Hindawi Publishing Corporation
Discrete Dynamics in Nature and Society
Volume 2016, Article ID 5013954, 8 pages
http://dx.doi.org/10.1155/2016/5013954

Research Article

P2P Lending Risk Contagion Analysis Based on a Complex Network Model

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Received 22 March 2016; Revised 2 June 2016; Accepted 19 June 2016

Academic Editor: Guoqiang Hu

This paper analyzes two major channels of P2P lending risk contagion in China—direct risk contagion between platforms and indirect risk contagion with other financial organizations as the contagion medium. Based on this analysis, the current study constructs a complex network model of P2P lending risk contagion in China and performs dynamics analogue simulations in order to analyze general characteristics of direct risk contagion among China's online P2P lending platforms. The assumed conditions are that other financial organizations act as the contagion medium, with variations in the risk contagion characteristics set under the condition of significant information asymmetry in Internet lending. It is indicated that, compared to direct risk contagion among platforms, both financial organizations acting as the contagion medium and information asymmetry magnify the effect of risk contagion. It is also found that the superposition of media effects and information asymmetry is more likely to magnify the risk contagion effect.

1. Introduction

Based on Internet technology, P2P lending realizes information exchange, resource sharing, and capital flow among individuals. Many people who cannot obtain formal financing from banks or other financial institutions seek to meet their financing needs by network lending. Since 2005, when the world's first P2P lending platform, Zopa, was founded in the UK, the new lending model has rapidly gained market recognition. As of January 2016, there are 3917 P2P lending platforms in China, with the cumulative turnover of 1495.615 billion yuan (statistical data came from Online Lending House). However, together with this boom in the P2P lending market certain risks increased as well, most notably in the form of problematic platforms; there were 1351 such identified platforms in January 2016.

Apart from the fact that China's P2P lending infrastructure lacks necessary supervisory authorities, is governed by imperfect laws and regulations, contains outdated risk management techniques, and thus exposes P2P lending platforms to risks, networking lending platforms' risks are by themselves strong in transitive and spillover due to cross-business and consolidated operations. Given that many small-scale institutions with similar businesses may get in trouble at the same time or take similar behavior to the impact, this may trigger a collective importance, initiating systemic risks [1]. For this reason, the current study only discusses circumstances of risk contagion among P2P lending platforms and other financial institutions.

Currently, there exist few studies on network lending risk contagion effects. Most scholars believe that, due to the lack of effective regulations and legal status definitions of P2P lending platforms, there exist widespread credit risks, moral risks, operational risks, and liquidity risks, among others [2, 3]. Some of these studies emphasize the importance of credit systems for risk prevention, advising the credit system closely to protect investors' interests and thus effectively control credit risks [4, 5]. For example, Kai argues that the development of P2P lending platforms engenders a significant challenge to the commercial banks' traditional mode of operation and ultimately affects the wider financial environment and has a significant impact on commercial banks' existing financial platforms and channels [6].

Given continuous development of complex network technologies, they can arguably be applied to analyze the degree of risk contagion in financial systems. Allen and Gale found that the contagion of financial risks relies on the networked structure of a financial system, that is, the interrelated relationships between internal actors in the financial system [7]. Cassar and Duffy discovered that risks spread faster when banks are globally rather than locally connected but also when the problem of liquidity shortage is not outstanding [8]. Iori and Jafarey found that when the initial scale of banks is homogeneous, with the market concentration decreasing, the scale of bank failures tends to decrease [9]. Aleksiejuk and Hołyst argued that when banks are in a two-dimensional or four-dimensional network, the duration of their failures and degree of risk contagion present exponential decay and power-law distribution, respectively [10]. Based on a random network study, Georg and Poschmann found that the general impact of the risk contagion effect is not minor but is a serious threat to system stability [11]. Li found that while connectivity among banks reduces the risk contagion effect, it can also lead to liquidity problems [12]. Jianxin et al. analyzed factors affecting the speed with which banks' vulnerability contagion spreads and found that, under the same contagion rate and extinction rate, a single point of contagion reaches a stabilized status slower than three points of contagion [13]. Jianmin and Tingqiang's study found that the more popular the social network, the higher the possibilities of credit risk contagion; conversely, as the heterogeneity of a lending network increases, the credit risk contagion rate decreases. Gang et al. built a dynamical model for supply chain network contagion risks, finding that as supply chain network members' nodes contagion threshold value increases, the average degree lowers, and the reduction of the contagion risk node density becomes more clear [14]. While existing literature focuses on the complex network theory and financial risk contagion, studies regarding network financial risk contagion, especially with regard to P2P lending risk contagion, are relatively rare. In addition, there is currently no risk contagion network model incorporating P2P lending risk transmission characteristics and descriptions of the dynamic process at play.

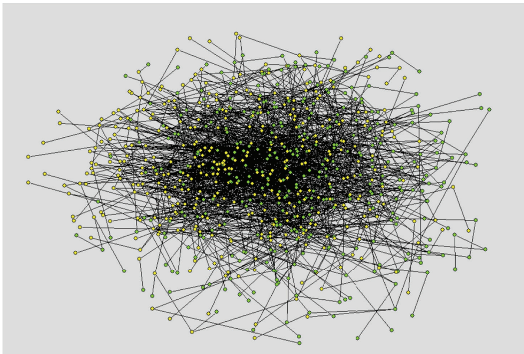
In the P2P lending market, the relationships between lending platforms and financing institutions may be seen as a type of social relation. If risk contagion is investigated only by means of data collection and statistical surveys, this may yield a significantly erroneous impression. Moreover, available data that reflects the actual development and transactions in China's P2P lending market are quite limited; in particular, data released from the platforms themselves is fairly scarce. Acquisition of real and reliable data is a difficult job. In response to these challenges, the current study aims to build a complex network model of P2P lending risk contagion, analyze the process of risk contagion, and reveal the mechanism of risk contagion. These findings may hold significance for further improving China's P2P lending supervision system and perfecting its risk management system. By combining the characteristics of P2P lending risk contagion, this study analyzes general features of the risk contagion of P2P lending platforms, and, based on this, it then considers changes that may occur in the dynamics of risk contagion when other financial institutions, such as banks, small loan companies, security agencies, group company, or securities institutions, act as vectors and when asymmetric information exists.

2. Description of P2P Lending Risk Contagion

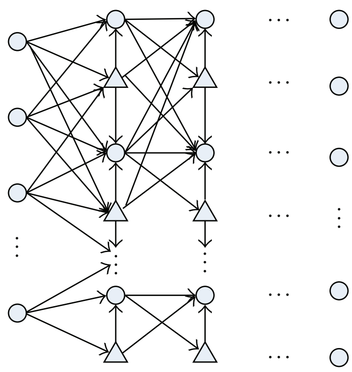
In terms of P2P lending risk contagion, the present study mainly analyzes it from two perspectives. First, there is a focus on risk contagion among P2P lending platforms. China's P2P lending industry is focused on providing services to the tail market, which is not covered, due to lack of either capacity or willingness, by traditional financial institutions. Investors and borrowers serviced by the P2P lending industry are actors in the long chain of financial service groups, whose financial knowledge, risk awareness, and risk tolerance are relatively insufficient, and thus they are prone to make individual and group irrational decisions. Once one P2P lending platform exposes a risk, the long chain tends to panic and quickly spread the fear. This then leads to the spread of risks to other related or even unrelated P2P lending platforms.

Second, risk contagion mainly relies on financial institutions which have assets-based relationships with P2P lending platforms [15]. Asset relationships are defined as relationships formed between P2P lending platforms and other financial institutions by means of associated debts, credit guarantees, credit derivatives, and so forth. In China, these financial institutions mainly include banks, small loan companies, security agencies, corporate groups, and securities institutions [16]. While one P2P lending platform might not be directly related to another, both platforms may have an asset-based relationship with the same financial institution. Therefore, risks exposed in the first P2P lending platform can spread to the second one through the common financial institution. This leads to the process of risk contagion.

The present paper focuses on the current situation in China's P2P lending market. According to data on P2P lending platforms issued by the Online Lending House, there were a total of 3917 identified P2P lending platforms in China as of January 2016, of which 1351 platforms were recorded as those operating improperly. This study gathered and organized information on existing P2P lending platforms, including their location, background, subject types, interest rate levels, main business types, and guarantee- and trusteeship-related financing institutions. Risk contagion was then primarily investigated via two channels, and the financial institutions that have business relationships with P2P lending platforms were adopted as node sets. In the first channel, if platform A and platform B are in the same region and have identical subject types, almost the same interest rate levels, and main business types, it can be said that investors in that network lending market may make poor evaluations or have low expectations of platform B once a risk appears in platform A, leading to an increase in risks of platform B; that is, risk contagion does occur. In this case, there exists an edge connecting platform A to platform B. In the second channel, data processing revealed existence of 275 financing institutions that have business relationships with existing P2P lending platforms; that is, platform A shares an edge with financing



(a) Risk contagion topology of network lending



(b) Network hierarchy diagram of risk contagion of network lending

Figure 1: Risk contagion topology of network lending.

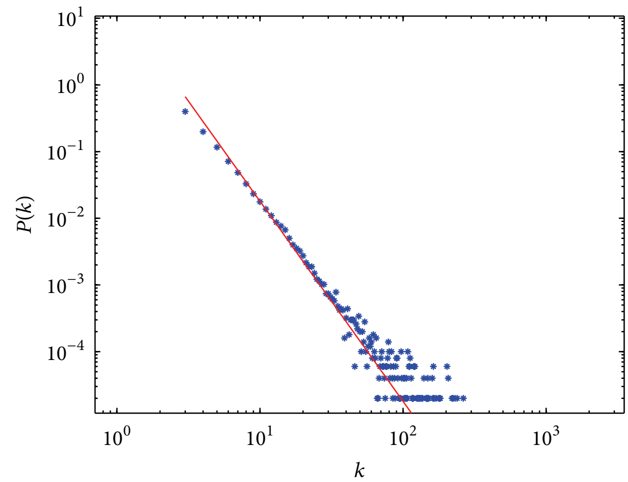


Figure 2: Distribution of relation degrees in the P2P lending market.

institution C, which, in turn, has a business relationship with platform A. Accordingly, a complex network consisting of 4192 nodes and 39982 edges was constructed, as shown in Figure 1.

The topology consists of two different types of nodes. The first type is a P2P loan platform, indicated by ○ (marked in yellow in Figure 1(a)), which we define as individuals initially exposed to a risk. The second type refers to the other financial institutions, represented in the figure by △ (marked in green in Figure 1(a)), which we define as an intermediate vector. As we can see in the figure, there is a direct risk of contagion among the network loan platforms. At the same time, platforms can also spread risks to their affiliated financial institutions, in which case these financial institutions may then spread the risk to other network loan platforms. Here, for the purpose of simplification, we assume that there is no significant risk contagion among financial institutions. From calculations, the average structural degree of a P2P lending market is 9.53, the focusing coefficient is 0.142, and the scaling parameter is 2.8433. Figure 2 shows the structural degree distribution of the network lending market, in which we can observe that the structural degree distribution of this market in China follows the power-law distribution. Due to substantial development of China's P2P lending market, the number of P2P lending platforms in the P2P lending market indeed increases continuously, and newly created P2P lending platforms also choose existing larger P2P lending platforms and financial institutions to build business relations to improve their credibility level and further attract more investors. The above two characteristics also correspond to two important properties (new platforms and preferential selection) of the scale-free network. Accordingly, this paper assumes that the network lending market structure can be approximately regarded as a scale-free network.

At the same time, the focusing coefficient of the network topology of the P2P lending market is smaller than that of the traditional bank network topology, which shows that the traditional bank network topology possesses better nodes connectivity than the P2P lending market. It is also appropriate to the actual situation of China's P2P lending market at the early development stage. Since China's P2P lending market started recently and is currently still at an early stage, disclosed information and market databases are relatively insufficient. According to the database used in this paper, it can be found that the structural degree distribution of China's P2P lending market corresponds to the power-law distribution, which shows that the connectivity of most nodes in the market is relatively low. However, there exist a few nodes with very high node degrees that are very crucial to the network connectivity and that are also key nodes in the risk contagion process of network lending, such as powerful network lending platforms and large financial institutions.

From these findings, it can be argued that there exist two key differences between the contagion process of P2P lending platforms and traditional financial institutions. First, risk contagion occurs not only among network loan platforms but also through other financial institutions. Essentially, more intermediate vectors are added to the contagion process. Second, in contrast to traditional financial institutions, the supervision of network lending companies is relatively weak, their internal control and information disclosure mechanisms are relatively imperfect, and there is a problem with information asymmetry. Therefore, there is a time lag between internal risk perception and external risk exposure. This lag then creates further difficulties for financial institutions and other

P2P lending platforms when dealing with risks. In this paper, priority attention is paid to these two features, the risk intermediate vector and time lag in risk exposure, when discussing risk contagion among P2P lending platforms in China.

3. Complex Network-Based Internet Lending Risk Contagion Model

3.1. Model Setting. In this paper, we denote an Internet lending platform in a financial system as W; and we denote Internet lending platforms number as N. We denote the "other" category of financial institutions that have business contacts with Internet lending platforms in the financial system as F, regarded as the default propagation medium in the whole risk contagion process; and we denote their number as M. Regarding the traditional virus contagion model, both Internet lending platform W and the "other" category of financial institutions F in the financial system can only be in one of the following two states: tangible state S, representing that while there is no risk exposure on an Internet lending platform or financial institution, there is possibility of being contaminated; and contagion state I, representing that there has been risk exposure on an Internet lending platform or financial institution and that there is also possibility of contagion to other Internet lending platforms or financial institutions. It is assumed that initially there is no risk exposure for financial institutions F.

We assume that there is a direct risk of contagion among Internet lending platforms owing to investors' psychological anticipations; at time t, if there exists a relatively close investor relationship between a non-risk exposure Internet lending platform W and another Internet lending platform with risk exposure in the system, the non-risk exposure Internet lending platform W changes from the tangible state to the contagion state, with the infection rate of γ at time $t+1$ [17]. What should be noted here is the following: (1) the Internet lending platform W contaminated at time t will always maintain the state of risk exposure until $t+1+T$; with effective internal and external emergency troubleshooting, the Internet lending platform W will recover to the non-risk exposure state with probability δ, where the effective spreading rate is defined as $\lambda = \gamma/\delta$. (2) If there exists a business relationship between the financial institution F and Internet lending platform W which is in the state of risk exposure at time t, the financial institution F, which is in the non-risk exposure state, will be contaminated at time $t+1$ with probability γ_1, falling into the risk exposure state.

To simplify analysis, it is assumed that the number of nodes in the whole network remains unchanged after initial growth; that is, the current number of nodes remains unchanged, meaning that the network's topological structure also remains unchanged. Subsequently, the dynamic spreading process of risk contagion in the P2P lending market is investigated based on the mean-field theory.

3.2. Spreading Behavior Dynamics of Internet Lending Risk. The degrees of nodes of a scale-free network are different; that is, the numbers of other Internet lending platforms and financial institutions having risk or asset correlation relationships with a given Internet lending platform in the system differ, which is in accordance with the current situation in China's Internet lending market. We denote the relative density of the Internet lending platform W with risk exposure having degree k as $\rho_k(t)$, with the steady state expressed as ρ_k. The contagion of risks between the Internet lending platform W and the "other" category of financial institutions F can be regarded as uniform, that is, determined by the contagion rates γ and γ_1. We then obtain the dynamics mean-field reaction equation of the above system as follows [18]:

$$\begin{aligned}\partial_t \rho_k(t) &= -\rho_{k,T}(t) + \lambda k\left[1-\rho_k(t)\right]\theta(\rho(t)) \\ &\quad + \gamma_1\left[1-\rho_k(t)\right]\vartheta(t), \\ \partial_t \vartheta_k(t) &= -\vartheta(t) + \gamma\left[1-\vartheta(t)\right]\theta(\rho(t)),\end{aligned} \tag{1}$$

where $\rho_{k,T}(t)$ is the relative density of risk contagion of the Internet lending platform W with degree k at $t-T$ and $\theta(\rho(t))$ is the probability of connection between an arbitrary given edge of the whole network and the Internet lending platform with risk exposure, with the steady state value of θ. When calculating $\theta(\rho(t))$, it is necessary to take nonuniformity of the scale-free network into consideration, as well as the probability of arbitrarily selecting an edge pointing to the node W, where the edge direction degree s is proportional to $sP(s)$; that is, the connection probability between a random edge and a node having a larger degree is higher. In addition, the degree of the Internet lending platform with risk exposure is higher, and thus the probability of risk exposure to other Internet lending platforms and financial institutions caused by it is higher. The expression for $\theta(\rho(t))$ is

$$\theta(\rho(t)) = \sum_k \frac{kP(k)\rho_k}{\sum sP(s)}, \tag{2}$$

where $P(k)$ is the degree distribution function of the Internet lending platform W in a scale-free network. The mean density of the contaminated Internet lending platform W in the network structure can be expressed as follows:

$$\rho(t) = \sum_k P(k)\rho_k. \tag{3}$$

Using $\partial_t \rho_k(t) = 0$ and $\partial_t \vartheta(t) = 0$ and according to (1), we obtain

$$\begin{aligned}-\rho_{k,T} + \lambda k\left(1-\rho_k\right)\theta + \gamma_1\left(1-\rho_k\right)\vartheta &= 0, \\ -\vartheta + \gamma(1-\vartheta)\theta &= 0.\end{aligned} \tag{4}$$

According to (4), when the network structure (1) is in a steady state, the relative steady state density ρ_k of the Internet lending platform W with risk exposure due to contamination is a function of λ, γ, γ_1, and T; and θ is an implicit function of λ, γ, γ_1, and T.

According to the structure characteristics of the scale-free network, substituting $\rho_{k,T} = \rho_k/(T+1)$ into (4) obtains

$$-\frac{\rho_k}{T+1} + \lambda k (1-\rho_k)\theta + \gamma_1 (1-\rho_k)\vartheta = 0, \qquad \vartheta = \frac{\gamma\theta}{1+\gamma\theta}. \tag{5}$$

According to (5), the relative steady state density ρ_k of the Internet lending platform W with risk exposure having degree k can be derived as

$$\rho_k = \frac{(T+1)\lambda k\theta(1+\gamma\theta) + \gamma\gamma_1\theta}{1+\gamma\theta + (T+1)\lambda k\theta(1+\gamma\theta) + \gamma\gamma_1\theta}. \tag{6}$$

Using $\langle k\rangle = \sum_s sP(s)$ and (2), it can be seen that

$$\begin{aligned}\theta &= \sum_k \frac{kP(k)\rho_k}{\sum_s sP(s)} \\ &= \frac{1}{\langle k\rangle}\sum_k kP(k)\frac{(T+1)\lambda k\theta(1+\gamma\theta) + \gamma\gamma_1\theta}{1+\gamma\theta + (T+1)\lambda k\theta(1+\gamma\theta) + \gamma\gamma_1\theta}.\end{aligned} \tag{7}$$

In order to make risks infectious across the whole network, (7) needs to satisfy $\theta \neq 0$; that is, the following formula must be satisfied:

$$\begin{aligned}&\frac{d}{d\theta}\left(\frac{1}{\langle k\rangle}\sum_k kP(k)\right. \\ &\left.\left.\cdot\frac{(T+1)\lambda k\theta(1+\gamma\theta) + \gamma\gamma_1\theta}{1+\gamma\theta + (T+1)\lambda k\theta(1+\gamma\theta) + \gamma\gamma_1\theta}\right)\right|_{\theta=0} \geq 1.\end{aligned} \tag{8}$$

By further simplifying this, the spreading critical value λ_c of the scale-free network can be obtained as

$$\lambda_c = \frac{(1-\gamma\gamma_1)\langle k\rangle}{(T+1)\langle k^2\rangle}. \tag{9}$$

In (9), $\langle k^2\rangle = \sum_k k^2 P(k)$. When $T = \gamma = \gamma_1 = 0$, that is, under the condition of no spreading delay and a spreading medium, it can be seen that $\lambda_c = \langle k\rangle/\langle k^2\rangle$. Therefore, under the condition of a spreading delay and in the presence of a spreading medium, the spreading clinical value of the scale-free network is significantly reduced. That is to say, when there is a lack of information transparency provided by an Internet lending platform and business-related financial institution, the risk contagion probability of the Internet lending platform may increase.

In order to make the network model more in accordance with practice, a scale-free network of a limited scale was taken into consideration [19]. In the scale-free network with a limited quantity of Internet lending platforms, the degree of the Internet lending platform W is distributed as $P(k) = 2m^2k^{-3}$, where m is the minimum value of other Internet lending platforms or financial institutions connected to each Internet lending platform W in the network. From this, it can be derived that $\langle k\rangle = \int_m^\infty kP(k)dk = 2m$. By introducing the maximum connection degree K_c of the limited scale-free network, when $K_c \to \infty$, $\langle k^2\rangle \approx \int_m^{K_c} k^2P(k)dk = 2m^2\ln(K_c/m)$. According to this, the risk contagion clinical value in the limited scale-free network can be calculated as

$$\lambda_c \approx \frac{(1-\gamma\gamma_1)}{(T+1)m\ln(K_c/m)}. \tag{10}$$

According to existing research results on scale-free networks, it is apparent that K_c is determined by the total quantity of Internet lending platforms W in the limited scale-free network; that is, $K_c \approx mN^{1/2}$. By substituting $K_c \approx mN^{1/2}$ into (10), the following expression can be acquired:

$$\lambda_c \approx \frac{2(1-\gamma\gamma_1)}{(T+1)m\ln N}. \tag{11}$$

According to (11), the risk contagion critical value λ_c of the whole limited scale-free network is related to T, γ, and γ_1. In the limited scale-free network, when only the spreading delay state is taken into consideration, the contagion critical value is $\lambda_c = 2/((T+1)m\ln N)$, and if only the existence of a contagion medium is taken into consideration, the risk contagion critical value is $\lambda_c = 2(1-\gamma\gamma_1)/(m\ln N)$. It can further be seen that when both contagion delay and contagion medium are taken into consideration, the risk contagion probability of the limited scale-free network increases.

Further, when $\lambda > \lambda_c$, substituting $P(k)$ and $\langle k\rangle$ into (7) obtains

$$\begin{aligned}&\frac{1}{m} \\ &= \int_m^{+\infty}\frac{(T+1)\lambda k(1+\gamma\theta) + \gamma\gamma_1}{k^2\left[1+\gamma\theta + (T+1)\lambda k\theta(1+\gamma\theta) + \gamma\gamma_1\theta\right]}dk \\ &= A\ln\frac{1+\gamma\theta + (T+1)\lambda k\theta(1+\gamma\theta) + \gamma\gamma_1\theta}{m(T+1)\lambda\theta(1+\gamma\theta)} + \frac{B}{m}.\end{aligned} \tag{12}$$

In (12),

$$\begin{aligned}A &= \frac{(T+1)\lambda(1+\gamma\theta)^2}{(1+\gamma\theta+\gamma\gamma_1\theta)^2}, \\ B &= \frac{\gamma\gamma_1}{1+\gamma\theta+\gamma\gamma_1\theta}, \\ C &= -\frac{(T+1)^2\lambda^2\theta(1+\gamma\theta)^3}{(1+\gamma\theta+\gamma\gamma_1\theta)^2}.\end{aligned} \tag{13}$$

Therefore, a formula can be derived to express θ:

$$\begin{aligned}&\ln\left(1 + \frac{1+\gamma\theta+\gamma\gamma_1\theta}{m(T+1)\lambda\theta(1+\gamma\theta)}\right) \\ &= \frac{(1+\gamma\theta+\gamma\gamma_1\theta)(1+\gamma\theta+\gamma\gamma_1\theta-\gamma\gamma_1)}{m(T+1)\lambda(1+\gamma\theta)^2}.\end{aligned} \tag{14}$$

It is clear that (14) has a unique solution. Based on this, we substitute $P(k)$ into (3) to obtain

$$\begin{aligned}\rho &= \sum_K P(k)\rho_k \\ &= \sum_k 2m^2 k^{-3} \frac{(T+1)\lambda k\theta(1+\gamma\theta)+\gamma\gamma_1\theta}{1+\gamma\theta+(T+1)\lambda k\theta(1+\gamma\theta)+\gamma\gamma_1\theta} \\ &= 2m^2\theta\int_m^{+\infty}\frac{(T+1)\lambda k(1+\gamma\theta)+\gamma\gamma_1}{k^3\left[1+\gamma\theta+(T+1)\lambda k\theta(1+\gamma\theta)+\gamma\gamma_1\theta\right]}dk.\end{aligned} \tag{15}$$

By combining (12) and (15), we can obtain the density of the Internet lending platform W when it is contaminated during the steady state and with risk exposure:

$$\begin{aligned}\rho &= 2m^2\theta\left[\frac{(T+1)\lambda(1+\gamma\theta)-(T+1)\lambda k(1+\gamma\theta)}{m(1+\gamma\theta+\gamma\gamma_1\theta)}\right. \\ &\quad \left.+\frac{\gamma\gamma_1}{2m^2(1+\gamma\theta+\gamma\gamma_1\theta)}\right]=\theta \\ &\quad \cdot\frac{2m(T+1)\lambda(1+\gamma\theta)(1-\theta)+\gamma\gamma_1}{1+\gamma\theta+\gamma\gamma_1\theta}.\end{aligned} \tag{16}$$

According to (14) and (16), it is clear that in the presence of a spreading delay and contagion medium in a limited scale-free network, there are significant changes in the networks' risk contagion dynamic behavior.

4. Simulation Experiment

In order to further depict general characteristics of Internet lending risk contagion in China and take changes in the risk contagion effect under conditions of asymmetry of the contagion medium and information into consideration, we conducted visualization of the network structure in light of the aforementioned analysis and results. We set $m = 2$ in the limited scale-free network [20]. China's first network lending platform, PPDAI.com, appeared in 2007, following which other P2P lending platforms appeared one by one. Considering the current developmental conditions of China's network lending market, this study found that when the network model is constructed, the initial number of nodes is four. In addition, the nodes of financing institutions were found to be connected to the first network lending platform and, therefore, from a relatively conservative perspective, it can be assumed that when adding a new node, three corresponding new edges are added.

Figure 3 depicts, under different risk spreading delay effects and contagion probabilities, changes in the contagion density ρ alongside changes in the effective spreading rate λ in the limited scale-free network.

It can be seen from Figure 3 that, under the condition of taking different values of T and γ (γ_1), the system achieves a relatively steady state. This is basically in accordance with the spreading situation of the basic risk contagion model in a limited scale-free network; however, by comparing this with the contagion rate and contagion density under different T and γ (γ_1) values, it becomes evident that if the risk contagion delay is ignored, that is, $T = 0$, and if there exists a risk contagion medium in the network structure, that is, there is the other category of financial institutions with business relationships with the Internet lending platform, the risk contagion probability in the whole network system is increased, which is in accordance with practical situations. When taking the risk contagion delay into consideration at the same contagion medium state, the risk contagion delay effect increases the risk contagion probability in the whole network. The practical outcome is that if one Internet lending platform W is contaminated by risk, given the asymmetry of information, the risk exposure condition cannot be acknowledged by investors and financial institutions in time. This, in turn, leads to failure of countermeasures for risk isolation by related investors and financial institutions, thus increasing investors' and the "other" category financial institutions' difficulties with handling risks and reducing their ability to eliminate risks. Ultimately, this increases the probability of risk contagion across the whole system.

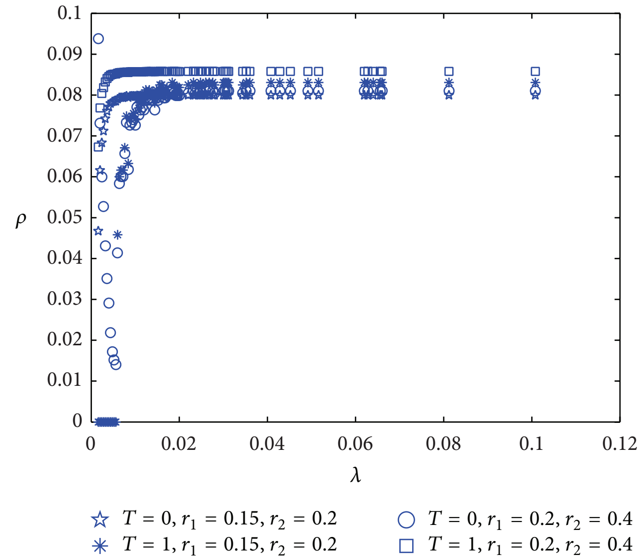


Figure 3: Changes in the contagion density ρ as a function of changes in the effective spreading rate λ in the limited scale-free network.

Figure 4 depicts changes in the risk contagion density ρ alongside changes in the risk contagion probability γ (γ_1) in the limited scale-free network, under different values of the risk contagion delay and effective contagion rate.

Figure 4 shows that when there exists a risk spreading delay effect and a contagion medium at the same time and when the risk contagion rate is $\lambda = 0.01$, then there exists a power-law relationship between the risk contagion density ρ and γ (γ_1) of the Internet lending platform W in the steady state. Across the whole network structure, the existence of a risk contagion medium increases the probability of risk contagion of the network system, which also increases with an increase in the probability of risk contagion γ among different Internet lending platforms, as well as γ_1 among Internet lending platforms and financial institutions. In the state of the other same conditions, a delay in risk contagion significantly

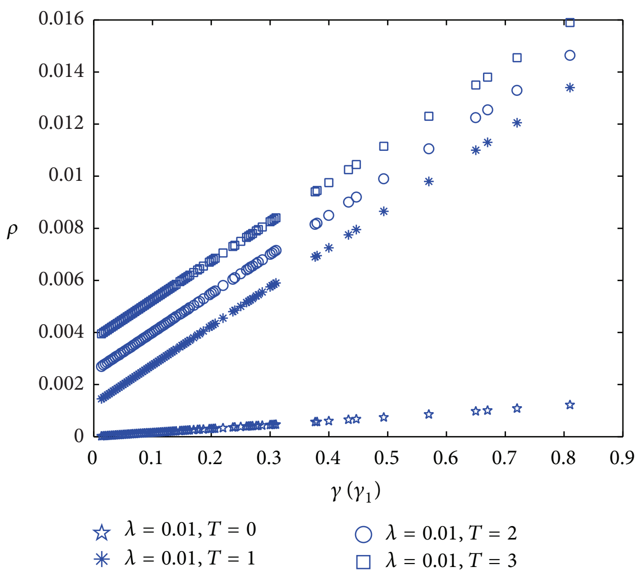


Figure 4: Changes in the contagion density ρ with γ (γ_1) in the limited scale-free network.

increases the probability of risk contagion in the system. Comparing the risk contagion delay effect and contagion medium, the latter was found to exert more significant influence on the risk contagion probability of the system as a whole.

Comparing the case when only either the risk contagion delay or the contagion medium is taken into consideration with that when both are taken into consideration, the latter was found to exert more significant influence on the probability of risk contagion of the whole network system. On one hand, when both of these conditions exist at the same time, this increases the number of Internet lending platforms or financial institutions with risk exposure, caused by one-time contagion in the network. On the other hand, it also reduces the coping capacity of Internet lending platforms or financial institutions when facing risks, thus significantly increasing the probability of risk contagion across the whole Internet lending system.

5. Conclusions

This paper analyzes the network structure and characteristics of risk infection in China's online network lending systems, through establishment of a dynamic model of risk contagion. At the same time, based on the characteristics of China's network lending market, the paper analyzes the impact that the risk intermediate vector and contagion lag have on network lending risk contagion as a whole. The following conclusions are reached:

(1) With no risk contagion delay taken into account, risk contagion media exist in the network. That is, the existence of other financing institutions that have business relationships with P2P lending platforms can increase the danger of risk contagion in the whole network. In light of this, it is recommended that appropriate regulatory authorities establish risk contagion firewalls between financing institutions and P2P lending platforms, rather than cut off business relationships between them owing to the existing possibility of aggravating risk contagion. In combination with the risk contagion monitoring system, when the contagion probability and density exceed preset threshold values, leading financing institutions and P2P lending platforms should be isolated in a timely manner to achieve the goals of early warning and isolation.

(2) With the risk contagion delay taken into account, the danger of risk contagion in the whole network increases under the same contagion media conditions. Although the communication of information seems to be adequate in the network lending process, both the truthfulness and actual transparency of information provided are relatively low in China's current network lending process, due to the country's incomplete credit system and banks' undisclosed credit information system. Moreover, information asymmetry is also very severe, and the lack of information transparency can directly lead to time lags in risk exposure. Since both P2P lending platforms and borrowers can hide the truth deliberately or unintentionally, for other P2P lending platforms, investors, and financing institutions involved it becomes more difficult to respond when risk information is disclosed. Therefore, regulatory authorities should construct and disseminate more detailed information disclosure guidelines to both borrowers and platforms in the network lending process to abide by and thus enhance information transparency. In other words, they should take appropriate measures not only to reduce the probability of risk in advance but also to allow other market participants to acquire risk information as early as possible and thus be able to undertake prevention measures and respond to risks in a timely manner.

(3) Compared to the time lag effects of risk contagion, the effects of the vectors were found to be more significant in terms of the possibility of systematic risk contagion.

(4) The combined impacts that the contagion lag and intermediate vectors have on the possibility of systematic risk contagion are clearer than the impact caused by either of them separately. When both factors exist, the number of platforms and other financial institutions vulnerable to a single wave of risk contagion increases. Simultaneously, the coping ability of those institutions is lowered, and this largely increases the possibility of risk contagion across the whole networked lending system.

For the purposes of concision, this paper has not dealt with risk contagion among traditional financial institutions, although it is acknowledged that the possibility of risk contagion in the network lending infrastructure is likely to be further increased if the spread of risk among these traditional institutions is also taken into consideration. The details of this potential impact will be further analyzed in the following studies.

Competing Interests

The authors declare that they have no competing interests.

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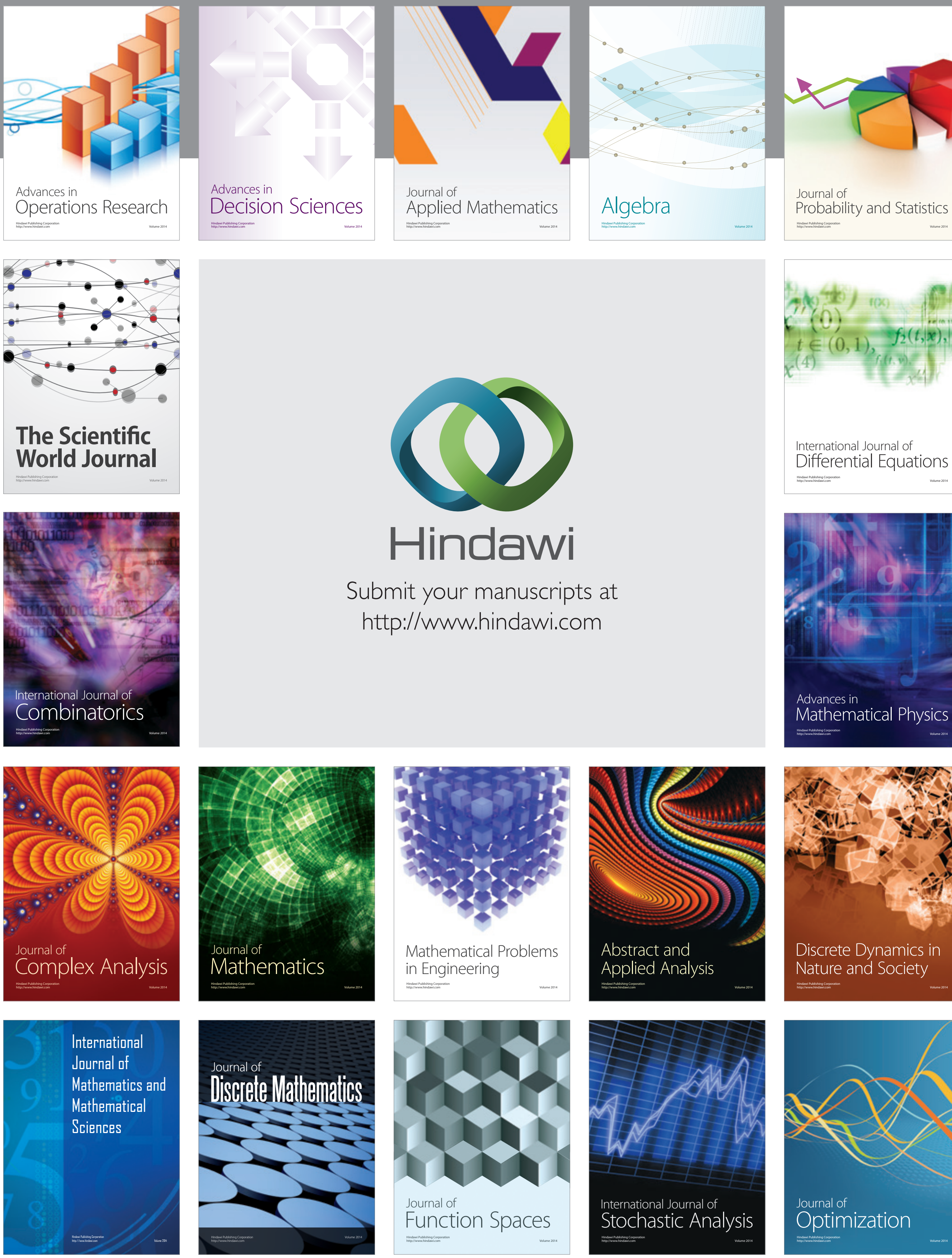

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