The Optimal Stratification of Platform Market

Abstract

In this article, with the theory of two-side market, we study an emerging phenomenon, “Platform Stratification”, i.e. a market designer can stratify its centralized platform into several sub-platforms to maximize its total profit. By assuming user heterogeneity, we identify and characterize three key factors affecting platform stratification: density, congestion and security of the market. Our analytical results show that the optimal number of stratification is positively correlated with the degree of market congestion and market security as well, but negatively correlated with market density.

Key Words:

Two-side Market; Market Stratification; User Heterogeneity; Market Design

1. Introduction

With the development of the digital economy, we have seen a new phenomenon in online market platform, platform stratification. There are many platform operators stratify their centralized platform into several sub-platforms. For example, Alibaba divides its e-commerce platform "Taobao" into three sub-platforms: Idle Fish, Taobao and T-Mall. i.e. the Idle Fish platform for second-hand transactions, the Taobao platform for ordinary commodity transactions and T-Mall platform for famous brands and genuine products. Amazon has also stratified its customers through Prime membership system. By stratification, platform operators can maximize their profits.

However, according to the traditional theory of two-side market, it is impossible to explain the phenomenon of platform stratification. Because the existing two-side market theory mostly discusses the benefits brought by the positive externality of cross network, with the increase of users it will further strengthen the positive externality of cross network. In this way, the platforms have no incentive to stratify. Therefore, we suppose to use user heterogeneity in order to explain the phenomenon of platform stratification. User heterogeneity was first proposed by Weyl (2010), which is due to the heterogeneity of user's individual preferences, that is, different users' potential evaluation of different trading partner is different, so the potential benefits of their transactions are also different.

After introducing the assumption of user heterogeneity, we find that the original cross network externalities can be divided into positive externalities and negative externalities. Positive externalities refer to the increase of utility brought by the increase of users on one side of the platform to users on the other side. While negative externalities refer to the loss of utility brought by the increase of users on one side of the platform to users on the same side. But usually the positive externalities have more influence than the negative externalities, hence we observe that the platforms generally present the positive externalities of cross network in reality. If user heterogeneity doesn't exist, with the continuous increasing of users will strengthen the positive externality of cross network, it will generate positive feedback and further intensify the expansion of the platform. If user heterogeneity exists, users on both sides of the platform want to trade with their expected partners. The increase of users will not only enhance the positive externalities, but also add the transaction costs. As a result, it will affect the efficiency of matching and lead users who are sensitive to matching efficiency choose to quit the platform, which eventually affects the profit of the platforms.

In order to avoid the above situation, the platform operators will adopt the operation strategy of stratification. As a means of market design, the purpose of stratification is dividing the users according to their different characteristics and make the same type of trading partners match together, which can reduce the transaction cost and improve the matching efficiency. Alvin Roth (2008) concluded three factors should be considered in designing an effective market: market thickness, market congestion and market safety.

In our opinion, market thickness means that the platforms expect to gather the participants who are willing to trade together. The more participants, the denser the market will become, so as to expand the scope of trade selection and improve the success rate of trade. Therefore, the essence of market density is the positive externality of cross network in the two-side market. If the platform is stratified, it will cause market segmentation, that is, users can only trade in their own stratum. Compared with the situation of no stratification, it is equivalent to reducing the number of users participating in transactions in each stratum. It will reduce the positive externality of cross network, that is, reducing the market density. This is also one of the negative factors that need to be considered in the platform's decision of stratification.

Market congestion comes from the existence of user heterogeneity, if there are too many users on one side of the market, the search cost required to complete the transaction is too high, thus it will affect the matching efficiency of the transaction. This phenomenon is similar to "traffic jam". And it will result in some users who are sensitive to matching efficiency choose to quit the platform. Therefore, congestion is the negative externality of cross network caused by user heterogeneity. One of the important benefits of platform stratification is reducing the loss due to the market congestion.

Market security is also related to the user heterogeneity. Because each user has its own best trading partner. When the gap between the user's actual trading partner and the best trading partner is too large, some users who are more sensitive to transaction risk may choose to quit the platform. Because they are unwilling to bear the mismatching risk. When more and more users choose to quit the platform due to the transaction security problem, it will appear similar to the phenomenon of "Bank Run".

So we build a market design model with the assumption of user heterogeneity. In this model, we analyze the impact of market density, market congestion and market security on platform stratification and then discuss the optimal number of the stratification.

The structure of the rest of this paper is as follows: the second part is the review of related literature; the third part is the model; the last part is the conclusion.

2. Related literature

The study of two-side market begins with the existence of cross network externalities: Katz & Shapiro (1985, 1986) and Farrell & Saloner (1985, 1986) first put forward the concept of "non-internalized externalities" between users and gave the definition of network externalities: if the value increase of network is due to the expansion of network because of the addition of B user, then we can say there exist cross network externalities. Starting from this definition, many scholars have put forward many explanations for the concept of externality. As for the cross network externality in the field of platform, Rochet & Tirole (2003) and Armstrong (2006) first brought the positive externality of cross network of platform into the analysis through modeling and built the user utility function with the positive externality of cross network under the situation of complete monopoly. Then compares it with the total social welfare under the situation of social planners. It is found that the positive externality of cross network of two-side market will lead to the expansion of the platform and the monopoly platform will not necessarily damage the social welfare. Up to now, most of the researches are still focused on the positive externalities of cross networks in the platform.

Secondly, there is a lot of study of user heterogeneity in two-side market. User heterogeneity was first proposed by Weyl (2010). He studied the general theory of internet monopoly pricing. User heterogeneity mainly comes from the heterogeneity of user preferences, because different users have different preferences, so the same goods and services will bring different effects to different users. After Weyl (2010), many scholars have verified the existence of user heterogeneity in different fields: Tobias (2014) has proved that there exists significant user heterogeneity in the financial market; Julien & Pavan (2018) has studied the impact of user heterogeneity on user preferences. They analysis its influence on demand elasticity and equilibrium price. So far, no scholars have discussed the impact of user heterogeneity on cross network externalities, which is one of the innovations of this paper.

Due to the existence of user heterogeneity, the platform may be congested. In order to avoid this situation, the platform usually adopts the following two strategies:

1) According to the identity information and user's usage data, the platform discriminates users' price to solve the problem of user heterogeneity. There are abundant literatures on price discrimination in two-side market: Bernard Caillaud & Julien (2003) conducted extensive empirical research on price discrimination based on user identity and usage through the construction of incomplete price competition model between intermediary service providers; Enrico Böhme (2016) focused on the existence of second level price discrimination in monopoly platform and analysis the total social welfare with such price discrimination; Qihong Liu (2013) studied the impact of price discrimination on platform profits and total social welfare in the two-side market and found that the price discrimination beneficial to the traditional unilateral market may not be applicable in two-side market; Qihong Liu & Jie Shuai (2013) further studied in multidimensional the impact of price discrimination on the profit and social welfare of two-side market in the model.

2) The platform divides users into different types according to their characteristics and then carries out matching among users with similar types to solve the problem of user heterogeneity. At present, the literature on the field of stratification mainly focuses on the study of one-side market:

Reich (1973) first made a preliminary analysis of the stratification phenomenon in the labor market; Dickson (1987) further distinguished the two concepts of market stratification and product differentiation; Wilkinson (2013) further studied the dynamic stratification in the labor market; Later, the study of stratification has been further extended to the financial market: Chen (2001) studied the impact of stratification on user returns in the stock market; Ruth (2003) studied the impact of stratification strategy adopted by users with different cultural backgrounds in the B2B market.

At present, there are quite a lot of literature on price discrimination to solve the problem of user heterogeneity. In the research of market stratification, although the stratification phenomenon has existed in the past, the previous literature only studied the stratification in the one-side market. The second innovation of our study is that the stratification in the platform market is that we have stratified both two-side users at the same time, which is different from the previous stratification for the one-side market. This is a new stratification strategy and research thinking.

3. Modelling

By Rochet and Tirole (2003) and Armstrong (2006), we assume the utility function μ_i of the agent i:

$$\mu_i = \delta_i + \alpha_i n_{-i} - p_i \qquad (1)$$

Where $i \in (B,S)$,(B indicates buyer; S indicates seller). n_{-i} indicates the number of users on the other side of i; α_i represents the coefficient of the positive externalities of the cross-network; δ_i indicates that the users standing on the i side and participating in the platform that he can obtain the fixed externalities.

The impact of user heterogeneity on utility can be divided into two aspects: first, different users participate the platform can obtain different fixed utility, that is, different users' evaluation of the same platform exist heterogeneity. Second, different users participate the platform can generate different cross network externalities, that is, different users can bring external to other users is heterogeneous.

Rochet & Tirole (2003) assumes that δ_i is a constant value, so he only considered the impact of user heterogeneity on the external utility. Armstrong (2006) assumes that α_i only depends on which side of the platform the user is on, he only considered the impact of user heterogeneity on the user's fixed utility, but the impact of the external utility of users caused by user heterogeneity is ignored. Summarizing the previous analysis of heterogeneity, they only considered the partial effect of user heterogeneity on utility, so we will build a new users' utility function by considering two effects comprehensively:

$$U_N = U_{trade} + U_{net} - P_i \qquad (2)$$

According to the effect of user heterogeneity on utility, we divide the total utility into three parts: U_{trade} represents the users' fixed utility that can be obtained by participating platforms, U_{net} represents the users' external utility, P_i represents the price that the platforms charge the user i.

3.1 Two-side matching model with user heterogeneity

Our model assumes that there are N_i (i=B stands for the buyer, i=S stands for the seller) represent the total users in the i side of the market. Jullien and Paven (2018) found that heterogeneity of user preferences, different users have different comments on different trading objects. Thus the potential benefits from trading with them may vary. Based on Jullien's research, our paper assumes that the matching type of two-side users of the platform is X_i And the matching types of both sides are evenly distributed in the interval [0,1] (ie $X_i \sim [0,1]$). When the matching type between the two-side users who conduct the transaction is closer(which means $|X_B - X_s|$ is more close to zero), the transaction results are more favorable for both parties. In contrast, if the matching types of the two parties are too different, the users may choose to quit the platform, resulting in market failure. Our study is based on the examples of the buyers, because the buyers and the sellers have a symmetrical relationship, so we can derive the sellers by studying the buyers' utility.

In order to avoid the transaction results with big differences in matching types, the platform needs to do stratification for users according to their matching types. According to the matching types, two-sided users are divided into k-levels, where the matching coefficient interval of level m users is $[\frac{m-1}{k}, \frac{m}{k}]$ （m=1， 2， …， k）. Then the platform carries out matching in the same level of users, which can ensure that the matching types between users and trading partners are not too different. At this time, each level of the two sides of the platform has n_i users actually participate in the transaction, but not all users will participate in the platform. Only when their utility satisfy the constraints they will participate in the platform transaction (the derivation of n_i

will be discussed later in this article). We take the buyers in level *m* as an example, whose trading partner is distributed in the range of matching coefficient$\left[\frac{m-1}{k},\frac{m}{k}\right]$, so the expectation of the buyers in level m for the matching coefficient of trading partner is:

$$E\left(X_S \middle| \frac{m-1}{k} \le X_S \le \frac{m}{k}\right) = \frac{2m-1}{2k} \tag{3}$$

3.11 User's fixed utility

Therefore, the fixed utility U_{trade} that the buyers of level *m* can obtain when they trade on the platform is:

$$U_{trade} = f_B - a\left|\frac{2m-1}{2k} - X_S\right| \tag{4}$$

Where f_B represents the maximum fixed utility that a buyer can obtain when trading with its best trading partner, $\left|\frac{2m-1}{2k} - X_S\right|$ measures the difference between the buyers expected trading partner and their best trading partner; *a* represents the utility loss caused by the degree of unit deviation.

Because the matching coefficient of different users are also different, the deviation degree between the best trading partner and the actual trading partner is different, so the fixed utility is different, which is the impact of user heterogeneity on the fixed utility of users.

3.12 User's externality utility

Armstrong (2006) only analyzed the positive externality of cross network caused by the increase of users on the other side of the platform. Corresponding to the model in this paper, we introduce the positive externality coefficient μ_i to describe this effect and measure the density of the market. However, he did not consider the negative externality of cross network and the user's demand for platform security, which led to the increase of search cost and the reduction of matching efficiency due to the excessive number of users on the same side.

In this paper, we introduce the congestion coefficient b_i to measure the degree of decline of matching efficiency caused by too many users. For the characterization of market security, we will use the risk variance coefficient d_i and the risk aversion tendency θ to describe them. It is assumed that the utility generated by the cross network effect that the platform seller can bring to the platform buyer's for each additional user is Z_i （$i = 1，2，...n$）. So we can write the expected $E(Z_i)$ and variance $D(Z_i)$ of the externality utility Z_i of a single user.

$$E\left(Z_q\right) = \mu_i - b_i n_B \qquad (5)$$

$$\mathrm{D}\left(\mathrm{Z_q}\right) = \frac{\mathrm{d_i}}{\mathrm{k}^2} \qquad (6)$$

Z_q is a random variable and its randomness comes from the difference of user preferences between two sides of the platform. Among them, μ_i represents the revenue obtained by users through the positive externalities of cross network; b_i represents the difficulty of platform matching caused by the increase of the users on the same side of the platform; $b_i n_i$ measures the total congestion loss, that is, the total utility loss brought by the negative externalities of cross network to users. Variance $\mathrm{D}\left(\mathrm{Z}_j\right)$ represents the risk variance of cross network negative externalities, which is inversely proportional to the square $\frac{1}{k^2}$ of the number of levels k, indicating that the more level, the smaller the risk loss of cross network negative externalities, and the safer the platform for users.

According to the above analysis, the total externalities of cross network externalities on the buyers is as follows:

$$U_{net} = W_1 + W_2 + \cdots + W_n \quad (7)$$

Total expect utility $E(U_{net})$ and total variance $D(U_{net})$ can be represent:

$$E(U_{net}) = \mu_B n_S - b_B n_B n_S \quad (8)$$

$$D(U_{net}) = \frac{n_S d_B}{k^2} \quad (9)$$

When n_B is large enough, according to the Central Limit Theorem (CLT), the distribution of U_{net} is approximately normal distribution:

$$U_{net} \sim N(\mu_B n_S - b_B n_B n_S, \frac{n_S d_B}{k^2})$$

Next, consider the charging decision of the platform, assuming that the platform charges users in the form of membership fee. If the fee charged to the buyers is p_B and the fee charged to the sellers is p_S, then the total utility U_N that the buyers' can obtain by participating in the transaction on the platform is:

$$U_N = U_{trade} + U_{net} - P_B = f_B - a\left|\frac{2m-1}{2k} - X_B\right| + \mu_B n_S - b_B n_B n_S - p_B \quad (10)$$

We assume that all two-side users have the same absolute risk aversion tendency θ ($\theta > 0$), so we could use VNM utility function to get the expected utility of buyer's participation in level m transactions:

$$U_m = E\left(1 - e^{-\theta U_N}\right) = 1 - e^{-\theta\left(f_B - a\left|\frac{2m-1}{2k} - X_B\right| + \mu_B n_S - b_B n_B n_S - p_B\right) + \frac{\theta^2 n_S d_B}{2k^2}} \quad (11)$$

U_N represents the total utility of the sum of fixed utility and external utility; U_m represents the expected total utility after the introduction of risk aversion tendency of users. Compared with the classic two-way platform model, we consider the impact of user heterogeneity on fixed utility and external utility. We also include three important factors of market design into the analysis framework.

3.2 Optimal stratification in maximizing platform profit

In the previous analysis, we mentioned that not all users on each side of the platform will participate in the transaction. Only when they utility obtained by participating in the platform satisfy specific constraints, users will choose to enter the platform. Next, we will consider the utility constraints for users participating in the platform: Firstly, only when the expected utility of transactions is greater than 0, users will be encouraged to enter the platform, which can be understood as the participation constraints of members. In addition to participation constraints, by assuming that each user can only choose one level of the platform to enter, so rational users will definitely choose the level with the biggest expected utility. It can be understood as the incentive compatibility constraints of members:

$$\begin{cases} U_m > 0 & [\boldsymbol{IR}] \\ U_m > U_{m'},\ (m' = 1,2,\cdots,m-1,m+1,\cdots,k) & [\boldsymbol{IC}] \end{cases} \quad (12)$$

In order to simplify the calculation, we assume that $N_B = N_S = N$, $P_B = P_S = P$, $f_B = f_S = f$, $\mu_B = \mu_S = \mu$, $b_B = b_S = b$, $d_B = d_S = d$, that is to say, we assume that the two-side users are symmetric, so we can solve (11) and (12) in combination (see the appendix for the specific derivation process):

$$n_B = n_S = n = \frac{-\left(\frac{\theta d}{k^2} - 2\mu + \frac{a}{Nk}\right) + \sqrt{\left(\frac{\theta d}{k^2} - 2\mu + \frac{a}{Nk}\right)^2 - 8b(2p - 2f)}}{4b}$$

$$= \frac{4(f-p)}{\frac{\theta d}{k^2} - 2\mu + \frac{a}{Nk} + \sqrt{\left(\frac{\theta d}{k^2} - 2\mu + \frac{a}{Nk}\right)^2 + 16b(f-P)}} \leq \frac{N}{k} \qquad (13)$$

The number of users（n_B、n_S）who actually participate in the platform transaction is smaller than the number of users （$\frac{N}{k}$） on each stratum of the platform, which verifies that not all users will choose to participate in the platform.

The costs of stratification mainly include the information rent of searching the user information of both sides to identify their matching type. Therefore, we assume that the unit stratification cost of the platform to the two-side users is *ck*, the unit stratification cost is proportional to the level number *k*. That is to say, if the platform wants to stratify the users more accurately, the more information it needs to search, so the cost will rise. And the stratification cost needs to be less than the membership fee charged by the platform, so that the platform can survive. The total cost of platform stratification is two times of that of one side, since the two-sided users of the platform are symmetrical. According to the above analysis, the total profit π of the platform can be calculated:

$$\pi = 2pkn - 2ck^2n \qquad (14)$$

The platform needs to make the optimal stratification decision so as to ensure the maximization profit. Therefore, we calculate the first derivative of the profit function:

$$\frac{\partial \pi}{\partial k} = 2pn + 2pk\frac{\partial n}{\partial k} - 4ckn - 2ck^2\frac{\partial n}{\partial k} = 0 \qquad (15)$$

In order to simplify the analysis, we assume that the unit stratification cost *c* of the platform is 0, because most of the platform in reality hold a large number of transaction data of users, so the marginal cost of the platform stratification can be regarded as 0. In addition, we also assume that the membership fee p charged by the platform to the user is exogenous and the membership fee is equal to the fixed utility *f*, which is the user can obtain from the platform. This is because the internet platform can make full use of big data to make the full price discriminate of the users and collect all the fixed utility that the users can obtain from the platform. In short, the membership fee charged by the platform to one side equals the fixed income that can be obtained when the user enters the platform and participates in the transaction. According to the above analysis, we can combine the simplified (14) and (15) to get the following formula:

$$n = \frac{2\mu - \frac{\theta d}{k^2} - \frac{a}{Nk}}{2b} \leq \frac{N}{k} \tag{16}$$

$$\pi = \frac{2\mu pk - \frac{p\theta d}{k} - \frac{ap}{N}}{b} \leq 2pN \tag{17}$$

According to (16) (17), the optimal number of stratification k^*:

$$k^* = \frac{2Nb + \frac{a}{N} + \sqrt{\frac{a^2}{4N^2} + N^2 b^2 + ab + 2\mu\theta d}}{2\mu} \tag{18}$$

According to the optimal number of the stratification k^*, we summarize the following four theorems:

Theorem 1: The optimal number of stratification k^* of the platform decreases with the increase of the positive externality coefficient μ. That is, the optimal number of stratification is inversely proportional to the benefits brought by the Market Density.

Proof: If (18) is deviating from μ, we can get:

$$\frac{\partial k}{\partial \mu}=\frac{\sqrt{2\mu\theta d}-4Nb-2\frac{a}{N}-2\sqrt{\frac{a^2}{4N^2}+N^2b^2+ab+2\mu\theta d}}{4\mu^2}<0$$

We can easily get $\sqrt{2\mu\theta d}-2\sqrt{\frac{a^2}{4N^2}+N^2b^2+ab+2\mu\theta d}<0$.

Theorem 1 shows that the larger the positive externality coefficient of cross network is, the more profit users can get from the increase of users on the other side, which means the greater the profit brought by market density to users. The finer the platform stratification is, the less the number of users on each stratification will be. Then the positive externality profit will be reduced. Therefore, when the positive externality of users' cross network is large, the platform should reduce the stratification to expand the overall user size and it will enhance the benefits of positive externality.

Theorem 2: The optimal number of stratification k^* of the platform increases with the increase of the negative externality coefficient of the network, including the deviation coefficient *a* of the user matching type and the congestion coefficient *b* of the matching type, that is to say, the optimal number of stratification is directly proportional to the loss caused by the market congestion.

Proof: By taking (18) as partial derivatives for a, b and d respectively, we can get:

$$\frac{\partial k}{\partial a}=\frac{1}{2\mu N}+\frac{\frac{a}{2N^2}+b}{4\mu\sqrt{\frac{a^2}{4N^2}+N^2b^2+ab+2\mu\theta d}}>0$$

$$\frac{\partial k}{\partial b}=\frac{N}{\mu}+\frac{2N^2b+a}{4\mu\sqrt{\frac{a^2}{4N^2}+N^2b^2+ab+2\mu\theta d}}>0$$

It is easy to know that all terms are greater than 0, and then deduces that the number of stratification *k* increases with the increase of the negative externality coefficient of the network, including the deviation coefficient *a* of the matching type and the congestion coefficient *b* of the matching type.

Theorem 2 shows that the larger the negative externality coefficient is, the greater the utility loss of market congestion will be. At this time, platform doing the stratification can improve the total utility of users by reducing the loss of negative externality. What' more, the finer the platform stratification, the smaller the loss of negative externality can be reduced. Therefore, the platform will adopt stratification and the number of stratification is proportional to the negative externality coefficient of the network.

Theorem 3: The optimal number of stratification k^* increases with the increase of user's risk variance coefficient *d* and risk aversion tendency θ. In other words, the sensitivity of user to "market security" is directly proportional.

Proof：By partial deriving (18) from d and θ, we can get：

$$\frac{\partial k}{\partial d} = \frac{\theta}{2\sqrt{\frac{a^2}{4N^2} + N^2b^2 + ab + 2\mu\theta d}} > 0$$

$$\frac{\partial k}{\partial \theta} = \frac{\mu d}{2\mu\sqrt{\frac{a^2}{4N^2} + N^2b^2 + ab + 2\mu\theta d}} > 0$$

It is easy to know that all terms are greater than 0, and then it is deduced that the optimal number of stratification k^* increases with the increase of risk variance coefficient *d* and risk aversion tendency θ of users.

Theorem 3 shows that the greater the risk variance coefficient d of the user which means the higher uncertainty of the trading. The greater of risk aversion tendency θ, it indicates that users are more serious about market security. At this time, users are more concerned about whether the risk loss caused by participating in the platform can be reduced and the degree of loss reduction. If the platform doing the stratification, the risk loss of user participation in the platform will be smaller than without stratification.

Theorem 4: The optimal number of stratification k^* will decreases first and then increases with the increase of the total number of users *N*.

Proof： We define $h = 2Nb + \frac{a}{N}$, then take h into（15）：

$$k = \frac{h + \sqrt{h^2 + 2\mu\theta d}}{2\mu}$$

Then we can get the partial derivative of N：

$$\frac{\partial k}{\partial N} = \frac{\partial k}{\partial h}\frac{\partial h}{\partial N} = \frac{1 + h(h^2 + 2\mu\theta d)^{-\frac{1}{2}}}{2\mu}(2b - \frac{a}{N^2})$$

We can find that when the partial derivative is greater than 0, the value of N satisfies:

$$\frac{1 + h(h^2 + 2\mu\theta d)^{-\frac{1}{2}}}{2\mu}\left(2b - \frac{a}{N^2}\right) > 0 \rightarrow N > \sqrt{\frac{a}{2b}}$$

Then it is deduced that when the total number of users N is less than $\sqrt{\frac{a}{2b}}$, the number of stratification k decreases with the increase of the total number of users N, and when the total number of users n is more than $\sqrt{\frac{a}{2b}}$, the number of stratification k increases with the increase of the total number of users N.

Theorem 4 shows that the number of people in the initial stage of the platform is small and the "market congestion" loss is also small. The positive externality of the cross network between users occupies a dominant position and the main factor affecting the user utility is the positive externality of the cross network. At this time, a small number of stratification is conducive to increasing the number of users, it will improve the positive externalities of cross network and attract more users to participate in the platform. while when the number of users increases gradually, the loss of negative externalities of network caused by user heterogeneity gradually highlights. At this time, it is necessary to reduce the loss of negative externalities through stratification, so the number of stratification increases gradually to the optimal number.

4. Conclusion

Based on the assumption of user heterogeneity proposed by Weyl (2010), this paper extends the classic two-sided platform model of Rochet & Tirole (2003) and Armstrong (2006). We construct a two-side market model and analyze We analyzed the factors that affect platform stratification. Finally, we explain the phenomenon of platform stratification in real life.

By constructing the model, we find that the optimal number of stratification is directly proportional to the positive externality of the cross network. That is to say, the stronger the positive externality of the cross network of the platform, the platform is more likely to choose fewer stratification or even without stratification. In reality, there are some platforms with strong positive externalities of cross networks, such as social platform “WeChat”and “Facebook” and short video social platform "TikTok " and "YouTube". We can find that these platforms are rarely doing stratification. Because the positive externality of cross network in these platforms is strong. Therefore, the increase in the number of users will help platform users enhance their social influence and ability to obtain information. Therefore, doing stratification will weaken the positive externalities of cross network among these users.

At the same time, we also find that the optimal number of stratification is inversely proportional to the negative externalities of the cross network, including the deviation coefficient and congestion coefficient, which means the market congestion loss. In short, if the user heterogeneity is stronger, the greater the loss caused by market congestion is, the platform is more likely to choose the stratification. And the greater the loss caused by congestion is, the optimal number of stratification will be larger. In reality, we often use e-commerce platforms in our life, such as "Taobao" and "Amazon" and dating platforms, "Baihe " and "Match". These products and services expected by different types of users on these platforms vary widely. Therefore, if the platform can identify different types of users' demand, it can significantly reduce the mismatch between users and improve the product experience of users.

Then we find that the optimal number of stratification of the platform is directly proportional to the sensitivity of users to risk, which means the security of the market. If users are more sensitive to loss, then the platform is more likely to do stratification. In our life, we often use a variety of online car-hailing platforms, such as “DiDi ” and “Uber”, as well as delivery platforms, such as “MeiTuan” and “Seamless”. Users pay special attention to the safety of these platforms, because these platforms will affect the safety of users' lives. The online car-hailing platforms involve the travel safety of users and the take out platforms involve the food safety of users. Therefore, users are more sensitive to the risk of using this kind of platforms. Considering that the travel needs and catering needs of users are different, the more stratification, the more different kinds of needs of users can be met.

Finally, we find that there is a dynamic relationship between the optimal number of stratification with the number of users. When the number of users is small, the congestion loss caused by user heterogeneity is small, so the main determinant of user utility is the positive externality of cross network. We can get the optimal number of stratification is small at this time. While with the increase of the users， the congestion loss caused by user heterogeneity will also increase. At this time, the main factor determining the user utility is the loss caused by congestion. Therefore, the optimal number of stratification will be larger compared with that before. According to the above analysis, we can explain the development process of platform enterprises: in the early stage of establishment, the platform usually without the stratification to attract users and strengthen the positive externality of cross network. When the users' number reaches the inflection point, it will comprehensively consider the optimal number of stratification according to the coefficient of positive externality of cross network and the coefficient of negative externality of cross network.

However, there are still some aspects to be further studied: This paper only discusses the platform stratification strategy when the charging structure is in the membership fee, but not the platform stratification strategy when the charging structure is the charging by transaction. Moreover, the academic community lacks more empirical evidence to test other inferences of this model; these are the questions we will further study in the future question.

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APPENDIX

1) Deduce the actual number of participants in each stratification of the platform n_B and n_S

Through our above analysis, we list the IC and IR constraints that enable users to participate in platform transactions as follows:

$$\begin{cases} f_B - a\left|\dfrac{2m-1}{2k} - X_B\right| + \mu_B n_S - b_B n_B n_S - p_B > 0 \\ \left|\dfrac{2m-1}{2k} - X_B\right| < \left|\dfrac{2m'-1}{2k} - X_B\right|, \quad m' = 1,2,\cdots,m-1,m+1,\cdots,k \end{cases}$$

Then we can deduce the conditions that the buyer users of the platform participating in the m-level transaction need to meet under such a hierarchical mechanism by combining them：

$$\begin{cases} \dfrac{2m-1}{2k} - \dfrac{-b_B n_B n_S + \mu_B n_S - \dfrac{\theta n_S d_B}{2k^2} - p_B + f_B}{a} < X_B < \dfrac{2m-1}{2k} + \dfrac{-b_B n_B n_S + \mu_B n_S - \dfrac{\theta n_S d_B}{2k^2} - p_B + f_B}{a} \\ \dfrac{m-1}{k} < X_B < \dfrac{m}{k} \end{cases}$$

We can use the above constraints to find out the number of users who actually participate in the transaction in each level. In order to facilitate the calculation, we can first find out the probability of the buyer's users actually participating in the platform level transaction as follows：

$$P\left\{\begin{matrix} \frac{2m-1}{2k}-\frac{-b_B n_B n_S+\mu_B n_S-\frac{\theta n_S d_B}{2k^2}-p_B+f_B}{a}<X_B<\frac{2m-1}{2k}+\frac{-b_B n_B n_S+\mu_B n_S-\frac{\theta n_S d_B}{2k^2}-p_B+f_B}{a} \\ \frac{m-1}{k}<X_B<\frac{m}{k} \end{matrix}\right\}$$

$$=2\frac{-b_B n_B n_S+\mu_B n_S-\frac{\theta n_S d_B}{2k^2}-p_B+f_B}{a}\leq\frac{1}{k}$$

Therefore, the probability that users of the buyer actually participate in the platform transaction is:

$$\mathrm{P}\left\{\bigcup_{m=1}^{k}\left(\begin{matrix} \frac{2m-1}{2k}-\frac{-\mathrm{b}_B\mathrm{n}_B\mathrm{n}_S+\mu_B\mathrm{n}_S-\frac{\theta\mathrm{n}_S\mathrm{d}_B}{2k^2}-\mathrm{p}_B+\mathrm{f}_B}{a}<\mathrm{X}_B<\frac{2m-1}{2k}+\frac{-\mathrm{b}_B\mathrm{n}_B\mathrm{n}_S+\mu_B\mathrm{n}_S-\frac{\theta\mathrm{n}_S\mathrm{d}_B}{2k^2}-\mathrm{p}_B}{a} \\ \frac{m-1}{k}<\mathrm{X}_B<\frac{m}{k} \end{matrix}\right.\right.$$

$$=2k\frac{-b_B n_B n_S+\mu_B n_S-\frac{\theta n_S d_B}{2k^2}-p_B+f_B}{a}\leq 1$$

Then we can get that the proportion of the number of users actually participating in the transaction of this level in the total number of users of the buyer is r_B：

$$r_B=2\frac{-b_B n_B n_S+\mu_B n_S-\frac{\theta n_S d_B}{2k^2}-p_B+f_B}{a}$$

Because the proportion of the number of users who actually participate in the transaction of this level in the number of users of the buyer is r_B, the number of users whose r_B must be less than $\frac{1}{k}$ of the total number of the buyer.

$$r_B = 2\frac{-b_B n_B n_S + \mu_B n_S - \frac{\theta n_S d_B}{2k^2} - p_B + f_B}{a} \leq \frac{1}{k}$$

Therefore, we can calculate the proportion of the number of users actually participating in the transaction to the total number of users of the buyer r_B^T:

$$r_B^T = 2k\frac{-b_B n_B n_S + \mu_B n_S - \frac{\theta n_S d_B}{2k^2} - p_B + f_B}{a} \leq 1。$$

In our analysis framework, the situation of the seller is similar to that of the buyer, and the two sides are extremely symmetrical. Therefore, it can be concluded that the proportion of the number of users actually participating in this level of transaction in the seller's total number of users r_S:

$$r_S = 2\frac{-b_S n_B n_S + \mu_S n_B - \frac{\theta n_B d_S}{2k^2} - p_S + f_S}{a} \leq \frac{1}{k},$$

The proportion of the number of users actually participating in the transaction of the seller in the total number of users of the seller r_S^T is:

$$r_S^T = 2k\frac{-b_S n_B n_S + \mu_S n_B - \frac{\theta n_B d_S}{2k^2} - p_S + f_S}{a} \leq 1。$$

Because $n_i = N_i r_i$, and the total number of people N_i is fixed in our hypothesis. Therefore, when the number of users of the buyer n_B participating in the platform increases from 0, the participation rate of the seller's users r_S increases, which drives the number of users of the seller participating in the platform n_S increase, and makes the participation rate of the buyer's users r_B increase, which further promotes the number of participants of the buyer's platform to increase. When n_B and n_S increase to $\frac{\mu-\frac{\theta d}{2k^2}}{b}$, r_B will decrease with the increase of n_S, r_S will decrease with the increase of n_B, and then with the increase of n_B and n_S, r_B and r_S will gradually decrease until they reach equilibrium.

By combining the following equations, we can find the expression of the actual number of participants in each stratification：

$$\begin{cases} r_B = 2\dfrac{-b_B n_B n_S + \mu_B n_S - \dfrac{\theta n_S d_B}{2k^2} - p_B + f_B}{a} \le \dfrac{1}{k} \\ r_S = 2\dfrac{-b_S n_B n_S + \mu_S n_B - \dfrac{\theta n_B d_S}{2k^2} - p_S + f_S}{a} \le \dfrac{1}{k} \\ n_B = N_B r_B \\ n_S = N_S r_S \end{cases}$$

这里为了简化计算，我们假设$N_B = N_S = N$，$P_B = P_S = P$，$f_B = f_S = f$，$\mu_B = \mu_S = \mu$，$b_B = b_S = b$，$d_B = d_S = d$，即双边用户是极其对称的，即平台双边的用户总数量、平台对于双边的收费和双边用户参与平台能够获得的固定收益相同，因此上式联立可以解出：

In order to simplify the calculation, we assume that：$N_B = N_S = N$，$P_B = P_S = P$，$f_B = f_S = f$，$\mu_B = \mu_S = \mu$，$b_B = b_S = b$，$d_B = d_S = d$. So the total number of users on both sides of the platform, the charges for both sides of the platform and the fixed income that the two sides of the platform can get are the same, so the above formula can be solved jointly:

$$n_B = n_S = n = \frac{-\left(\frac{\theta d}{k^2} - 2\mu + \frac{a}{Nk}\right) + \sqrt{\left(\frac{\theta d}{k^2} - 2\mu + \frac{a}{Nk}\right)^2 - 8b(2p - 2f)}}{4b}$$
$$= \frac{4(f-p)}{\frac{\theta d}{k^2} - 2\mu + \frac{a}{Nk} + \sqrt{\left(\frac{\theta d}{k^2} - 2\mu + \frac{a}{Nk}\right)^2 + 16b(f-P)}} \le \frac{N}{k}$$

According to the above functional relationship, we can find the relationship between the above influencing factors and the number of people participating in each platform.