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Platform Competition in Peer-to-Peer Lending Considering Risk Control Ability

He Liu, Han Qiao, Shouyang Wang, Yuze Li

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Highlights

- We model peer-to-peer lending platform competition considering risk control.
- Platforms with higher risk control ability charge agents more in symmetric setting.
- We define risk-price coefficients to measure the impact of risk control on prices.
- The optimal risk control ability decreases in risk-price coefficients.

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Corresponding Author: Dr. Han Qiao

Order of Authors: He Liu, Han Qiao, Shouyang Wang, Yuze Li

Affiliations of Authors:

1. He Liu, Academy of Mathematics and Systems Science, Chinese Academy of Sciences; University of Chinese Academy of Sciences
2. Han Qiao, School of Economics and Management, University of Chinese Academy of Sciences
3. Shouyang Wang, Academy of Mathematics and Systems Science, Chinese Academy of Sciences; School of Economics and Management, University of Chinese Academy of Sciences
4. Yuze Li, Department of Mechanical and Industrial Engineering, University of Toronto

Email Addresses and Postal Addresses of Authors:

1. He Liu, liuhe@amss.ac.cn, Academy of Mathematics and Systems Science, Chinese Academy of Sciences, 55 Zhongguancun East Road, Haidian District, Beijing 100190, China; University of Chinese Academy of Sciences, 19(A) Yuquan Road, Shijingshan District, Beijing 100049, China
2. Han Qiao, qiaohan@ucas.ac.cn, School of Economics and Management, University of Chinese Academy of Sciences, 80 Zhongguancun East Road, Haidian District, Beijing 100190, China
3. Shouyang Wang, sywang@amss.ac.cn, Academy of Mathematics and Systems Science, Chinese Academy of Sciences, 55 Zhongguancun East Road, Haidian District, Beijing 100190, China; School of Economics and Management, University of Chinese Academy of Sciences, 80 Zhongguancun East Road, Haidian District, Beijing 100190, China
4. Yuze Li, richardyz.li@mail.utoronto.ca, Department of Mechanical and Industrial Engineering, University of Toronto, 27 Kings College Circle, Toronto M5S 1A1, Toronto, Canada

Platform Competition in Peer-to-Peer Lending Considering Risk Control Ability

Abstract

As a new e-commerce phenomenon in financing, peer to peer (P2P) lending has received increased attention recently. For P2P lending platforms, risk control ability (i.e., the ability to accurately assess and screen borrowers to control the credit risk of loans) is a competitive differentiator. The paper models a three-stage game to investigate optimal risk control ability and corresponding optimal prices of P2P lending platforms under different tariffs and agents' homing choices. Risk-price coefficients for lenders and borrowers are introduced to measure the impact of risk control ability on prices, where higher risk-price coefficients indicate that prices are more sensitive to risk control ability. Moreover, the paper investigates the role of platforms' scales in deciding optimal risk control ability, prices and market shares. To our best knowledge, this is the first theoretical paper to study the competition in P2P lending considering risk control ability based on game theory. The analytical results show that: 1) In equilibrium, optimal risk control ability decreases in risk-price coefficients; 2) The risk-price coefficient for lenders contributes less than that for borrowers to optimal risk control ability if some lenders multi-home; 3) Smaller platforms have higher risk control ability, prices and attract more borrowers than larger platforms under specific conditions.

Keywords:
E-commerce; peer-to-peer (P2P) lending; risk control ability; two-sided markets; game theory

1. Introduction

Peer-to-peer (P2P) lending provides an alternative way of financing without the intermediation of financial institutions where individuals lend to and borrow from each other directly. As a new e-commerce phenomenon in the financial field, P2P lending has the potential to reduce financing costs and provide more economical efficiencies with the benefit of collective intelligence and the elimination of a traditional financial intermediary (Guo et al., 2016; Gao et al., 2018). Since the first P2P lending platform, ZOPA, emerged in England in 2005, P2P lending has experienced rapid growth in recent years around the world. As a leading platform in China, PPDai (www.PPDai.com), built in Shanghai in 2007, facilitated approximately $10.1 billion in loans in 2017[1] . In the United States, Lending Club, one of the largest online lending intermediaries in the world, reached $33.6 billion in total loan issuance from 2010 to 2017[2].

Since P2P lending platforms connect borrowers and lenders directly without the involvement of conventional intermediaries, the inherent risk mainly comes from the risk of default when transacting with strangers without collateral (Yum et al., 2012). When choosing between different P2P lending platforms, lenders care most about the collectibility of their money. However, the information offered by borrowers may not be verified or credible, which will make it difficult for lenders to assess the default risk of borrowers. Thus, the key challenge for P2P lending platforms is how to control the credit risk to attract more lenders and borrowers (Mild et al., 2015). However, it is understandably hard to assess the credit risk of each loan and screen borrowers when allocating credit. The main reason is that the credit risk of borrowers is obtained not only from mechanical financial calculus, but also from the complexities and idiosyncrasies of human behaviors (Iyer et al., 2016). To tackle this problem, many state-of-the-art P2P lending platforms provide their users with risk ratings for each loan, which results in loans classified into a number of risk buckets. The real amount of financial risk that lenders bear is measured by the degree to which they lend money to high-risk versus low-risk borrowers (Zhu & Iansiti, 2012). For example, Lending Club divides the loans into 35 risk buckets according to the relative credit risk and the requested loan amount. The loans in each risk bucket are posted with the same default rate and the same interest rate by the company (Paravisini et al., 2016). Investors (lenders) can pick loans from different risk buckets to diversify risks according to their preferences, while borrowers in different risk buckets are charged different types of fees. If there are loans in default, Lending Club begins the collection procedure, and investors will pay the collection fee for successful collections. Thus, the classification of risk buckets has a great impact on the charges to lenders and borrowers.

As the market of P2P lending becomes increasingly competitive, the ability to provide more precise classification of risk buckets that helps control credit risk has become the key differentiator. In this paper, such classification ability is denoted as risk control ability. Platforms with high risk control ability can lower the default risk and hence enhances their market influence and prestige,

[1]Data from PPDAI Group Inc. Reports Fourth Quarter and Fiscal Year 2017 Unaudited Financial Results, PPDai Corporation in China (http://ir.ppdai.com/2018-03-21-PPDAI-Group-Inc-Reports-Fourth-Quarter-and-Fiscal-Year-2017-Unaudited-Financial-Results)

[2]Data from Lending Club Statistics: 2017, LendingClub Corporation in the United States (https://www.lendingclub.com/info/statistics.action)

resulting in higher market share. However, there is a tradeoff between gaining the market share and profit. Higher risk control ability is associated with higher investment on risk control, which may hurt profit. Therefore, it is essential for P2P lending platforms to find optimal risk control ability and evaluate the possible impact of applying such control ability.

In spite of the importance of the topic, there is limited theoretical analysis regarding optimal risk control ability. In this paper, we take an initial step toward analyzing optimal risk control ability and its impacts for platforms with different characteristics (e.g., scales, agents' homing choices, different tariffs). Risk control ability, referring to accuracy and rationality of credit rating, is given at the beginning stage of the platform, which is determined by the initial investment on risk control. Given risk control ability, P2P lending platforms will decide the prices for the maximization of profits. When choosing between platforms, agents take both risk control ability and prices into account to maximize their utilities. Take Lending Club for example. Lending Club controls the default risk by two steps: (1) checking whether the borrowers satisfy the credit criteria setting by the platform; (2) qualified borrowers will be assigned one of 35 loan grades according to credit scoring models developed by the platform[3]. Specifically, after a borrower completes a loan request from Lending Club, the platform will evaluate whether the borrower meets the credit criteria which includes the minimum FICO score, maximum debt-to-income ratio, minimum credit history, etc. For borrowers who are qualified, the platform assigns each loan a grade and a corresponding interest rate according to the scoring models. These models are based on algorithms that are used to evaluate factors such as behavioral data and employment information. Lending Club has been utilizing these effective scoring models to evaluate borrowers' credit profile and predict their likelihood of default. If the platform has a higher risk control ability, the borrowers will be classified more precisely. The borrower who has a lower default risk will be assigned to a lower risk grade and pay a lower interest rate. In this way, lenders can choose proper notes corresponding to different loans. Thus, risk control ability of the platform matters a lot to both borrowers and lenders. Each agent will balance risk control ability and prices to make the best choice between platforms. To investigate the competition between P2P lending platforms, we propose a three-stage game involving the lenders, borrowers and platforms. By solving this game, we find that the difference in prices offered by the duopoly is caused by different risk control ability. To measure the impact of risk control ability on corresponding prices, we define the risk-price coefficients for lenders and

[3]From Member Payment Dependent Notes of Lending Club (https://www.lendingclub.com/)

borrowers. Our results show that risk-price coefficients vary with agents' different homing choice and the way platforms charge their agents. Moreover, optimal risk control ability decreases in risk-price coefficients, and the risk-price coefficient for lenders contributes less than that for borrowers to risk control ability if some lenders multi-home. When considering the case where platforms have different scales, we find smaller platforms may have higher risk control ability, prices and more borrowers than larger platforms.

The paper is structured as follows. A literature review is performed in Section 2. Section 3 proposes a three-stage model of the two-sided platform to analyze optimal risk control ability and its impacts on pricing and the market share of P2P lending platforms. Section 4 describes an extended three-stage model to analyze the game of asymmetric platforms with different scales. Finally, Section 5 concludes this work.

2. Literature review

Various scholars have investigated platform competition in two-sided markets (Parker & Alstyne, 2005; Armstrong, 2006; Zhu & Iansiti, 2012; Roger, 2017). Prior literature examining the competition in two-sided markets has focused on pricing strategies in platform settings such as payment systems (Wright, 2004), B2B spot markets (Xing et al., 2012; Oliveira, 2017) and telecommunication (Economides & Katsamakas, 2006; Chakravarty & Werner, 2011). Recent efforts also study other factors beyond pricing, such as the first-party content (Hagiu & Spulber, 2013) and openness decisions (Boudreau, 2010). However, two-sided markets competition in P2P lending is relatively new to the academic literature. Two-sided markets are defined as markets in which one or several platforms enable interactions between distinct groups of agents, and try to get various sides "on board" by appropriately charging each side (Rochet & Tirole, 2006; Koh & Fichman, 2014). P2P lending platform, connecting borrowers and lenders, is a type of two-sided markets (Koh & Fichman, 2014). In P2P lending platforms, individuals post their borrowing needs and investors can view and fund consumer loans without collateral. Therefore, risk control ability is a very important factor as mentioned above, and can be treated as a strategic instrument chosen by platforms for competitions. The key contribution of this paper is to introduce risk control ability and expand the formal study of the competition in P2P lending platforms.

There are various risks in P2P lending coming from the behaviors of borrowers involved in online transactions (Chen et al., 2014). As online loan transactions are conducted without collateral, the assessment of the credit default risk of each loan is the most important task (Zhang et al., 2014;

Verbraken et al., 2014). There are various factors determining the default risk in P2P lending, and many efforts have been taken to identify them. Lin et al. (2013) study the value of social networks in evaluating the credit risk, and find that friendship ties act as a signal of the credit quality. Iyer et al. (2016) show that the nonstandard or soft information about borrowers, drawing on individual lenders' own experiences and understanding of human behavior, can help evaluate their credit risks. Duarte et al. (2012) analyze the role of appearance plays in financial transactions in P2P lending. The study also shows that borrowers who appear more trustworthy have higher credit scores, and often default less. Burtch et al. (2014) regard cultural differences and the geography as determinants of online lending platforms.The findings by Emekter et al. (2015) suggest that borrowers with high FICO score, high credit grades, the low revolving line utilization and low debt-to-income ratio are associated with low default risks. Dorfleitner et al. (2016) focus on description texts to the probability of successful funding and to the default probability in peer-to-peer lending. Zhang & Liu (2012) find evidence of lenders' rational herding when inferring the creditworthiness of borrowers that lenders observe peer lending decisions to moderate their inferences. As for the impact of risk control ability on prices, Berkovich (2011) finds that high quality loans provide excess returns even after considering risk-aversion.

Considering the multiplicity and the complexity of influence factors, risk assessment, risk management and risk control are understandably difficult (Aven, 2016). However, risk control is essential for decision making in the P2P lending platform competition. Risk control ability of a P2P lending platform has the potential to affect the behavior of both sides of the market, the profit and competitiveness of the lending platform itself, which makes this an important research topic. However, there is limited research on how to optimize the ability of risk control of P2P lending platforms. Therefore, our study based on a three-stage game of two-sided platform considering the risk in P2P lending will shed some important lights on how to determine optimal risk control ability of P2P lending platforms.

3. The model

This model involves two competing platforms, and we use Hotelling model as our basic setup. Suppose agents are uniformly distributed on $[0, 1]$, and two platforms are located on the endpoints of the segment, respectively. An agent is characterized by her location on the line segment, which shows her preference of the platforms. There are two groups of agents in the market, borrowers and lenders.

In order to have a thorough understanding of the model, we mainly consider four scenarios according to the characteristics of the pricing strategy of each platform and homing choices of agents. As for the pricing strategy, platforms have two choices: subscription fees or two-part tariffs consisting of subscription fees and per-transaction charges. Many P2P lending platforms like Yirendai and Lending Club charge consumers two-part tariffs while some other P2P lending platforms charge lenders monthly subscription fee. As for agents, they can choose to be single-homing or multi-homing. When an agent chooses to join only one platform, we say the agent is "single-homing"; when an agent joins several platforms, he/she is said to be "multi-homing" (Armstrong, 2006). To our best knowledge, little literature concerning P2P lending platforms has drawn a conclusion on the agents' homing issue. Overall, the homing choice of agents depends on many factors, which results in different homing characteristics in different markets. For example, in the emerging P2P lending market such as the Chinese market, lenders tend to be multi-homing in order to diversify risk because some platforms go bankrupt and run off with lenders' money. In contrast, in the developed markets where the regulation policy is strict and credit system is mature, agents may choose to be single-homing. Moreover, P2P lending platform can sign exclusive contracts with agents to render them single-homing (Armstrong & Wright, 2007).

For the sake of providing insights to different markets and giving different types of platforms instructions, our analysis investigates the following situations: (1) both sides are single-homing; (2) one side is single-homing and some members of the other side are multi-homing. We do not analyze the case when both sides are multi-homing because it is uncommon (Armstrong, 2006).

Therefore, our model includes the following four scenarios: (1) two-part tariffs with two-sided single-homing; (2) subscription fees with two-sided single-homing; (3) two-part tariffs with some lenders multi-homing; (4)subscription fees with some lenders multi-homing. Under each scenario, we model the problem as a three-stage game. In the first stage, each P2P lending platform sets its risk control ability. In the second stage, each platform decides the prices charged to borrowers and lenders. Finally, based on the estimated risk control ability on each platform and the prices, agents decide which platforms to join. We use backward induction to solve this problem.

3.1. ***Two-sided single-homing***

In a market where two-sided agents are single-homing, suppose there are two P2P lending platforms, denoted 1 and 2, and there are two groups, lenders and borrowers. We use the subscript L to denote lenders, B to denote borrowers. There are $n_B^i (i = 1, 2)$ borrowers and $n_L^i (i = 1, 2)$ lenders

Table 1: Notation list, $i \in \{1, 2\}$

Symbol	Defination
k_i	Risk control ability of Platform i
p_B^i	Subscription fee charging borrowers by Platform i
p_L^i	Subscription fee charging borrowers by Platform i
n_B^i	The number of single-homing borrowers on Platform i
n_L^i	The number of single-homing lenders on Platform i
N_L^i	The number of multi-homing lenders on Platform i
u_B^i	Net utility of borrowers joining Platform i
u_L^i	Net utility of lenders joining Platform i
u_0	Common utilities shared by each borrower or lender
β_B	The benefit a borrower obtains from each lender
β_L	The benefit a lender obtains from each borrower
t_B	The unit transportation cost on borrowers' side
t_L	The unit transportation cost on lenders' side
γ	Matching capacities of the platform
D_B	Per-transaction fee of borrowers
D_L	Per-transaction fee of lenders
b	Risk-utility coefficient
λ_{x_L}	The proportion of risk control ability estimated by lenders on x_L to true risk control ability
a	Risk-cost coefficient

on Platform i. Both lenders and borrowers are single-homing. Without loss of generality, we assume the total number of lenders as 1, and the same for borrowers, which means $n_B^1+n_B^2 = 1, n_L^1+n_L^2 = 1$. Here we analyze two kinds of tariffs: (1) two-part tariffs; (2) subscription fees.

3.1.1. Scenario 1: Two-part tariffs with two-sided single-homing

In this scenario, we analyze the case where each platform charges two-part tariffs to single-homing agents through subscription fees and per-transaction charges. In addition to the subscription fees, agents pay an extra charge for each successful transaction. We introduce a marginal number of transaction γ, which measures the increase in number of transactions when an agent on the other side joins the platform, and describes matching capacities of the platform.

(1) Agent behavior

We first discuss the agent behavior. When an agent makes her decision, the prices of each platform will be common knowledge. Lenders and borrowers obtain the respective utilities u_L^i, u_B^i if they join Platform i, and $u_0 > 0$ is the common part of utilities shared by each agent. The price charged by Platform i to each group is denoted as p_L^i, p_B^i. We denote the per-transaction fee of lenders and borrowers by D_L and D_B, respectively. On Platform i, based on the definition of γ, the number of transactions for lenders is given by $d_L^i = \gamma n_B^i$ and that for borrowers is given by $d_B^i = \gamma n_L^i$. The utility of one group is related to the difference of the platform, the platform price and the number of agents in the other group. Here we use β_L to measure the benefit a lender enjoys from interacting with each borrower, β_B to measure the benefit a borrower obtains from each lender. Comparing with lenders, borrowers who need the money urgently gain more utilities while interacting with a member from the other group. Therefore, we assume $\beta_B > \beta_L > 0$.

Suppose agents are uniformly distributed on the interval $[0, 1]$. Platform 1 is located at the end point 0 and Platform 2 is located at the end point 1. Under Hotelling's setting, the cost of access is the product of agent's distance and the unit cost of transportation. In our model, the agent's distance to a platform is a measure of her familiarity with this platform. The unit cost of transportation $t_B, t_L > 0$ are measures of the degree of the product differentiation for two groups. Specifically, a smaller distance shows the agent is more familiar with the platform, and a bigger unit cost of transportation shows products on the two platforms are more different from each other. In Table 1, we summarize the notation.

For borrowers locating on x_B, the net utilities of single-homing on the respective platform are given by the following expressions:

$$u_B^1 = u_0 + \beta_B n_L^1 - p_B^1 - D_B d_B^1 - t_B x_B; \quad u_B^2 = u_0 + \beta_B n_L^2 - p_B^2 - D_B d_B^2 - t_B(1 - x_B). \tag{1}$$

When it comes to the net utilities of single-homing lenders, risk control ability of a platform matters a lot. Higher risk control ability can lower the default risk of borrowers, which will increase lenders' utilities. For simplicity, we assume lenders' utilities will increase linearly as risk control ability increases. In our model, k_i denotes risk control ability of the Platform i and we use a parameter $b > 0$, termed "risk-utility coefficient", to measure the impact of risk control ability on the utilities of lenders, then larger b indicates that lenders pay more attention to risk control ability when considering their utilities.

In reality, for lenders locating on x_L, they may feel it difficult to measure the real risk control ability accurately. To address this issue, we assume that lenders estimated value of risk control ability is proportional to the true value, and denote this proportion as a new random variable λ_{x_L}. Under this assumption, $\lambda_{x_L} k_i$ is the estimate of the risk control ability for a lender located on x_L. $\lambda_{x_L} > 1$ indicates that the lender overestimates the risk control ability, $\lambda_{x_L} < 1$ indicates that the lender underestimates the risk control ability, and $\lambda_{x_L} = 1$ indicates that the lender estimates the risk control ability accurately. For the sake of simplicity, we follow the similar assumption in Markopoulos & Hosanagar (2017) and assume that λ_{x_L} follows a uniform distribution $U[0, 2e]$. Since some lenders may underestimate platform's risk control ability while others may overestimate, we assume that $e > \frac{1}{2}$.

For lenders locating on x_L, their single-homing net utilities on each platform are given by

$$u_L^1 = u_0 + \beta_L n_B^1 - p_L^1 - D_L d_L^1 + b\lambda_{x_L} k_1 - t_L x_L; \quad u_L^2 = u_0 + \beta_L n_B^2 - p_L^2 - D_L d_L^2 + b\lambda_{x_L} k_2 - t_L(1 - x_L). \tag{2}$$

In order to figure out the marginal agent, firstly we derive the average net utilities of lenders locating on x_L

$$\bar{u}_L^1 = u_0 + \beta_L n_B^1 - p_L^1 - D_L d_L^1 + bek_1 - t_L x_L; \quad \bar{u}_L^2 = u_0 + \beta_L n_B^2 - p_L^2 - D_L d_L^2 + bek_2 - t_L(1 - x_L). \tag{3}$$

Equating the respective average utility to solve for marginal agent, then we find

$$\begin{aligned} x_B^* &= \frac{1}{2} + \frac{1}{2t_B}(p_B^2 - p_B^1) + \frac{\beta_B - \gamma D_B}{2t_B}(n_L^1 - n_L^2); \\ x_L^* &= \frac{1}{2} + \frac{\beta_L - \gamma D_L}{2t_L}(n_B^1 - n_B^2) + \frac{1}{2t_L}(p_L^2 - p_L^1) + \frac{be}{2t_L}(k_1 - k_2). \end{aligned} \tag{4}$$

Since agents are uniformly located on the unit interval, we have $n_B^1 = P(x < x_B^*), n_L^1 = P(x < x_L^*)$. Suppose platforms offer the respective price pairs (p_B^1, p_L^1) and (p_B^2, p_L^2) with the respective risk control ability k_1 and k_2. Noticing that $n_B^1 = P(x < x_B^*), n_L^1 = P(x < x_L^*), n_B^2 = 1 - n_B^1, n_L^2 = 1 - n_L^1$, by solving these equations simultaneously we obtain

$$\begin{cases} n_B^i = \dfrac{1}{2} + \dfrac{t_L(p_B^j - p_B^i)}{2[t_L t_B - (\beta_L - \gamma D_L)(\beta_B - \gamma D_B)]} + \dfrac{(\beta_B - \gamma D_B)[p_L^j - p_L^i + be(k_i - k_j)]}{2[t_L t_B - (\beta_L - \gamma D_L)(\beta_B - \gamma D_B)]}; \\ n_L^i = \dfrac{1}{2} + \dfrac{(\beta_L - \gamma D_L)(p_B^j - p_B^i)}{2[t_L t_B - (\beta_L - \gamma D_L)(\beta_B - \gamma D_B)]} + \dfrac{t_B[p_L^j - p_L^i + be(k_i - k_j)]}{2[t_L t_B - (\beta_L - \gamma D_L)(\beta_B - \gamma D_B)]}; \end{cases} \tag{5}$$

where $i, j = 1, 2, i \neq j$.

Here we assume that $\beta_m - \gamma D_m \geq 0, t_m > \beta_B > \beta_L (m \in \{B, L\})$. Hence, the number of each group is increasing by improving risk control ability. Specifically, more lenders choose to join the platform for the direct increase of their utilities, which also attracts more borrowers due to the existence of network externality.

(2) Platforms' optimal prices

In this stage, each platform should decide optimal prices (i.e., subscription fees) with the knowledge of risk control ability of itself and agents' average estimate of risk control ability of the other platform. Suppose each platform has two kinds of cost, the cost for risk control and the cost for serving each group. Risk control ability k_i is determined by the cost for risk control $m_i > 0$. According to diminishing marginal effect, marginal output (risk control ability) decreases as the amount of a single factor of production (the cost for risk control) incrementally increases, keeping the other factors constant. Taking account of diminishing marginal effect and for the sake of modelling, here we assume $k_i=\sqrt{\frac{m_i}{a}}(a > 0)$, then we have $m_i = a(k_i)^2$. Similar assumption can also be found in Markopoulos & Hosanagar (2017). The parameter a, termed "risk-cost coefficient", is a measure of the efficiency of cost for risk control ability. Therefore, for the same risk control ability, the smaller the value of a, the less cost for risk control. As for the cost for serving each group, we suppose each platform has a per-agent cost c_L for serving lenders and c_B for serving borrowers.

Since each platform charges two-part tariffs to agents, the profit Platform i gains under this circumstance is given by

$$\begin{aligned}\pi_i &= (p_L^i - c_L)n_L^i + (p_B^i - c_B)n_B^i + D_B d_B^i n_B^i + D_L d_L^i n_L^i - a(k_i)^2 \\ &= (p_L^i - c_L)n_L^i + (p_B^i - c_B)n_B^i + \gamma D_B n_L^i n_B^i + \gamma D_L n_B^i n_L^i - a(k_i)^2,\end{aligned} \tag{6}$$

For simplicity, we have the following notations:

$$\begin{aligned}A_1 &= \frac{bet_B(2\beta_B - 2\beta_L - 3D_B\gamma + D_L\gamma)}{2(9t_Bt_L - 5\beta_B\beta_L - 2\beta_B^2 - 2\beta_L^2 + D_B\beta_B\gamma + 2D_B\beta_L\gamma + 2D_L\beta_B\gamma + D_L\beta_L\gamma - D_BD_L\gamma^2)} \\ A_2 &= \frac{be(D_L^2\gamma^2 + D_L\beta_B\gamma - D_BD_L\gamma^2 - 2\beta_LD_L\gamma - 2\beta_B^2 + D_B\beta_B\gamma - 4\beta_L\beta_B + 2D_B\beta_L\gamma + 6t_Bt_L)}{2(9t_Bt_L - 5\beta_B\beta_L - 2\beta_B^2 - 2\beta_L^2 + D_B\beta_B\gamma + 2D_B\beta_L\gamma + 2D_L\beta_B\gamma + D_L\beta_L\gamma - D_BD_L\gamma^2)}.\end{aligned} \tag{7}$$

Given risk control ability of itself k_i and agents' average estimate of risk control ability ek_j, Platform i maximizes the profit with respect to p_L^i and p_B^i. Solving the first-order condition, we obtain the equilibrium prices

$$\begin{cases} p_B^i = c_B + t_B - \beta_L + \dfrac{\gamma(D_L - D_B)}{2} + A_1(k_i - k_j); \\ p_L^i = c_L + t_L - \beta_B + \dfrac{\gamma(D_B - D_L)}{2} + A_2(k_i - k_j). \end{cases} \tag{8}$$

Therefore, A_1, A_2 measure the impact of risk control ability to prices for borrowers and lenders, respectively. For the sake of discussion, A_1, A_2 are termed as "risk-price coefficients". They are introduced to describe the relationship between prices and risk control ability and are the rate of change of price with respect to an increase in risk control ability.

Comparing our results with traditional findings obtained by Armstrong(2006), we notice that risk control ability has great impact on the P2P lending platforms' optimal prices. Furthermore, the difference between the respective prices is given by

$$p_B^i - p_B^j = 2A_1(k_i - k_j); \quad p_L^i - p_L^j = 2A_2(k_i - k_j). \tag{9}$$

We see from Eq.(9) that the difference of risk control ability exclusively determines the difference of prices between two given platforms. If the difference between risk control ability increases, the difference between prices on both sides will also increase. Platform with higher risk control ability charges agents more. Take Yirendai and PPDai for example. The risk control performance of Yirendai is higher than that of PPDai, and both subscription fee and per-transaction fee of Yirendai are higher than those of PPDai.[4]

(3) Platforms' optimal risk control ability

In this stage, platforms decide optimal risk control ability. Substitute Eq.(8) into Eq.(5), then the market share is expressed by risk control ability k_i. Substituting expressions for the market share and prices into Eq.(6), and maximizing the profit with respect to k_i, we obtain

$$k_1 = k_2 = \frac{be}{4a} - \frac{A_1 + A_2}{4a}. \tag{10}$$

Using the value of k_1, k_2, we obtain the equilibrium price as

$$p_B^1 = p_B^2 = c_B + t_B - \beta_L + \frac{\gamma(D_L - D_B)}{2}; \quad p_L^1 = p_L^2 = c_L + t_L - \beta_B + \frac{\gamma(D_B - D_L)}{2}. \tag{11}$$

Further, the equilibrium market share is

$$n_B^1 = n_B^2 = \frac{1}{2}; \quad n_L^1 = n_L^2 = \frac{1}{2}. \tag{12}$$

In the following proposition, we state several interesting results concerning the equilibrium risk

[4] Data from Yirendai Report: Fourth Quarter and Full Year 2017 Financial Results(http://ir.yirendai.com/phoenix.zhtml?c=254635&p=quarterlyEarnings), PPDAI Group Inc. Reports Fourth Quarter and Fiscal Year 2017 Unaudited Financial Results, PPDai Corporation in China (http://ir.ppdai.com/2018-03-21-PPDAI-Group-Inc-Reports-Fourth-Quarter-and-Fiscal-Year-2017-Unaudited-Financial-Results.)

control ability and prices.

Proposition 1. *In a market where P2P lending platforms charge two-part tariffs and two sides are single-homing, the equilibrium risk control ability and equilibrium prices of the duopoly are respectively the same. The equilibrium risk control ability, $k_1 = k_2 = \frac{be}{4a} - \frac{A_1+A_2}{4a}$, increases in risk-utility coefficient, b; decreases in the risk-cost coefficient, a; and decreases in risk-price coefficients, A_1 and A_2. The equilibrium prices are $p_B^1 = p_B^2 = c_B + t_B - \beta_L + \frac{\gamma(D_L - D_B)}{2}$, $p_L^1 = p_L^2 = c_L + t_L - \beta_B + \frac{\gamma(D_B - D_L)}{2}$.*

Proposition 1 provides several expected results, which to some extent shows the validity of the model. First, we find that the equilibrium risk control ability increases in risk-utility coefficient b. A larger b shows that lenders tend to pay more attention to platforms' risk control ability, which motivates each platform to reach a higher ability of risk control in order to attract more lenders. Second, we also find that the equilibrium risk control ability decreases in the risk-cost coefficient a. A larger a shows that platforms need to invest more to reach the same risk control ability, which hinders platforms to increase risk control ability considering the corresponding cost. Therefore, risk control ability will reach equilibrium at a lower value.

These results give P2P lending platforms instructions on judging the current state of themselves and managing the optimal risk control ability properly. First, the results can help the P2P lending platform that already has a risk control ability to judge whether the current risk control ability is the optimal one. One can see from Eq.(11) and Eq.(12) that the equilibrium prices and the equilibrium market shares of the duopoly are equal, respectively. This helps P2P lending platforms with the judgement of optimal risk control ability. In practice, each platform can gain the data related to the prices and the market shares of platforms with similar scales from some third-party data providers, such as P2PEYE.com in China. More intuitively, if the market share of Platform 1 is much lower than that of Platform 2 with similar prices and scales, Platform 1 will realize that its current risk control ability must be lower than the optimal one and thus should increase its risk control ability for more profits.

Second, these results are also helpful for the platform that needs to adjust its own risk control ability to the optimal one. Take the enhancement of risk control ability for example. From $k_i = \sqrt{\frac{m_i}{a}}$, the risk control ability of platform i is directly determined by the cost for risk control m_i and risk-cost coefficient a. Therefore, platforms with lower risk control ability than the optimal one (judging from the above first instruction) should increase its risk control ability by two means:

investing more in risk control ability (increasing m_i) or increasing the cost efficiency for risk control (decreasing a). In order to make sure that risk control ability of this platform will converge to the optimal one, platforms should also bear in mind the optimal risk control ability derived from the model during the adjustment process. The model indicates that the optimal risk control ability is determined by risk-utility coefficient b, risk-cost coefficient a and risk-price coefficients A_1, A_2. Thus, each platform should gather some relative data in order to evaluate these parameters in the model. Specifically, platforms can judge risk-utility coefficient b, i.e., lenders' sensitivity to risk control ability through conducting surveys on lenders' risk preference. If lenders value risk control ability significantly, the optimal risk control ability should be higher and thus the enhancement of risk control ability should be higher. As for risk-cost coefficient a, platforms can evaluate this value from some public financial data regarding risk control, such as cost for risk control. As for risk-price coefficients A_1, A_2, platforms can investigate the relationship between the measure of risk performance (such as delinquency rates and charge-off rates) and prices from different platforms and thus can calculate this sensitivity parameter.

However, platforms with limited resources may have trouble in finding the optimal risk control ability. The model also sheds light on setting the second optimal strategy for these platforms: improving themselves and paying attention to the competitors. The platforms should increase their efficiency of cost for risk control as much as possible. In this way, they can obtain higher risk control ability with same cost comparing with their competitors, which can benefit themselves. Moreover, keeping an eye on the risk control ability of their competitors and keeping pace with them are also helpful.

Apart from the insights, we find an interesting result with respect to the relationship between risk control ability and risk-price coefficients. According to our model, as prices become more sensitive to risk control ability, the equilibrium risk control ability goes lower. The result is interpreted in the following manner.

Without loss of generality, we assume risk control ability $k_1 > k_2$ before reaching the equilibrium. If A_1, A_2 are large enough, Eq.(9) shows Platform 1's prices are significantly higher than Platform 2's prices, resulting in an extremely lower market share. At this time, Platform 1 has a strong motivation to raise its market share. Therefore, Platform 1 will choose to reduce its prices. According to Eq.(9), Platform 1 can sharply lower its risk control ability, which reduces the cost and prices to expand its market share rapidly. On the other hand, Platform 2, the platform with a huge market share, does not have the motivation to change its risk control ability. Therefore, in this case, k_1 drops rapidly to approach k_2, and they reach the equilibrium at a lower risk control ability.

If A_1, A_2 are extremely small, there is a slight difference between prices according to the Eq.(9). In this case, agents tend to pay more attention to risk control ability, which becomes the determining factor of equilibrium market share. As a result, Platform 1, with higher risk control ability, attracts much more users than Platform 2. At this time, Platform 2 has a strong motivation to improve its risk control ability rapidly. Hence, the equilibrium will be reached at a relatively higher risk control ability.

3.1.2. Scenario 2: Subscription fees with two-sided single-homing

Let $\gamma = 0$ in Scenario 1, then the net utility function of borrowers located on x_B and the average net utility of lenders located on x_L are

$$\begin{aligned} &u_B^1 = u_0 + \beta_B n_L^1 - p_B^1 - t_B x_B; u_B^2 = u_0 + \beta_B n_L^2 - p_B^2 - t_B(1 - x_B); \\ &\bar{u}_L^1 = u_0 + \beta_L n_B^1 - p_L^1 + bek_1 - t_L x_L; \bar{u}_L^2 = u_0 + \beta_L n_B^2 - p_L^2 + bek_2 - t_L(1 - x_L). \end{aligned} \tag{13}$$

The profit function of Platform i is

$$\pi_i = (p_L^i - c_L)n_L^i + (p_B^i - c_B)n_B^i - a(k_i)^2. \tag{14}$$

Therefore, we can derive the equilibrium results where each platform charges borrowers and lenders subscription fees by letting $\gamma = 0$. Here the risk-price coefficients are denoted by

$$A_1^{'} = \frac{bet_B(\beta_B - \beta_L)}{9t_Bt_L - 2\beta_B^2 - 5\beta_B\beta_L - 2\beta_L^2} > 0; A_2^{'} = \frac{be(-\beta_B^2 - 2\beta_L\beta_B + 3t_Bt_L)}{9t_Bt_L - 2\beta_B^2 - 5\beta_B\beta_L - 2\beta_L^2} > 0. \tag{15}$$

In this paper, we assume that $t_L + \beta_L > 2\beta_B$ and then we have $A_2^{'} > A_1^{'}$.

The equilibrium risk control ability is

$$k_1 = k_2 = \frac{be}{4a} - \frac{A_1^{'} + A_2^{'}}{4a}. \tag{16}$$

Using the value of k_1, k_2, we obtain the equilibrium prices are

$$p_B^1 = p_B^2 = c_B + t_B - \beta_L; \quad p_L^1 = p_L^2 = c_L + t_L - \beta_B. \tag{17}$$

Further, the equilibrium market share is

$$n_B^1 = n_B^2 = \frac{1}{2}; \quad n_L^1 = n_L^2 = \frac{1}{2}. \tag{18}$$

We can see that the expressions become much more concise by letting $\gamma = 0$ under this scenario. Therefore, it is easier to gain more insights. In the following proposition, we first study the determinants of the risk-price coefficients.

Proposition 2. *Risk-price coefficients A_1', A_2', increase in the unit costs of transportation t_B, t_L.*

In our model, unit costs of transportation t_B, t_L are measures of the degree of the product differentiation for borrowers and lenders respectively. According to Proposition 2, risk-price coefficients increase in the degree of the product differentiation. The larger the product differentiation, the larger the risk-price coefficients. The result can be explained in the following manner. On P2P lending platforms, the product differentiation refers to differences between the financing products. If financing products on the two platforms largely differ from each other, it is quite complex for agents to evaluate the default risk individually. Therefore, agents pay more attention to platforms' risk control ability, and would be more willing to pay more for the platform with higher risk control ability. In this way, the prices are more sensitive to risk control ability. According to this result, if product differentiation between P2P lending platforms changes, it is beneficial for them to balance the relationship between price and risk control ability.

Moreover, due to $A_2' > A_1'$, the increase in the difference between prices for lenders is larger than that for borrowers, which shows the price for lenders is more sensitive to risk control ability. It makes sense because risk control ability directly affects lenders' utilities. The result provides normative guidance on the adjustment of prices and risk control ability for P2P lending platforms: Lenders are more willing to pay for the enhancement of risk control ability than borrowers. If platforms increase risk control ability, the consequent increase of price for lenders is supposed to be larger than that for borrowers. The discussion is summarized in the following proposition.

Proposition 3. *For two given platforms, the difference of risk control ability exclusively determines the difference of optimal prices. Price for lenders is more sensitive to risk control ability than that for borrowers.*

3.1.3. Comparison between Scenario 1 and Scenario 2

Given the results under Scenario 1 in Proposition 1, we find that main results are similar under Scenario 2 where platforms charge subscription fees to agents, which shows that the determinants of risk control ability remain the same. Specifically, equilibrium risk control ability is also increasing in risk-utility coefficient, and decreasing in risk-cost coefficient and risk-price coefficients. Comparing with Proposition 1, we investigate the effect of different tariffs on risk control ability and prices and summarize them in the following proposition.

Proposition 4. *When platforms charge different tariffs, the equilibrium risk control ability changes due to different risk-price coefficients. The effect of different tariffs on equilibrium prices is measured by* $\frac{\gamma(D_L - D_B)}{2}$*, increasing in* γ *and* $|D_B - D_L|$.

From Proposition 4, we obtain several interesting and counterintuitive results with respective to the prices (i.e., subscription fees). With one additional part tariff, it is common to expect the subscription fee in Scenario 1 to be lower than that in Scenario 2. However, it is surprised to find that the value of the subscription fee is not always lower in Scenario 1, which is really counterintuitive. Actually, the value of the subscription fee in Scenario 1 is related to the difference between two-sided per-transaction fees, i.e., the relationship between D_B and D_L. Specifically, if both sides are charged the same per-transaction fee($D_B = D_L$), the subscription fee will remain the same under different tariffs. If the per-transaction fee for lenders is higher than that for borrowers ($D_L > D_B$), the subscription fee for borrowers and lenders will be higher and lower than that in Scenario 2, respectively. If the per-transaction fee for lenders is lower than that for borrowers ($D_B > D_L$), the subscription fee for borrowers and lenders will be lower and higher than that in Scenario 2, respectively. Putting the result into practice, we can see that one additional part tariff does not result in lower subscription fee.

3.2. ***Some lenders multi-homing***

In this scenario, we study the case where each platform charges two-part tariffs to agents having different homing choices (i.e., borrowers are single-homing and some lenders are multi-homing). Similar to Scenario 1, agents pay subscription fees as well as per-transaction charges. The parameter γ refers to the increase of transactions when an agent on the other side joins the platform. Let $n_B^i (i = 1, 2)$ be the number of single-homing borrowers on Platform i; let $n_L^i (i = 1, 2)$ be the number of single-homing lenders on Platform i; and let N_L^i be the total number of lenders on Platform i, including single-homing and multi-homing lenders. Without loss of generality, we assume the total number of lenders on the market as 1, and the same for borrowers, which means

$n_B^1 + n_B^2 = 1, N_L^1 + n_L^2 = 1, N_L^2 + n_L^1 = 1.$

3.2.1. ***Scenario 3: Two part tariffs with some lenders multi-homing***

(1) Agent behavior

We denote the per-transaction fee of lenders and borrowers by D_L and D_B respectively. The number of transactions for lenders on Platform i is $d_L^i = \gamma N_B^i$, and the number of transactions for borrowers is $d_B^i = \gamma N_L^i$.

For borrowers locating on x_B, net utilities of single-homing on the respective platform are given by the following expressions:

$$u_B^1 = u_0 + \beta_B N_L^1 - p_B^1 - D_B d_B^1 - t_B x_B; \quad u_B^2 = u_0 + \beta_B N_L^2 - p_B^2 - D_B d_B^2 - t_B(1 - x_B). \tag{19}$$

Similar with the analysis in Scenario 1, for lenders locating on x_{L1}, their average single-homing net utilities on Platform 1 are given by

$$\bar{u}_L^1 = u_0 + \beta_L n_B^1 - p_L^1 - D_L d_L^1 + bek_1 - t_L x_{L1}. \tag{20}$$

For lenders locating on x_{L2}, their average single-homing net utilities on Platform 2 are given by

$$\bar{u}_L^2 = u_0 + \beta_L n_B^2 - p_L^2 - D_L d_L^2 + bek_2 - t_L(1 - x_{L2}). \tag{21}$$

For simplicity, we assume the average utility that multi-homing lenders obtain from risk control ability as $\frac{be(k_1+k_2)}{2}$. Hence, the average net utilities of multi-homing lenders are

$$\bar{u}_L^{1,2} = u_0 - p_L^1 - p_L^2 - t_L + \frac{be(k_1 + k_2)}{2} + \beta_L - \gamma D_L. \tag{22}$$

Equating the expressions for utility (i.e., $u_B^1 = u_B^2, \bar{u}_L^1 = \bar{u}_L^2 = \bar{u}_L^{1,2}$), noticing $N_L^1 - N_L^2 = n_L^1 - n_L^2$ and solving for the marginal agent, we obtain

$$\begin{cases} x_B^* = \dfrac{1}{2} + \dfrac{1}{2t_B}(p_B^2 - p_B^1) + \dfrac{\beta_B - \gamma D_B}{2t_B}(n_L^1 - n_L^2); \\ x_{L1}^* = \dfrac{\beta_L - \gamma D_L}{t_L} n_B^1 + \dfrac{p_L^2}{t_L} + \dfrac{t_L - (\beta_L - \gamma D_L)}{t_L} + \dfrac{be(k_1 - k_2)}{2t_L}; \\ x_{L2}^* = -\dfrac{\beta_L - D_L\gamma}{t_L} n_B^2 - \dfrac{p_L^1}{t_L} + \dfrac{\beta_L - \gamma D_L}{t_L} + \dfrac{be(k_1 - k_2)}{2t_L}. \end{cases} \tag{23}$$

Notice that $n_B^1 = P(x < x_B^*), n_L^1 = P(x < x_{L1}^*), N_L^1 = P(x < x_{L2}^*), n_B^2 = 1 - n_B^1, n_L^1 = 1 - N_L^2$, $n_L^2 = 1 - N_L^1$, and solve these equations simultaneously, then we obtain

$$\begin{cases} n_B^i = \dfrac{1}{2} + \dfrac{t_L(p_B^j - p_B^i)}{2[t_B t_L - (\beta_B - \gamma D_B)(\beta_L - \gamma D_L)]} + \dfrac{(\beta_B - \gamma D_B)[(p_L^j - p_L^i) + be(k_i - k_j)]}{2[t_B t_L - (\beta_B - \gamma D_B)(\beta_L - \gamma D_L)]}; \\ n_L^i = 1 - \dfrac{\beta_L - \gamma D_L}{2t_L} + \dfrac{(\beta_L - \gamma D_L)(p_B^j - p_B^i) + be(k_i - k_j)t_B}{2[t_B t_L - (\beta_B - \gamma D_B)(\beta_L - \gamma D_L)]} \\ \qquad + \dfrac{[2t_B t_L - (\beta_B - \gamma D_B)(\beta_L - \gamma D_L)]p_L^j - (\beta_L - \gamma D_L)(\beta_B - \gamma D_B)p_L^i}{2t_L[t_B t_L - (\beta_B - \gamma D_B)(\beta_L - \gamma D_L)]}. \end{cases} \tag{24}$$

(2) Platforms' optimal prices

In this stage, each platform decides optimal prices (i.e., subscription fees) with the knowledge of risk control ability of itself and agents' average estimate of risk control ability of the other platform. The profit of Platform i is given by

$$\begin{aligned} \pi_i &= (p_L^i - c_L)N_L^i + (p_B^i - c_B)n_B^i + D_B d_B^i n_B^i + D_L d_L^i N_L^i - a(k_i)^2 \\ &= (p_L^i - c_L)N_L^i + (p_B^i - c_B)n_B^i + \gamma D_B N_L^i n_B^i + \gamma D_L n_B^i N_L^i - a(k_i)^2. \end{aligned} \tag{25}$$

For simplicity of results, we define the following notations:

$$\begin{aligned} A_{11} &= \frac{be\{\beta_L\beta_B^2 - 2t_B t_L \beta_B + \beta_L t_B t_L + [(\gamma D_B)^2 - 2\beta_B(\gamma D_B)][\beta_L - \gamma D_L] + 3t_B t_L(\gamma D_B) - \beta_B^2(\gamma D_L)\}}{2t_L(\beta_B^2 + 4\beta_B\beta_L + \beta_L^2 - 6t_B t_L - 2D_L\beta_B\gamma - 2D_B\beta_L\gamma + 2D_B D_L\gamma^2)}; \\ A_{22} &= \frac{be(2\beta_B\beta_L - 3t_B t_L + \beta_B^2 - D_B\beta_L\gamma + D_L\beta_L\gamma + D_B D_L\gamma^2)}{2(\beta_B^2 + 4\beta_B\beta_L + \beta_L^2 - 6t_B t_L - 2D_L\beta_B\gamma - 2D_B\beta_L\gamma + 2D_B D_L\gamma^2)}. \end{aligned} \tag{26}$$

Given risk control ability of itself k_i and agents' average estimate of risk control ability ek_j, Platform i maximizes the profit with respect to p_L^i and p_B^i. Solving the first-order condition, we obtain the equilibrium prices

$$\begin{cases} p_B^i = c_B + \dfrac{\beta_L + \gamma D_B}{2t_L}c_L + t_B + \dfrac{-\beta_L(3\beta_B + \beta_L) + \gamma D_B(\beta_L - \beta_B) + 2\gamma D_L(\beta_B - \gamma D_B)}{4t_L} + A_{11}(k_i - k_j); \\ p_L^i = \dfrac{c_L}{2} + \dfrac{\beta_L - \beta_B}{4} - \dfrac{\gamma D_L}{2} + A_{22}(k_i - k_j). \end{cases} \tag{27}$$

A_{11}, A_{22} are "risk-price coefficients" to measure the impact of risk control ability on prices in the case where some lenders are multi-homing. Further, we have the relative difference of prices between the duopoly as

$$p_B^i - p_B^j = 2A_{11}(k_i - k_j); \quad p_L^i - p_L^j = 2A_{22}(k_i - k_j). \tag{28}$$

(3) Platforms' optimal risk control

In this stage, each platform decides optimal risk control ability. Similar with Scenario 1, maximizing the profit with respect to risk control ability k_i, we obtain the equilibrium risk control ability

$$k_1 = k_2 = \frac{be}{4a} - \frac{A_{11}}{4a} - \frac{A_{22}}{4a}\frac{\beta_B - \gamma D_B}{t_L} - \frac{2bec_L + 4bet_L - 3be\beta_B - be\beta_L + 2be\gamma D_B}{16at_L}. \tag{29}$$

Using the value of k_1, k_2, we obtain the equilibrium price

$$\begin{cases} p_B^1 = p_B^2 = c_B + \dfrac{\beta_L + \gamma D_B}{2t_L}c_L + t_B + \dfrac{-\beta_L(3\beta_B + \beta_L) + \gamma D_B(\beta_L - \beta_B) + 2\gamma D_L(\beta_B - \gamma D_B)}{4t_L}; \\ p_L^1 = p_L^2 = \dfrac{c_L}{2} + \dfrac{\beta_L - \beta_B}{4} - \dfrac{\gamma D_L}{2}. \end{cases} \tag{30}$$

Further, expressions for the market share are given by

$$n_B^1 = n_B^2 = \frac{1}{2}; \quad n_L^1 = n_L^2 = 1 + \frac{2c_L - (\beta_B + \beta_L)}{4t_L}. \tag{31}$$

In the following proposition, we show the determinants of equilibrium risk control ability and prices in a market with two-part tariffs and some lenders multi-homing.

Proposition 5. *In a market where P2P lending platforms charge two-part tariffs and some lenders are single-homing, the equilibrium risk control ability and equilibrium prices of the duopoly are respectively the same. The equilibrium risk control ability* $k_1 = k_2 = \frac{be}{4a} - \frac{A_{11}}{4a} - \frac{A_{22}}{4a}\frac{\beta_B-\gamma D_B}{t_L} - \frac{2bec_L+4bet_L-3be\beta_B-be\beta_L+2be\gamma D_B}{16at_L}$*, decreases in risk-price coefficients,* A_{11} *and* A_{22}*. The equilibrium prices are* $p_B^1 = p_B^2 = c_B + \frac{\beta_L+\gamma D_B}{2t_L}c_L + t_B + \frac{-\beta_L(3\beta_B+\beta_L)+\gamma D_B(\beta_L-\beta_B)+2\gamma D_L(\beta_B-\gamma D_B)}{4t_L}$;
$p_L^1 = p_L^2 = \frac{c_L}{2} + \frac{\beta_L-\beta_B}{4} - \frac{\gamma D_L}{2}$.

The results also give P2P lending platforms useful instructions when some lenders are multi-homing. First, a platform can judge whether its risk control ability is the optimal one by the market share in borrowers' side. One can see from Eq.(31) that the equilibrium market share in borrowers' side of the duopoly should be the same, which helps each platform with the judgement. Specifically, if Platform 1 has a lower number of borrowers comparing with the Platform 2 with similar prices and similar scales, this indicates that Platform 1 should adjust its risk control ability to a higher value. Second, for platforms that have trouble in evaluating the optimal risk control ability, achieving the similar risk control performance with the similar platforms is another rational choice.

3.2.2. *Scenario 4: Subscription fees with some lenders multi-homing*

Similar to Scenario 2, let $\gamma = 0$ in Scenario 3, then we can derive the following results where each platform charges borrowers and lenders subscription fees with some lenders multi-homing (Scenario 4). The risk-price coefficients under this scenario are

$$A'_{11} = \frac{be(\beta_L\beta_B^2 - 2t_Bt_L\beta_B + \beta_Lt_Bt_L)}{2t_L(\beta_B^2 + 4\beta_B\beta_L + \beta_L^2 - 6t_Bt_L)}; \quad A'_{22} = \frac{be(2\beta_B\beta_L - 3t_Bt_L + \beta_B^2)}{2(\beta_B^2 + 4\beta_B\beta_L + \beta_L^2 - 6t_Bt_L)}. \tag{32}$$

The equilibrium risk control ability is

$$k_1 = k_2 = \frac{be}{4a} - \frac{A'_{11}}{4a} - \frac{A'_{22}}{4a}\frac{\beta_B}{t_L} - \frac{2bec_L + 4bet_L - 3be\beta_B - be\beta_L}{16at_L}. \tag{33}$$

Using the value of k_1, k_2, we obtain the equilibrium price

$$p_B^1 = p_B^2 = c_B + \frac{\beta_L}{2t_L}c_L + t_B + \frac{-\beta_L(3\beta_B + \beta_L)}{4t_L}; \quad p_L^1 = p_L^2 = \frac{c_L}{2} + \frac{\beta_L - \beta_B}{4}. \tag{34}$$

Then we obtain expressions for the market share

$$n_B^1 = n_B^2 = \frac{1}{2}; \quad n_L^1 = n_L^2 = 1 + \frac{2c_L - (\beta_B + \beta_L)}{4t_L}. \tag{35}$$

In the following proposition, we state determinants of the equilibrium risk control ability and prices.

Proposition 6. *In a market where P2P lending platforms only charge subscription fees and some lenders are multi-homing, the equilibrium risk control ability and equilibrium prices of the duopoly are respectively the same. The equilibrium risk control ability* $k_1 = k_2 = \frac{be}{4a} - \frac{A'_{11}}{4a} - \frac{A'_{22}}{4a}\frac{\beta_B}{t_L} - \frac{2bec_L+4bet_L-3be\beta_B-be\beta_L}{16at_L}$*, decreases in risk-price coefficients,* A'_{11} *and* A'_{22}*. The equilibrium prices are* $p_B^1 = p_B^2 = c_B + \frac{\beta_L}{2t_L}c_L + t_B + \frac{-\beta_L(3\beta_B+\beta_L)}{4t_L}, p_L^1 = p_L^2 = \frac{c_L}{2} + \frac{\beta_L-\beta_B}{4}$.

We can also see from Eq.(35) that the number of single-homing lenders on each platform increases in lenders' service cost. This result indicates that increasing lenders' service cost helps P2P lending platform increase the proportion of single-homing lenders and thus decrease the proportion of multi-homing lenders, which is beneficial to each platform (Armstrong & Wright, 2007). In practice, some platforms have an incentive to increase lenders' service cost. For example, sales and marketing expenses of Yirendai were \$152.1 million in the fourth quarter of 2017, which accounted for 7.4% of amount of loans facilitated[5]. This percentage increases by 0.5% comparing with that of the third quarter of 2017. The company attributed the increase to more expense on lenders' service cost, which supports our findings.

3.2.3. ***Comparison between Scenario 2 and Scenario 4***

When each platform only charges lenders and borrowers subscription fee, the expressions are much more concise to analyze. Taking advantage of this, now we compare the scenario under which platforms only charge subscription fee to two-sided single-homing agents (Scenario 2) with the scenario under which platforms only charge subscription fee to multi-homing lenders and single-homing borrowers (Scenario 4). This provides us with an opportunity to study the effect of different homing choices when each platform only charges lenders and borrowers subscription fee. Through the comparison between Scenario 2 and Scenario 4, we find that the homing choice of agents sheds great light on the equilibrium risk control ability and prices. Firstly, we state the effects on the equilibrium risk control ability. On the one hand, different homing choices will result in different risk-price coefficients, e.g., the risk-price coefficient for lenders under Scenario 4 is lower than that under Scenario 2 (i.e., $A'_{22} < A'_2$). The result is consistent with the expectation because the risk is diversified. On the other hand, the risk-price coefficient for lenders contributes less than that for borrowers to risk control ability under Scenario 4 since the coefficient $\frac{\beta_B}{t_L}$ is less than 1 in Eq.(33).

Next, we investigate the effects of homing choices on equilibrium prices. The price charged to borrowers is affected by the unit transportation cost of lenders t_L under Scenario 4. It is quite different from the two-sided single-homing case (Scenario 2) in which the price charged to borrowers does not depend on lenders' transportation cost. Under the specified condition(iff $c_L > \frac{(3\beta_B+\beta_L)}{2}$), as the unit transportation cost of lenders increases, the price charged to borrowers under Scenario 4 decreases. By contrast, the price charged to lenders is irrelevant to the transportation cost of lenders under the scenario with some lenders multi-homing (Scenario 4), which is counterintuitive. Moreover, we see from Eq.(34) that borrowers take not only their own service cost but also a part of lenders' service cost, and lenders only take half of the service cost. This indicates the competition for lenders is more severe as each platform attempts to attract more lenders.

We now summarize the effects of homing choices in the following proposition.

Proposition 7. *Under the scenario with subscription fees and some lenders multi-homing, the*

[5]From Yirendai Report: Fourth Quarter and Full Year 2017 Financial Results (http://ir.yirendai.com/phoenix.zhtml?c=254635&p=quarterlyEarnings)

risk-price coefficient for lenders is lower than that under two-sided single-homing (i.e., $A'_{22} < A'_2$). In addition, the risk-price coefficient for lenders contributes less than that for borrowers to risk control ability. If $c_L > \frac{(3\beta_B+\beta_L)}{2}$, platforms lower the lenders' price and raise the borrowers' price compared with the single-homing case, and the price charged to borrowers decreases in the unit transportation cost of lenders t_L.

3.2.4. *Comparison between Scenario 3 and Scenario 4*

Using the results under Scenario 3 and Scenario 4, we are now ready to investigate the effects of different tariffs on risk control ability and prices when some lenders are multi-homing.

As for the effect on the risk control ability, we find that different tariffs change risk control ability in two ways. First, with per-transaction fees, risk-price coefficients under Scenario 3 are different from those with only subscription fees (Scenario 4). Second, under Scenario 3, the risk-price coefficient for lenders plays a less important role than that for borrowers in determining the equilibrium risk control ability because the coefficient $\frac{\beta_B-\gamma D_B}{t_L}$ is less than 1 in Eq.(29). Compared with the case where only subscription fees exist (Scenario 4), the risk-price coefficient for lenders under Scenario 3 becomes less important because the coefficient $\frac{\beta_B-\gamma D_B}{t_L}$ in Eq.(29) is less than the respective coefficient $\frac{\beta_B}{t_L}$ in Eq.(33).

It is difficult to investigate the effects of different tariffs on prices due to the complexity of parameters when some lenders are multihoming. However, by comparing Eq.(30) with Eq.(34), we see that each platform will charge less subscription fees to lenders if per-transaction fees exist (Scenario 3). If $c_L > \frac{\beta_B-\beta_L}{2}$, each platform charges more to borrowers under Scenario 3 than that under Scenario 4. So it is different from the two-sided single-homing case where the effects of two-part tariffs are uncertain. We summarize the results in the following proposition.

Proposition 8. *Under the case where some lenders are multi-homing, each platform charges less subscription fees to lenders but more subscription fees to borrowers (if $c_L > \frac{\beta_B-\beta_L}{2}$) under two-part tariffs than the relative prices when only subscription fees exit.*

The result can provide P2P lending platforms with useful instructions on price structure. Unlike the case with two-sided agents single-homing, the price structure suggests that platforms should balance the subscription fee between lenders and borrowers. Charging lenders less subscription fee under two-part tariffs is a good choice for platforms attempting to attract more lenders.

Up to now we have analyzed optimal risk control ability and prices under different scenarios. In addition, we investigate the effects of homing choices of agents and different tariffs on risk control ability and prices. Our analysis above is based on the assumption that two platforms have similar scales. We notice that there are also asymmetric duopoly platforms with different scales in reality. Next, we analyze the market where asymmetric platforms compete with each other.

4. An extended model

In this section, we study the competition between asymmetric platforms by an extended three-stage game. For simplicity, we only consider the case where each platform charges subscription fees and both groups are single-homing. Suppose agents are uniformly distributed on $[0, 1]$. Platform 1 is located at end point 0 and Platform 2 is located at end point 1. The scales of the duopoly are different, which are respectively expressed as s_1, s_2. In our model, we assume s_1, s_2 are exogenous variables and $s_1 > s_2$. The notations of risk control ability, subscription fees and market share are same as those in Section 3, respectively. Here we also assume $n_B^1 + n_B^2 = 1, n_L^1 + n_L^2 = 1$.

4.1. Agent behavior

In this stage, each agent chooses to join one platform. Besides prices, risk control ability and the number of agents in other group we have discussed before, the utility of one group is related to the scales of the platforms as well.

Here the impact of other factors such as transportation cost, risk control ability, the numbers of agents is the same as Section 3. Now we are going to analyze effects of the platforms' scale on the utility of each group. For lenders, it is easy for them to believe that large platforms are stable and competitive, which is the belief called "too big to fail". As a result, they put more trusts on platforms with larger scales. For borrowers, they believe that larger platforms can provide more information and match more transactions. So they think the efficiency of borrowing on large platforms is higher than that on small platforms. We see that the utility of each group increases in the platforms' scale and we use parameter α to measure the effect. The utility from platforms' scale is denoted by $z_i = \alpha s_i$.

Based on the analysis above, the net utilities of single-homing on Platform 1 or Platform 2 for borrowers locating on x_B are expressed as

$$u_B^1 = z_1 + \beta_B n_L^1 - p_B^1 - t_B x_B; \quad u_B^2 = z_2 + \beta_B n_L^2 - p_B^2 - t_B(1 - x_B). \tag{36}$$

Similar with Section 3, the average net utilities of single-homing lenders locating on x_L are expressed as

$$\bar{u}_L^1 = z_1 + \beta_L n_B^1 - p_L^1 + bek_1 - t_L x_L; \quad \bar{u}_L^2 = z_2 + \beta_L n_B^2 - p_L^2 + bek_2 - t_L(1 - x_L). \tag{37}$$

By solving the equations $u_B^1 = u_B^2, \bar{u}_L^1 = \bar{u}_L^2$, we obtain the location of the indifferent borrowers and lenders

$$\begin{aligned} x_B^* &= \frac{1}{2} + \frac{\beta_B}{2t_B}(n_L^1 - n_L^2) + \frac{1}{2t_B}(p_B^2 - p_B^1 + z_1 - z_2); \\ x_L^* &= \frac{1}{2} + \frac{\beta_L}{2t_L}(n_B^1 - n_B^2) + \frac{1}{2t_L}(p_L^2 - p_L^1 + z_1 - z_2) + \frac{be}{2t_L}(k_1 - k_2). \end{aligned} \tag{38}$$

Hence, we obtain expressions for the market shares:

$$\begin{cases} n_B^i = \dfrac{1}{2} + \dfrac{t_L(p_B^j - p_B^i)}{2(t_L t_B - \beta_L \beta_B)} + \dfrac{\beta_B[p_L^j - p_L^i + be(k_i - k_j)]}{2(t_L t_B - \beta_L \beta_B)} + \dfrac{(\beta_B + t_L)(z_i - z_j)}{2(t_B t_L - \beta_B \beta_L)}; \\ n_L^i = \dfrac{1}{2} + \dfrac{\beta_L(p_B^j - p_B^i)}{2(t_L t_B - \beta_L \beta_B)} + \dfrac{t_B[p_L^j - p_L^i + be(k_i - k_j)]}{2(t_L t_B - \beta_L \beta_B)} + \dfrac{(\beta_L + t_B)(z_i - z_j)}{2(t_B t_L - \beta_B \beta_L)}. \end{cases} \tag{39}$$

4.2. Platforms' optimal prices

In this stage, each platform decides optimal prices. Same as that in Eq.(14), the profit of Platform i is

$$\pi_i = (p_B^i - c_B)n_B^i + (p_L^i - c_L)n_L^i - a(k_i)^2. \tag{40}$$

Denote

$$X_1 = \frac{3t_B t_L - \beta_L^2 - 2\beta_B \beta_L + t_B(\beta_B - \beta_L)}{(9t_B t_L - 2\beta_B^2 - 5\beta_B \beta_L - 2\beta_L^2)}; X_2 = \frac{3t_B t_L - \beta_B^2 - 2\beta_B \beta_L + t_L(\beta_L - \beta_B)}{(9t_B t_L - 2\beta_B^2 - 5\beta_B \beta_L - 2\beta_L^2)}. \tag{41}$$

Maximizing the profit with respect to p_L^i and p_B^i and solving the first-order condition, we get Platform i's optimal prices are

$$p_B^i = c_B + t_B - \beta_L + A_1'(k_i - k_j) + X_1(z_i - z_j); p_L^i = c_L + t_L - \beta_B + A_2'(k_i - k_j) + X_2(z_i - z_j). \tag{42}$$

As denoted in Section 3, A_1', A_2' are "risk-price coefficients" and $A_1' = \frac{bet_B(\beta_B - \beta_L)}{9t_B t_L - 2\beta_B^2 - 5\beta_B \beta_L - 2\beta_L^2} > 0, A_2' = \frac{be(-\beta_B^2 - 2\beta_L \beta_B + 3t_B t_L)}{9t_B t_L - 2\beta_B^2 - 5\beta_B \beta_L - 2\beta_L^2} > 0$. Similarly, we define X_1, X_2 as "scale-price coefficients", which measure the impact of platform's scale to the prices for borrowers and lenders respectively.

In order to investigate the difference of prices clearly, we have

$$p_B^i - p_B^j = 2A_1'(k_i - k_j) + 2X_1(z_i - z_j); \quad p_L^i - p_L^j = 2A_2'(k_i - k_j) + 2X_2(z_i - z_j). \tag{43}$$

Now we state several interesting results concerning "risk-price coefficients" and "scale-price coefficients" in the following proposition.

Proposition 9. *For two platforms with different scales, the difference of prices between the duopoly is determined by the difference of risk control ability and scales of the platforms. Price for lenders is more sensitive to risk control ability than that for borrowers, i.e., $A_2^{'} > A_1^{'}$. In contrast, the price for borrowers is more sensitive to the scale of platform than that for lenders, i.e., $X_1 > X_2$.*

Results indicate that the platform with higher risk control ability and larger scale charges more to agents. The difference of risk control ability has bigger impact on the difference of prices for lenders than that for borrowers ($A_2^{'} > A_1^{'}$), which shows that lenders tend to pay more attention to risk control ability. For two given platforms, the scales are determined exogenously. The difference of scales contributes more to the difference of prices for borrowers than that for lenders ($X_1 > X_2$), which shows that borrowers place a higher value on the scale of platforms. This is because borrowers who want to obtain the money as soon as possible tend to believe a larger platform is more efficient to find lenders.

4.3. Platforms' optimal risk control ability

In this stage, each platform decides optimal risk control ability to maximize the profit. Similar with that in Section 3, maximizing the profit with respect to risk control ability and denoting $Y = \frac{be(\beta_B+\beta_L+2t_B)}{4[t_B b^2 e^2 - a(9t_B t_L - 2\beta_B^2 - 5\beta_B\beta_L - 2\beta_L^2)]}$, we obtain the equilibrium risk control ability as

$$k_1 = \frac{be}{4a} - \frac{A_1^{'} + A_2^{'}}{4a} - Y(z_1 - z_2); \quad k_2 = \frac{be}{4a} - \frac{A_1^{'} + A_2^{'}}{4a} + Y(z_1 - z_2). \tag{44}$$

Besides the factors mentioned in Section 3, it turns out that the equilibrium risk control ability is also affected by the scale of the platform. Due to the difference of scales, the equilibrium risk control ability of the duopoly are not the same. However, under the setting where platforms have different scales, the relationship between risk control ability and risk-price coefficients does not change. Risk control ability still decreases in risk-price coefficients, which shows the robustness of our finding. Surprisingly, the larger platform may not have higher risk control ability. Now we state some interesting results in the following proposition.

Proposition 10. *In a market where platforms have different scales, the difference of platforms' scales will affect the equilibrium risk control ability. The equilibrium risk control ability of the duopoly are no longer the same. If $t_B b^2 e^2 > a(9t_B t_L - 2\beta_B^2 - 5\beta_B\beta_L - 2\beta_L^2)$, risk control ability of* *smaller platforms (Platform 2) is higher; if* $t_B b^2 e^2 < a(9t_B t_L - 2\beta_B^2 - 5\beta_B\beta_L - 2\beta_L^2)$*, risk control ability of larger platforms (Platform 1) is higher. Risk control ability still decreases in risk-price coefficients,* $A_1^{'}, A_2{'}$*.*

Using the value of k_1, k_2, we have the equilibrium prices of two platforms

$$p_B^i = c_B + t_B - \beta_L + (X_1 - 2A_1^{'}Y)(z_i - z_j); \quad p_L^i = c_L + t_L - \beta_B + (X_2 - 2A_2^{'}Y)(z_i - z_j). \quad (45)$$

Further, the equilibrium market share is

$$\begin{cases} n_L^i = \dfrac{1}{2} + \dfrac{z_i - z_j}{4}\{\dfrac{\beta_B - \beta_L}{9t_B t_L - (2\beta_B + \beta_L)(\beta_B + 2\beta_L)} - \dfrac{3a(\beta_B + \beta_L + 2t_B)}{b^2e^2t_B - a[9t_Bt_L - (2\beta_B + \beta_L)(\beta_B + 2\beta_L)]}\}; \\ n_B^i = \dfrac{1}{2} + \dfrac{z_i - z_j}{6t_B} + \dfrac{(\beta_B + 2\beta_L)}{3t_B}(n_L^i - \dfrac{1}{2}). \end{cases} \quad (46)$$

We see from Eq.(45) and Eq.(46) that the scale of platforms also has a great impact on prices and market shares. In Section 3, where two platforms have similar scales, the equilibrium prices and market shares of the duopoly are respectively the same. However, if the scale of platforms is different, the equilibrium results with respect to prices and market shares change significantly. As for equilibrium prices, which platform charges higher prices depends on the relationship between parameters. As for the equilibrium market share, it turns out that the number of borrowers on the smaller platform may be larger than the larger platform. In the following proposition, we summarize the discussion above.

Proposition 11. *In a market where platforms have different scales, the larger platform (Platform 1) charges more to borrowers , i.e.,* $p_B^1 > p_B^2$ *if and only if* $3t_Bt_L - \beta_L^2 + \beta_Bt_B - \beta_Lt_B - 2\beta_B\beta_L > \frac{b^2e^2t_B(\beta_B - \beta_L)(\beta_B + \beta_L + 2t_B)}{2[b^2e^2t_B - a(9t_Bt_L - 2\beta_B^2 - 5\beta_B\beta_L - 2\beta_L^2)]}$*; and the larger platform (Platform 1) charges more to lenders , i.e.,* $p_L^1 > p_L^2$ *if and only if* $3t_Bt_L - \beta_B^2 + \beta_Lt_L - \beta_Bt_L - 2\beta_B\beta_L > \frac{b^2e^2(3t_Bt_L - \beta_B^2 - 2\beta_L\beta_B)(\beta_B + \beta_L + 2t_B)}{2[b^2e^2t_B - a(9t_Bt_L - 2\beta_B^2 - 5\beta_B\beta_L - 2\beta_L^2)]}$*. The number of borrowers on the smaller platform (Platform 2) may be larger than the larger platform (Platform 1).*

5. Conclusions

P2P lending platforms connect borrowers and lenders directly without any collateral. Therefore, the ability to manage the risk of default plays a vital role in P2P lending platform competition. This paper analyzes optimal risk control ability of P2P lending platforms and its impact on equilibrium prices and market shares. A three-stage game model of symmetric platforms is proposed under four scenarios according to different tariffs and homing choices of agents. Moreover, the model is extended to asymmetric platforms with different scales to study more general situations. To our best knowledge, this paper is the first theoretical paper to analyze platforms' risk control ability and its effects based on two-sided market theory.

Our study on risk control ability of P2P lending platforms has yielded important insights. While it is common in the real world that platforms with higher risk control ability tend to charge more to cover the cost for risk control, the extant literature has not considered how to measure the impact of risk control ability on prices. To tackle this problem, we introduce risk-price coefficients to describe the relationship between prices and risk control ability, which will change under different tariffs and agents' homing choices. We find that the difference of prices is caused by different risk control ability. Moreover, we theoretically show that platforms with higher risk control ability charge agents more and risk-price coefficients are the rate of change of price with respect to an increase in risk control ability, which gives P2P lending platforms instructions on reasonable pricing. Using our results, managers of P2P lending platforms can adjust their prices to keep pace with the change of risk control ability.

Second, we investigate the determinants of risk control ability and find that risk control ability decreases in risk-price coefficients. As risk-price coefficients become larger (i.e., prices become more sensitive to risk control ability), the equilibrium risk control ability goes lower. This counterintuitive result holds for duopoly P2P lending platforms, regardless of different tariffs, scales and agents' homing choices. If both groups are single-homing, risk-price coefficients for lenders and borrowers contribute equally to risk control ability. In contrast, if borrowers are single-homing and some lenders are multi-homing, the risk-price coefficient for lenders contributes less than that for borrowers to risk control ability.

In addition to management insights, we also obtain some interesting results when considering the game of asymmetric platforms with different scales. As for risk control ability, it is surprising to find that sometimes smaller platforms have higher risk control ability. As for equilibrium prices and market shares, we find that it is the smaller platform that has more borrowers under specific conditions.

We take an initial step toward understanding the interplay between risk control ability and prices. In this study, we assume risk control ability as a decision variable of platforms. In reality, some P2P lending platforms manage the credit risk by relying on third-party companies. Therefore, an immediate direction for future researches is to introduce third-party companies and analyze the relationship between price and risk control ability under the new setting.

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