses on the impact of user’s behavior and advertising strategy on the optimal decisions of two-sided platforms [32], [33], [34], [35]. Duan et al. [36] develop a two-sided model to analyze the impacts of information disclosure level and user’s privacy concerns for information disclosure on the optimal pricing strategy and surplus of users and advertisers. They find that when the information disclosure is at an intermediate level, the surplus of advertisers and users reaches the maximum. Athey et al. [37] find that a higher level of consumer switching will bring on stiff competition among the advertisers, with more advertisements and a decrease in price. Furthermore, they note that the platform’s advertising volumes are extremely unstable, exhibiting periodicity. Zhou et al. [38] examine the pricing and choice of advertising schemes for a two-sided platform considering two business models, each with two advertising schemes.

Different from the above researches, our research regards advertisers as a major user group in knowledge payment platforms, forming a multi-party market with consumers and knowledge providers. The participation of advertisers will not only affect the behavior choice of consumers, but also indirectly affect the utility and benefits of knowledge providers,
which has been ignored in previous studies. The pricing strategy and profit of platforms will inevitably be affected by advertising price and transaction fees.

### III. MODEL

The research on pricing decisions between multiple platforms is relatively common, but for a single platform that has developed in a personalized direction in recent years, such as the knowledge payment platform with exclusive knowledge providers and loyal consumers, the research on its pricing strategy is a noteworthy direction. In this section, we build the pricing model for the knowledge payment platform with consumers, knowledge providers, and advertisers on the basis of Armstrong [39]. On the one hand, the knowledge platform attracts high-quality providers to provide original new content to consumers and charges consumers the transaction fees $C$. Then the platform distributes the transaction fees to providers in the proportion of $\emptyset$. On the other hand, based on the huge consumer market, the platform attracts advertisers to advertise and charges them a price $p$ for the advertising slot. At this time, the platform has two main revenue sources: transaction service for consumers and selling of advertising slots. In addition, we suppose that $n_i$ ($i=1,2,3$) represent the number of consumers, providers, and advertisers, respectively, and $N_i$ ($i=1,2,3$) denote the market of consumers, providers, and advertisers, respectively. The total market is standardized as 1; that is $N_i \leq 1$. Therefore, the profit of the knowledge payment platform $\eta$ is:

$$\eta = pn_3 + \emptyset Cn_1$$  \hspace{1cm} (1)

where $\emptyset = 1 - \emptyset'$. Consumers are heterogeneous in their valuation of the service, which is uniformly distributed across the consumers’ population [40]. We use the parameter $V$ to designate the initial valuation of consumers when using the service offered by the knowledge platform and assume that $V$ is uniformly distributed in $[0, 1]$. Let $\alpha_1$ be a consumer’s utility from an additional consumer and $\beta$ be a consumer’s utility from an additional provider. The utility that the consumer get from the consumer base and provider base are $\alpha_1n_1$ and $\beta n_2$, respectively. However, consumers tend to be averse to advertisements [41]. As the platform’s advertisements increase, the benefit of the consumer will decrease. We use the parameter $\gamma$ to describe this negative network externality. Therefore, the utility of consumers can be shown as:

$$U_1 = V + \alpha_1n_1 + \beta n_2 - \gamma n_3 - C$$  \hspace{1cm} (2)

where $-\gamma n_3$ means that the more the number of advertisements on the platform, the greater the consumer’s dissatisfaction utility.

Basic service capacity of the platform, the number of consumers and the content manufacturing cost are considered when knowledge providers decide to join the platform. Providers can get the basic service valuation $S$ when using platform’s service. $f_2$ is the content cost of providers, which varies according to creative ability and quality. We assume that $f_2$ is uniformly distributed in $[0, 1]$. Furthermore, as the platform’s consumer base increases, the benefit of the provider will increase. We use parameter $\alpha_2$ to describe this network externality. Therefore, the utility that providers get from the consumer base is $\alpha_2n_1$ and the utility of providers can be shown as:

$$U_2 = S + \alpha_2n_1 + \emptyset' C - f_2$$  \hspace{1cm} (3)

For advertisers, we use parameter $f_3$ to designate the advertising cost, which satisfies uniform distribution with support $[0, 1]$. Let $\alpha_3$ be an advertiser’s utility from an additional consumer. $\alpha_3n_1$ means that the greater the consumer base, the greater the advertiser’s utility. So the utility of advertisers can be shown as:

$$U_3 = \alpha_3n_1 - p - f_3$$  \hspace{1cm} (4)

Table 1 summarizes all parameters used in this paper.

### IV. ANALYSIS

#### A. EQUILIBRIUM ANALYSIS

The users who receive a positive utility will decide to join the platform, namely, $U_i > 0$ ($i=1,2,3$). Let $\bar{V}$, $\bar{f}_2$, $\bar{f}_3$ be the marginal users who participate in the platform. Therefore, the consumer will sign to the platform when the initial utility is in the range $[\bar{V}, 1]$. The knowledge provider will join the platform when the content production cost is in the range of $[0, \bar{f}_2]$. Similarly, the advertiser will join the platform when the advertising production cost is in the range of $[0, \bar{f}_3]$. Otherwise, they will not participate in the platform.

### TABLE 1. Summary of notations.

| Parameters | Description |
|------------|-------------|
| $\alpha_1$ | The intra-group network externality of consumers |
| $\alpha_2$ | The network externality from consumers to providers |
| $\alpha_3$ | The network externality from consumers to advertisers |
| $\beta$    | The network externality from providers to consumers |
| $\gamma$   | The network externality from advertisers to consumers |
| $n_1$      | The number of consumers on the platform |
| $n_2$      | The number of providers on the platform |
| $n_3$      | The number of advertisers on the platform |
| $V$        | The initial valuation of consumers provided by the platform |
| $S$        | The basic valuation of providers provided by the platform |
| $f_2$      | The content cost of providers |
| $f_3$      | The advertising cost of advertisers |
| $\bar{V}$  | The advertising price |
| $\emptyset$| The proportion of transaction fees charged by the platform |
| $\emptyset'$| The proportion of transaction fees distributed to providers |
| $C$        | The transaction fees charged from consumers |
| $N_1$      | The market of consumers |
| $N_2$      | The market of providers |
| $N_3$      | The market of advertisers |
| $U_1$      | The utility of consumers |
| $U_2$      | The utility of providers |
| $U_3$      | The utility of advertisers |
The number of consumers, providers, and advertisers of the platform should satisfy the following equation:

\[ n_1 = N_1(1 + \alpha_1 n_1 + \beta n_2 - \gamma n_3 - C) \]
\[ n_2 = N_2(S + \alpha_2 n_1 + \emptyset C) \]
\[ n_3 = N_3(\alpha_3 n_1 - \emptyset) \]

(5)

Let \( H = 1 - N_1 \alpha_1 - \beta N_1 N_2 \alpha_2 \) and \( K = H + \gamma N_1 N_3 \alpha_3 \). It can be seen from Table 1 that \( \alpha_1, \alpha_2, \) and \( \beta \) are network externalities, which means that \( 0 < \alpha_1 < 1, 0 < \alpha_2 < 1, \) and \( 0 < \beta < 1 \). Meanwhile, the total market of consumers and providers are standardized as 1. That means \( 0 \leq N_1 \leq 1 \) and \( 0 \leq N_2 \leq 1 \). Therefore, we can get that \( H > 0 \). When the advertising price and transaction fees meet the conditions of \( = \{(p, C) \mid 0 \leq p \leq [N_1 \alpha_3(1 + \beta N_2 C + \beta N_2 \emptyset C - \beta N_2 \emptyset C - \gamma N_3 p)/(1 + \beta N_2 S + \gamma N_3 p)/(1 + \beta N_2 \emptyset - \beta N_2)]\}, \) the number of advertisers \( n_3 \geq 0 \). The equilibriums of users can be expressed as:

\[ n_1 (p, C) = \frac{N_1(1 + \beta N_2 S + \beta N_2 C - \beta N_2 \emptyset C + \gamma N_3 p - C)}{K} \]
\[ n_2 (p, C) = \frac{\alpha_2 N_1 N_2 (1 + \beta N_2 S + \beta N_2 C - \beta N_2 \emptyset C + \gamma N_3 p - C)}{K} + N_2 S + (1 - \emptyset) C \]
\[ n_3 (p, C) = \frac{\alpha_3 N_1 N_3 (1 + \beta N_2 S + \beta N_2 C - \beta N_2 \emptyset C + \gamma N_3 p - C)}{K} - \gamma N_3 p \]

(6)

From the above derivation, the platform’s decision problem can be expressed as:

\[ \max_{(p, C) \in \Gamma} N \eta (p, C) = \eta N_1(1 + \beta N_2 \emptyset - \beta N_2) \]

(7)

Let \( I = 1 + \beta N_2 \emptyset - \beta N_2 \). When \( \emptyset \geq [N_1 N_3 (\emptyset \gamma - \alpha_3 I)^2]/(4IH) \), the Hessian matrix of \( \eta (p, C) \) is negative, that is \( \eta \) has an optimal solution over \( \Gamma \). In the following of this paper, we assume that \( \emptyset > [N_1 N_3 (\emptyset \gamma - \alpha_3 I)^2]/(4IH) \) which makes the optimal advertising price and the optimal profit of the platform exist. As a result, the optimal advertising price and transaction fees can be deduced as:

\[ p^* = \frac{\emptyset N_1 (1 + \beta N_2 S) (\emptyset \gamma + \alpha_3 I)}{4\emptyset IH - N_1 N_3 (\emptyset \gamma - \alpha_3 I)^2} \]
\[ C^* = \frac{(1 + \beta N_2 S) (2\emptyset H + \alpha_3 N_1 N_3 (\emptyset \gamma - \alpha_3 I))}{4\emptyset IH - N_1 N_3 (\emptyset \gamma - \alpha_3 I)^2} \]

(8)

(9)

Bring the optimal advertising price \( p^* \) and the optimal transaction fees \( C^* \) into equation (6) and (7), we conclude the equilibriums in Lemma 1.

**Lemma 1:** Under conditions \( \emptyset > [N_1 N_3 (\emptyset \gamma - \alpha_3 I)^2]/(4IH) \) and \( (p, C) \in \Gamma \), the equilibriums of the model are as follows:

**B. SENSITIVITY ANALYSIS**

In this part, we simulate the properties of equilibrium outcomes derived in Lemma 1. To simplify the analysis, we assume that the market of knowledge consumers, providers, and advertisers is 1, that is \( N_1 = N_2 = N_3 = 1 \). Fig. 1-2 graphically illustrates the impact of the proportion of transaction fees charged by the platform \( \emptyset \) on advertising price \( p \) and the profit of platform \( \eta \) with the conditions of \( \alpha_1 = 0.4, \alpha_2 = 0.5, \alpha_3 = 0.3, \beta = 0.6, \gamma = 0.3, S = 2 \).

**Observation 1:** As the proportion of transaction fees charged by the platform increases, the advertising price first increases rapidly, then decreases slightly and then increases steadily.

It can be seen from Fig. 1 that when the proportion of transaction fees charged by the platform is at a low level (\( \emptyset \leq 0.1 \)), the platform distributes most of the transaction fees to knowledge providers, which effectively attracts providers to join the platform and has great positive effect on consumers utility. In this case, more consumers are willing to sign to the platform and attract advertisers to join, which makes the advertising price increase rapidly. When \( 0.1 < \emptyset \leq 0.2 \), a slightly increase in the proportion of transaction fees charged by the platform causes providers to worry about their benefits, which leads to a small decrease in the number of providers and consumers. The narrowed consumer market...
ultimately promotes the number of advertisers and profit of utility that consumers get from the platform is increasing, and consumer’s experience increases, which means that the positive utility that meets his manifold needs and in this case, the consumer can find knowledge and attracts providers to share knowledge and enriches the content of the platform. That is, the consumer can find knowledge that meets his manifold needs and in this case, the consumer’s experience increases, which means that the positive utility that consumers get from the platform is increasing, and ultimately promotes the number of advertisers and profit of the platform. However, when the proportion charged by the platform exceeds a certain threshold (\( \phi > 0.1 \)), the platform profit will diminish gradually. Note that when the proportion charged by the platform is in a higher range, the main source of the platform profit transforms from the consumer’s market.

Under the influence of high proportion of transaction fees charged by the platform in this stage, the utility of consumers will decrease due to the sharply decrease in the number of providers. Combined with Fig. 2, it can be observed that although the platform choose to raise the advertising price at this time to increase the revenue, compared with the great negative utility brought by providers, the profit of the platform decreases.

### C. NUMERICAL ANALYSIS

In this part, we will numerically explore how the different level of network externalities affect the advertising price and platform profit to provide a reference for the platform’s decision-making.

**Observation 2:** As the proportion of transaction fees charged by the platform increases, the platform’s profit first increases, and then decreases gradually.

Fig. 2 illustrates the impact of the proportion of transaction fees charged by the platform on knowledge payment platform’s profit. Low-level proportion charged by the platform assumes that providers can obtain higher benefits, which attracts providers to share knowledge and enriches the content of the platform. That is, the consumer can find knowledge that meets his manifold needs and in this case, the consumer’s experience increases, which means that the positive utility that consumers get from the platform is increasing, and ultimately promotes the number of advertisers and profit of the platform. However, when the proportion charged by the platform exceeds a certain threshold (\( \phi > 0.1 \)), the platform profit will diminish gradually. Note that when the proportion charged by the platform is in a higher range, the main source of the platform profit transforms from the consumer’s market.

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fees charged by the platform as the negative externality $\gamma$ increase. It is understandable that within the initial scope of the increase of the proportion charged by the platform, the positive utility of a large number of providers is greater than the negative utility of increased advertisements. At this time, the proportion of transaction fees charged by the platform has a greater impact on advertising price than the aversion of consumers to advertisements. Hence we find that when the platform decides to distribute most of the transaction fees to providers, the change in the level of network externality $\gamma$ does not have a significant effect on advertising price. When $\theta > 0.1$, from Observation 1, we can find that the aversion of consumers to advertisements has a greater impact on advertising price than the proportion of transaction fees obtained by platform. Therefore, platform should give more consideration to consumers’ aversion to advertisements if it wants to get the optimal advertising price.

It can be seen from Fig. 4 that with the increase of the network externality $\gamma$, the profit of the platform is less sensitive to the proportion of transaction fees charged by the platform. Under strong aversion to advertisements, consumers are unwilling to join the platform. At this time, the utility of network externality $\gamma$ is greater than the utility of proportion of transaction fees charged by the platform.

**Observation 4:** As the proportion of transaction fees charged by the platform and network externality $\beta$ increase:
(i) The advertising price is more sensitive to the proportion of transaction fees charged by the platform.
(ii) The profit of the platform is more sensitive to the proportion of transaction fees charged by the platform.

It can be observed from Fig. 5 that when the platform distributes most of the transaction fees to providers ($\theta \leq 0.1$), the greater the network externality $\beta$, the higher the advertising price. However, with the increasing proportion of transaction fees obtained by platform, the rise of advertising price is basically the same under different network externalities $\beta$. It shows that when the proportion of transaction fees obtained by the platform is low ($\theta \leq 0.1$), the network externalities of knowledge providers to consumers have a greater impact on advertising price than the transaction fees obtained by the platform. Therefore, the platform should give more consideration to the network externalities of providers to consumers if it wants to set a higher advertising price at this time.

Similarly, we also find that with the increase of network externality $\beta$, the platform’s profit is more sensitive to the proportion of transaction fees charged by the platform. This is because the utility that consumers get from providers...
becomes greater as the network externality $\beta$ increase, and therefore causes a big change in the platform’s profit.

Observation 7: As the proportion of transaction fees charged by the platform increases:

(i) With the increase of network externality $\alpha_1$, both of the advertising price and platform’s profit are more sensitive to the transaction fees charged by the platform.

(ii) With the increase of network externality $\alpha_2$, both of the advertising price and platform’s profit are more sensitive to the transaction fees charged by the platform.

(iii) With the increase of network externality $\alpha_3$, both of the advertising price and platform’s profit are more sensitive to the transaction fees charged by the platform.

Fig.7-12 show how the network externalities affect the relationship between advertising price, platform’s profit and the proportion of transaction fees charged by the platform. It means that the positive utility that providers and advertisers get from consumers is greater as the network externalities increase, which ultimately promotes a relatively big change of the advertising price and platform’s profit. Therefore, the
advertising price and platform’s profit will change significantly as the network externalities increase to a certain extent.

We can also find from Fig.8 that as the proportion of transaction fees charged by the platform and the network externality increase ($\theta > 0.9$ and $\alpha_1 = 0.5$), the profit of the platform is negative. It indicates that when the degree of interaction among consumers is high, the increase of the proportion of transaction fees cannot be measured with the decrease of revenue caused by the loss of consumers.

### V. CONCLUSION

In this paper we present a three-sided model to investigate the pricing strategy of knowledge payment platform of how to balance the revenue of advertisers and consumers. Considering the influence of multiple factors such as the proportion of transaction fees charged by the platform and network externalities, the platform needs to choose the optimal pricing strategy to maximize its profit.

There are several important implications for pricing strategy that knowledge payment platforms can choose. Among the limited information on knowledge payment platforms, the pricing strategy in prior papers is usually studied from the perspective of consumers and knowledge providers. Different from prior research, we take the impact of advertisers into consideration to analytically investigate the knowledge payment platform’s pricing decisions. Our model describes the impact of the proportion of transaction fees charged by the platform on advertising price and platform’s profit under which the platform charges advertising fees and transaction fees at the same time. Interestingly, we find that with the increasing proportion of transaction fees charged by the platform, the advertising price shows an upward trend in general. However, once the proportion of transaction fees charged by the platform is too high, which will have a negative impact on the platform’s profit although the platform adopts a strategy of increasing advertising price for advertisers. The increase in advertising price cannot make up for the contraction of the consumer market caused by the massive loss of knowledge providers, and therefore causes a reduction in platform’s profit. When the proportion of transaction fees charged by the platform is at a low level, the platform’s profit reaches the maximum. Therefore, knowledge providers is a crucial factor affecting the development of platform. The platform should attract more knowledge providers to join and expand their scale by increasing the proportion of transaction fees obtained by providers, which has a positive impact on platform’s profit. In practice, the Himalaya FM, for example, usually attracts well-known providers with high proportion of transaction fees to expand its consumer market.

Meanwhile, the network externality is a key consideration for managers when formulating pricing strategies for these platforms. In this paper, we investigate how different level of network externalities affect pricing strategy of the platform. The results show that with the increase of proportion of transaction fees charged by the platform and network externalities, both of the advertising price and platform’s profit are more sensitive to the proportion of transaction fees charged by the platform. On the contrary, as the degree of consumers’ aversion to advertisements increases, the platform’s profit is less sensitive to the proportion of transaction fees charged by the platform.

There are several limitations to this research. Firstly, our model only considers a single platform and investigates the impact of platform strategy on optimal profits. In fact, there will always be more similar platforms competing with each other. Studying pricing strategies under multi-platform competition can further provide platforms with practical decisions. Therefore, investigating the competition platforms’ pricing strategy would be an interesting research direction in the future. Secondly, advertisements may be beneficial to consumers to a certain extent, and therefore a possible way to expand our study is to classify consumers’ attitudes to advertisements in further research. Finally, transaction fees charged from providers or consumers is another popular business strategy in knowledge payment platforms. Therefore, in subsequent studies, studying the transaction fees charged from providers or consumers will also be interesting.

### APPENDIX

*Proof for Lemma 1:* From equation (6), under the premise of $n_1 \geq 0$, $n_2 \geq 0$, and $n_3 \geq 0$, we can get the conditions that advertising price and transaction fees need to meet, namely, $\Gamma = \{(p, C) \mid 0 \leq p \leq [N_1(1 + \beta N_2 C + \beta N_2 S - \beta N_2 \theta C - C)/H, 0 \leq C \leq (1 + \beta N_2 S + \gamma N_3 p)/\theta C - \beta N_2 S - C]$. Bring $n_1 (p, C)$ and $n_3 (p, C)$ into equation (1), the platform’s profit $\eta(p, C)$ can be expressed as:

$$\eta(p, C) = \frac{\alpha_3 N_1 N_3 p (1 + \beta N_2 S + \beta N_2 C - \beta N_2 \theta C + \gamma N_3 p - C)}{K}$$

$$\frac{\partial \eta}{\partial C} N_1 (1 + \beta N_2 S + \beta N_2 C - \beta N_2 \theta C + \gamma N_3 p - C) - N_3 p^2$$

From the above equation, we take the first derivatives of $\eta(p, C)$ with respect to $p$ and $C$, respectively. $\partial \eta/\partial p$ and $\partial \eta/\partial C$ can be expressed as:

$$\frac{\partial \eta}{\partial p} = \frac{\alpha_3 N_1 N_3 (1 + \beta N_2 S + \beta N_2 C - \beta N_2 \theta C - C + 2\gamma N_3 p)}{K}$$

$$\frac{\partial \eta}{\partial C} = \frac{\theta C N_1 N_3}{K} - 2N_3 p$$

$$\frac{\partial \eta}{\partial C} = \frac{(\alpha_3 N_1 N_3 p + 2\theta C N_1) (\beta N_2 - \beta N_2 \theta - 1)}{K}$$

$$+ \frac{\theta C N_1 (1 + \beta N_2 S + \gamma N_3 p)}{K}$$

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Therefore, the Hessian matrix can be expressed as
\[
\eta(p^*, C^*) = \frac{2\alpha_3 N_1 N_3 (1 + \beta N_2 S) (\theta_N + \gamma p N_1 N_3)}{4\alpha N_1 K (\theta_N - \gamma I)} - 2N_3
\]
\[
\frac{2\alpha_3 N_1 N_3 (\beta N_2 - \beta N_2 \theta - 1) + \gamma p N_1 N_3}{K}
\]
\[
\frac{2\alpha_3 N_1 N_3 (\beta N_2 - \beta N_2 \theta - 1) - 1}{K}
\]
Let \( I = 1 + \beta N_2 \theta - \beta N_2 \).

Therefore, the Hessian matrix of \( \eta(p, C) \) is negative.

In order to derive the optimal advertising price and transaction fees, we let \( \partial \eta/\partial p = 0 \) and \( \partial \eta/\partial C = 0 \). The optimal advertising price \( p^* \) and transaction fees \( C^* \) can be expressed as:
\[
p^* = \frac{\theta N_1 (1 + \beta N_2 S) (\theta_N + \gamma p N_1 N_3)}{4\alpha N_1 K (\theta_N - \gamma I)}
\]
\[
C^* = \frac{(1 + \beta N_2 S) [\theta N_1 (\theta_N + \gamma p N_1 N_3)]}{4\alpha N_1 K (\theta_N - \gamma I)}
\]

Similarly, bring \( p^* \) and \( C^* \) into equation (7) and the profit of the platform can be deduced as:
\[
\eta(p^*, C^*) = \frac{2\alpha_3 I \theta N_1 N_3 (1 + \beta N_2 S) (\theta_N + \gamma p N_1 N_3)}{4\alpha N_1 K (\theta_N - \gamma I)} - 2N_3
\]
\[
\frac{2\alpha_3 N_1 N_3 (\beta N_2 - \beta N_2 \theta - 1) + \gamma p N_1 N_3}{K}
\]
\[
\frac{2\alpha_3 N_1 N_3 (\beta N_2 - \beta N_2 \theta - 1) - 1}{K}
\]
Let \( H = 1 - N_1 \alpha_3 - \beta N_1 N_2 \alpha_2 \) and \( K = H + \gamma N_1 N_3 \alpha_3 \).

When \( \theta > \frac{[N_1 N_3 (\theta_N - \gamma I)]}{(4\alpha N_1 K)} \), we can deduce that
\[
|A_1| = (\theta N_1 N_3 (\theta_N - \gamma I))/(4\alpha N_1 K) < 0,
\]
\[
|A_2| = [4\alpha N_1 K (K - \gamma N_1 N_3)]/(4\alpha N_1 K) > 0.
\]

As a result, the Hessian matrix of \( \eta(p, C) \) is negative.

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