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Asset securitization, cross holdings, and systemic risk in banking☆

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ABSTRACT

We present a theoretical framework for studying how the cross holdings of asset securitization products may affect systemic risk in banking. We demonstrate that cross holdings can be understood from the perspective of profit seeking and credit creation; these motives drive up banks' leverage. We also show that the capital adequacy ratio regulatory constraint may become invalid with cross holdings, which adversely impacts the monitoring of the stability of a system. We demonstrate that, generally, the impact of asset securitization on systemic risk is nonmonotonic and critically hinges on the banking asset structure, cross-holding degree among banks, and asset securitization characteristics including its state of risk retention. We empirically examine theoretical predictions using a comprehensive set of data from 27 countries/regions spanning the past 15 years.

1. Introduction

Asset securitization has become a common instrument for bank risk management. According to a report by the International Monetary Fund (IMF) in 2009, approximately 20%–60% of new residential mortgage loans were subject to a securitization transaction in the United States, Western Europe, and Australia. The securitization market, however, collapsed in 2007–08. Since then, the impact of asset securitization on financial systemic risk has been widely debated. A common view argues that securitization not only reduces banks' own risk and the reliance on deposits (Instefjord, 2005; Allen and Carletti, 2006), but also provides greater asset diversification in the financial system (Jobst, 2006). In contrast, others have suggested that securitization has limited banks to effectively transferring risk (Gorton, 2009) and functioning as a destabilizing force in the banking system (Shleifer and Vishny, 2010). The ineffective monitoring and supervision by official agencies have been regarded as a critical cause of the global financial crisis (GFC) of 2007–08 (Goodhart, 2008; Schwarcz, 2008; Acharya, 2009; Laeven and Levine, 2009). Using a three-period model, Shleifer and Vishny (2010) discuss the cases of securitization with and without leveraged banks. The authors find that leverage accelerates banks' balance sheets; they explain how banks' involvement in securitization is motivated by profit-seeking, and how this business model is inherently unstable.

There are other mechanisms through which securitization can influence banks' systemic risk. Specifically, securitization increases banks' lending (Wagner, 2007), which can result in price bubbles and systemic risk (Loutskina and Strahan, 2009; Mian and Sufi, 2009; Shin, 2009; Demyanyk and Van Hemert, 2011). Meanwhile, securitization affects banks' lending policies (Shivdasani and Wang, 2011) or risk preferences (Keys et al., 2012; Battaglia and Gallo, 2013; Casu et al., 2013) and weakens their effort on ex post monitoring (Keys et al., 2009, 2010; Nadauld and Sherlund, 2013; Wang and Xia, 2014). Even if securitization does not increase individual banks' risks, it can increase systemic risk (Nijskens and Wagner, 2011). Further, while securitization is ostensibly beneficial, reducing the costs of idiosyncratic shocks and shrinking interest rate spreads, it leads to amplified systemic risks in equilibrium (Brunnermeier and Sannikov, 2014).

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To reconcile the conflicting perspectives mentioned above, this study provides a theoretical framework for studying how the cross holding of asset securitization may affect systemic risk in banking.[1] Our models are motivated by a financial system in which different banks are linked to one another through the cross holdings of asset securitization products. Our approach enables us to compare a sequence of theoretical results that highlights the implications of the cross-holding structure of asset securitization products for the extent of financial contagion and systemic risk. When examining the impact of securitized products on systemic risk, our model considers not only banks' issuing behaviors, but also banks' cross-holding behaviors that is crucial, though it has been overlooked for a long time. Bank behaviors can affect the level of risk they take. According to Santomero and Trester (1998), a situation that encourages asset liquidity leads the bank to allocate more of its portfolio to risky assets. Hence, the bank's performance would be adversely affected if these assets performed poorly. Using a micro founded agent-based model, Tedeschi et al. (2019) suggest that strategic behavior of banks contributes to financial distress in the short run. Therefore, examining behaviors of banks during the securitization process is the foundation for assessing the securitization products' impact on systemic risk. In fact, more than ten years ago, there is a consensus that banks that purchased large quantities of securitized products from other banks suffered severe and considerable losses during the subprime crisis (Diamond and Rajan, 2009). However, the importance of focusing on cross-holding behaviors and the lack of related studies are still emphasized in the recent study (Deku et al., 2019).

Putting it another way, there has been a growing body of literature on the impact of banks' interdependence on systemic risk. Interconnectedness among banks can have a significant impact on risk contagion and systemic risk (Martínez-Jaramillo et al., 2010). Based on a partial equilibrium model with heterogeneous banks, Ladley (2013) points out that the optimal inter-bank market connectivity varies with shock size. Analyzing the dynamics of failure cascades, Battiston et al. (2012) conclude that the relationship between the probability of systemic default and connectivity is U-shaped. The related studies by Elliott et al. (2014), Acemoglu et al. (2015) and Gofman (2017) each examine how shocks of varying magnitude propagate through networks based on debt/stock holdings or interbank lending. Additionally, they are interested in how the propagation of risk depends on the architecture of the banking network. It is worth pointing out that in the aforementioned studies, the existence of cross holdings is presupposed.

We present a set of banking business models in which asset securitization products and their cross holdings are considered sequentially. We begin with a basic business model for a bank that only accepts deposits and extends loans. We then add the functions of asset securitization to the model, which we call the Securitized model, to illustrate how the bank can create credit and transfer risk. Last, we introduce banks' cross holdings, conduct the Cross-holding model and present a more comprehensive view of banking credit creation within a profit-seeking context.

We demonstrate that cross-holding behavior weakens both the credit creation and the risk transfer functions associated with securitization in a period. However, cross-holding can help banks gain more profits especially when the economy is struggling. Noteworthily, the trade-offs between the strengthened inter-bank correlation and the weakened credit expansion result in nonmonotonic effects in shaping the systemic risk in banking. It is surprising yet reasonable that through cross-holdings, banks not only have the capability, but are also willing to indefinitely issue securitization products for profit seeking without breaching the capital adequacy ratio (CAR) constraint. We further demonstrate that cross-holding behavior strengths banks' motivation to raise their leverages. A banking system, with high leverage, connectivity and invalid regulation, has a high likelihood of systemic risk. Thus, the neglect of cross holdings can lead to serious consequences.

We use the simulation to visualize and verify the aforementioned nonmonotonic relationship, and the empirical tests to explore the appearance of the relationship in reality. We provide further empirical evidence using a comprehensive dataset from 27 countries/regions during the past 15 years. We find that there is no simple linear relation between the issuance volume of asset securitization products and the al level of systemic risk measured by SRISK/LRMES (Brownlees and Engle, 2012, 2017). Instead, the relationship is shown to have a U shape. Relatively, mortgage-backed securities (MBS) may have a more significant impact on systemic risk than asset-backed securities (ABS). Notably, our theoretical findings and simulation consistently indicate that the relationship between securitization and systemic risk is highly dependent on parameters describing banks' issuing and cross-holding behaviors; thus, we include the issuance volume of securitization as an available explanatory variable representing these two parameters. Accordingly, we conclude that the finding of empirical tests is consistent with the theoretical predictions mentioned above.

We contribute to the literature in several ways. First, the paper explores the motives of the cross-holding behaviors that occurred in the banking system. For the question of how the cross-holding occurred in the first place, we suggest that individual banks can avoid regulation and manage their risk by cross-holding. Hence, they can generate more credit and realize higher profits. The consequence of the cross-holding behavior is that the contagion risk in the financial network increases. Second, our study mathematically demonstrates that, with cross holdings, the current CAR regulation fails to effectively monitor the systemic risk in banking. Thus, allowing unlimited cross-holding among banks could increase leverage and lead to systemic risk accumulation in the banking system. Third, our model points out that there are various different nonmonotonic forms of relationships between securitization and systemic risk. Our empirical studies confirm our theoretical references that there is indeed a U-shape relationship between the issuance of securitization and the systemic risk in reality. Fourth, when analyzing cross holdings, the characteristics of some specific financial products may increase the complexity of the problem. Hence, the proposed framework in the study can accommodate further extensions in respect of other financial products with different features, alternative definitions of financial institutions, and even some inter-temporal transactions that are incurred.

Considering cross-holding behaviors, Section 2 provides a modeling framework for the following analysis. Using the aforementioned framework and focusing on cross-holding behaviors, Sections 3 and 4 examine the impact of asset securitization on the validity of the CAR constraint and the systemic risk, respectively. For cross-validation with Sections 3 and 4, we present and report our simulation result as well as our empirical result based on a quadratic polynomial regression in Section 5, followed by concluding remarks in Section 6.

2. Modeling framework

This section constructs the modeling framework for the subsequent analysis. Inspired by Shleifer and Vishny (2010), we propose a set of nested and upgraded models to describe the process of securitization with cross-holding behaviors. We first construct a Basic model comprising the basic business of banks. We then incorporate asset securitization into the Basic model and generate the Securitized model. Furthermore, we consider cross-holding behavior and suggest the Cross-holding model. We then examine the properties of these models, focusing on their created credits, transferred risks, and expected profits.

[1] Without loss of generality, we consider in the paper an example of asset securitization where the underlying assets are credit assets held by commercial banks. Our conclusion can also be applied to other types of asset securitization.

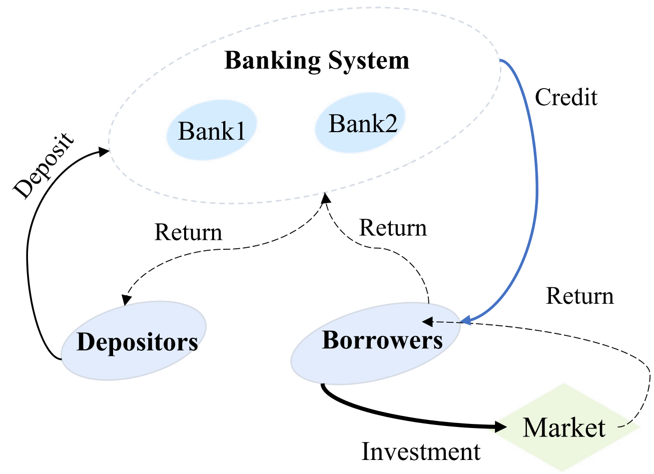

Fig. 1. Schematic diagram of the Basic model. This figure is a schematic diagram of the Basic model. There are banks, depositors, and borrowers. Depositors conserve their capital in banks and earn interest returns thereon. Banks borrow money from depositors and lend it to borrowers in return for interest payments paid by the latter. The borrowers invest in target markets with the capital borrowed from the banks.

2.1. Nested and upgraded models

In this subsection, we present and discuss three models: the Basic, Securitized, and Cross-holding models, the latter model being an extension of the former two. Through these models, we can theoretically analyze the impacts of asset securitization on the financial system, including systemic risk. Our models are two-period models. The bank starts operating at Time 0, with no settlement until Time 1.

2.1.1. Basic model

We begin with the Basic model, i.e., the business model in which the bank only accepts deposits and loans. Fig. 1 depicts a financial system in which there are only capital providers, final borrowers, and a banking system. We indicate one bank in this model by the superscript, b. Without loss of generality, we assume no maturity mismatch, no statutory reserve requirements and CAR constraints.

Without loss of generality, at Time 0, it is assumed that a representative bank has an exogenous equity, E, while deposits amount to D, which should be repaid to depositors by the bank at a rate of interest of r_c. The bank utilizes all of its available cash (asset) to extend loans, charging an interest rate of r_a on senior loans and r_b on subordinate loans. The ratios of senior loans and subprime loans to total loans are α and η, respectively, such that $\alpha + \eta = 1$.

Denote the bank's assets as A, which equals $E + D$. Then, the leverage, μ, of the bank is

$$\mu = \frac{D}{A} = \frac{D}{E + D}.$$

The total loans (both senior and subprime loans) being supported via the credit creation process, B^b, can be expressed as

$$B^b = A = \frac{E}{1-\mu}. \tag{1}$$

Remark 1. $\frac{\partial B^b}{\partial \mu} = \frac{E}{(1-\mu)^2}$ and $\frac{\partial B^b}{\partial E} = \frac{1}{1-\mu}$.

Remark 1 reveals that the total amount of credit that a bank can create is determined by its leverage ratio, μ, and its capital, E. Other things being equal, the higher the leverage, or the higher its own capital, the stronger the credit creation capacity.

At Time 1, the bank recovers both the principals and the interest on issued loans. For senior loans, we set the probability of default at p_a, whereas for subprime loans, we set it at p_b. Obviously, the default rate of subprime loans is higher than that of senior loans; according to the risk-return trade-off, the interest rate of subprime loans is also higher than that of senior loans. Then we have $p_b > p_a$ and $r_b > r_a$. Denoting the profit in this case as π^b, its expected value is therefore

$$E(\pi^b) = A\{\alpha\left[(1+r_a)(1-p_a)-1\right] + (1-\alpha)\left[(1+r_b)(1-p_b)-1\right]\} - r_c D. \tag{2}$$

Noting that $E(\pi^b)$ is related to the probabilities of default, p_a and p_b, we define

$$F = \alpha\left[(1+r_a)(1-p_a)-1\right] + (1-\alpha)\left[(1+r_b)(1-p_b)-1\right] \tag{3}$$

to simplify the expression so that (2) can be expressed as

$$E(\pi^b) = AF - r_c D. \tag{4}$$

Since F is a decreasing function of the default probability of loans, it can serve as an indicator of the "financial robustness" of the economy. In fact, F is the average expected return on loans, i.e., the weighted average of the expected returns on senior and subprime loans with weights equal to the respective shares in the bank's portfolio α and $\eta = 1-\alpha$. Analogously, denote the average return on loans $\bar{r}$ with $\bar{r} = \alpha r_a + (1-\alpha) r_b$, then (3) can be rewritten as $F = \bar{r} - \alpha(1+r_a)p_a - (1-\alpha)(1+r_b)p_b$. Assuming for simplicity that $p_a = 0$,[2] we further have

$$F = \bar{r} - (1-\alpha)(1+r_b)p_b. \tag{5}$$

We assume that the bank will enter and stay in the business of lending if and only if $E(\pi^b) > 0$ (participation constraint), which is equivalent to $F - \mu r_c \geq 0$. In light of this participation constraint, p_b is expected to satisfy

$$p_b \leq \frac{\bar{r} - \mu r_c}{(1-\alpha)\left(1+r_b\right)} = p_b^b. \tag{6}$$

This implies that the banker will enter the lending business only if the system is financially robust, or equivalently, the probability of default of subprime loans is smaller than a threshold p_b^b. Analogously, denote the corresponding cut-off value of F as F^b such that $F^b = \mu r_c$.

2.1.2. Securitized model

We explore this model, which is shown in Fig. 2, by allowing the bank to issue asset securitization products. We refer to it as the Securitized model, and denote the representative bank by the superscript, s.

At Time 0, the bank's deposit and lending operations are set similarly to those in the Basic model. Denote the times of issuance of the asset securitization products as n. To simplify the analysis, it is assumed that all the issuances occur at Time 0. When $n = 0$, we assume that all of the senior loans, αA, and some of the subordinated loans, βA, are fully purchased as off-balance sheet asset securitization products by outside investors at an interest rate of r_d. These loans have become more liquid because banks securitize them, replacing deposits with bonds as a source of finance (Loutskina and Strahan, 2009; Altunbas et al., 2009; Affinito and Tagliaferri, 2010; Loutskina, 2011). Due to the risk retention requirement, the rest, γA, of the subordinated loans remain on the balance sheet, where $\beta + \gamma = \eta$ and $\alpha + \beta + \gamma = 1$. The bank then recovers $(\alpha + \beta)A$ cash, and uses the cash for credit expansion. For the sake of simplicity, we disregard the price fluctuations associated with the securitized products. The business described above is repeated until all of the bank's on-balance sheet assets are converted into subordinated loans as n approaches infinity. Fig. 3 shows part of the process.

Remark 2. In reality, we may observe the increase in the scale of securitization and the increase in bank deposits at the same time. However, securitization and deposits are two different ways banks

[2] We provide the case of $p_a > 0$ in appendices.

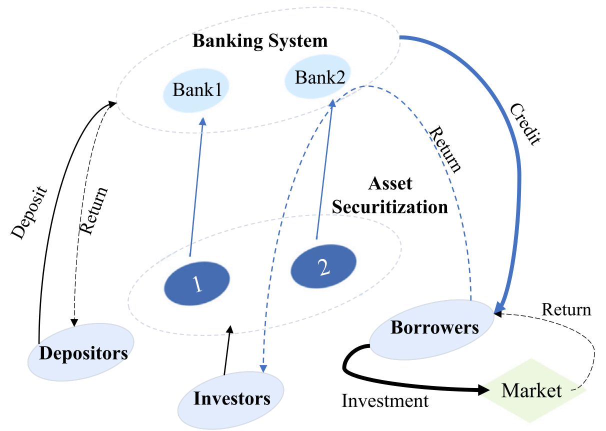

Fig. 2. Schematic diagram of the Securitized model. This figure is a schematic diagram of the Securitized model. In this case, banks issue asset securitization products that are purchased by investors. Hence, with increased liquidity, the banking system can lend more money to borrowers, while borrowers can obtain more money to invest. The solid lines describing investment and credit in Fig. 2 are noticeably coarser than the corresponding lines in Fig. 1, which means that, in the Securitized model, credit and investment are generally on a higher scale than in the Basic model.

provide liquidity. Traditionally, loans originated by depository institutions are primarily deposit funding. This model of banking is known as originate-to-hold model. Securitization engender the originate-to-distribute(or originate-repackage-sell) model, which provides lenders with an alternative form of financing to moderate their reliance on deposit funding. Therefore, the original securitization process will not cause fluctuations in the number of bank deposits (Altunbas et al., 2010). To more clearly observe the impact of securitization on banks and to simplify our analysis, we only use deposits as a source of bank liquidity when banks create credit for the first time, that is, when banks issue loans totaling A; at other times, we use securitization as a way for banks to obtain liquidity. Thus, in our model, the number of the deposit remains unchanged in one term.

According to the above process, credit supplied after n times of issuances has the following equation:

$$B_n = A + (1-\gamma)B_{n-1}, \tag{7}$$

which (7) is the law of motion of credit creation, a linear difference equation. In the steady state, the total credit scale created by the bank in the Securitized model, B^s, is given by

$$B^s = \frac{1}{1-(1-\gamma)}A = \frac{1}{\gamma}A. \tag{8}$$

The volume of loans, $B^{s,o}$, that the bank transfers off its balance sheet in this model is given by

$$B^{s,o} = (1-\gamma)B^s = (1-\gamma)\frac{1}{\gamma}A = \frac{1-\gamma}{\gamma}A.$$

At Time 1, borrowers repay the principal and interest to the bank, depositors receive the bank's repayment, while investors who purchased the asset securitization products receive their return from the bank. Based on this setting, it is easy to conclude that there is a proportion, α, of senior loans and a proportion, $(\beta+\gamma)$, of subprime loans in the loans that the bank creates. Hence, we can compute the expectation of the bank's profit, π^s, as follows:

$$E(\pi^s) = \frac{A}{\gamma}\left[F-(1-\gamma)r_d\right] - r_c D = \frac{A}{\gamma}\left[F-(1-\gamma)r_d - \mu\gamma r_c\right]. \tag{9}$$

The participation constraint in the Securitized model, $E(\pi^s) \geq 0$, therefore boils down to $F \geq (1-\gamma)r_d + \mu\gamma r_c$. Rewriting this formula gives:

$$p_b \leq \frac{\bar{r} - (1-\gamma)r_d - \mu\gamma r_c}{(1-\alpha)\left(1+r_b\right)} = p_b^s \tag{10}$$

This implies that the banker will enter the lending business only if the probability of default is less than a threshold value p_b^s. Correspondingly, denote the cut-off value of F as F^s such that $F^s = (1-\gamma)r_d + \mu\gamma r_c$.

2.1.3. Cross-holding model

Next, we allow banks to purchase asset securitization products from other banks, which is a realistic behavior in the banking system. With heterogeneities among banks, this behavior helps match different liquidity demands and enhance inter-bank liquidity. Meanwhile, securitization products have a relatively high-quality asset pool that is strictly supervised following the GFC, which ensures banks' safety requirement. Regarding profitability, the yield to maturity of asset securitization products is generally higher than that of general bonds with the same credit rating.

We now examine the impact of credit securitization on banks in terms of cross-holding behavior. We denote the representative bank by the superscript, c, and refer to the model as the Cross-holding model, which is shown in Fig. 4.

The settings in the Cross-holding model are similar to those in the previous models, including the bank's credit business and the process of issuing asset securitization products. The difference is that, at Time 0, after recovering $(\alpha+\beta)A$ cash, the bank uses a proportion, ρ, of the cash to issue loans. The remaining proportion, θ, of $(\alpha+\beta)A$ cash is used to purchase asset securitization products issued by other banks, at a return rate of r_d. Noting that $\rho+\theta = 1$, θ is used to represent the cross-holding degree. As with the Securitized model, the bank can repeat the business until n approaches infinity and its on-balance sheet assets are converted into subordinated loans due to risk retention and the asset securitization products it purchased from other banks.

According to the above process, credit supplied after n times of issuance satisfies the equation:

$$B_n = A + (1-\theta)(1-\gamma)B_{n-1}, \tag{11}$$

which is the law of motion of credit, a simple linear difference equation. In the steady state, the credit scale created by the bank, B^c, is given by

$$B^c = \frac{1}{1-(1-\theta)(1-\gamma)}A = \frac{1}{\theta+\gamma-\theta\gamma}A. \tag{12}$$

$B^{c,o}$, the volume of the off-balance sheet subordinated loans, becomes

$$B^{c,o} = (1-\gamma)B^c = \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A. \tag{13}$$

$B^{c,k}$, the volume of the on-balance sheet subordinated loans, is given by

$$B^{c,k} = \gamma B^c = \frac{\gamma}{\theta+\gamma-\theta\gamma}A. \tag{14}$$

$B^{c,p}$, the total amount of others' asset securitization products purchased by the bank is given by

$$B^{c,p} = \theta B^{c,o} = \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A. \tag{15}$$

The partial derivatives of $B^{c,o}$ with respect to γ and θ are given by

$$\frac{\partial B^{c,o}}{\partial\gamma} = \frac{-1}{(\theta+\gamma-\theta\gamma)^2} < 0 \text{ and } \frac{\partial B^{c,o}}{\partial\theta} = \frac{-(\gamma-1)^2}{(\theta+\gamma-\theta\gamma)^2} < 0, \tag{16}$$

respectively. It is obvious that $B^{c,o}$ is a decreasing function of γ and θ, which means that the higher the intensity of risk retention and the cross-holding degree, the less the risk transfer.

At Time 1, borrowers repay principal and interest to the bank. The bank pays the principal and interest to depositors. In return for purchasing securitization products, the bank pays investment costs and returns to investors. The expected value of the bank's profit, $E(\pi^c)$, is given by

$$\begin{aligned} E(\pi^c) &= \frac{A}{\theta+\gamma-\theta\gamma}\left[F-(1-\theta)(1-\gamma)r_d\right] - r_c D \\ &= \frac{A}{\theta+\gamma-\theta\gamma}\left[F-(1-\theta)(1-\gamma)r_d - \mu r_c(\theta+\gamma-\theta\gamma)\right]. \end{aligned} \tag{17}$$

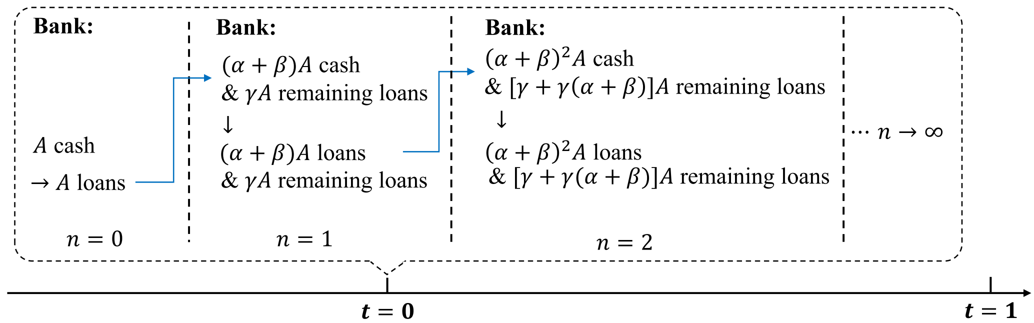

Fig. 3. Schematic diagram of the issuance process for asset securitization products. This figure shows the issuance process for asset securitization products. When $n = 1$, through the securitization based on A in loans from $n = 0$, the bank gains $(\alpha + \beta)A$ in cash and γA in subordinated loans that require balancing. When $n = 2$, $(\alpha + \beta)A$ in cash is used for credit. The securitization brings $(\alpha + \beta)^2 A$ in cash and $\gamma(1 - \gamma)A$ in subordinated loans to the bank. We use this setting in Gong and Wang (2013) to simplify our model.

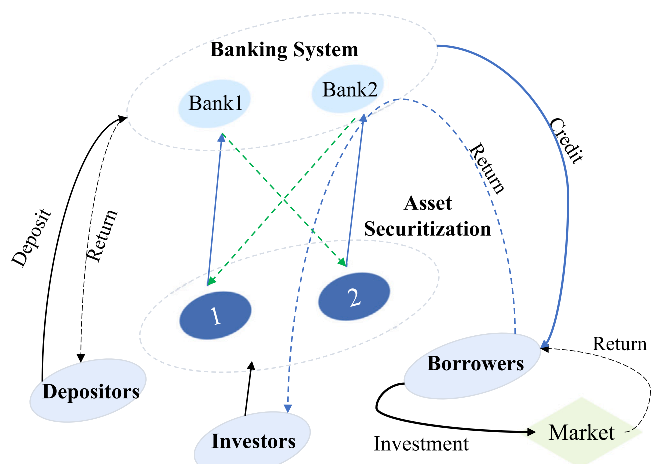

Fig. 4. Schematic diagram of the Cross-holding model. This figure is a schematic diagram of the Cross-holding model. Cross-holding behavior is represented by the green dotted line linking banks and asset securitization products. It will be noted that both the solid black line representing investment and the solid blue line representing credit are thinner than their counterparts in Fig. 2. That is, in the Cross-holding model, the scales of credit and investment are generally smaller than in the Securitized model.

The participation constraint in the Cross-holding model, $E(\pi^c) \geq 0$, therefore boils down to $F \geq (1-\theta)(1-\gamma)r_d + \mu r_c(\theta + \gamma - \theta\gamma)$, which can be expressed as

$$p_b \leq \frac{\bar{r} - (1-\theta)(1-\gamma)r_d - \mu r_c(\theta + \gamma - \theta\gamma)}{(1-\alpha)\left(1 + r_b\right)} = p_b^c. \tag{18}$$

This implies that the banker will enter the lending business only if the probability of default is less than a threshold value p_b^c. Correspondingly, denote the cut-off value of F as F^c such that $F^c = (1-\theta)(1-\gamma)r_d + \mu r_c(\theta + \gamma - \theta\gamma)$.

2.2. Functions and profitability of asset securitization

Thus far, we have developed three models for further analysis. In this section, we first analyze the functions of asset securitization and the effect of cross-holding behavior on these. We then compare the different models' profits and find that using asset securitization may encourage the bank to improve its leverage, which can affect systemic risk.

2.2.1. Functions of asset securitization

We first explore the credit creation function of asset securitization and the effect of cross-holding behavior on this function. In particular, we compare the amounts of credits in the three models above. In terms of credit creation, the differences among the three models are as follows:

$$\Delta B^{s-b} = B^s - B^b = \frac{1-\gamma}{\gamma} A, \tag{19}$$

$$\Delta B^{c-b} = B^c - B^b = \frac{1 - \theta - \gamma + \theta\gamma}{\theta + \gamma - \theta\gamma} A, \tag{20}$$

$$\Delta B^{c-s} = B^c - B^s = \frac{-\theta(1-\gamma)}{\gamma(\theta + \gamma - \theta\gamma)} A. \tag{21}$$

Essentially, in the Securitized model, the number of loans originated by means of securitization is ΔB^{s-b}. Analogously, in the Cross-holding model, the number of loans originated by means of securitization is ΔB^{c-b}. ΔB^{c-s} indicates the reduced credit supply of due to the cross-holding behavior. Obviously, $\Delta B^{s-b} > 0$, i.e., B^s is higher than B^b; $\Delta B^{c-b} > 0$, i.e., B^c is higher than B^b; and $\Delta B^{c-s} < 0$, i.e., B^c is smaller than B^s. Thus, asset securitization products assist banks in creating more credit, which is the credit creation function. Fig. 5 illustrates a comparison of credit supplies of three different models. With other things being equal, the amount of credit supply created by the Cross-holding model, B^c, is between that of the Basic model, B^b, and that of the Securitized model, B^s, i.e., $B^b < B^c < B^s$.

The incremental credit provided by asset securitization is related to own capital, E, leverage, μ, and the degree of risk retention, γ, in the securitized process (recall (19)). Regarding the effect of cross-holding behavior on the credit creation function of asset securitization, it obviously weakens but does not eliminate the credit creation function brought about by credit securitization (recall (20) and (21)). The partial derivative of ΔB^{c-b} with respect to θ is $\frac{\partial \Delta B^{c-b}}{\partial \theta} = \frac{(\gamma-1)A}{(\theta+\gamma-\theta\gamma)^2} < 0$, which implies that the greater the cross-holding degree, the lower the credit creation capacity in the Cross-holding model.

Next, we explore the risk transfer function of securitization and the effect of cross holdings on this function. There is no transferred risk in the Basic model; thus, we compare the amount of transferred risk between the Cross-holding and the Securitized models, that is,

$$\Delta B^{c,o-s,o} = B^{c,o} - B^{s,o} = \frac{-\theta(1-\gamma)^2}{\theta + \gamma - \theta\gamma} A.$$

Obviously, $\Delta B^{c,o-s,o} < 0$, since $B^{s,o}$ is higher than $B^{c,o}$. Hence, the incremental transferred risk brought about by asset securitization is reduced by cross-holding behaviors. Furthermore, the partial derivative of $\Delta B^{c,o-s,o}$ with respect to θ is $\frac{\partial \Delta B^{c,o-s,o}}{\partial \theta} = \frac{-\gamma(1-\gamma)^2}{(\theta+\gamma-\theta\gamma)^2} A < 0$, which implies that the greater the degree of cross-holding, the lower the risk transfer capacity in the Cross-holding model.

To summarize, asset securitization products have credit creation and risk transfer functions, which are weakened by the cross-holding behavior.

2.2.2. Additional profit from asset securitization

Although the bank could create a greater scale of credit and transfer the asset risk by using asset securitization products, its ultimate

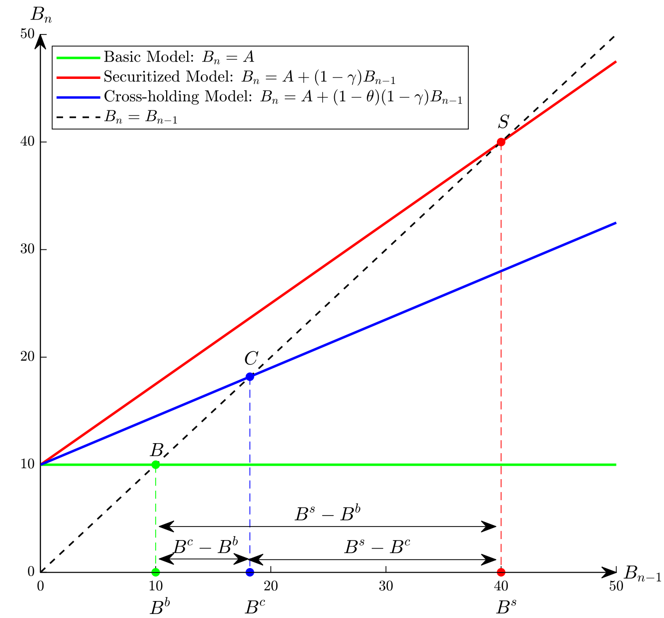

Fig. 5. Credit supplies of three models. This figure is drawn for the case of $A = 10$, $\gamma = 0.25$, and $\theta = 0.4$. Points B, S, and C correspond to the steady states of the three models, respectively. Similarly, B^b, B^s, and B^c correspond to credit creation in each of the three models.

objective remains more profit, which can also be achieved with asset securitization products. Indeed, based on the greater scale of credit and the transferred risk, the bank is likely to gain more profit from interest. We compare the expected profits from the three models. The change in expected profit from the Securitized model to the Basic model is given by

$$\Delta E(\pi^{s-b}) = E(\pi^s) - E(\pi^b) = \frac{1-\gamma}{\gamma}(F - r_d)A. \tag{22}$$

Thus, when the default probabilities, p_a and p_b, are sufficiently low for $F - r_d > 0$, we have $\Delta E(\pi^{s-b}) > 0$, and asset securitization can generate additional positive profits for banks. However, when the default probabilities increase and result in $F - r_d < 0$, we have $\Delta E(\pi^{s-b}) < 0$. That is, there is no additional profit but further loss through asset securitization.

The change in expected profit from the Cross-holding model to the Basic model is given by

$$\Delta E(\pi^{c-b}) = E(\pi^c) - E(\pi^b) = \frac{1-(\theta+\gamma-\theta\gamma)}{\theta+\gamma-\theta\gamma}(F - r_d)A. \tag{23}$$

According to the definition of F, credit securitization can bring about additional profits for banks when the default probabilities, p_a and p_b, are sufficiently low for $F - r_d > 0$ and $\Delta E(\pi^{c-b}) > 0$. However, when the default probabilities, p_a and p_b, satisfy $F - r_d < 0$, so that $\Delta E(\pi^{c-b}) < 0$, the credit securitization business not only prevents the bank from gaining additional profit, but also causes further losses.

By (22) and (23), and recalling (1), we have

$$\frac{\partial \Delta E(\pi^{s-b})}{\partial \mu} = \frac{1-\gamma}{\gamma(\mu-1)^2}(F - r_d)E,$$
$$\frac{\partial \Delta E(\pi^{c-b})}{\partial \mu} = \frac{1-\theta-\gamma+\theta\gamma}{(\theta+\gamma-\theta\gamma)(\mu-1)^2}(F - r_d)E.$$

Accordingly, we have the following results on the relationship between the profit from asset securitization and the leverage.

Proposition 1. *$\frac{\partial \Delta E(\pi^{s-b})}{\partial \mu} > 0$ if and only if $F - r_d > 0$. Similarly, $\frac{\partial \Delta E(\pi^{c-b})}{\partial \mu} > 0$ if and only if $F - r_d > 0$.*

Proposition 1 means that when the bank can earn an additional return through asset securitization in an economic boom, the higher the leverage of the bank, the higher the additional profits. Thus, regardless of cross-holding behaviors, asset securitization could strengthen banks' motivation to increase leverage, which might lead to the accumulation of systemic risk. Specifically, as the leverage rises, the credit scale of the economic-finance system becomes larger. From an endogenous perspective, the marginal rate of return declines and the interest rate rises as credit expands, which influences the development of the economy. From an exogenous perspective, an economy with a high level of leverage is more sensitive to exogenous shocks and easily collapses. Once the economy stagnates or experiences a shock, investors will realize that debt financing may not be repaid from future returns, which will negatively impact investment demand. Additionally, banks will be unwilling to borrow money, leading to a severe drop in the money supply. Thus, the system becomes more and more sensitive to investors' expectations and interest rates. Such mechanisms will lead to a decline in economic conditions. Thus, it is easy for the system to enter a Minsky moment (Minsky, 1986). Naturally, the system itself, with a high level of leverage, is unstable.

2.2.3. Effect of cross-holding behavior on banks' profits

After analyzing the impact of asset securitization on banks' leverage, we examine it in a realistic model, i.e., the Cross-holding model, and how cross-holding behavior may affect a bank. We conclude that this behavior is beneficial to a bank's operation, especially in an economic downturn.

First, we discuss the problem of whether $E(\pi^c)$ is always smaller than $E(\pi^s)$. The difference between the two, $\Delta E(\pi^{c-s})$, is given by

$$\begin{aligned}\Delta E(\pi^{c-s}) = E(\pi^c) - E(\pi^s) &= \frac{-\theta(1-\gamma)\left(F - r_d\right)A}{\gamma(\theta+\gamma-\theta\gamma)} \\ &= \frac{-\theta(1-\gamma)\left(F - r_d\right)}{\gamma(\theta+\gamma-\theta\gamma)}\frac{E}{1-\mu}.\end{aligned} \tag{24}$$

Proposition 2. *$\Delta E(\pi^{c-s}) > 0$ if and only if $F < r_d$, and $\frac{\partial \Delta E(\pi^{c-s})}{\partial \mu} > 0$ if and only if $F < r_d$.*

Proposition 2 says that when the default probabilities, p_a and p_b, are sufficiently low for $F \geq r_d$, we have $\Delta E(\pi^{c-s}) \leq 0$, i.e., the bank gains less profit from the cross-holding of asset securitization. Moreover, when the probability of default increases to the extent that $F < r_d$, $\Delta E(\pi^{c-s}) > 0$, since the bank purchases other banks' products that are about to pay returns to the bank. Therefore, $E(\pi^c)$ is not always smaller than $E(\pi^s)$. When there is a high probability of default, banks with cross-holding behavior are more likely to gain additional profits, so that $E(\pi^c)$ may be higher than $E(\pi^s)$.

Recalling (22), (23), and (24), it is a common and important discriminant, for all three models, whether $(F - r_d)$ is positive. Thus, when $F - r_d = 0$, we have

$$p_b = \frac{\bar{r} - r_d}{(1-\alpha)\left(1+r_b\right)}. \tag{25}$$

Denote $p_b^d = \frac{\bar{r}-r_d}{(1-\alpha)(1+r_b)}$ and $F^d = r_d$. (25) provides the threshold condition on the probability for $F - r_d = 0$. That is to say, the case of $F - r_d \geq 0$ correspond to $p_b \leq p_b^d$ while $F - r_d < 0$ is equivalent to $p_b > p_b^d$.

Proposition 3. *The probability thresholds satisfy $p_b^d < p_b^s < p_b^c < p_b^b$. Furthermore, if $p_a = 0$, then $p_b^d > 0$.*

We provide the proof of Proposition 3 in Appendix B. The schematic given in Fig. 6 illustrates the associated results.[3] Let us firstly analyze the situation of $p_b^s < p_b^c < p_b^b$. F is a decreasing function of p_b, hence,

[3] We also consider the case of $p_a > 0$ in Fig. A.1.

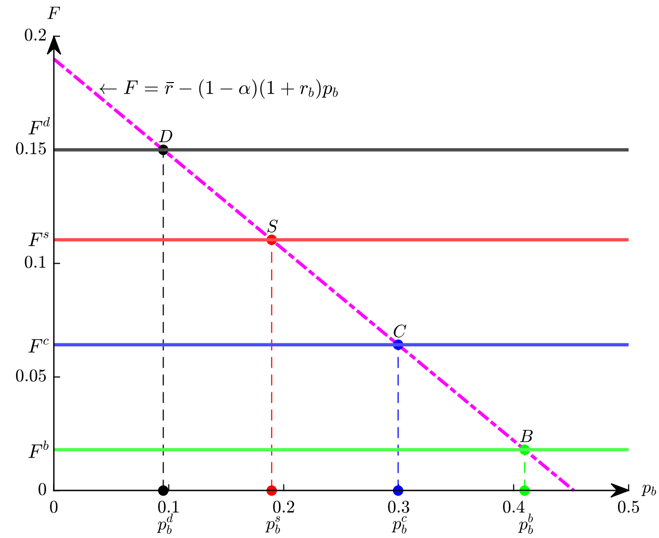

Fig. 6. Cut-off values of default probabilities deduced from the business constraints. This figure is drawn for the case of $p_a = 0$, $\alpha = 0.7$, $r_a = 0.10$, $r_b = 0.40$, $r_c = 0.02$, $r_d = 0.15$, $\mu = 0.9$, $\gamma = 0.3$ and $\theta = 0.5$. The dotted oblique line represents the relationship between F and p_b. The solid lines indicate the values of F obtained by solving equations $E(\pi^b) = 0$, $E(\pi^s) = 0$, $E(\pi^c) = 0$, and $\Delta E(\pi^{s-b}) = \Delta E(\pi^{c-b}) = \Delta E(\pi^{c-s}) = 0$, respectively. The solid points illustrate the different cut-off values of p_b in different circumstances.

$F^s > F^c > F^b$. This relationship indicates that when the financial robustness of the economy is relatively high, such as when $F > F^s$ ($p_b < p_b^s$), banks have an incentive to engage in securitization business and profit from it, and the credit created by banks is the highest. As the financial robustness gradually declines, when F is in the range of $[F^c, F^s]$ (that is, $p_b \in [p_b^s, p_b^c]$), banks must engage in cross-holding behavior to ensure positive profits when conducting securitization business, and the amount of credit created is the second highest at this point. When the financial robustness is at a lower level, such as when $F \in [F^b, F^c]$ ($p_b \in [p_b^c, p_b^b]$), banks will no longer engage in any other business except for basic business, and the credit created by banks is the least. The aforementioned phenomenon is consistent with the credit procyclicality observed in reality.

As for p_d, it is known from $p_b^d < p_b^b$ that both $F \geq r_d$ ($p_b \in [0, p_b^d]$) and $F < r_d$ ($p_b \in (p_b^d, p_b^b]$) can be achieved under the normal operation of the Basic model. Recalling that $p_b^d < p_b^s$ and $p_b^d < p_b^c$, it is clear that the previous statement can hold similarly in the Securitized and Cross-holding models. If $p_b \in [0, p_b^s]$, regardless of the models, the bank can carry out its operations normally. When $p_b \in [0, p_b^d]$, we have $F \geq r_d$ and $E(\pi_s) \geq E(\pi_c) \geq E(\pi_b)$. Otherwise, when $p_b \in (p_b^d, p_b^s]$, we have $F < r_d$ and $E(\pi_s) < E(\pi_c) < E(\pi_b)$.

Propositions 1 to 3 show that in a single term, the credit creation exhibit procyclicality when asset securitization products are introduced to the banking system. During periods of higher financial robustness, profits from securitization operations strengthen the bank's incentive to increase leverage. The cross-holding behavior brings about additional profits to the bank, especially in the economic condition with low financial robustness.

3. Impacts of cross-holding on long-term credit creation and regulation circumvention

This section analyzes the impact of cross-holdings in two scenarios that are more closely related to the reality. We examine the effects of cross-holdings on banks' credit creation capacity in the long term, as well as the potential impact on banks' leverage and systemic risk. Besides, we discuss the effects of cross-holdings on the validity of CAR regulation and the potential consequences thereof.

3.1. Effect of cross-holding behavior on banks' long term credit creation

For completeness, we consider the business operation in the next term, starting from Time 1 and ending at Time 2. That is, we focus on both the Securitized and the Cross-holding models at Time 2. Recalling (8), (12) and Remark 1, it is obvious that the bank's capital, E, is an important factor in the bank's credit creation ability. When $\Delta E(\pi^{c-s}) > 0$, the initial capital in the Cross-holding model is higher than that in the Securitized model at Time 1, which may influence the bank's ability to originate credits in the next term.

Specifically, in the next term of operations, denote the expected initial capitals of the representative banks in the Securitized and the Cross-holding models as E_1^s and E_1^c, respectively. Thus, we have $E_1^s = E + E(\pi^s)$ and $E_1^c = E + E(\pi^c)$. Without loss of generality, let us assume that the leverage in this period remains μ, which is defined as deposits divided by assets. When the bank's own capital changes, it can keep its leverage by absorbing more deposits than D. Recalling (1), (8), and (12), at Time 2, the expected credit scales created in the Securitized and the Cross-holding models are given by

$$B_1^s = \frac{E_1^s}{\gamma(1-\mu)} \text{ and } B_1^c = \frac{E_1^c}{(1-\mu)(\theta+\gamma-\theta\gamma)}, \tag{26}$$

respectively. Recalling (1), (9) and (17), during the second term (i.e., from Time 1 to Time 2), the expected profits in the Securitized and the Cross-holding models are given by

$$E(\pi_1^s) = \frac{E_1^s}{(1-\mu)\gamma}\left[F - (1-\gamma)r_d - \mu\gamma r_c\right],$$

$$E(\pi_1^c) = \frac{E_1^c}{(1-\mu)(\theta+\gamma-\theta\gamma)}\left[F - (1-\theta)(1-\gamma)r_d - \mu r_c(\theta+\gamma-\theta\gamma)\right],$$

respectively. Considering the participation constraints in these two models, i.e., $E(\pi_1^s) \geq 0$ and $E(\pi_1^c) \geq 0$, the cut-off values of default probability in the second terms, p_{b1}^s and p_{b1}^c, are proved to be the same with those in the first term, p_b^s and p_b^c. In other words, $p_{b1}^s = p_b^s$ and $p_{b1}^c = p_b^c$.

Recalling (26), (22) and (24), we then have the following result in terms of credit creation.

Proposition 4. *$B_1^c > B_1^s$ if and only if* $\Delta E(\pi^{c-s}) > \frac{\theta}{\gamma}\left[\Delta E(\pi^{s-b}) + (1-\gamma)(1-\mu-r_c\mu+r_d)A\right]$.

Proposition 4 says that when the probabilities of default are high and $\Delta E(\pi^{c-s})$ satisfies a certain condition, the bank's holdings of other banks' products provide capital replenishment under the Cross-holding model, so that the subsequent credit creation function is likely to be higher than that in the Securitized model. Therefore, as the leverage becomes higher, it becomes easier for $\Delta E(\pi^{c-s})$ to satisfy the condition in Proposition 4, which will result in more credit creation. In other words, in the Cross-holding model, banks' motivation to raise their leverages remains strong, and banks have strong long-term credit creation capability.

In addition, $B_1^c = B_1^s$ is equivalent to $\Delta E(\pi^{c-s}) = \frac{\theta}{\gamma}\left[\Delta E(\pi^{s-b}) + (1-\gamma)(1-\mu-r_c\mu+r_d)A\right]$ (recall Proposition 4). Recall (22) and (24) and rewrite the previous equation as:

$$\frac{-\theta(1-\gamma)}{\gamma(\theta+\gamma-\theta\gamma)}(F-r_d)A = \frac{\theta}{\gamma}\left[\frac{1-\gamma}{\gamma}(F-r_d)A + (1-\gamma)(1-\mu-r_c\mu+r_d)A\right].$$

Denote the value of F that can satisfy the above equation as F_1^B. By (5), calculating the value of p_b corresponding to F_1^B yields the cut-off value p_{b1}^B.

In Fig. 7, we exemplify the credit supply for two terms, starting at Time 0 and ending at Time 2. If $p_{b1} \in [0, p_{b1}^s]$, regardless of the models, the bank can normally carry out its operations. Point H with an abscissa of p_{b1}^B corresponds to the case where $B_1^c = B_1^s$. Noting that under the parameters setting corresponding to Fig. 7, $p_{b1}^B < p_{b1}^s$. Thus,

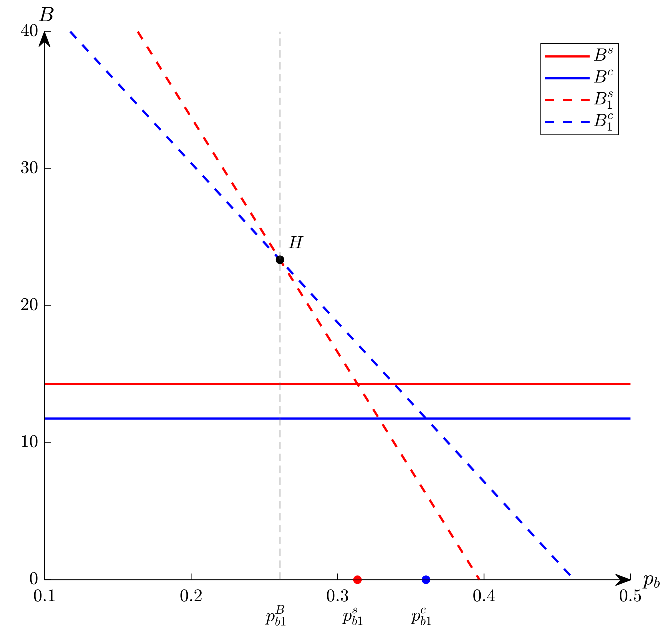

Fig. 7. Expected profits in the current and the next terms. This figure is drawn for the case of $p_a = 0$, $\alpha = 0.7$, $r_a = 0.10$, $r_b = 0.40$, $r_c = 0.02$, $r_d = 0.15$, $\mu = 0.95$ $\gamma = 0.7$, $\theta = 0.5$ and $A = 10$. The solid lines depict the relationships between the credit supplies (i.e., B^s and B^c) and the default probabilities of subprime loans (i.e., p_b^s and p_b^c) for the current term. The two oblique dashed lines depict the relationships between the credit supplies (i.e., B_1^s and B_1^c) and the default probabilities of subprime loans (i.e., p_{b1}^s and p_{b1}^c) for the next term. Point H is the intersection of these two oblique dashed lines.

when $p_b \in (p_{b1}^B, p_{b1}^s]$, the condition of Proposition 4 is satisfied so that $B_1^c > B_1^s$. Otherwise, $B_1^c \leq B_1^s$.

This subsection provides a proposition that the cross-holding behavior can help the bank maintain its credit creation ability in a long term. Bad economic conditions or high leverages enhance the effect specified in Proposition 4. Bad economic conditions or high leverages can help exert the previous effect more pronounced. Hence, the cross-holding behavior may lead to more credit supplies and higher banking leverages, which could lead to the accumulation of systemic risk. The cross-holding behavior also encourages the bank to evade regulatory constraints, which could also lead to the accumulation of systemic risk. In the next subsection, we examine a crucial mechanism through which the regulation fails in inhibiting the credit expansion behavior of the bank.

3.2. Effect of cross-holding behavior on the validity of regulation

The previous discussion is intended to simplify the model and therefore does not consider any regulatory restrictions on the banking system. However, in practice, there always exist some regulatory constraints in banks' operation; the most typical of these is the CAR. In the following, we discuss whether the CAR constraint is effective for the most realistic model, the Cross-holding model, compared with the Securitized model. If the CAR constraint is valid for the Securitized model but not for the Cross-holding model, it would indicate that cross-holding behavior should not be ignored when setting the constraint. We highlight the result that cross-holding behavior can affect the effectiveness of the CAR restriction and help a bank evade regulatory constraints. Therefore, in the regulatory process, neglecting the cross-holding behavior may lead to serious consequences.

The CAR constraint is a restriction on the ratio of equity to risk-weighted assets, which is widely used to protect depositors and improve the stability of banking systems globally. Denote the risk weights for senior loans and subordinated loans in calculating CAR as w_1 and w_2,

Table 1
Balance sheet of the bank in the Basic model. Recalling (1), this table shows the balance sheet of the bank in the Basic model.

Asset A		Liability and Equity $(L+E)$
Products from other banks	αA	Deposit D
Subprime loans(Risk retention)	$(\beta+\gamma)A$	Equity E

Table 2
Balance sheet of the bank in the Cross-holding model. Recalling (14) and (15), this table shows the balance sheet of the bank in the Cross-holding model.

Asset A		Liability and Equity $(L+E)$
Products from other banks	$\frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A$	Deposit D
Subprime loans(Risk retention)	$\frac{\gamma}{\theta+\gamma-\theta\gamma}A$	Equity E

respectively. Considering the credit enhancement, and noting that the asset securitization products issued by banks are essentially a mixture of senior loans and subordinated loans, we reasonably assume that its risk weight, w_3, for the CAR calculation satisfies

$$w_1 < w_3 < w_2.$$

Suppose that the CAR restriction should be satisfied when issuing asset securitization products. Notice that the asset securitization products are assumed to be issued at Time 0. Setting the required CAR to be ζ^q, therefore, means that the maximum risk-weighted asset, ξ^q, should satisfy

$$\frac{E}{\xi^q} = \frac{E}{w_1 \times \text{senior loans} + w_2 \times \text{subordinated loans} + w_3 \times \text{asset securitization products}} = \zeta^q.$$

Notice that there is no such term as "$w_3 \times$asset securitization products" in the Securitized model. By assuming, reasonably, that not all the bank's loans are subordinated loans, we obviously have

$$\xi^q < w_2 A.$$

Intuitively, if there is a CAR constraint, the bank cannot infinitely issue asset securitization products, and its maximum issuance times n should be limited so that it cannot grows to infinity. To simplify the expression, define

$$\widetilde{w}^q = \frac{\xi^q}{A}. \tag{27}$$

We first analyze the cases of risk-weighted asset of the bank in the Basic and the Cross-holding models without considering the CAR constraint, respectively.

According to the Basic model, as shown in Table 1, a bank's asset side consists of αA in senior loans and $(\beta+\gamma)A$ in subordinated loans when it only engages in basic business. Here, α represents the proportion of senior loans, and $(\beta+\gamma)$ represents the proportion of subprime loans. Therefore, the bank's risk-weighted assets amount is represented by $\left[w_1\alpha + w_2(\beta+\gamma)\right]A$, which proportionally weighs the different types of assets based on their respective risks. Thus, we define $w_1\alpha + w_2(\beta+\gamma)$ as the "asset risk multiplier" in the Basic model, denoted by κ^b. This multiplier can, to some extent, be used as an indicator of the level of risk on a bank's asset side.

Similarly, according to the Cross-holding model, when a bank's issuance and cross-holding of securitization products are unrestricted, as shown in Table 2, its asset side eventually consists of $\frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A$ of products purchased from other banks and $\frac{\gamma}{\theta+\gamma-\theta\gamma}A$ of subprime loans held in the balance sheet due to risk retention requirements. Accordingly, the amount of the bank's risk-weighted assets is represented by $\frac{w_2\gamma+w_3\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A$, and the asset risk multiplier of the bank is denoted as κ^c, which is equal to $\frac{w_2\gamma+w_3\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}$.

Table 3
Balance sheet of the bank which is subject to CAR in the Securitized model. This table presents the bank's balance sheet with a CAR constraint in the Securitized model after the issuance of n^s times.

Asset A		Liability and Equity $(L+E)$
Senior loans	$\alpha(1-\gamma)^{n^s}A$	Deposit D
Subprime loans	$(\beta+\gamma)(1-\gamma)^{n^s}A$	Equity E
Subprime loans(Risk retention)	$\left[1-(1-\gamma)^{n^s}\right]A$	

Subsequently, we consider the scenario in which the Securitized model is subject to CAR constraint. After the issuance of n^s times at Time 0, the bank's balance sheet resembles Table 3.

In the process of issuing asset securitization products, the bank must satisfy the CAR constraint

$$w_1\alpha A\phi^s + w_2(\beta+\gamma)A\phi^s + w_2(1-\phi^s)A \le \widetilde{w}^q A < w_2 A,$$

where $\phi^s = (1-\gamma)^{n^s}$. We must then have

$$n^s \le [\ln(1-\gamma)]^{-1}\ln\left[\frac{\widetilde{w}^q - w_2}{\alpha\left(w_1-w_2\right)}\right]. \tag{28}$$

Without confusion, we also denote the largest times of asset securitization issuance in the Securitized model under the CAR constraint as n^s, for simplicity. According to (8), we can calculate $\widehat{B^s}$, the credit scale in the Securitized model with the CAR constraint, as

$$\widehat{B^s} \le \sum_{n=0}^{n^s}(1-\gamma)^n A = \frac{A(1-\phi^s)}{\gamma} < B^s;$$

recalling (9), we can also calculate $E(\widehat{\pi^s})$, the expected profit in the Securitized model with the CAR constraint, as

$$E(\widehat{\pi^s}) \le \frac{FA(1-\phi^s)}{\gamma} - \frac{r_d(1-\gamma)A(1-\phi^s)}{\gamma} - r_c D < E(\pi^s). \tag{29}$$

The above analysis claims that the CAR regulatory restriction in the Securitized model is a valid constraint that can reduce credit expansion, which also affects profit. We now consider the case of the Cross-holding model. We assume that the same CAR restriction set in the Securitized model applies to the Cross-holding model. After the issuance of n^c times at Time 0, the bank's balance sheet resembles Table 4.

Denote $[(1-\theta)(1-\gamma)]^{n^c}$ as ϕ^c. Thus, the risk-weighted asset, ξ^c, is

$$\begin{aligned}
\xi^c &= w_1\alpha A\phi^c + w_2(\beta+\gamma)A\phi^c + w_3\frac{1-\phi^c}{\theta+\gamma-\theta\gamma}\theta(1-\gamma)A \\
&\quad + w_2\frac{1-\phi^c}{\theta+\gamma-\theta\gamma}\gamma A \\
&= \left[w_1\alpha + w_2(\beta+\gamma) - \frac{w_2\gamma + w_3\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}\right]A\phi^c \\
&\quad + \frac{w_2\gamma + w_3\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A \\
&= \left(\kappa^b-\kappa^c\right)A\phi^c + \kappa^c A.
\end{aligned}$$

Define

$$K_1 = \left(\kappa^b-\kappa^c\right)A \text{ and } K_2 = (\widetilde{w}^q-\kappa^c)A$$

for convenience of expression. Thus, if

$$K_1\phi^c \le K_2, \tag{30}$$

we have $\xi^c \le \xi^q$ (recall $\xi^q = \widetilde{w}^q A$), i.e., the CAR constraint is satisfied.

If $\theta \to 1$ ($\rho \to 0$), we have

$$K_1 \to \left[(w_1-w_3)\alpha + (w_2-w_3)\beta\right]A \text{ and } K_2 \to \left[\widetilde{w}^q - w_2\gamma - w_3(\alpha+\beta)\right]A.$$

Thus, clearly, both K_1 and K_2 can be non-negative or non-positive, depending on some specific parameters. Notice that when $K_1 > 0$, $K_2 = 0$ or, for $K_1 \ge 0$, $K_2 < 0$; then the CAR constraint is not satisfied, which is excluded from the analysis.

Suppose $K_2 > 0$. If $K_1 \le 0$, then the CAR constraint is always satisfied, irrespective of the value of n^c. That is, the CAR constraint is invalid. Otherwise, if $K_1 > 0$, by (30), we have that

$$n^c \ge \{\ln[(1-\theta)(1-\gamma)]\}^{-1}\ln\frac{K_2}{K_1}.$$

Thus, we can claim that for the case $K_2 > 0$, the CAR constraint becomes invalid in the sense that the times of securitization issuance, n^c, can go to infinity. For the case of $K_2 = 0$, if $K_1 \le 0$, then the CAR constraint is always satisfied for any n^c, which means that the CAR constraint is invalid. Consider the case of $K_2 < 0$. If $K_1 < 0$ and the constraint is satisfied, we have $\phi^c \ge \frac{K_2}{K_1}$. Noting that $\phi^c < 1$, there is a positive upper limit to n^c such that

$$n^c \le \{\ln[(1-\theta)(1-\gamma)]\}^{-1}\ln\frac{K_2}{K_1},$$

which indicates that the CAR constraint is valid. Table 5 illustrates the relationships described above. The shaded parts mean that in those cases, n^c can still approach infinity even if there is a CAR constraint, which equates to the CAR constraint being invalid. The non-shaded parts correspond to two different cases, one indicating that the CAR constraint is not satisfied, and one implying that there exists an upper bound for n^c so the CAR constraint is valid.

Hence, for the Cross-holding model with the CAR regulatory restriction, under the condition that $K_2 > 0$ or $K_2 = 0$ and $K_1 \le 0$, the bank can still securitize indefinitely, as the CAR constraint is invalid. In other words, n^c could approach infinity, because the bank purchases securitized products issued by others with lower risk weight $\left(w_3\right)$ than subprime loans' $\left(w_2\right)$, which drives the bank to continue securitizing.

Proposition 5. *If $K_2 > 0$, or $K_2 = 0$ and $K_1 \le 0$, then the CAR constraint is invalid for the Cross-holding model.*

Furthermore, the values of K_1 and K_2 have important economic implications. $K_1 > 0$ implies that the asset risk multiplier κ^b in the Basic model is greater than the asset risk multiplier κ^c in the unconstrained Cross-holding model. In other words, banks are mitigating their asset risk through cross-holding behavior. Conversely, when $K_1 < 0$, banks are increasing their asset risk via cross-holding behavior. As shown in Table 5, the CAR regulation is always invalid when $K_2 > 0$. Recall that $K_2 > 0$ is equivalent to $\widetilde{w}^q > \kappa^c$. In fact, recalling (27), $\widetilde{w}^q$ represents the upper limit of the asset risk multiplier imposed by regulation. Hence, $K_2 > 0$ implies that the regulation is relatively lenient, as the upper limit of the asset risk multiplier is higher than the multiplier generated by banks operating in the unconstrained Cross-holding model. Consequently, the CAR constraint is invalid. This also implies that, $\widetilde{w}^q < \kappa^c$ is the only valid CAR constraint for the Cross-holding model. Therefore, the relationship among K_1, K_2 and 0 indicates whether banks are mitigating or increasing asset risk through cross-holding behavior, and whether the CAR constraint is valid.

When the conditions in Propositions 5 are satisfied, the CAR regulation is invalid, which will affect the bank's credit creation and expected profit. Specifically, both the credit, $\widehat{B^c}$, and the profit, $E(\widehat{\pi^c})$, of the Cross-holding model with the CAR regulatory restriction are the same as those without such a constraint, that is, $\widehat{B^c} = B^c$ and $E(\widehat{\pi^c}) = E(\pi^c)$.

Suppose the CAR constraint is invalid for the Cross-holding model. By (12), if

$$\frac{A}{\gamma}(1-\phi^s) < \frac{A}{\theta+\gamma-\theta\gamma}, \tag{31}$$

we then have $\widehat{B^s} \le \frac{A}{\gamma}(1-\phi^s) < \widehat{B^c} = B^c$. By a simple calculation, we have that (31) is equivalent to

$$n^s < [\ln(1-\gamma)]^{-1}\ln\left(\frac{\theta-\theta\gamma}{\theta+\gamma-\theta\gamma}\right). \tag{32}$$

Noting (28), we have that

$$\frac{\widetilde{w}^q - w_2}{\alpha\left(w_1-w_2\right)} > \frac{\theta-\theta\gamma}{\theta+\gamma-\theta\gamma} \tag{33}$$

Table 4

Balance sheet of the bank which is subject to CAR in the Cross-holding model. This table presents the bank's balance sheet with a CAR constraint in the Cross-holding model after the issuance of n^c times.

Asset A		Liability and Equity $(L+E)$
Senior loans	$\alpha\left[(1-\theta)(1-\gamma)\right]^{n^c} A$	Deposit D
Subprime loans	$(\beta+\gamma)\left[(1-\theta)(1-\gamma)\right]^{n^c} A$	Equity E
Products from other banks	$\frac{1-\left[(1-\theta)(1-\gamma)\right]^{n^c}}{\theta+\gamma-\theta\gamma}\theta(1-\gamma)A$	
Subprime loans(Risk retention)	$\frac{1-\left[(1-\theta)(1-\gamma)\right]^{n^c}}{\theta+\gamma-\theta\gamma}\gamma A$	

Table 5

Brief summary of the cases corresponding to K_1 and K_2. This table presents the corresponding n^c and whether the CAR constraint can be satisfied for different cases in the Cross-holding model.

	$K_1<0$	$K_1=0$	$K_1>0$
$K_2>0$	For any n^c, CAR constraint is always satisfied (invalid).	For any n^c, CAR constraint is always satisfied (invalid).	$n^c \geq \{\ln\left[(1-\theta)(1-\gamma)\right]\}^{-1}\ln\frac{K_2}{K_1}$
$K_2=0$	For any n^c, CAR constraint is always satisfied (invalid).	For any n^c, CAR constraint is always satisfied (invalid).	CAR constraint is not satisfied.
$K_2<0$	$n^c \leq \{\ln\left[(1-\theta)(1-\gamma)\right]\}^{-1}\ln\frac{K_2}{K_1}$	CAR constraint is not satisfied.	CAR constraint is not satisfied.

is a sufficient condition for $\widehat{B^s} < \widehat{B^c} = B^c$.

Rewrite (33) as $\frac{\theta+\gamma-\theta\gamma}{\alpha\theta(1-\gamma)} > \frac{w_2-w_1}{w_2-\widetilde{w}^q}$ and denote the left hand side (LHS) as $g(\theta,\alpha)$. The partial derivatives of $g(\theta,\alpha)$ with respect to θ and α are given by

$$\frac{\partial g(\theta,\alpha)}{\partial\theta} = \frac{-\gamma}{\alpha(1-\gamma)\theta^2} < 0, \tag{34}$$

$$\frac{\partial g(\theta,\alpha)}{\partial\alpha} = \frac{\theta+\gamma-\theta\gamma}{\alpha^2\theta(\gamma-1)} < 0, \tag{35}$$

respectively. It is obvious that as θ increases, the condition in (33) becomes more difficult to achieve. That is, the cross-holding behavior weakens the credit creation function of the Cross-holding model, which we discussed in Section 2.2.1. According to (35), $\frac{\partial g(\theta,\alpha)}{\partial\alpha}$ is negative, so that the condition in (33) becomes easier to achieve as α decreases. Intuitively, when α decreases, i.e., the share of high-quality assets becomes smaller, the CAR constraint of the Securitized model becomes relatively stronger; thus, its credit creation is reduced, which results in easier achievement of the condition in (33).

By (17) and (29), if

$$\frac{FA(1-\phi^s)}{\gamma} - \frac{r_d(1-\gamma)A(1-\phi^s)}{\gamma} - r_cD \leq \frac{A}{\theta+\gamma-\theta\gamma}\left[F - r_d(1-\theta)(1-\gamma)\right] - r_cD, \tag{36}$$

we have $E(\widehat{\pi^s}) < E(\widehat{\pi^c}) = E(\pi^c)$.

Simplifying the formula, Condition (36) can be reformulated as

$$\phi^s\left[F-(1-\gamma)r_d\right] > \frac{\theta-\theta\gamma}{\theta+\gamma-\theta\gamma}\left(F-r_d\right),$$

which is equivalent to

$$n^s < \left[\ln(1-\gamma)\right]^{-1}\left\{\ln\left(\frac{\theta-\theta\gamma}{\theta+\gamma-\theta\gamma}\right) + \ln\left[\frac{F-r_d}{F-r_d(1-\gamma)}\right]\right\} \tag{37}$$

under the condition that $F > r_d$. Noting (28), we have that

$$\frac{\widetilde{w}^q - w_2}{\alpha\left(w_1-w_2\right)} > \left(\frac{\theta-\theta\gamma}{\theta+\gamma-\theta\gamma}\right)\left[\frac{F-r_d}{F-r_d(1-\gamma)}\right] \text{ and } F > r_d \tag{38}$$

is a sufficient condition for $E(\widehat{\pi^s}) < E(\widehat{\pi^c}) = E(\pi^c)$. The analysis of (38) is similar to that of (33).

We can now summarize these findings in the following proposition.

Proposition 6. *Given an invalid CAR constraint for the Cross-holding model, which is valid in the Securitized model, $\widehat{B^s} < \widehat{B^c}$ holds under Condition (33) and $E(\widehat{\pi^s}) < E(\widehat{\pi^c})$ holds under Condition (38).*

Proposition 6 essentially suggests that holding asset securitization products issued by other banks may be a natural demand by banks due to the pursuit of credit creation and profitability under CAR supervision. Recall Propositions 2 and 4: the bank in the Cross-holding model, i.e., the most realistic model, can gain additional profit and create a greater scale of credit, especially during an economic boom. Thus, cross-holding behavior is a natural choice in a bank's operation, which can essentially drive up a bank's leverage, and thus may finally result in the accumulation of potential systemic risk.

We next provide a numerical example to verify the theoretical results in this subsection.

Example 1. We consider two banks that are from the Securitized and the Cross-holding models, respectively. Initially, both of their assets are $A = 10$, and they are faced with the same CAR constraint. Table 6 presents the basic parameters that we set and some key values that we calculated.

Noting that K_2 is positive, and according to Proposition 6, the CAR constraint of the Cross-holding model should be invalid. Recalling (12), (17), and Table 6, we obtain $B^c = 19.608$ and $E(\pi^c) = 1.623$, which are the same as $\widehat{B^c}$ and $E(\widehat{\pi^c})$ in this table, respectively. Meanwhile, $\xi_c < \xi_q$, the CAR constraint of the Cross-holding model, is satisfied. Hence, the CAR constraint of the Cross-holding model is certainly invalid in this case.

Recalling (3), we have $F = 0.165 > r_d = 0.150$. The LHSs of (33) and (38) are higher than their respective RHSs. That is, both Conditions (33) and (38) are satisfied. Considering Proposition 6, $\widehat{B^s} < \widehat{B^c}$ and $E(\widehat{\pi^s}) < E(\widehat{\pi^c})$ should hold. As can be seen from the table, $\widehat{B^s} = 10.000 < \widehat{B^c} = 19.608$ and $E(\widehat{\pi^s}) = 0.614 < E(\widehat{\pi^c}) = 1.623$. In other words, for the Securitized model with the CAR constraint, its upper bound of times of securitization is 1.404. It cannot reach 2.488, let alone 6.313, which is a critical value for $\widehat{B^s} = \widehat{B^c}$ or $E(\widehat{\pi^s}) = E(\widehat{\pi^c})$. This further demonstrates the implications of Proposition 6.

We also provide Fig. 8 to visualize the illustration above. In this case, since both Conditions (33) and (38) are always achieved, we always have $\widehat{B^c} > \widehat{B^s}$ and $E(\widehat{\pi^c}) > E(\widehat{\pi^s})$ (recall Proposition 6). Besides, the value of the horizontal coordinate of point I is the value of p_b^d (recall (25)). Hence, when p_b is higher than the value of p_b^d, we have $E(\pi^s) < E(\pi^c) = E(\widehat{\pi^c})$. Otherwise, $E(\pi^s) \geq E(\pi^c)$.

Previous literature has suggested that asset securitization products help banks turn assets into capital and circumvent capital adequacy regulations. Since the GFC, regulators and Basel III have focused on this

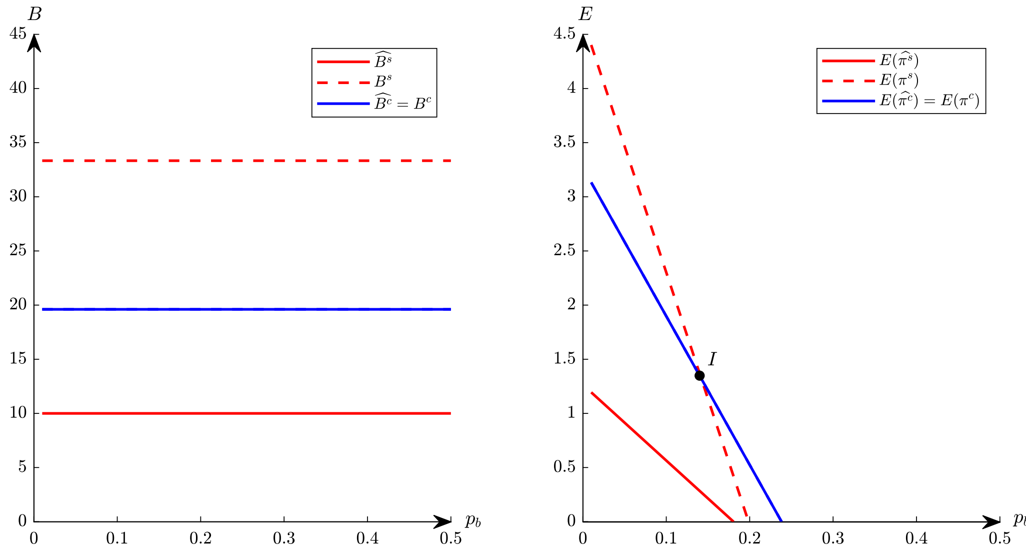

Fig. 8. Credit supplies and expected profits with/without CAR constraint. The parameters of this figure are the same as those in Example 1, with the exception of p_b, which is considered an independent variable. As shown in the figure, solid lines represent the actual value of B (or E) under the CAR constraint, while dashed lines reflect the values that B (or E) can reach without the CAR constraint. Point I is the intersection of the blue solid line and the red dashed line defined by $E(\widehat{\pi^c})(= E(\pi^c))$ and $E(\widehat{\pi^s})$, respectively.

Table 6
Parameters in the illustration example on the invalid CAR constraint. This table shows parameters and key values in our example. RHS in the table refers to value setting for the right hand side of the corresponding equation/inequation in the paper. LHS in the table refers to value setting for the left hand side of the corresponding equation/inequation in the paper.

Parameter Setting				Key Values			
α	0.500	r_b	0.400	K_1	−2.279	K_2	0.971
β	0.200	p_b	0.120	ξ_q	12.500	ξ_c	11.529
γ	0.300	r_c	0.020	LHS of (33)	0.606	RHS of (33)	0.412
μ	0.900	r_d	0.150	LHS of (38)	0.606	RHS of (38)	0.105
θ	0.300	w_1	0.100	$\widehat{B^s}$	10.000	$\widehat{B^c}$	19.608
ρ	0.700	w_2	1.750	$E(\widehat{\pi^s})$	0.614	$E(\widehat{\pi^c})$	1.623
r_a	0.100	w_3	0.300	RHS of (28)	1.404	RHS of (32)	2.488
p_a	0.001	ζ_q	0.080	RHS of (37)	6.313	F	0.165

business. Nevertheless, according to our analysis, purchasing securitization products issued by other banks also allows banks to circumvent capital adequacy regulation. Through cross-holding, banks can enhance their capacity for credit creation and further expand their credit scale without being constrained by CAR; and the credit expansion without restrictions is likely to result in a gradual accumulation of systemic risk. Consequently, our analysis indicates that it is crucial to regulate cross-holding behaviors between banks in relation to their products.

To summarize, the issuance and the cross-holding behavior of asset securitization products do not only facilitate banks' flexibility and profitability, but also affect their individual risks and the risk of the banking system. Hence, it is necessary to examine the level of systemic risk when faced with a severe shock, which is the highlight of the discussion in the next section.

4. Nonmonotonic impact of asset securitization on systemic risk

In this section, we further discuss the impact of asset securitization products on the systemic risk of the banking system by introducing a severe shock to the system. Without loss of generality, we consider a banking system that comprises three representative banks: Bank 1, Bank 2, and Bank 3. Denote the equity of Bank 1 as E_1. Similarly, E_2 and E_3 denote the equities of the other banks. The relationship among them is as follows:

$$E_2 = \lambda_2 E_1 \text{ and } E_3 = \lambda_3 E_1, \tag{39}$$

where λ_2 and λ_3 represent the size of Bank i relative to Bank 1.

As mentioned earlier, to observe a property of the banking system under a situation of distress, it is necessary to introduce some severe shock into our models. We therefore suppose that the banking system is subject to an external shock that leads to default on all loans issued by one of the banks. Furthermore, according to the definition of systemic risk, we calculate the capital loss rate, υ, defined as the capital loss divided by the total initial capital.

This intuitive and concise setting stems from several considerations. First, capital is crucial for the financial system. The surplus or shortfall of capital can be a measure of the state of the financial system. The capital shortfall experienced by a financial institution generates negative externalities to the entire economy (Acharya et al., 2010), which in turn may lead to systemic risk. Therefore, it is reasonable to regard the capital loss rate as an indicator of systemic risk, and a higher capital loss rate means higher systemic risk. Second, this setting helps reduce the gap between the theoretical model and the empirical test. In our empirical tests, we use SRISK (Brownlees and Engle, 2017), defined as the expected capital shortfall of a financial entity conditional on a prolonged market decline, to measure systemic risk. Echoing SRISK, in the theoretical analysis, our systemic risk measure is defined as the realized capital loss rate of a financial system conditional on a large shock. Besides, there is a similar setup in Leventides et al. (2019). They measure the extent of contagion by the total capital loss in the banking system.

By comparing the capital loss rates of the banking system under the different models, we theoretically investigate the impact of the issuance and cross-holding of asset securitization products on the systemic risk.

4.1. Capital loss rates in the basic and securitized models

Suppose that there are no differences in the leverage, μ, of the banks, and that they are all in the same position in terms of having completed the business process but not yet having reached settlement. We describe the pre-shock state of Bank 1's balance sheet in the Basic model. The assets of Bank 1, A_1, comprise αA_1 senior loans and $(\beta+\gamma)A_1$ subordinated loans. The liabilities and equity are D_1 (deposits) and E_1 (own capital), respectively. The same procedure is used to obtain the states of Banks 2 and 3. Notice that the respective equities are E_2 and E_3, which are equal to $\lambda_2 E_1$ and $\lambda_3 E_1$.

Suppose that the shock happens to Bank 1. Considering the limited liability in clearing, the upper bound for Bank 1's capital loss is its own capital, E_1. Under this shock, all of Bank 1's assets are lost. Bank 1 therefore becomes insolvent and loses all of its capital, E_1, while Banks 2 and 3 are not affected in any way. Thus, the capital loss rate, v^b, of the banking system is given by

$$v^b = \frac{E_1}{E_1+E_2+E_3} = \frac{E_1}{(1+\lambda_2+\lambda_3)E_1} = \frac{1}{1+\lambda_2+\lambda_3}. \tag{40}$$

We then describe the pre-shock state of Bank 1's balance sheet in the Securitized model. All of Bank 1's assets comprise subordinated loans that equal A_1. The liabilities and equity are D_1 (deposits) and E_1 (own capital), respectively. The same procedure is used to obtain the state of Bank 2's balance sheet. Given the aforementioned shock, Bank 1 loses its capital, while the shock has no effect on Banks 2 and 3, since there is no business connection between them. The capital loss rate, v^s, for the banking system is given by

$$v^s = \frac{E_1}{E_1+E_2+E_3} = \frac{E_1}{(1+\lambda_2+\lambda_3)E_1} = \frac{1}{1+\lambda_2+\lambda_3}. \tag{41}$$

Recalling (40) and (41), the following proposition is suggested:

Proposition 7. *Suppose the banking system is subject to an external shock that leads to default on all loans issued by Bank 1. For the Basic and the Securitized models, the capital loss rates of the system, v^b and v^s, are $\frac{1}{1+\lambda_2+\lambda_3}$, a monotonically decreasing function of $(\lambda_2+\lambda_3)$.*

Proposition 7 implies that the lower λ_2 is, the higher the capital loss rate. That is, when the shock happens to a larger bank, the capital loss rate will be higher. Proposition 7 also claims that the Basic and the Securitized models have the same capital loss rates. The reason is that there is no connection among banks. Thus, the impact on Bank 1 cannot transmit to the other banks through the balance sheet channel. We note that having the same capital loss rates does not imply that the two models have the same impact on the economy. Recalling the credit creation scales in the Basic and the Securitized models ((1) and (8)), the number of defaults in the former is $\frac{E_1}{1-\mu}$, while that in the latter is $\frac{E_1}{\gamma(1-\mu)}$. Depending on the model used, the spillover effects of the same default event on the economy differ. It is worth mentioning that when calculating v^b and v^s, it is not necessary to use the parameters related to securitization, i.e., θ and γ. Obviously, the result of Proposition 7 can be extended to a general banking system with more than three banks.

4.2. Capital loss rate in the cross-holding model

We have learned that the capital loss rates in the Basic and the Securitized models are at the same level that depends only on the parameters, λ_2 and λ_3. Naturally, in the Cross-holding model, we analyze the capital loss rate of the banking system comprising three representative banks and explore whether it is influenced by parameters such as γ or θ that are related to asset securitization. Table 7 describes the state of Bank 1's pre-shock balance sheet in the Cross-holding model.

Table 7
Balance sheet of Bank 1 in the Cross-holding model. Recalling (14) and (15), this table shows the balance sheet of Bank 1 in the Cross-holding model.

Asset A_1		Liability and Equity (L_1+E_1)
Products from other banks	$\frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_1$	Deposit D_1
Subprime loans(Risk retention)	$\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1$	Equity E_1

The characteristics of Bank 2 are similar to Bank 1's, while Bank 2's equity is E_2, which is equal to $\lambda_2 E_1$. For simplicity, without loss of generality, the parameters, α, β, γ, θ, and μ, are set the same for these two representative banks. It is noteworthy that in the Cross-holding model, Bank 3 is only used to make up the balance of asset securitization products and to ensure that Banks 1 and 2 can purchase the asset securitization products they need from the banking market; there is no other relationship between Bank 3 and the other banks.

Since the shock is imposed on Bank 1, we pay attention to two characteristics related to the cross-holding: One is $B_1^{c,o}$, the total volume of asset securitization products offered by Bank 1. According to (13), we have $B_1^{c,o} = \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1$. The other is $B_2^{c,p}$, the total volume of asset securitization products purchased by Bank 2. Recalling (15), we have $B_2^{c,p} = \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2$. Comparing $B_1^{c,o}$ with $B_2^{c,p}$, we can divide the problem into two cases and discuss them separately.

In the one case, $B_1^{c,o} \le B_2^{c,p}$, following the shock that results in all the loans issued by Bank 1 going into default, all the securitizations issued by Bank 1 and purchased by Bank 2 are also in default. On the asset side of Bank 1, the products from the other banks are not influenced while the retention loans are in default. Considering the limited liability in liquidation, the upper bound for Bank 1's capital loss is its own capital, E_1. Hence, Bank 1's capital loss is $\min\left\{E_1, \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1\right\}$. On Bank 2's asset side, all the products offered by Bank 1 are in default. Similarly, Bank 2's capital loss is $\min\left\{E_2, \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1\right\}$. Combining this with (39), the capital loss rate of the banking system, v^{c_1}, is shown in (42).

$$v^{c_1} = \begin{cases} \frac{1}{(1-\mu)(1+\lambda_2+\lambda_3)(\theta+\gamma-\theta\gamma)}, & E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1 \\ \frac{\gamma}{(1-\mu)(1+\lambda_2+\lambda_3)(\theta+\gamma-\theta\gamma)} + \frac{\lambda_2}{1+\lambda_2+\lambda_3}, & E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 \le \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1 \\ \frac{1-\gamma}{(1-\mu)(1+\lambda_2+\lambda_3)(\theta+\gamma-\theta\gamma)} + \frac{1}{1+\lambda_2+\lambda_3}, & E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1 \\ \frac{1+\lambda_2}{1+\lambda_2+\lambda_3}, & E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 \le \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1 \end{cases} \tag{42}$$

In the other case, $B_1^{c,o} > B_2^{c,p}$, following the shock in which all the loans issued by Bank 1 go into default, all the others' products on Bank 2's records will also be in default. Similarly, Bank 1's capital loss is $\min\left\{E_1, \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1\right\}$. On Bank 2's asset side, all the products it purchased are in default. Thus, Bank 2's capital loss is $\min\left\{E_2, \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2\right\}$. The capital loss rate, v^{c_2}, for the banking system is shown in (43).

$$v^{c_2} = \begin{cases} \frac{\gamma+\lambda_2\theta(1-\gamma)}{(1-\mu)(1+\lambda_2+\lambda_3)(\theta+\gamma-\theta\gamma)}, & E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2 \\ \frac{\gamma}{(1-\mu)(1+\lambda_2+\lambda_3)(\theta+\gamma-\theta\gamma)} + \frac{\lambda_2}{1+\lambda_2+\lambda_3}, & E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 \le \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2 \\ \frac{\lambda_2\theta(1-\gamma)}{(1-\mu)(1+\lambda_2+\lambda_3)(\theta+\gamma-\theta\gamma)} + \frac{1}{1+\lambda_2+\lambda_3}, & E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2 \\ \frac{1+\lambda_2}{1+\lambda_2+\lambda_3}, & E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 \le \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2 \end{cases} \tag{43}$$

v^c, the capital loss rate in the Cross-holding model, comprises v^{c_1} and v^{c_2}. According to (42) and (43), we have the following propositions, which are proven in the appendices. We first consider the relationship between υ^c and υ^b.

Proposition 8. *υ^c may be higher or lower than υ^b, depending on the parameters, θ, γ, μ, and λ_2.*

Proposition 8 says that when subjected to shocks, the banking system with cross-holding behavior could suffer a greater capital loss rate than other systems. The reason is that the issuance and cross-holding of credit securitization products enhance the correlation among banks through the channel of asset overlap. By holding products issued by the other banks, the bank is essentially holding the same loan assets as they do. The risks and shocks that an individual bank faces are transmitted to other banks in the cross-holding network through the credit securitization products they issue, and risk contagion occurs. Meanwhile, Proposition 8 also claims that the banking system in the Cross-holding model may suffer from a lower capital loss rate than the other models in the presence of shocks. Therefore, asset securitization may increase or reduce systemic risk with cross-holding behavior.

To explore the impact of μ on υ^c, we have Proposition 9.

Proposition 9. *In the Cross-holding model, $\frac{\partial \upsilon^{c1}}{\partial \mu} > 0$ and $\frac{\partial \upsilon^{c2}}{\partial \mu} > 0$ always hold.*

Proposition 9 says that the higher the banking system's leverage, the higher the capital loss rate. Combining Propositions 1 and 9, it is obvious that banks obtain additional profits by using asset securitization products, which reinforces banks' incentive to raise their leverages. As their leverage rises, the banking system's capital loss rate increases when a severe shock occurs. That is, the effect of asset securitization of increasing banks' leverage raises the banking system's systemic risk.

In contrast to the Basic and the Securitized models, the leverage, μ, can raise the capital loss rate in the Cross-holding model. It is natural to discuss whether other parameters could also influence the capital loss rate, υ_c. To some extent, the risk retention degree, γ, and the cross-holding degree, θ, may be regarded as related parameters describing the issuing and trading process of asset securitization. Thus, we discuss the impact of these parameters. Recalling (42) and (43), we have Proposition 10.

Proposition 10. *In the Cross-holding model, the impacts of both γ and θ on υ^c are nonmonotonic.*

For the impact of γ on the capital loss rate, υ^c, Proposition 10 says that, under certain conditions, the higher the degree of risk retention, the lower the banking system's capital loss rate when shocks occur. Under other specific conditions, the opposite conclusion holds. In the former case, the number of asset securitization products increases and other banks purchase a large proportion of the asset securitization products due to cross-holding behavior. In the latter case, although the number of securitization products issued increases, other banks do not purchase many of them due to some limitations, such as their small-scale assets.

Regarding the impact of θ on the capital loss rate, υ^c, Proposition 10 suggests the same nonmonotonic mode as that for γ. When the part of the banking system that shocks occur, λ_2, and the leverage of the banking system, μ, change, one of an intermediate, a higher, and a lower degree of cross-holding, θ, could lead to the higher systemic risk. A possible explanation is that, although cross-holding behavior enhances inter-bank correlation, which may contribute to risk contagion, it also limits the extent of credit expansion and helps banks replenish their capital.

Up to now, we have analyzed the impact of γ and θ on the capital loss rate, υ^c. Both are key parameters that describe the securitization process. Recalling Proposition 7, we can rigorously conclude that it is the cross-holding behavior that creates the nonmonotonic relationship between asset securitization products and the capital loss rate. For completeness, we further briefly analyze the impact of λ_2 on υ^c. Based on the partial derivatives with respect to λ_2 (recall (42) and (43)), we have Proposition 11.

Proposition 11. *In the Cross-holding model, the impact of λ_2 on υ^c is nonmonotonic.*

Proposition 11 states that, in contrast to the situation in the Basic and the Securitized models, the impact of λ_2 on the systemic risk is nonmonotonic in this model. On the one hand, under certain conditions, the higher the λ_2, the lower the rate of capital losses in the banking system when shocks occur. This phenomenon usually occurs when a bank's equity is sufficient to cover its losses. In that case, the higher λ_2 indicates more capital in the banking system, and the capital loss rate declines accordingly. On the other hand, Proposition 11 also suggests that, under certain conditions, the higher the λ_2, the higher the capital loss rate, especially when the bank's equity is insufficient to cover losses and the cross-holding degree is at a high level. That is, increased capital is sometimes insufficient to stabilize a banking system, while the degree of cross-holding aggravates the instability.

Thus far, some exciting conclusions have been drawn from comparing these models. In Section 2, compared to the Basic model, the Securitized model demonstrates that asset securitization provides both credit creation and risk transfer capabilities. Additionally, asset securitization provides positive profits for banks when the economy appreciates, which enhances banks' leverage (recall Proposition 1). Combined with Proposition 9, it is fully demonstrated that asset securitization can drive up banks' leverage and further raise systemic risk. This is the indirect impact of asset securitization on risk.

We mainly focus on the Cross-holding model due to its authenticity. The cross-holding behavior increases the complexity of the impact of securitized products on systemic risk. On the one hand, a moderate level of cross-holding improves the stability of the banking system. We show, in Proposition 4, that banks in the Cross-holding model could obtain capital replenishment at the time of settlement of non-defaulted securitized credit assets. Meanwhile, the cross-holding behavior weakens banks' credit creation function, which may slow down the recovery of the underlying assets' prices and help to reduce the market risk caused by price bubbles in reality. On the other hand, the cross-holding behavior may also aggravate the systemic risk of the banking system. Proposition 6 suggests that cross-holdings may help banks evade capital adequacy regulation, which may raise systemic risk. This interesting finding helps explain the occurrence of the GFC and emphasizes the importance of regulating crossover operations among financial institutions.

Faced with severe shock, the capital loss rate in the Cross-holding model may be higher than that in the Basic or the Securitized model (recall Proposition 8). This is due to the fact that the cross-holding behavior enhances the inter-bank correlation, thus exposing the other individuals to the shock due to risk contagion. Moving a step further, in Proposition 10, we demonstrate that from the perspective of those parameters that directly described the real operation of asset securitization characterized by cross-holding, the impact of credit securitization on systemic risk is nonmonotonic.

5. Simulation analysis and empirical test

Now we have theoretically demonstrated the nonmonotonic relationship between asset securitization and systemic risk when cross-holding behavior is considered. In order to visually present and corroborate the previous theoretical results, and to explore their representation in reality, we conduct simulation analysis and empirical tests in this section. Our simulation results are consistent with the theoretical results. Our empirical results suggest that the aforementioned nonmonotonic relationship could present as a U-shaped state in real economy.

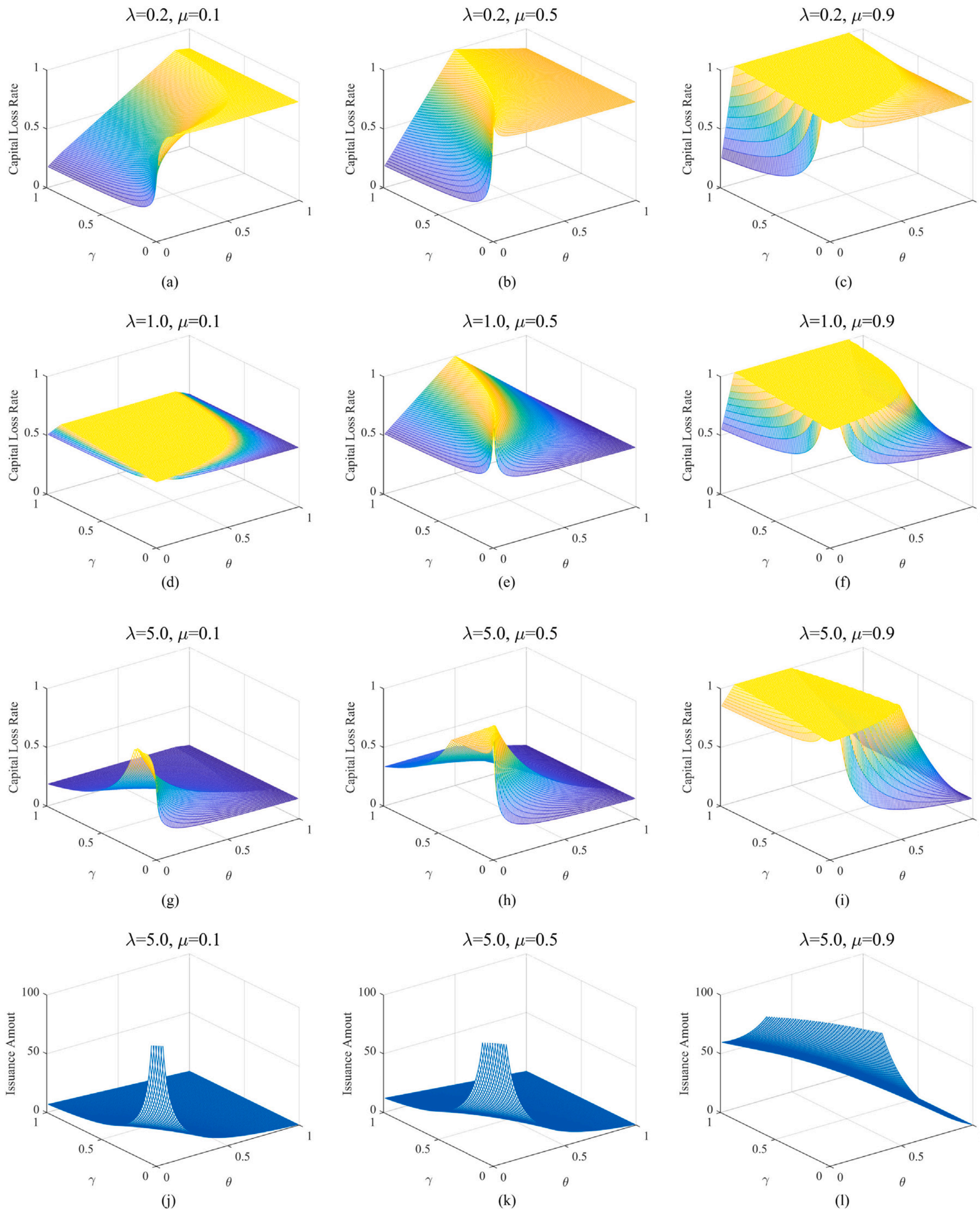

Fig. 9. Capital loss rates in different conditions. This figure shows a set of capital loss rates and the issuance amount of asset securitization products. Notably, the abscissa and ordinate ranges of all the panels are from 0.01 to 1. Specifically, Panels (a) to (i) respectively describe the capital loss rates under parameter conditions of $\lambda = 0.2$ and $\mu = 0.1$, $\lambda = 0.2$ and $\mu = 0.5$, and so on. We provide information on the parameters above each panel. We also provide the corresponding asset securitization issuance amounts. Panels (j) to (l) present the relationships between the asset securitization issuance amount, γ, and θ under the respective parameter conditions of $\lambda = 5.0$ and $\mu = 0.1$, $\lambda = 5.0$ and $\mu = 0.5$, and $\lambda = 5.0$ and $\mu = 0.9$, which correspond to Panels (g), (h), and (i), respectively. Considering that too high a critical value may mask some characteristics when the related value is low, we limit the upper bounds of Panels (g), (h), and (i). Panels (j), (k), and (l) show similar relationships between the issuance, γ, and θ; that is, as γ or θ increases, the issuance amount declines. We therefore omit the panels that correspond to Panels (a) to (f) to simply the figure.

Table 8
Descriptive statistics. This table reports the mean, standard deviation, minimum and maximum for the list of asset securitization products considered in the empirical experiments. Although we use standardized data in our regressions, we have provided the descriptive statistics of variables that have not been standardized to directly describe their descriptive statistics.

Variable	Obs	Mean	Std.Dev.	Min	Max
SRISK	1,539	72.451	85.345	0.000	565.361
LRMES	1,539	92.681	111.257	2.232	610.717
MBS	1,539	2.358	6.765	0.000	24.262
MBS2	1,539	51.294	148.476	0.000	588.630
ABS	1,539	3.377	7.609	0.000	24.585
ABS2	1,539	69.260	158.780	0.000	604.400
OTHER	1,539	14.064	10.697	0.000	28.860
OTHER2	1,539	312.132	248.759	0.000	832.872
SIZE	1,539	14.296	1.585	9.205	17.429
NPL	1,539	4.130	5.946	0.080	45.570
LEND	1,539	7.191	8.874	0.673	75.590
M1	1,539	8.825	8.727	−22.578	96.163
M2	1,539	8.018	7.977	−25.138	53.423
FINANCE	1,539	90.580	57.304	1.588	311.154
VOL	1,539	17.691	9.526	3.417	73.493
GDP	1,539	2.334	3.590	−10.940	28.780
FIXEDI	1,539	2.919	12.819	−67.703	260.525
EXCHANGE	1,539	99.445	14.691	49.800	161.256
DEFLATOR	1,539	3.485	5.991	−12.837	51.667
CREDIT	1,539	153.583	66.143	16.900	401.600

5.1. Simulation analysis

To elucidate the nonmonotonic relationship between asset securitization and systemic risk in the above section, we focus on the effects of γ and θ, which represent the bank's issuing and cross-holding behaviors on securitization. Fig. 9 presents an example of a numerical simulation. The simulation results confirm Proposition 10, i.e., that the relationship between asset securitization issuance and systemic risk is nonmonotonic. Other simulation results are also consistent with the theoretical conclusions of Section 4. Notably, according to our setting for Bank 3, when λ_3 is close to 0, it can still work. Therefore, to simplify and visualize our simulation, we let λ_3 equal to 0 in the calculation, which does not influence the shapes of the panels and the relative relations. Hence, the λ in Fig. 9 is equivalent to λ_2 in the above discussion.

Considering Panels (a), (d), and (g), which are at the same level of leverage in the pair of examples, we analyze the relationship between the capital loss rate, two parameters (recall γ and θ), and the issuance amount. In Panel (a), when γ and θ are high and lead to a low issuance amount, the loss rate is high. When the issuance amount increases slightly, for example, at the point where $\gamma = 0.99$ and $\theta = 0.01$, the issuance amount reaches a median level. In this case, the capital loss rate is almost the lowest. When the issuance amount reaches a high level, for example, at the point where $\gamma = 0.01$ and $\theta = 0.01$, the corresponding capital loss rate is almost the highest. Panel (a) means that there may exist a U-shaped relationship between the issuance amount and systemic risk. In Panel (d), a particular case in which banks' assets are at the same level, clearly, when at least one of γ and θ is close to 1, the capital loss rate is at a low level; and when the condition above is not satisfied, the capital loss rate rises rapidly. It is evident from Panel (d) that the issuance amount has a nonlinear relationship with the capital loss rate. However, Panel (g) shows that the capital loss rate and the issuance amount are essentially synchronous.

To summary, Fig. 9 provides a comprehensive illustration of the multiple relationships between asset securitization and systemic risk. When the directionality of changes in the γ and θ parameters is unknown, the relationship between asset securitization and systemic risk can be characterized as nonmonotonic.

Now we have illustrated the nonmonotonic relationship between asset securitization and systemic risk in the Cross-holding model through simulation and verified the associated propositions. A natural question is whether this non-monotonicity exists in reality. In the next subsection, we consider empirical tests of a quadratic model to examine the specific form of the relationship between asset securitization and systemic risk.

5.2. Empirical test

As we discussed earlier, asset securitization product issuance has a nonmonotonic impact on systemic risk. While the use of this securitization can reduce systemic risks by increasing liquidity and other channels, it can also lead to excessive credit expansion and increase systemic risks. Thus, we now investigate this special relationship based on relevant data from 27 countries and regions globally, spanning the past 15 years.

We need to clarify two key points in advance. The first one is about our data. Many empirical tests related to systemic risk are conducted at the bank level, choosing a set of banks and making analyses with the data obtained from banks' balance sheets or stock markets. The bank-level data provides a microscopic perspective on systemic risk. Systemic risk, however, does not exist independently in an individual financial entity but is closely linked to the overall financial system. Therefore, we employ the country/region level data rather than the bank-level data to describe systemic risk from a macro and essential perspective. The second one concerns the variables in our empirical tests. Our explained variable is SRISK/LRMES and our core explanatory variable is the issuance of asset securitization products. For the explained variable, the use of SRISK/LRMES corresponds to the capital loss rate, a measure of systemic risk defined in our theoretical analysis, and we have clarified the relationship between these two types of systemic risk indicators in Section 4. For the core explanatory variable, recalling (16) and our simulation, the issuance volume of asset securitization products is monotonous in the degree of risk retention and the degree of cross holding, two key factors related to banks' behaviors. Thus, the issuance volume of the asset securitization products can be used as a synthetical factor to conduct empirical tests on the relationship between systemic risk and securitization.

5.2.1. Data and empirical model

As we mentioned before, our core explanatory variable is the issuance of asset securitization products whose underlying assets are credit assets. We hence choose the MBS and ABS issuance data from the Bloomberg database. After excluded countries and regions with a low frequency of issuance, we obtained data on 27 countries and regions, as shown in Table C.1. The time interval is 2005Q4–2019Q4, while the data frequency is quarterly.

To measure systemic risk, we choose SRISK (Brownlees and Engle, 2012, 2017), which was originally defined as an individual institution's expected capital shortfall in a systemic crisis event. In detail, SRISK is defined as

$$SRISK_{it} = E_t(CS_{it}|Crisis),$$

where CS_{it} is the capital shortfall for Institution i at Time t, while a crisis event is defined as one in which the market yield falls below a certain critical value within a given time range. The value of $SRISK_{it}$ is related to $LRMES_{it}$, the long run marginal expected shortfall (Brownlees and Engle, 2012, 2017) for Institution i at Time t, which represents the expectation of multi-period institutional returns under systemic crisis conditions. We also use LRMES to measure systemic risk. Note that systemic risk in this study is measured at the country/region level, i.e., the original "institution" is replaced by a country or region.

Besides MBS, ABS and their quadratic terms, a set of control variables that may affect systemic risk are also considered. Considering that the size of the banking system significantly affects systemic risk (Laeven et al., 2016), we therefore regard the size of the banking system as a

Table 9
Time-series regression results on SRISK. This table reports the regressions of explanatory and control variables on SRISK. Specifically, we run regressions with stepwise introductions of explanatory variables. We firstly regress the core explanatory variables(recall MBS, ABS, other collateralized bonds and their squared terms) and control variables on SRISK, respectively. The first to sixth columns correspond to results of using MBS, ABS, other collateralized bonds, and their squared terms as core explanatory variables. Further, for comparison, we also regress the couple of core explanatory variables and control variables on SRISK, respectively. Columns (7) (8) (9) present results of the above regressions. Finally, we show our prime regression in the last column, i.e., the Column (10). ***, **, and * denote significant values at the levels of 1%, 5%, and 10%, respectively.

SRISK	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
MBS	0.2233***						−1.2799***			−1.2702***
MBS2		0.2646***					1.6209***			1.6003***
ABS			0.0571***					−0.5061*		0.1100
ABS2				0.0669***				0.5873*		−0.0908
OTHER					0.0539***				−0.3658**	−0.0944
OTHER2						0.0679***			0.4700**	0.1414
SIZE	0.7041***	0.7127***	0.5117***	0.5065***	0.5224***	0.5179***	0.6515***	0.4852***	0.4975***	0.6296***
NPL	0.0458***	0.0483***	0.0370***	0.0381***	0.0424***	0.0449***	0.0523***	0.0405***	0.0505***	0.0620***
LEND	−0.1159**	−0.1161**	−0.1046**	−0.1024**	−0.1290***	−0.1307***	−0.1169**	−0.0971**	−0.1287***	−0.1217***
M1	−0.0028	−0.0047	0.0019	0.0015	0.0016	0.0015	−0.0110	−0.0003	0.0018	−0.0111
M2	0.0321*	0.0333**	0.0278	0.0281	0.0261	0.0256	0.0350**	0.0272	0.0210	0.0354**
FINANCE	−0.2784***	−0.2810***	−0.2578***	−0.2588***	−0.2657***	−0.2658***	−0.2819***	−0.2672***	−0.2600***	−0.2823***
VOL	0.0312	0.0337	0.0269	0.0278	0.0234	0.0239	0.0401	0.0290	0.0251	0.0432
GDP	−0.0690***	−0.0667***	−0.0826***	−0.0818***	−0.0843***	−0.0838***	−0.0647***	−0.0784***	−0.0816***	−0.0636***
FIXEDI	0.0035	0.0035	0.0027	0.0028	0.0019	0.0018	0.0031	0.0042	0.0028	0.0017
EXCHANGE	−0.0538**	−0.0626***	0.0010	−0.0022	0.0059	0.0046	−0.0689***	−0.0174	0.0012	−0.0710***
DEFLATOR	−0.0329	−0.0330	−0.0388	−0.0398	−0.0285	−0.0277	−0.0331	−0.0408	−0.0261	−0.0324
CREDIT	0.2550**	0.2357**	0.3441***	0.3387***	0.3483***	0.3433***	0.1969**	0.3071***	0.3185***	0.1913*
C	−0.0842**	−0.0821**	−0.1012**	−0.1013**	−0.0988**	−0.0997**	−0.0823**	−0.1032**	−0.1082***	−0.0830**
N	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F	139.9309	144.3958	281.2502	252.1911	420.7428	378.1292	282.3350	237.5083	489.4890	508.9313
R^2	0.3230	0.3338	0.2842	0.2865	0.2812	0.2827	0.3606	0.2957	0.2873	0.3647

Table 10
Time-series regression results on LRMES. This table reports the regressions of explanatory and control variables on LRMES. Specifically, we run regressions with stepwise introductions of explanatory variables. We firstly regress the core explanatory variables(recall MBS, ABS, other collateralized bonds and their squared terms) and control variables on LRMES, respectively. The first to sixth columns correspond to results of using MBS, ABS, other collateralized bonds, and their squared terms as core explanatory variables. Further, for comparison, we also regress the couple of core explanatory variables and control variables on LRMES, respectively. Columns (7) (8) (9) present results of the above regressions. Finally, we show our prime regression in the last column, i.e., the Column (10). ***, **, and * denote significant values at the levels of 1%, 5%, and 10%, respectively.

LRMES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
MBS	0.0636***						−0.4225***			−0.3664***
MBS2		0.0765***					0.5242***			0.4532***
ABS			0.0264***					−0.2501***		−0.0997**
ABS2				0.0311***				0.2883***		0.1237**
OTHER					0.0017				−0.0775**	0.0235
OTHER2						0.0035			0.0887**	−0.0338
SIZE	0.3415***	0.3447***	0.2835***	0.2809***	0.2917***	0.2913***	0.3245***	0.2704***	0.2870***	0.3103***
NPL	−0.0040	−0.0033	−0.0056	−0.0051	−0.0078	−0.0074	−0.0020	−0.0039	−0.0062	−0.0022
LEND	−0.0195*	−0.0196*	−0.0144	−0.0133	−0.0198*	−0.0201*	−0.0198*	−0.0107	−0.0197*	−0.0130
M1	0.0020	0.0014	0.0032	0.0030	0.0035	0.0035	−0.0007	0.0021	0.0035	−0.0007
M2	0.0064	0.0068	0.0058	0.0060	0.0043	0.0043	0.0074	0.0055	0.0034	0.0081*
FINANCE	−0.0323	−0.0332	−0.0264	−0.0269	−0.0267	−0.0269	−0.0335*	−0.0311	−0.0257	−0.0338*
VOL	−0.0156	−0.0148	−0.0158	−0.0154	−0.0183*	−0.0183*	−0.0127	−0.0148	−0.0180*	−0.0116
GDP	−0.0225***	−0.0218***	−0.0259***	−0.0255***	−0.0271***	−0.0271***	−0.0211***	−0.0239***	−0.0266***	−0.0206***
FIXEDI	0.0066	0.0066	0.0062	0.0062	0.0066	0.0066	0.0065	0.0069	0.0068	0.0066
EXCHANGE	0.0342**	0.0314*	0.0482**	0.0466**	0.0524***	0.0522***	0.0293*	0.0392**	0.0515***	0.0267*
DEFLATOR	−0.0040	−0.0041	−0.0069	−0.0074	−0.0037	−0.0036	−0.0041	−0.0079	−0.0033	−0.0073
CREDIT	0.1158***	0.1098***	0.1394***	0.1369***	0.1438***	0.1434***	0.0970***	0.1212***	0.1382***	0.0956***
C	0.0017	0.0024	−0.0030	−0.0030	−0.0034	−0.0034	0.0023	−0.0039	−0.0052	0.0016
N	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F	29.1535	27.9332	47.4128	49.0263	41.4917	39.8215	40.6122	68.0656	49.2190	60.8523
R^2	0.4031	0.4121	0.3849	0.3897	0.3690	0.3691	0.4381	0.4095	0.3710	0.4492

control variable. As a channel connecting credit securitization products, individual bank risk, and systemic risk, bank loan quality has an impact on system risk. Therefore, the non-performing loan (NPL) ratio is also considered as a control variable. Since securitization is associated with a process of credit expansion, which may affect the level of economic leverage and ultimately increase systemic risk, we use the ratio of credit to GDP as a proxy for measuring an economy's leverage level. Other variables are also used to control for factors that may affect systemic risk, such as liquidity and volatility of the financial market, financialization, and macroeconomic conditions. Table C.2 reports the details and sources of these variables; Table C.3 lists the correlation coefficient matrix of variables, showing that most of the explanatory variables are significantly correlated with explained variables; and Table 8 shows the descriptive statistics for these variables.

In light of the conclusions from our theoretical model, it is evident that the impact of asset securitization products on the systemic risk of the banking system is nonmonotonic. Therefore, we incorporate the quadratic term into our empirical model to describe the nonlinear

Table 11
Time-series regression results on ASRISK. This table presents the regressions of explanatory variables on ASRISK, which is used to replace SRISK or LRMES in our prime regression. Specifically, we run regressions with stepwise introductions of explanatory variables. We firstly regress the core explanatory variables (recall MBS, ABS, other collateralized bonds and their squared terms) and control variables on ASRISK, respectively. The first to sixth columns correspond to results of using MBS, ABS, other collateralized bonds, and their squared terms as core explanatory variables. Further, for comparison, we also regress the couples of core explanatory variables and control variables on ASRISK, respectively. Columns (7) (8) (9) present results of the above regressions. Finally, we show our prime regression in the last column, i.e., the Column (10). ***, **, and * denote significant values at the levels of 1%, 5%, and 10%, respectively.

ASRISK	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
MBS	0.0633***						−0.4914***			−0.4193***
MBS2		0.0774***					0.5981***			0.5078***
ABS			0.0271***					−0.2925***		−0.1341***
ABS2				0.0325***				0.3332***		0.1605***
OTHER					0.0001				−0.0934**	0.0177
OTHER2						0.0021			0.1048**	−0.0294
SIZE	0.3137***	0.3178***	0.2557***	0.2529***	0.2643***	0.2640***	0.2943***	0.2406***	0.2588***	0.2773***
NPL	−0.0102	−0.0093	−0.0116	−0.0111	−0.0142*	−0.0138	−0.0078	−0.0096	−0.0124	−0.0083
LEND	−0.0175*	−0.0176*	−0.0122	−0.0111	−0.0174	−0.0178*	−0.0179*	−0.0080	−0.0173	−0.0099
M1	0.0008	0.0002	0.0020	0.0018	0.0024	0.0023	−0.0022	0.0008	0.0024	−0.0021
M2	0.0044	0.0048	0.0038	0.0040	0.0023	0.0023	0.0055	0.0035	0.0011	0.0060
FINANCE	−0.0353	−0.0362*	−0.0294	−0.0299	−0.0295	−0.0297	−0.0366*	−0.0348	−0.0282	−0.0370*
VOL	−0.0255***	−0.0247***	−0.0257**	−0.0252**	−0.0283***	−0.0283***	−0.0223**	−0.0245**	−0.0280***	−0.0212**
GDP	−0.0221***	−0.0212***	−0.0254***	−0.0250***	−0.0267***	−0.0266***	−0.0205***	−0.0230***	−0.0261***	−0.0198***
FIXEDI	0.0075	0.0075	0.0071	0.0071	0.0076	0.0075	0.0074	0.0079*	0.0078*	0.0077*
EXCHANGE	0.0372**	0.0341**	0.0510***	0.0493***	0.0554***	0.0552***	0.0317**	0.0405***	0.0544***	0.0286**
DEFLATOR	−0.0006	−0.0006	−0.0035	−0.0041	−0.0004	−0.0003	−0.0007	−0.0047	0.0001	−0.0042
CREDIT	0.1256***	0.1191***	0.1490***	0.1462***	0.1536***	0.1533***	0.1042***	0.1279***	0.1470***	0.1018***
C	0.0100	0.0108	0.0055	0.0054	0.0049	0.0050	0.0107	0.0043	0.0028	0.0096
N	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F	36.4419	35.3502	86.3256	89.4219	57.2809	56.3667	45.7816	75.8937	60.3225	70.5790
R^2	0.4127	0.4238	0.3946	0.4008	0.3767	0.3767	0.4613	0.4298	0.3796	0.4765

relationship between securitization and systemic risk and perform the following regression to formally examine the above relationship:

$$Systemic_{i,t} = \alpha + \boldsymbol{\beta} \boldsymbol{Securitization}_{i,t} + \boldsymbol{\gamma} \boldsymbol{Securitization}^2_{i,t} + \boldsymbol{\delta} \boldsymbol{W}_{i,t} + \varepsilon_{i,t},$$

where $Systemic_{i,t}$ denotes the systemic risk of Individual i at Time t, and $\boldsymbol{Securitization}_{i,t}$ is a vector comprising MBS issuance, ABS issuance, and other collateralized bond issuance for Individual i at Time t. $\boldsymbol{Securitization}^2_{i,t}$ is a vector comprising the quadratic terms of corresponding elements in vector $\boldsymbol{Securitization}_{i,t}$, and $\boldsymbol{W}_{i,t}$ represents the control variables for Individual i at Time t. $\boldsymbol{\beta}$, $\boldsymbol{\gamma}$, and $\boldsymbol{\delta}$ are coefficient vectors that must be estimated. α is the constant term and $\varepsilon_{i,t}$ the error term.

We correct autocorrelation, heteroscedasticity, and cross-sectional correlation by Driscoll–Kraay estimation. Therefore, the R^2 values reported in the following tables are with-in sample. Considering the heteroscedasticity of the panel data, we make judgments based on the modified Hausman statistics and the Wald statistics based on the overidentification test, which indicate that the fixed-effect model should be selected in the regressions. We therefore control for individual effects at both country and time levels.

5.2.2. Estimation of the empirical model

First, we set SRISK as the explained variable, and gradually introduce core explanatory variables into the regression. The results are reported in Table 9. It can be seen from Columns (1), (3), and (5) that, without considering the squared terms, the issuance of MBS, ABS, and other collateralized bonds has a positive effect on systemic risk. The coefficients of the linear and the squared terms for MBS are 0.2233 and 0.2646, respectively, which are larger than those of other types of products, indicating that MBS has a more significant impact on systemic risk.

As shown in Columns (7), (8), and (9), if the squared terms of issuances are introduced in turns, the coefficients of the linear terms become significant and negative, while the coefficients of the squared terms are significant and positive. The introduction of the squared term better portrays the relationship between issuance and systemic risk, which is consistent with the results of the theoretical analysis. The regression coefficients associated with MBS issuance are significant at the 1% level, which are the most significant compared with those associated with other asset securitization products.

Column (10) reports the results when both the linear and the square terms of all product issuances are included in the regression. In this regression, regarding securitization products other than MBS, neither the linear nor the squared terms of their issuance quantity have a significant impact on systemic risk, whereas the MBS issuance quantity and its squared term are significant at the 1% level. Specifically, the coefficient of the MBS issuance quantity is −1.2702, which is significant and negative, while the coefficient of its square is 1.6003, which is significant and positive. This suggests that when issuance quantity is low, MBS can reduce systemic risk. However, as the issuance increases, the above relationship will change so that increased MBS issuance ultimately leads to increased systemic risk. The impact of asset securitization on systemic risk is nonmonotonic but depends on the scale of securitization issuance. In Table C.4, we present the results when control variables are introduced stepwise into the regression.

In Column (10), among the control variables, the positive relationship between the banking size and SRISK is significant. The magnitude of its coefficient is second only to that of the squared term of MBS quantity, which implies the vital impact of banking size on systemic risk. The relationship between the NPL ratio and systemic risk is also significant and positive, indicating that the worse the quality of credit assets in the economy, the higher the systemic risk (Bostandzic and Weiß, 2018). The significant and positive coefficient of CREDIT indicates that systemic risk is higher when the credit size of an economy is larger. Notably, the credit size of an economy can be regarded as the level of leverage in some way. The year-on-year GDP growth rate shows a negative relationship with systemic risk. Thus, the better the economic condition, the lower the systemic risk.

For completeness and robustness, we additionally use LRMES as the explained variable and report the regression results in Tables 10 and C.5. The results of Column (10) in Table 10 and Column (13) in Table C.5 are similar to those discussed above, in that the coefficient of MBS is significant and negative while that of its squared term is significant and positive. Meanwhile, the relationship between bank size,

Table 12
Robustness checks. This table presents the regressions whose control variables have been replaced. Specifically, in Panel A, Column (1) replaces VOL with VOLG that is the volatility of stock indexes in recent two year. Column (2) uses the change in consumer prices (named CPIP) as a substitute for DEFLATOR. Column (3) uses the ratio of the total non-financial credit to GDP, named NF CREDIT, to replace CREDIT. Columns (4) and (5) introduce budget balance and public debt to the original regression model. The models in Panel B are similar to those in Panel A at explanatory variables, while its explained variable is LRMES. ***, **, and * denote significant values at the levels of 1%, 5%, and 10%, respectively.

Panel A: SRISK	(1)	(2)	(3)	(4)	(5)
MBS	−1.2589***	−1.2724***	−1.2187***	−1.2668***	−1.2783***
MBS2	1.5858***	1.6026***	1.5355***	1.5966***	1.6115***
ABS	0.1035	0.0990	0.1578	0.1106	0.1373
ABS2	−0.0847	−0.0791	−0.1422	−0.0903	−0.1183
OTHER	−0.0965	−0.0959	−0.1196	−0.1048	−0.1332
OTHER2	0.1434	0.1406	0.1727	0.1518	0.1887
SIZE	0.6107***	0.6412***	0.6325***	0.6161***	0.6396***
NPL	0.0609***	0.0575***	0.0135	0.0639***	0.0268
LEND	−0.1155**	−0.0950**	−0.1265***	−0.1222***	−0.1301***
M1	−0.0125	−0.0150	−0.0171	−0.0119	−0.0163
M2	0.0382**	0.0348**	0.0465***	0.0381**	0.0460**
FINANCE	−0.2961***	−0.2957***	−0.2831***	−0.2759***	−0.2825***
VOL		0.0432	0.0371	0.0421	0.0386
GDP	−0.0767***	−0.0651***	−0.0689***	−0.0617***	−0.0653***
FIXEDI	0.0009	0.0005	0.0001	0.0027	0.0009
EXCHANGE	−0.0737***	−0.0743***	−0.0528**	−0.0708***	−0.0602**
DEFLATOR	−0.0348		−0.0264	−0.0310	−0.0319
CREDIT	0.1946*	0.1851*		0.1823*	0.2008**
VOLG	0.0169				
CPIP		−0.0632**			
NF CREDIT			0.3456***		
BUDGET				−0.0151	
PUBLICDEBT					0.1618*
C	−0.0768	−0.0848**	−0.0103	−0.0864**	−0.0377
N	1,539	1,539	1,539	1,539	1,539
Time&Country	Yes	Yes	Yes	Yes	Yes
F	535.8506	518.7352	828.8722	477.9952	1,049.6238
R^2	0.3620	0.3662	0.3791	0.3653	0.3700
Panel B: LRMES	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
MBS	−0.3713***	−0.3668***	−0.3475***	−0.3679***	−0.3688***
MBS2	0.4592***	0.4537***	0.4299***	0.4548***	0.4565***
ABS	−0.0982**	−0.1000**	−0.0807*	−0.0999**	−0.0917*
ABS2	0.1227**	0.1239**	0.1033*	0.1235**	0.1157**
OTHER	0.0233	0.0228	0.0088	0.0280	0.0122
OTHER2	−0.0332	−0.0329	−0.0159	−0.0382	−0.0199
SIZE	0.3154***	0.3112***	0.3171***	0.3161***	0.3132***
NPL	−0.0020	−0.0022	−0.0221**	−0.0030	−0.0125
LEND	−0.0147*	−0.0147	−0.0152*	−0.0128	−0.0154*
M1	−0.0007	−0.0011	−0.0036	−0.0003	−0.0022
M2	0.0077	0.0075	0.0124***	0.0069*	0.0112**
FINANCE	−0.0282	−0.0340*	−0.0341*	−0.0366**	−0.0339*
VOL		−0.0115	−0.0139	−0.0112	−0.0130
GDP	−0.0165***	−0.0209***	−0.0229***	−0.0214***	−0.0210***
FIXEDI	0.0070	0.0064	0.0060	0.0062	0.0064
EXCHANGE	0.0275*	0.0265*	0.0336**	0.0266*	0.0298*
DEFLATOR	−0.0065		−0.0050	−0.0079	−0.0071
CREDIT	0.0937***	0.0955***		0.0995***	0.0984***
VOLG	−0.0015				
CPIP		−0.0044			
NF CREDIT			0.1493***		
BUDGET				0.0065	
PUBLICDEBT					0.0474***
C	−0.0014	0.0019	0.0320***	0.0031	0.0149
N	1,539	1,539	1,539	1,539	1,539
Time&Country	Yes	Yes	Yes	Yes	Yes
F	65.3597	62.8910	56.1098	61.8122	60.3269
R^2	0.4472	0.4490	0.4690	0.4502	0.4532

leverage, and year-on-year GDP growth and systemic risk is consistent with the results when SRISK is the systemic risk measure.

The difference is that ABS issuance and its squared term are significant when LRMES is used as the measure of systemic risk. Specifically, the coefficients of ABS issuance and its squared term, −0.0997 and 0.1237, respectively, are smaller and less significant than those of their MBS counterparts, which are −0.3664 and 0.4532, respectively. Meanwhile, the coefficients of MBS in this regression are smaller than those in the regression with SRISK (recall −1.2702 and 1.6003) as the systemic risk measure.

A possible explanation is the difference in the underlying assets between ABS and MBS. MBS primarily comprise housing mortgage loans, while ABS primarily comprise auto and credit card loans. The real estate industry, one of the most critical sectors in an economy, is closely linked to macroeconomic and systemic risks. Therefore, the effect of MBS is more evident: The quadratic impact of MBS on systemic risk is reflected under both SRISK and LRMES, while ABS only show a quadratic impact on LRMES.

Table C.1
Sample countries and regions and the corresponding stock indices. This table presents the sample countries and regions, as well as their corresponding stock indices, which are used to calculate the volatility of their stock markets. To ensure the representativeness of our results, we select worldwide countries from Asia, Europe, America, Oceania, and Africa.

Countries and Regions	Stock Index	Countries and Regions	Stock Index
Argentina	MERV	Korea, Rep.	KS11
Australia	AS51	Malaysia	KLS
Belgium	BFX	Mexico	MXX
Brazil	MSCI Brazil	Netherlands	AEX
Canada	GSPTSE	New Zealand	NZSE.GI
China Mainland	000001.SH	Portugal	PSI
Finland	HEX	Russian Federation	MOEX
France	CAC40	South Africa	MSCI South Africa
Germany	DAX	Spain	IBEX
Greece	ASE	Sweden	OMXSPI
India	SENSEX	Switzerland	SMI
Ireland	ISEQ	United Kingdom	FTSE
Italy	MSCI Italy	United States	S&P500
Japan	TPX		

Table C.2
Description of variables and data source. This table summarizes the data source of variables and their description. We obtain the data of explanatory variables from the NYUVLab[a], and collect the macro-economic data mainly from World Development Indicators (WDI) and Economist Intelligence Unit (EIU). We use the Chow-in method to convert annual indicators to quarterly frequencies.

Variable Category	Variable	Description	Data Source
Explained Variables	SRISK	Systemic risk measures	V-lab
	LRMES	Long Run Marginal Expected Shortfall	V-lab
Explanatory Variables	MBS	MBS issuance	Bloomberg
	MBS2	Square of MBS	Bloomberg; Authors' calculation
	ABS	ABS issuance	Bloomberg
	ABS2	Square of ABS	Bloomberg; Authors' calculation
	OTHER	Other collateralized bonds' issuance	Bloomberg
	OTHER2	Square of OTHER	Bloomberg; Authors' calculation
Control Variables	SIZE	Bank size	CEIC; National Central Banks
	NPL	Non-performing loan ratio	CEIC; National Central Banks
	LEND	Lending interest rate	EIU
	M1	M1 (% pa)	EIU
	M2	M2 (% pa)	EIU
	FINANCE	Market value of stock market accounts for GDP (%)	CEIC; Wind; Authors' calculation
	VOL	Volatility of stock index in recent one year	Wind; Authors' calculation
	GDP	GDP (% real change pa)	EIU
	FIXEDI	Gross fixed investment (% GDP; real change pa)	EIU
	EXCHANGE	Real effective exchange rate (CPI-based)	EIU
	DEFLATOR	GDP deflator (% change; av)	EIU
	CREDIT	Total credit (% GDP)	BIS

[a] https://vlab.stern.nyu.edu/zh.

5.2.3. Robustness checks

Although we have shown that there is a strong quadratic relationship between asset securitization product issuance and systemic risk (see Tables 9–10), it would be interesting to examine whether this relationship remained robust when another measure of systemic risk and other combinations of control variables were used.

Considering that banks with large capital buffers can reduce systemic risk during crisis events, we adjust the compute mode for SRISK and substitute an adjusted variable as a new proxy for systemic risk, denoted ASRISK. Specifically, we consider the negative capital shortfall rather than only the positive values. This variable now comprises negative values rather than being restricted to values above zero. As a measure of systemic risk, ASRISK is relatively slack compared to SRISK. That is, it measures less systemic risk. Should the core explanatory variables remain statistically significant using ASRISK, the regression robustness would be further verified. The results shown in Table 11 are consistent with the above conjecture. The coefficient of the MBS term is significant and negative, while the coefficient of the square term for MBS is significant and positive. Meanwhile, the coefficients of MBS in this regression are smaller than those in the regression with SRISK.

In addition, other combinations of control variables are chosen for robustness testing. In these combinations, we find that the linear and the squared terms for MBS quantity are significantly positive, especially the latter. Additionally, for Panel B in Table 12, the coefficients of MBS, ABS, and their squared terms remain significant. These multiple alternative checks confirm the robustness of our findings.

5.2.4. Results and discussion

Based on the global samples, our empirical study indicates a U-shaped relationship between the quantity of asset securitization product issuance and systemic risk. This finding means that there is an optimal level of asset securitization issuance that minimizes systemic risk. This level is also the critical point at which the effect of asset securitization products on systemic risk shifts. Noteworthily, the effects of MBS issuance on systemic risk are significantly greater than those of ABS, which may be due to their different underlying asset pools. Our results on the relationships between systemic risk and variables such as bank size, economic development status, and credit expansion are consistent with existing research (Laeven et al., 2016; Bostandzic and Weiß, 2018).

Table C.3
Correlation coefficient matrix. This table presents the correlation coefficient matrix consisting of all variables. Our two measures of systemic risk, i.e, SRISK and LRMES, have a significantly positive correlation. The correlation coefficients between financial products and systemic risk are also significantly positive.

Variables	SRISK	LRMES	MBS	MBS2	ABS	ABS2	OTHER	OTHER2	SIZE	NPL	LEND	M1	M2	FINANCE	VOL	GDP	FIXEDI	EXCHANGE	DEFLATOR	CREDIT
SRISK	1.000																			
LRMES	0.763***	1.000																		
MBS	0.344***	0.085***	1.000																	
MBS2	0.353***	0.090***	0.997***	1.000																
ABS	0.391***	0.519***	0.099***	0.101***	1.000															
ABS2	0.411***	0.547***	0.112***	0.115***	0.995***	1.000														
OTHER	0.370***	0.353***	0.087***	0.096***	0.227***	0.237***	1.000													
OTHER2	0.419***	0.452***	0.060**	0.069***	0.280***	0.295***	0.985***	1.000												
SIZE	0.415***	0.454***	0.182***	0.199***	0.230***	0.255***	0.435***	0.495***	1.000											
NPL	−0.050**	−0.132***	−0.135***	−0.136***	−0.003	−0.008	−0.087***	−0.098***	−0.172***	1.000										
LEND	−0.211***	−0.137***	−0.087***	−0.091***	0.006	0.004	−0.259***	−0.272***	−0.261***	−0.018	1.000									
M1	−0.130***	−0.088***	−0.037	−0.038	−0.040	−0.043*	−0.112***	−0.128***	−0.210***	−0.059**	0.147***	1.000								
M2	−0.158***	−0.086***	−0.042*	−0.046*	−0.029	−0.030	−0.155***	−0.172***	−0.274***	−0.220***	0.368***	0.643***	1.000							
FINANCE	0.020	0.186***	−0.041*	−0.036	−0.041*	−0.042*	0.060**	0.050**	−0.036	−0.365***	−0.124***	0.049*	0.025	1.000						
VOL	−0.019	−0.113***	−0.082***	−0.082***	−0.036	−0.031	−0.124***	−0.138***	−0.146***	0.212***	0.455***	0.079***	0.212***	−0.214***	1.000					
GDP	−0.052**	0.027	0.027	0.024	0.065**	0.060**	−0.065**	−0.086***	−0.150***	−0.083***	−0.023	0.307***	0.348***	0.117***	−0.290***	1.000				
FIXEDI	−0.079***	−0.019	−0.009	−0.011	0.019	0.012	−0.008	−0.022	−0.087***	−0.028	−0.038	0.208***	0.218***	0.055**	−0.201***	0.514***	1.000			
EXCHANGE	0.014	0.149***	−0.050**	−0.052**	0.203***	0.222***	0.001	0.034	0.308***	−0.076***	0.208***	−0.164***	0.002	−0.239***	0.012	0.057**	0.010	1.000		
DEFLATOR	−0.216***	−0.156***	−0.092***	−0.094***	−0.056**	−0.058**	−0.153***	−0.179***	−0.366***	−0.089***	0.587***	0.415***	0.579***	0.015	0.339***	0.075***	0.060**	−0.265***	1.000	
CREDIT	0.062**	0.058**	0.061**	0.069***	−0.035	−0.030	0.212***	0.235***	0.297***	−0.023	−0.501***	−0.312***	−0.476***	0.081***	−0.357***	−0.054**	0.008	0.092***	−0.543***	1.000

Table C.4
Time-series regression results on SRISK: Alternative estimations. This table reports results of regressions whose explained variable is SRISK. In those regressions, control variables are introduced gradually into the regression equation. Without controlling other variables, i.e., in Column (1), the regression coefficients of the primary and quadratic terms of MBS and other collateralized bond are significant. Gradually adding bank-level, macro-level and financial market-level control variables, coefficients of other collateralized bond issuance are insignificant after controlling the leverage of the economy, while the significance of coefficients of both MBS and its secondary term have not changed significantly. ***, **, and * denote significant values at the levels of 1%, 5%, and 10%, respectively.

SRISK	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
MBS	−1.3936***	−1.2631***	−1.2484***	−1.2501***	−1.2544***	−1.2552***	−1.2796***	−1.3240***	−1.3213***	−1.3216***	−1.3206***	−1.3184***	−1.2702***
MBS2	1.6951***	1.5961***	1.5778***	1.5808***	1.5849***	1.5859***	1.6124***	1.6628***	1.6517***	1.6521***	1.6713***	1.6685***	1.6003***
ABS	−0.1421	0.0881	0.0995	0.1115	0.1116	0.1119	0.0883	0.1064	0.1169	0.1173	0.0880	0.0849	0.1100
ABS2	0.1860	−0.0778	−0.0868	−0.1014	−0.1016	−0.1018	−0.0779	−0.0907	−0.1020	−0.1024	−0.0691	−0.0645	−0.0908
OTHER	−0.4743***	−0.2485**	−0.2937***	−0.2932***	−0.2937***	−0.2927***	−0.2048**	−0.1872*	−0.1646	−0.1641	−0.1562	−0.1508	−0.0944
OTHER2	0.5490***	0.2786**	0.3452***	0.3481***	0.3486***	0.3475***	0.2618**	0.2452**	0.2205**	0.2201**	0.2125*	0.2053*	0.1414
SIZE		0.7090***	0.7975***	0.7934***	0.7829***	0.7841***	0.6613***	0.6668***	0.5995***	0.5982***	0.7136***	0.7113***	0.6296***
NPL			0.0947***	0.0934***	0.0936***	0.0943***	0.0711***	0.0737***	0.0788***	0.0787***	0.0816***	0.0787***	0.0620***
LEND				−0.0431	−0.0452*	−0.0455*	−0.1226***	−0.1402***	−0.1527***	−0.1530***	−0.1502***	−0.1243***	−0.1217***
M1					−0.0079	−0.0089	−0.0181	−0.0170	−0.0131	−0.0131	−0.0176	−0.0164	−0.0111
M2						0.0023	−0.0078	0.0018	0.0159	0.0160	0.0244	0.0283	0.0354**
FINANCE							−0.3411***	−0.2729***	−0.2507***	−0.2509***	−0.2770***	−0.2826***	−0.2823***
VOL								0.0845***	0.0532	0.0531	0.0491	0.0478	0.0432
GDP									−0.0699***	−0.0692***	−0.0662***	−0.0647***	−0.0636***
FIXEDI										−0.0016	0.0010	0.0020	0.0017
EXCHANGE											−0.0848***	−0.0846***	−0.0710***
DEFLATOR												−0.0364	−0.0324
CREDIT													0.1913*
C	−0.2011*	−0.1164	−0.0802	−0.0785	−0.0792	−0.0798	−0.1078**	−0.1334***	−0.1275***	−0.1278***	−0.0963**	−0.0988**	−0.0830**
N	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F	16.1859	60.9899	108.5927	96.9990	108.5109	109.2283	376.1118	325.1969	470.3791	456.9378	492.3339	379.3078	508.9313
R^2	0.2075	0.2642	0.2775	0.2789	0.2791	0.2791	0.3256	0.3406	0.3498	0.3498	0.3565	0.3574	0.3647

Table C.5
Time-series regression results on LRMES: Alternative estimations. This table reports results of regressions whose explained variable is LRMES. In those regressions, control variables are introduced gradually into the regression equation. Without controlling other variables, i.e., in Column (1), the regression coefficients of the primary and quadratic terms of core explanatory variables are significant. Gradually adding bank-level, macro-level and financial market-level control variables, coefficients of other collateralized bond issuance are insignificant after controlling the leverage of the economy, while the significance of coefficients of both MBS and its secondary term have not changed significantly. ***, **, and * denote significant values at the levels of 1%, 5%, and 10%, respectively.

LRMES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
MBS	−0.4629***	−0.3892***	−0.3880***	−0.3884***	−0.3898***	−0.3911***	−0.3942***	−0.3928***	−0.3921***	−0.3908***	−0.3911***	−0.3905***	−0.3664***
MBS2	0.5489***	0.4930***	0.4915***	0.4921***	0.4934***	0.4952***	0.4985***	0.4969***	0.4941***	0.4925***	0.4880***	0.4873***	0.4532***
ABS	−0.2493***	−0.1194**	−0.1185**	−0.1162**	−0.1162**	−0.1157**	−0.1187**	−0.1193**	−0.1166**	−0.1183**	−0.1114**	−0.1122**	−0.0997**
ABS2	0.2943***	0.1453**	0.1446**	0.1419**	0.1418**	0.1414**	0.1444**	0.1448**	0.1420**	0.1435**	0.1357**	0.1369**	0.1237**
OTHER	−0.1441***	−0.0166	−0.0202	−0.0201	−0.0202	−0.0184	−0.0074	−0.0079	−0.0023	−0.0041	−0.0060	−0.0046	0.0235
OTHER2	0.1617***	0.0090	0.0143	0.0148	0.0150	0.0130	0.0022	0.0028	−0.0034	−0.0018	0.0000	−0.0018	−0.0338
SIZE		0.4003***	0.4073***	0.4066***	0.4032***	0.4055***	0.3901***	0.3900***	0.3731***	0.3787***	0.3517***	0.3511***	0.3103***
NPL			0.0075	0.0073	0.0073	0.0086	0.0057	0.0056	0.0069	0.0076	0.0069	0.0061	−0.0022
LEND				−0.0079	−0.0086	−0.0091	−0.0188**	−0.0182*	−0.0214**	−0.0202*	−0.0208*	−0.0142	−0.0130
M1					−0.0025	−0.0044	−0.0056	−0.0056	−0.0046	−0.0046	−0.0036	−0.0033	−0.0007
M2						0.0042	0.0030	0.0027	0.0062	0.0054	0.0035	0.0045	0.0081*
FINANCE							−0.0427***	−0.0449***	−0.0393***	−0.0386***	−0.0325*	−0.0339**	−0.0338*
VOL								−0.0027	−0.0105	−0.0099	−0.009	−0.0093	−0.0116
GDP									−0.0175**	−0.0208**	−0.0215**	−0.0211***	−0.0206***
FIXEDI										0.0071	0.0065	0.0068	0.0066
EXCHANGE											0.0198	0.0199	0.0267*
DEFLATOR												−0.0093	−0.0073
CREDIT													0.0956***
C	−0.0479	−0.0002	0.0027	0.0030	0.0028	0.0017	−0.0018	−0.0010	0.0005	0.0017	−0.0057	−0.0063	0.0016
N	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539	1,539
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F	6.0380	17.9057	34.0892	35.7358	33.7750	90.8400	71.8128	111.2535	99.9364	97.9967	115.7992	100.4765	60.8523
R^2	0.2536	0.4145	0.4152	0.4157	0.4158	0.4161	0.4226	0.4227	0.4278	0.4292	0.4325	0.4330	0.4492

6. Concluding remarks

Despite numerous studies that have explored the relationship between credit securitization and systemic risk, most do not consider bank behavior. To some extent, this implies the assumption that bank behavior cannot influence securitization and systemic risk, which is not the case in practice. Evidently, banks' behavior does affect securitization product issuance and the risks associated with it.

Regarding the cross-holding behavior in respect of asset securitization products, we construct theoretical models to explore the effect of securitization products and their impact on systemic risk. Furthermore, to verify the theoretical results, we conduct a simulation analysis as well as an empirical study based on the panel data of 27 countries and regions over the period 2005Q4–2019Q4. To better meet the definition of systemic risk, we use country-level rather than bank-level data in empirical tests. Both theoretical and empirical results indicate a nonmonotonic relationship between securitization product issuance and systemic risk, which may be described as a U-shaped relationship in practice, when asset securitization is characterized by its issuance quantity. These findings indicate an optimal securitization level that minimizes systemic risk.

We also conclude that the cross-holding behavior regarding securitization helps banks evade the CAR constraint, which is unexpected yet reasonable. For the effective supervision of securitization and related risks, it is not just necessary to regulate banks' issuance of securitized products, but also to regulate their cross-holding behaviors on securitized products issued by other banks.

Last, we offer an unprecedented perspective related to banks' cross-holding behaviors that allows further research. Based hereon, future research could consider how not only cross-holding behaviors but also other important characteristics and financial innovations of the banking system affect systemic risk. While asset securitization may lead to the formation and transmission of systemic risk, its capacity to reduce systemic risk and its positive role in revitalizing bank assets cannot be ignored. Therefore, there remains considerable theoretical and practical significance in exploring the relationship between financial products and systemic risk, especially in the context of the cross-holding phenomenon, which has been naturally created in actual transactions but has received little attention.

Data availability

Data will be made available on request.

Appendix A

Illustration of the case of $p_a > 0$. When $p_a > 0$, we have:

$$F = \bar{r} - \alpha(1+r_a)p_a - (1-\alpha)(1+r_b)p_b.$$

Suppose $E(\pi^b) = 0$ (recall (4)). Thus, we have

$$E(\pi^b) = AF - r_c D = A\left[\bar{r} - \alpha(1+r_a)p_a - (1-\alpha)(1+r_b)p_b\right] - r_c D = 0.$$

Rewriting the above equation yields

$$p_a = \frac{A\left[\bar{r} - (1-\alpha)(1+r_b)p_b\right] - r_c D}{\alpha(1+r_a)}.$$

In other words, p_a can be written as a function of p_b when $E(\pi^b) = 0$. Similarly, assuming that $E(\pi^s) = 0$, $E(\pi^c) = 0$ or $\Delta E(\pi^{s-b}) = \Delta E(\pi^{c-b}) = \Delta E(\pi^{c-s}) = 0$, it is equally easy to rewrite p_a as the function on p_b, respectively. Accordingly, the upper subplot of Fig. A.1 shows the relationships between p_a and p_b for different cases.

It is worth to note that the cut-off values of F have not changed, i.e., $F^b = \mu r_c$, $F^s = (1-\gamma)r_d + \mu\gamma r_c$, $F^c = (1-\theta)(1-\gamma)r_d + \mu r_c(\theta+\gamma-\theta\gamma)$ and $F^d = r_d$. Recall (6), (10), (18), and (25). Analogously, suppose $p_a > 0$, the threshold values with respect to p_b are as follows:

$$p_b \le \frac{\bar{r} - \mu r_c - \alpha\left(1+r_a\right)p_a}{(1-\alpha)\left(1+r_b\right)} = p_b^b,$$

$$p_b \le \frac{\bar{r} - (1-\gamma)r_d - \mu\gamma r_c - \alpha\left(1+r_a\right)p_a}{(1-\alpha)\left(1+r_b\right)} = p_b^s,$$

$$p_b \le \frac{\bar{r} - (1-\theta)(1-\gamma)r_d - \mu r_c(\theta+\gamma-\theta\gamma) - \alpha\left(1+r_a\right)p_a}{(1-\alpha)\left(1+r_b\right)} = p_b^c,$$

$$p_b \le \frac{\bar{r} - r_d - \alpha\left(1+r_a\right)p_a}{(1-\alpha)\left(1+r_b\right)} = p_b^d.$$

The lower subplot of Fig. A.1 shows F and the cut-off values of F. Note that as p_a rises to 0.025, compared to the case of $p_a = 0$, the p_b thresholds of different situations decrease, but the relative relationship among the thresholds, i.e., $p_b^d < p_b^s < p_b^c < p_b^b$, is consistent with Proposition 3.

Appendix B

Proof of Proposition 3. We first provide proof of $p_b^d < p_b^s < p_b^c < p_b^b$ by contradiction. Now, assume that $p_b^c \ge p_b^b$ holds. Recall (6) and (18), it is

$$\frac{\bar{r} - (1-\theta)(1-\gamma)r_d - \mu r_c(\theta+\gamma-\theta\gamma)}{(1-\alpha)\left(1+r_b\right)} \ge \frac{\bar{r} - \mu r_c}{(1-\alpha)\left(1+r_b\right)},$$

which can be further simplified as

$$\mu \ge \frac{r_d}{r_c}.$$

However, in reality, μ ranges between 0 and 1. According to the risk-return trade-off, $r_d > r_c$, so that $\frac{r_d}{r_c} > 1$. Hence, $\mu \ge \frac{r_d}{r_c}$ contradicts the reality and does not hold. Therefore, $p_b^c < p_b^b$ holds.

Similarly, by (10), (18) and (25), we can show that both $p_b^s \ge p_b^c$ and $p_b^d \ge p_b^s$ also implies $\mu \ge \frac{r_d}{r_c}$. This contradiction indicates that $p_b^d < p_b^s < p_b^c$. In conclusion, we have $p_b^d < p_b^s < p_b^c < p_b^b$.

Recall (25) and notice that $\bar{r} = \alpha r_a + (1-\alpha)r_b$. If $p_a = 0$, the numerator of p_b^d is $\alpha r_a + (1-\alpha)r_b - r_d$. The risk-return trade-off indicates that $\alpha r_a + (1-\alpha)r_b > r_d$, which implies $p_b^d > 0$. In summary, if $p_a = 0$, we have $0 < p_b^d < p_b^s < p_b^c < p_b^b$. □

Proof of Proposition 8. When $B_1^{c,o} \le B_2^{c,p}$(recall (42)), it is easy to conclude that $v^{c_1} > v^b$ holds for the case $E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1$ and $E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1$. For the case $E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1$ and $E_2 \le \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1$, $v^{c_1} < v^b$ if and only if $\lambda_2 < 1 - \frac{\gamma}{(1-\mu)(\theta+\gamma-\theta\gamma)}$ is satisfied. When $B_1^{c,o} > B_2^{c,p}$(recall (43)), it is easy to conclude that $v^{c_2} > v^b$ holds for the case $E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1$. For the case $E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1$ and $E_2 > \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2$, $v^{c_2} < v^b$ if and only if $\lambda_2 < 1 - \mu + \frac{\mu\gamma}{\theta(1-\gamma)}$ is satisfied. For the case $E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1$ and $E_2 \le \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2$, $v^{c_2} < v^b$ if and only if $\lambda_2 < 1 - \frac{\gamma}{(1-\mu)(\theta+\gamma-\theta\gamma)}$ is satisfied. □

Proof of Proposition 9. According to (42) and (43), taking the partial derivatives of v^{c_1} and v^{c_2} with respect to μ yields

$$\frac{\partial v^{c_1}}{\partial \mu} = \begin{cases} \frac{1}{(1+\lambda_2+\lambda_3)(\mu-1)^2(\theta+\gamma-\theta\gamma)} > 0, & E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1 \\ \frac{\gamma}{(1+\lambda_2+\lambda_3)(\mu-1)^2(\theta+\gamma-\theta\gamma)} > 0, & E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 \le \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1 \\ \frac{1-\gamma}{(1+\lambda_2+\lambda_3)(\mu-1)^2(\theta+\gamma-\theta\gamma)} > 0, & E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1 \\ 0, & E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 \le \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1 \end{cases}$$

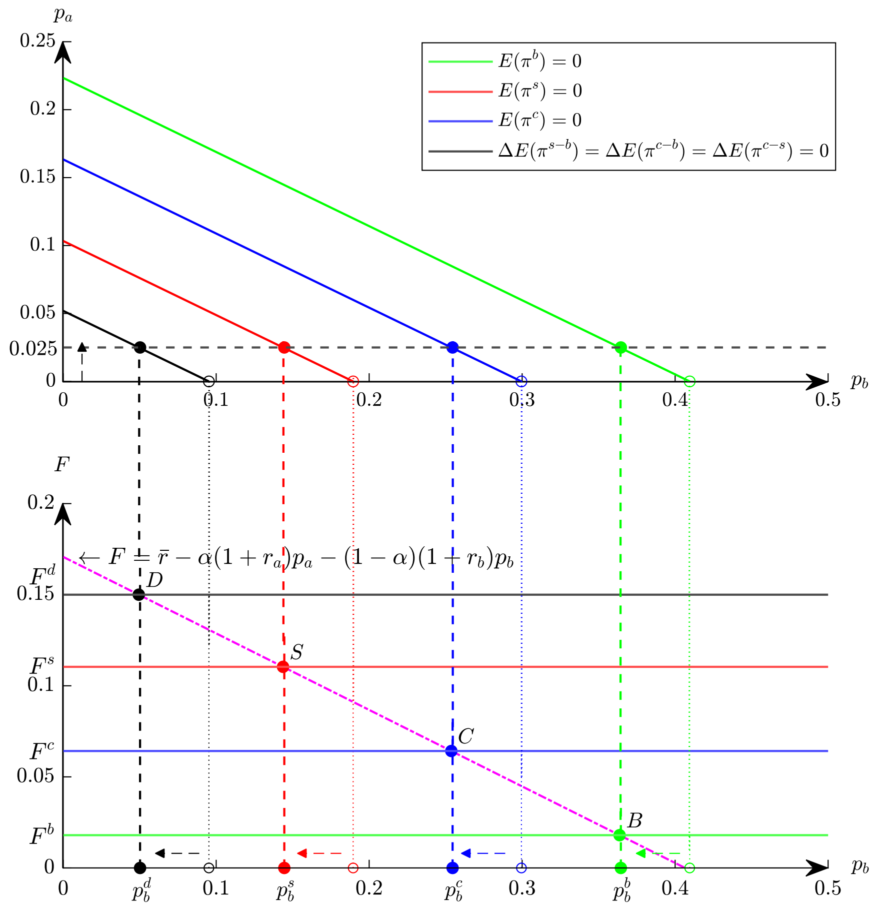

Fig. A.1. Relationships among p_b, p_a and F. This figure illustrates how the situation changes from $p_a = 0$ to $p_a = 0.025$. Simplifying $E(\pi^b) = 0$, $E(\pi^s) = 0$, $E(\pi^c) = 0$, and $\Delta E(\pi^{s-b}) = \Delta E(\pi^{c-b}) = \Delta E(\pi^{c-s}) = 0$, we can obtain the relationships among p_b, p_a and F in different cases, and thus draw the oblique solid lines in two subplots. In the upper subplot, the horizontal coordinates of the intersections of these solid lines with the dashed line $p_a = 0.025$ are the thresholds of p_b. In the lower subplot, the horizontal coordinates of the intersections of these solid lines with the dashed diagonal line are the thresholds of p_b. The empty dots indicate those p_b thresholds at $p_a = 0$ and the solid dots indicate those p_b thresholds at $p_a = 0.025$.

and

$$\frac{\partial \upsilon^{c_2}}{\partial \mu}=\begin{cases}\frac{\gamma+\lambda_2\theta-\lambda_2\theta\gamma}{(1+\lambda_2+\lambda_3)(\mu-1)^2(\gamma+\theta-\gamma\theta)}>0, & E_1>\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2>\frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2\\ \frac{\gamma}{(1+\lambda_2+\lambda_3)(\mu-1)^2(\gamma+\theta-\gamma\theta)}>0, & E_1>\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2\le\frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2\\ \frac{\lambda_2\theta(1-\gamma)}{(1+\lambda_2+\lambda_3)(\mu-1)^2(\gamma+\theta-\gamma\theta)}>0, & E_1\le\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2>\frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2\\ 0, & E_1\le\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2\le\frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2\end{cases}$$

Notice that that $\frac{\partial \upsilon^{c_1}}{\partial \mu}\ge 0$ and $\frac{\partial \upsilon^{c_2}}{\partial \mu}\ge 0$ always hold. This fact indicate that the higher the leverage of the banking system when it encounters a shock, the higher the capital loss rate of the banking system in the Cross-holding model. □

Proof of Proposition 10. Recalling (42) and (43), the partial derivatives of υ^{c_1} and υ^{c_2} with respect to γ are given as

$$\frac{\partial \upsilon^{c_1}}{\partial \gamma}=\begin{cases}\frac{\theta-1}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)^2}<0, & E_1>\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2>\frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1\\ \frac{\theta}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)^2}>0, & E_1>\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2\le\frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1\\ \frac{-1}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)^2}<0, & E_1\le\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2>\frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1\\ 0, & E_1\le\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2\le\frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1\end{cases}$$

and

$$\frac{\partial \upsilon^{c_2}}{\partial \gamma}=\begin{cases}\frac{\theta(1-\lambda_2)}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)^2}, & E_1>\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2>\frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2\\ \frac{\theta}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)^2}>0, & E_1>\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2\le\frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2\\ \frac{-\lambda_2\theta}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)^2}<0, & E_1\le\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2>\frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2\\ 0, & E_1\le\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2\le\frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2\end{cases}$$

respectively. It is obvious that both $\frac{\partial \upsilon^{c_1}}{\partial \gamma}$ and $\frac{\partial \upsilon^{c_2}}{\partial \gamma}$ could be negative, zero or positive under different conditions.

Recalling (42) and (43), the partial derivatives of υ^{c_1} and υ^{c_2} with respect to θ are shown as (B.1) and (B.2), respectively. When $B_1^{c,o}\le B_2^{c,p}$, $\frac{\partial \upsilon^{c_1}}{\partial \theta}$ is constantly less than zero, which implies that in the case where the asset securitization products issued by Bank 1 are purchased in full by Bank 2, the higher degree of cross-holding, the lower the capital loss rate of the banking system. However, in the case $B_1^{c,o}>B_2^{c,p}$, $\frac{\partial \upsilon^{c_2}}{\partial \theta}$ can be negative, zero or positive under different conditions.

$$\frac{\partial \upsilon^{c_1}}{\partial \theta}=\begin{cases}\frac{\gamma-1}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)^2}<0, & E_1>\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2>\frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1\\ \frac{\gamma(\gamma-1)}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)^2}<0, & E_1>\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2\le\frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1\\ \frac{-(\gamma-1)^2}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)^2}<0, & E_1\le\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2>\frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1\\ 0, & E_1\le\frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2\le\frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1\end{cases} \tag{B.1}$$

$$\frac{\partial v^{c_2}}{\partial \theta} = \begin{cases} \frac{\gamma(\lambda_2-1)(1-\gamma)}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)^2}, & E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2 \\ \frac{-\gamma(1-\gamma)}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)^2} < 0, & E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 \le \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2 \\ \frac{\lambda_2\gamma(1-\gamma)}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)^2} > 0, & E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2 \\ 0, & E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 \le \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2 \end{cases} \quad \square \tag{B.2}$$

Proof of Proposition 11. Recalling (42) and (43), the partial derivatives of v^{c_1} and v^{c_2} with respect to λ_2 are given as

$$\frac{\partial v^{c_1}}{\partial \lambda_2} = \begin{cases} \frac{-1}{(1+\lambda_2+\lambda_3)^2(1-\mu)(\theta+\gamma-\theta\gamma)} < 0, & E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1 \\ \frac{1}{1+\lambda_2+\lambda_3} + \frac{\lambda_2(\mu-1)(\theta+\gamma-\theta\gamma)-\gamma}{(1+\lambda_2+\lambda_3)^2(1-\mu)(\theta+\gamma-\theta\gamma)}, & E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 \le \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1 \\ \frac{\gamma-1-(1-\mu)(\theta+\gamma-\theta\gamma)}{(1+\lambda_2+\lambda_3)^2(1-\mu)(\theta+\gamma-\theta\gamma)} < 0, & E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1 \\ \frac{\lambda_3}{(1+\lambda_2+\lambda_3)^2} > 0, & E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 \le \frac{1-\gamma}{\theta+\gamma-\theta\gamma}A_1 \end{cases}$$

and

$$\frac{\partial v^{c_2}}{\partial \lambda_2} = \begin{cases} \frac{\lambda_2\theta(\gamma-1)-\gamma}{(1+\lambda_2+\lambda_3)^2(1-\mu)(\theta+\gamma-\theta\gamma)} + \frac{\theta(1-\gamma)}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)}, & E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2 \\ \frac{1}{1+\lambda_2+\lambda_3} + \frac{\lambda_2(\mu-1)(\theta+\gamma-\theta\gamma)-\gamma}{(1+\lambda_2+\lambda_3)^2(1-\mu)(\theta+\gamma-\theta\gamma)}, & E_1 > \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 \le \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2 \\ \frac{\theta(1-\gamma)}{(1+\lambda_2+\lambda_3)(1-\mu)(\theta+\gamma-\theta\gamma)} - \frac{(1-\mu)(\theta+\gamma-\theta\gamma)+\lambda_2\theta(1-\gamma)}{(1+\lambda_2+\lambda_3)^2(1-\mu)(\theta+\gamma-\theta\gamma)}, & E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 > \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2 \\ \frac{\lambda_3}{(1+\lambda_2+\lambda_3)^2} > 0, & E_1 \le \frac{\gamma}{\theta+\gamma-\theta\gamma}A_1, E_2 \le \frac{\theta(1-\gamma)}{\theta+\gamma-\theta\gamma}A_2 \end{cases}$$

respectively. Obviously, both $\frac{\partial v^{c1}}{\partial \lambda_2}$ and $\frac{\partial v^{c2}}{\partial \lambda 2}$ could be negative, zero or positive under different conditions. □

Appendix C

See Tables C.1–C.5.

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