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A LIQUIDITY RISK STRESS-TESTING FRAMEWORK WITH INTERACTION BETWEEN MARKET AND CREDIT RISKS

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Abstract

This study develops a stress-testing framework to assess liquidity risk of banks, where liquidity and default risks can stem from the crystallisation of market risk arising from a prolonged period of negative asset price shocks. In the framework, exogenous asset price shocks increase banks' liquidity risk through three channels. First, severe mark-to-market losses on the banks' assets increase banks' default risk and thus induce significant deposits outflows. Secondly, the ability to generate liquidity from asset sales continues to evaporate due to the shocks. Thirdly, banks are exposed to contingent liquidity risk, as the likelihood of drawdowns on their irrevocable commitments increases in such stressful financial environments. In the framework, the linkage between market and default risks of banks is implemented using a Merton-type model, while the linkage between default risk and deposit outflows is estimated econometrically. Contagion risk is also incorporated through banks' linkage in the interbank and capital markets. Using the Monte Carlo method, the framework quantifies liquidity risk of individual banks by estimating the expected cash-shortage time and the expected default time. Based on publicly available data as at the end of 2007, the framework is applied to a group of banks in Hong Kong. The simulation results suggest that liquidity risk of the banks would be contained in the face of a prolonged period of asset price shocks. However, some banks would be vulnerable when such shocks coincide with interest rate hikes due to monetary tightening. Such tightening is, however, relatively unlikely in a context of such shocks.

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Executive Summary

- *The development of the sub-prime crisis in the US and Europe shows that liquidity and default risks of banks can stem from market risk, and such interaction of risks can lead to systemic crises. While the banking systems in most other economies have remained relatively resilient, they are not immune to similar crises due to some common features running through all banking systems.*

- *This study develops a stress-testing framework to assess liquidity risk of banks, where liquidity and default risks can stem from the crystallisation of market risk arising from a prolonged period of negative asset-price shocks. In the framework, exogenous asset-price shocks increase banks' liquidity risk through three channels. First, severe mark-to-market losses on the banks' assets increase banks' default risk and thus induce significant deposits outflows. Secondly, the ability to generate liquidity from asset sales continues to evaporate due to the shocks. Thirdly, banks are exposed to contingent liquidity risk, as the likelihood of drawdowns on their irrevocable commitments increases in such stressful financial environments.*

- *Using the Monte Carlo method, the framework quantifies liquidity risk of individual banks by estimating the expected cash shortage time and the expected default time. Based on publicly available data at the end of 2007, the framework is applied to a group of banks in Hong Kong.*

- *The stress-testing results suggest that liquidity risk of the banks would be contained in the face of a prolonged period of asset-price shocks. However, some banks would be vulnerable when such shocks coincide with interest-rate hikes due to monetary tightening. Such tightening is, however, relatively unlikely in a context of such shocks. The results are consistent with the fact that during the sub-prime crisis, although some individual banks with higher leverage or lower asset quality may suffer from higher liquidity impact, the systemic risk of the banking sector in Hong Kong appears to be contained.*

- *This framework highlights the potentially destabilising dynamics linking liquidity risk and default risk of financial institutions, but concludes that the likelihood of a self-perpetuating deterioration in liquidity and default risks in the Hong Kong banking system is minimal.*

I. INTRODUCTION

As illustrated by recent developments in the US and European banking systems, liquidity and default risks of banks can stem from the crystallisation of market risk and such interaction of risks can lead to systemic crises, e.g. the sub-prime crisis emerged in 2007.[2] While the banking systems in most other economies have remained relatively resilient, they are not immune to similar crises because of three common features running through all banking systems. First, banks' balance sheets are inevitably exposed to common market-risk factors, as they generally hold similar financial assets. Thus, significant asset-price declines, even in a single market, could expose many banks to substantial market-risk losses. Secondly, the capital available for banks to serve as a buffer against such losses is limited, as banks usually operate with a relatively high level of financial leverage. This suggests that banking systems in general are vulnerable to multiple default risk during severe market shocks. Thirdly, interbank markets are sensitive to default risk. Significant increases in the default risk of banks could result in tightened interbank markets, creating systemic liquidity shortages.[3]

For banking stability it is, therefore, important to assess the extent to which a banking system is exposed to such an interaction of risks. However, in the literature, stress-testing frameworks capturing the interaction of risks are relatively scant. To fill this gap, this study develops a new stress-testing framework to assess the liquidity risk of banks in this context.

In the framework, we assume that there is a prolonged period (i.e., one year) of negative exogenous asset price shocks in some major financial markets, which affect

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[2] The development of the sub-prime crisis can be summarised as follows: In the early stage (around the second half of 2007), there were continual announcements of significant mark-to-market write-downs of sub-prime mortgage-related securities by financial institutions in the US and Europe as a result of deterioration in the asset quality of sub-prime mortgages. Such crystallisation of market risk triggered concerns of banks' default risk quickly, as evidenced by increases in credit default swap spreads of banks since the third quarter of 2007. Default risk of banks was amplified further following the debacle of some large financial institutions, including Bear Stearns, Freddie Mac and Fannie Mae. As default risk heightened, banks became increasingly reluctant to lend among themselves, resulting in the systemic liquidity problems in the global interbank markets in mid-September 2008 following the collapse of Lehman Brothers, despite the unprecedented actions and measures taken before by various central banks and governments to inject liquidity in the global banking system.

[3] It is however noted that the resilience of a banking system would depend on other bank-specific factors too (e.g. some well-managed banks may be able to anticipate a crisis and take pre-emptive measures to contain losses.)

banks' liquidity risk through three channels: (i) increases in banks' default risk and deposit outflows; (ii) reduction in banks' liquidity generation capability; and (iii) increases in contingent drawdowns. Default risk of banks is endogenously determined using a Merton-type model in the framework.[4] Contagious default risk is incorporated through banks' linkage with interbank and capital markets that is consistent with the theories in the literature.

With this framework, daily cash outflows of banks can be simulated given exogenous asset-price shocks. Using the Monte Carlo method, the framework quantifies the liquidity risk of individual banks by estimating the probability of cash shortage and the probability of default due to liquidity problems. In addition, conditional on occurrences of cash shortage and default in the simulations, the first cash shortage time and the default time can be estimated respectively. The corresponding probability of multiple defaults of banks in a banking system can also be estimated, which is an important measure for assessing the systemic risk in the banking system. The framework with two stress scenarios is applied to assess the liquidity risk of a group of 12 listed banks in Hong Kong with publicly available data.

This study draws on the literature that relates to the impact of asset-price declines on banks' default risk. Cifuentes et al. (2005) and Adrian and Shin (2008a and 2008b) provide a theoretical foundation on how a small asset-price shock can be amplified by its mark-to-market (MTM) effects on banks' balance sheets, and thus leads to a downward spiral in asset prices and contagious defaults of banks through interbank linkages.[5] The importance of the linkage between asset prices and default risk of banks has recently been recognised and studied empirically by Boss et al. (2006) and Alessandri et al. (2007)). However, the implications for banks' liquidity risk, which are crucial for policy markers in view of the sub-prime crisis, are not the main focus of these studies. van den End (2008) incorporates the interaction between market and funding liquidity and potential feedback on banks into a framework to assess liquidity risk of Dutch banks by

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4 Using Merton-type models to endogenise default risk of banks in systemic risk assessment frameworks is also adopted by Aspachs et al. (2006), which is based on the theoretical framework by Goodhart et al. (2006).

5 See also Allen and Gale (1994, 1998 and 2000a), Acharya and Yorulmazer (2007), and Nier et al (2007). In addition to the MTM effects, asset price collapse could cause bank failures because of widespread defaults of banks' lending to investors for acquiring risky assets (see Allen and Gale (2000b) and Goetz Von Peter (2004)).

estimating the distributions of liquidity buffers and probability of liquidity shortfall of banks. However, the effect of market-risk shocks on default risk of banks and in turn their deposit outflows (and liquidity risk) are not explicitly modelled in the framework. By contrast, the proposed framework in our paper tries to establish the linkages among the liquidity risk, market risk and banks' default risk. It is also related to the theoretical framework by Diamond and Rajan (2005) which shows that an aggregate liquidity shortage can be caused by bank runs perceived by bank insolvency.

This study contributes to the literature in two aspects. First, this is among few empirical studies to incorporate interaction of risks in a liquidity risk stress-testing framework. Given that the sub-prime crisis is highly relevant to such interaction of risks, the framework could be useful for policy makers to assess how resilient a banking sector is under liquidity shocks similar to or even severer than those occurred in the sub-prime crisis. Secondly, the framework could serve as a complementary tool to the bottom-up approach for liquidity-risk stress testing. This is particularly so in view of the difficulty to incorporate contagious default risk under the bottom-up approach.[6] By contrast, default risk of banks is endogenised in this framework and contagious default risk is thus possible through interbank and capital markets. The proposed framework can be readily applied to other banking system as the required input data are publicly available.

The reminder of the paper is organised as follows. The stress-testing framework is outlined in the following section. Sections III and IV discuss the data and the specifications of the stress scenarios respectively. Section V presents the stress-testing results for the Hong Kong banking sector and Section VI concludes.

II. STRESS-TESTING FRAMEWORK

The stress-testing framework consists of two parts:

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6 The bottom-up approach to stress testing is usually conducted by the following way: Bank supervisory authorities (or central banks) set up some stress scenarios. Participating banks then evaluate the impact of the scenarios on their own financial positions and report the stress testing results to the authorities. The supervisory authorities finally aggregate the results to assess the systemic impacts of the stress scenarios. It is, however, difficult for this approach to evaluate the likelihood of mutually dependent events, such as contagious defaults.

(1) An application of the Monte Carlo method to generate market risk shocks for different assets.

(2) A system of equations which characterises the interaction of risks and facilitates estimations of the evolution of balance sheet items, cash flows, default risk and liquidity risk of individual banks in the face of the market risk shocks.

Based on the simulated market-risk shocks and the system of equations, the liquidity risk indicators can be estimated for individual banks.

2.1 Monte Carlo Simulations of Market Risk Shocks

The Monte Carlo simulation method is adopted to generate market-wide stress scenarios to examine the liquidity risk of banks. The main source of the stress is from asset-market disruptions. In each stress scenario, we assume that there is a prolonged period (i.e., one year) of negative exogenous asset-price shocks in some major financial markets, including debt securities, equities, and structured financial assets. Each stress scenario can be treated as a prolonged period of market-wide fire sales of financial assets. The asset-price shocks are simulated from their historical price movements, when the respective asset prices had declined significantly.[7] For debt securities, the shocks are imposed by simulating future paths of the risk-free interest rate, credit spreads of AAA, AA, A, BBB, and high-yield non-financial corporate bonds. Shocks for equities and structured financial assets are simulated from some selected price indices. Since the shocks are based on their historical movements, the magnitude of the shocks varies across asset classes. Banks' asset value is assumed to be MTM on a daily basis. The across-the-board declines in asset prices lead to decreases in the MTM value of banks' assets, although the exact impacts vary across banks due to different asset compositions.

2.2 System of Equations

Figure 1 illustrates how the asset-price shocks increase banks' liquidity risk

[7] The Monte Carlo simulations can be extended by using different distributions of asset returns in addition to the historical price movements.

through the following three channels. First, severe MTM losses on the banks' assets increase their default risk and thus induce significant retail and interbank deposit outflows. Secondly, the ability to generate liquidity from asset sales continues to evaporate due to the shocks. Thirdly, banks are exposed to contingent liquidity risk, as the likelihood of drawdowns on their irrevocable commitments increases in such stressful financial environments.[8] To quantify the risks arising from these three channels, a system of equations is used in this framework, which can be broadly divided into three categories: (i) market risk; (ii) default risk; and (iii) liquidity risk. We will first discuss some important equations for each category, and then quantify the liquidity risk in the framework.

Market-risk equations

The equations for the market risk mainly consist of the MTM equations for different asset classes, which link up the exogenous asset-price shocks with the MTM of individual banks' assets. In the system of equations, banks' assets are divided into the following types: interbank lending, loans to customers, financial investment and other assets. Financial investment, which is subject to the exogenous asset price shocks, is further broken down into debt securities, equities, structured financial assets and other financial assets. Debt securities consist of three types, sovereign, bank and corporate issuers. Debt securities issued by corporates are further broken down by credit ratings (i.e., AAA, AA, A, BBB, and speculative grades (including unrated)). There are two groups of equities: Hong Kong equities and non-Hong Kong equities. Except for cash and other assets, all assets are assumed to be MTM on a daily basis. The MTM methods of banks' financial investment are as follows:

The MTM value of the debt securities are essentially determined by the following formula, with different specifications on the default-adjusted interest rate at time t, R_t^k,

[8] An obvious observation regarding contingent liquidity risk in the sub-prime crisis is that the risk is highly correlated with the prices of sub-prime mortgage-related securities. During the crisis, some banks bailed out some special investment vehicles (SIVs) because of either contractual obligations or reputational concerns, posing significant demand for liquidity. Those SIVs needed to be bailed out usually experienced significant declines in their net asset value as a result of decreases in the prices of sub-prime mortgage-related securities. To incorporate this into the framework, we postulate that a portion of banks' irrevocable credit commitments is correlated with the prices of sub-prime mortgage-related assets.

$$V_{t,T}^{k} = X_{T}^{k} \exp[-R_{t}^{k}(T-t)] \tag{1}$$

where $V_{t,T}^{k}$ is the MTM value of an asset *k* at time *t*, with time to maturity (*T-t*). X_{T}^{k} is the face value of the asset at maturity. R_{t}^{k} is equivalent to $r_t + el_t^k$, where r_t is the interbank interest rate at *t*; el_t^k is the expected default loss rate of asset *k* at *t*, which is equivalent to $h_t^k L^k$, where h_t^k is the default hazard rate and L^k is the loss-given-default of asset *k*.[9] We assume that L^k is time-invariant. Based on Equation (1), the percentage changes in the MTM value of asset *k* from time *t* to $t+\Delta t$ can be approximated by the following equation as Δt is very small[10]

$$\begin{aligned} \ln(V_{t+\Delta t,T}^{k}) - \ln(V_{t,T}^{k}) &= -\Delta R_{t+\Delta t}^{k}(T-t-\Delta t) \\ &= -(\Delta r_{t+\Delta t} + \Delta el_{t+\Delta t}^{k})(T-t-\Delta t) \end{aligned} \tag{2}$$

where $\Delta R_{t+\Delta t}^{k} = (R_{t+\Delta t}^{k} - R_{t}^{k})$, $\Delta r_{t+\Delta t} = (r_{t+\Delta t} - r_t)$, and $\Delta el_{t+\Delta t}^{k} = \Delta h_{t+\Delta t}^{k} L^k$ with $\Delta h_{t+\Delta t}^{k} = (h_{t+\Delta t}^{k} - h_t^k)$. As we assume all assets are MTM on a daily basis, Δt is set to be 1/252.[11] $\Delta r_{t+\Delta t}$ and $\Delta el_{t+\Delta t}^{k}$ in Equation (2) are the market risk shocks which are exogenous, except for the default hazard rate of debt securities issued by banks, which is determined endogenously according to individual banks' default risk. R_t^k for different debt securities are given by the following specifications.

Debt securities issued by sovereigns are assumed to be default-free[12] in the framework (i.e., $el_t^k = 0$), so that Δr_t is the only factor affecting their MTM value.[13]

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9 For theoretical justification for using default-adjusted interest rates to value defaultable debt securities, see Duffie and Singleton (1999) and Collin-Dufresne et al. (2004).

10 Since $V_{t+\Delta t,T}^{k} = X_{T}^{k}\exp[-R_{t+\Delta t}^{k}(T-t-\Delta t)]$ and $V_{t,T}^{k} = X_{T}^{k}\exp[-R_{t}^{k}(T-t)]$, $\ln(V_{t+\Delta t,T}^{k}) - \ln(V_{t,T}^{k}) = R_t^k \Delta t - (R_{t+\Delta t}^{k} - R_t^k)(T-t-\Delta t)$. If Δt is set to be very small, such as 1/252 (i.e., daily changes), the term $R_t^k \Delta t$ becomes very small, and thus the remaining term $-(R_{t+\Delta t}^{k} - R_t^k)(T-t-\Delta t)$ can be treated as a rough approximation of the MTM loss of asset *k* from *t* to $t+\Delta t$.

11 We assume that there are 252 business days in a year.

12 The assumption that all sovereign debt securities are default-free is debatable given the recent default of the Iceland government amid the sub-prime crisis. Nevertheless, the assumption can be relaxed in the framework, as the default risk can be simulated using the credit spreads of sovereign debt securities.

13 In the framework, we assume that all sovereign debt securities could be valued by using a single interest rate. In the case of Hong Kong, we adopt the US-dollar LIBOR. This can be justified by the fact that

The expected default-loss rate of AAA, AA, A, BBB, and high-yield non-financial corporate debt securities, which are denoted by Δel_t^{AAA}, Δel_t^{AA}, Δel_t^{A}, Δel_t^{BBB} and Δel_t^{HY} respectively, are simulated from their historical daily changes in the credit spreads of the corporate bonds of the respective credit ratings.[14]

For bank *i* in the banking system where *i = 1,…, N*, the daily changes in the default hazard rate of its holdings of debt securities issued by other banks (e.g. certificates of deposits issued by other banks) are given by

$$\Delta h_t^{BD,i} = \sum_{j \neq i}^{N} w_{i,j}^{BD} \Delta h_{j,t-\Delta t} \tag{3}$$

where $w_{i,j}^{BD}$ is the weight of bank *i*'s exposure to bank *j*, which is assumed to be time-invariant. $w_{i,j}^{BD}$ can be proxied by the ratio of the value of debt securities issued by bank *j* (that bank *i* holds) to the value of total debt securities issued by banks (that bank *i* holds).[15] $\Delta h_{j,t-\Delta t} = h_{j,t-\Delta t} - h_{j,t-2\Delta t}$, where $h_{j,t-\Delta t}$ is the default hazard rate of bank *j* given all information available at time *t-Δt*. $h_{j,t-\Delta t}$ is endogenously determined in the simulations.[16] The loss-given-default, L^{BD}, is assumed to be 0.5 for all banks.[17]

For equities, structured financial assets and other financial assets, the changes in MTM value are proxied by the changes of some selected price indices. Specifically, for any asset *k*, the percentage change in its MTM value from *t* to *t+Δt*, $\ln(V_{t+\Delta t}^k) - \ln(V_t^k)$, is determined by:

$$\ln(V_{t+\Delta t}^k) - \ln(V_t^k) = \Delta P_t^k \tag{4}$$

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banks in Hong Kong generally hold significant amount of US Treasuries and the Exchange Fund papers in the Hong Kong dollar. The yields of the Exchange Fund papers in general should follow closely to the US interest rate movements under the Linked Exchange Rate system.

14 We assume that the daily changes in interest rate spreads of corporate bonds reflect only the changes in credit risk of issuers.

15 For simplicity, we assume an equal weight for all banks in this study.

16 This will be discussed later in the default-risk equations.

17 The value is close to the implied value from the historical default recovery rate of senior unsecured bank loans for the period 1989 to 2003. See Altman et al. (2004).

where ΔP_t^k is the change in the logarithm of the price index for asset *k* from *t-1* to *t*. We denote the logarithm of price indices for Hong Kong equities, non-Hong Kong equities, structural financial assets and other financial assets by P_t^{EHK} , P_t^{EW} , P_t^{SFA} and P_t^{OFA} respectively. Asset-price shocks for these four assets are imposed by simulating their future paths of ΔP_t^k .

In addition to financial investment of banks, we assume that banks' interbank lending and loans to customers are also MTM according to Equation (2) as if they are debt securities. For interbank lending, the daily changes in the default hazard rate, $\Delta h_{i,t}^{BL}$, is endogenously determined in the same way as that for debt securities issued by banks (i.e., Equation (3)), but replacing the weight $w_{i,j}^{BD}$ by $w_{i,j}^{BL}$, which can be proxied by the ratio of bank *i*'s interbank lending to bank *j* to total interbank lending by bank *i*.[18] The default hazard rate is given by

$$\Delta h_t^{BL,i} = \sum_{j \neq i}^{N} w_{i,j}^{BL} \Delta h_{j,t-\Delta t} \tag{5}$$

where the loss-given-default, L^{BL} , is assumed to be 0.5 for all banks.

For loans to customers, we denote the daily changes in the default hazard rate of loans to customers by Δh_t^{CL} . We assume that the asset quality of banks' loan portfolios deteriorates along with the asset market disruptions. Δh_t^{CL} is assumed to be exogenous and will be specified in the scenarios. The loss-given-default of the loans, L^{CL} , is assumed to be 0.5.[19]

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[18] For simplicity, we assume an equal weight for all banks in this study. However, it should be pointed out that this assumption can be relaxed, as the required data to derive the weights are usually readily available for central banks or supervisory authorities. For the case in Hong Kong, the weights can be derived using the regulatory banking statistics from the "*Return of Large Exposures*", which are collected by the Hong Kong Monetary Authority on a quarterly basis.

[19] The value is close to the implied value from the historical default recovery rate of senior public corporate bonds for the period 1974 to 2003. See Altman et al. (2004).

Equations (1) to (4) facilitate the calculation of the market value of total assets of individual banks on a daily basis in the stress horizon for any given set of simulated future paths of Δr_t, Δel_t^{AAA}, Δel_t^{AA}, Δel_t^{A}, Δel_t^{BBB}, Δel_t^{HY} P_t^{EHK}, P_t^{EW}, P_t^{SFA}, P_t^{OFA}, and Δh_t^{CL}. The impacts of the shocks on the market value of banks' assets are summarised in Table 1.

Default-risk equations

An important feature of this framework is that a bank's default risk is dependent on the market value of total assets of the bank. This is implemented using the Merton-type structural model proposed by Briys and de Varenne (1997).[20, 21] In essence, the model suggests that default risk of bank *i* at time *t*, which is measured by the one-year probability of default (denoted by $PD_{i,t}$ or PD) in the framework, is determined by the bank's leverage ratio ($L_{i,t}$) and its associated volatility $\sigma_{i,t}$.[22] $L_{i,t}$ is defined as the ratio of the total value of financial liabilities ($D_{i,t}$) to the total market value of assets ($A_{i,t}$). Therefore, $PD_{i,t}$ can be expressed by

$$PD_{i,t} = PD(\frac{D_{i,t}}{A_{i,t}}, \sigma_{i,t}) \tag{6}$$

We assume that $\sigma_{i,t}$ is time-invariant (i.e., $\sigma_{i,t} = \sigma_i$) and the values of $D_{i,t}$ and $A_{i,t}$ change over time in the simulations. The daily percentage changes in $A_{i,t}$ are proportional to the corresponding changes in the MTM value of bank *i*'s total assets that derived from the market-risk equations. Similarly, the daily percentage changes in $D_{i,t}$ are proportional to the corresponding changes in the bank's liabilities, which are mainly

20 Generalisations of this model to more complex liability structures include the papers by Collin-Dufresne and Goldstein (2001) and Hui et al. (2003). Structural models have been extended to banking studies, in particular pricing of deposit insurance. See Merton (1977, 1978) and Ronn and Verma (1986), for example.

21 The Briys-de Varenne model is a two-factor model in which a firm's asset value follows a lognormal diffusion process and the risk-free interest rate follows a normal mean-reverting process. In our stress-testing framework, the interest rate is assumed to be constant. Longstaff and Schwartz (1995) shows that the effect of the interest-rate dynamics on default risk of a bond issuer is small.

22 PDs in this study are calculated using the method proposed by Hui et al. (2005).

determined by the liquidity risk equations.[23] With these two assumptions, the evolution of $PD_{i,t}$ in the stress horizon can be derived, given an initial value of the bank's leverage ratio $L_{i,0}$ and the value of σ_i. Since the MTM value of a bank's assets tends to decrease in stress scenarios as a result of continued negative asset-price shocks, the bank's leverage ratio and thus PD tend to increase in the stress horizon.

Contagion risk is incorporated into the framework through banks' linkage with the interbank and capital markets. An increase in default risk of a bank will reduce the market value of its outstanding debt securities. Other banks which either have interbank lending to the bank or hold the debt securities issued by the bank will result in MTM losses, and thus have higher default risk. The contagion effects arising from interbank lending and those from debt securities are incorporated by Equations (3) and (5) respectively into the framework.[24] The default hazard rate, $h_{i,t}$, which facilitates the calculation of the MTM value of interbank lending and debt securities issued by banks, is derived from $PD_{i,t}$ using the following formula $h_{i,t} = -\ln(1 - PD_{i,t})$.[25]

Liquidity risk equations

The liquidity-risk equations describe how the asset-price shocks affect banks' demand for liquidity. Banks' demands for liquidity mainly depend on (retail and interbank) deposit outflows and drawdowns on credit commitments, which are determined in the simulations.

Asset-price shocks affect banks' deposit outflows indirectly via their impacts on default risk of banks. The relationship between default risk of banks and the outflow rate of retail deposits is estimated econometrically using a monthly panel dataset

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[23] This will be discussed in the following sub-section.

[24] As shown in Equations (3) and (5), we assume that the effect of an increase in default risk of banks on the market value of interbank lending and debt securities issued by banks is lagged by one business day. This setting gives an easier way to implement the framework. In theory, in such an interconnected banking system, the PDs of banks, the MTM value of interbank lending and debt securities issued by banks in any given day should be determined simultaneously, as they are mutually dependent. However, incorporating these mutual dependences of the variables in the framework involves solving a system of simultaneous equations, which will complicate the implementation of the framework substantially.

[25] See page 483 of Hull (2006).

of 12 selected banks in Hong Kong for the period January 2006 - September 2008[26] from regulatory banking statistics obtained from the *"Return of interest rate exposures (supplementary information)"*, which are collected by the Hong Kong Monetary Authority. Based on the estimation result, the monthly retail deposit outflow rate is set to be $0.42 * PD_{i,t}$. Details of the empirical estimation are in Appendix A. The daily retail deposit outflows of bank *i* at time *t*, denoted by $DO_{i,t}$, are determined by the following equation:[27]

$$DO_{i,t} = Min[(0.42 \times PD_{i,t-\Delta t} / 21) TD_{i,t-\Delta t}, SD_{i,t-\Delta t}] \quad (7)$$

where $TD_{i,t-\Delta t}$ and $SD_{i,t-\Delta t}$ are total retail deposits and savings deposits respectively taken by bank *i* at the close of business at $t\text{-}\Delta t$. Equation (7) implies that the actual daily retail deposit outflow of a bank at time *t* is positively related to the bank's PD at the close of business at $t\text{-}\Delta t$, with the maximum potential outflow being capped by the total amount of savings deposits, which are payable on demand.[28] The economic intuition of Equation (7) is obvious: two banks with the same amount of total deposits and identical level of default risk, the one with more time deposits and longer average maturity should be subject to lower deposits outflows (i.e., smaller inherent maturity mismatch between assets and liabilities), implying stronger ability to withstand liquidity shocks.

The relationship between default risk of banks and the outflow rate of interbank deposits is estimated using information on the Bear Stearns debacle. Based on the Briys and de Varenne model, the PDs of Bear Stearns before and during the debacle are derived. It is observed that if the PD is higher than 0.08, interbank deposits start to be withdrawn, and if the PD is higher than 0.69, all interbank deposits will not be renewed after maturity. Detailed discussions can be found in Appendix B. The daily interbank deposit outflow rate of bank *i* at time *t*, $IOR_{i,t}$, is defined as

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[26] Monthly data are only available since January 2006. Data after end-September 2008 are not used in the estimation, as the introduction of the extent of coverage of the Deposit Protection Scheme, and the 100% deposit guarantee in Hong Kong on 14 October 2008 may generate a structural change on the relationship between the outflow rate of retail deposits and default risk of banks.

[27] To convert the monthly outflow rate of retail deposits into a daily rate, we divide the monthly rate by 21 (i.e., $0.42 \times PD_{i,t\text{-}\Delta t}/21$ in Equation (7)).

[28] In the framework, we assume that that (1) there are only two types of retail deposits, namely savings deposits and time deposits; (2) all time deposits are allowed to be withdrawn only at maturity; and (3) all time deposits at maturity, if being renewed, will shift to savings deposits.

$$IOR_{i,t} = \begin{Bmatrix} 0 & & PD_{i,t-\Delta t} \leq 0.08 \\ \dfrac{PD_{i,t-\Delta t} - 0.08}{0.69 - 0.08} & \text{if} & 0.08 < PD_{i,t-\Delta t} \leq 0.69 \\ 1 & & PD_{i,t-\Delta t} > 0.69 \end{Bmatrix} \tag{8}$$

and the daily interbank deposit outflow of bank *i* at time *t*, $IO_{i,t}$, is determined by the following equation:

$$IO_{i,t} = Min[IOR_{i,t} \times TID_{i,t-\Delta t}, OID_{i,t-\Delta t}] \tag{9}$$

where $TID_{i,t-\Delta t}$ and $OID_{i,t-\Delta t}$ are total interbank deposits and overnight interbank deposits taken by bank *i* at the close of business at t-Δt. Equation (9) implies that the actual daily interbank deposit outflow at time *t* is positively related to the PD of bank *i*, with the maximum potential outflow being capped by the total overnight interbank deposits, which are payable on demand at time *t* .[29]

In addition, the negative asset price-shocks increase banks' contingent liquidity risk because the likelihood of drawdowns on banks' irrevocable commitments increases in such stressful financial environments. It is assumed that a portion of individual banks' irrevocable commitments, α, is granted to SIVs which invest mainly in structured financial assets. Such SIVs are particularly vulnerable to funding risk if the asset quality of their holdings of structured financial assets deteriorates, and thus the net asset values of the SIVs decline significantly. This leads to a higher likelihood of drawdowns on credit commitments by the SIVs. In the simulations, we assume that the daily drawdowns on credit commitments from bank *i* at time *t*, $DCC_{i,t}$, are determined by[30]:

$$DCC_{i,t} = \max[-\Delta P_t^{SFA} UCC_{i,t-\Delta t}, 0] \tag{10}$$

and

[29] We assume that all interbank deposits are allowed to be withdrawn only at maturity and all time deposits at maturity, if being renewed, will only rollover in form of overnight interbank deposits.

[30] Recall that P_t^{SFA} is the logarithm of the price index for structural financial assets.

$$UCC_{i,t} = \max[TCC_{i,o}\alpha - \sum_{s=1}^{t-\Delta t} DCC_{i,s}, 0] \tag{11}$$

where $UCC_{i,t}$ and $TCC_{i,o}$ are the undrawn credit commitments at time t and the total commitments available at time 0 (i.e., at the beginning of the stress period) respectively.

With Equations (7) to (11), daily cash outflows of individual banks can be simulated given the exogenous asset price shocks. Other cash outflows arsing from banks' liabilities are assumed to follow their contractual maturities. For any business day t in the one-year stress period, each bank is assumed to counterbalance its cash outflows by using the cash available at t. The total amount of cash available at t is defined as the sum of the remaining cash balances at the close of business day *t-1*, operating income (including net interest income and fee and commission income) arrived at t, interbank lending, loans to customers and financial assets matured at t. In the simulations, banks' operating incomes arrived at t are assumed to be determined by $\beta \frac{ROA_i}{252} A_{i,t-\Delta t}^{MTM}$, where $\beta < 1$ is a stress factor of banks' incomes, ROA_i is the return on assets of bank i and $A_{i,t-\Delta t}^{MTM}$ is its MTM value of total assets at time $t-\Delta t$. We assume that all banks cannot generate additional liquidity from the liability side (by taking more deposits) and they have to liquidate financial assets to offset cash outflows if there is a shortfall in cash. With this framework, each bank's net cumulative cash outflow gap, defined as the net cumulative cash inflows minus the net cumulative cash outflows, can be estimated daily in the stress horizon.

Liquidity risk indicators

Using the Monte Carlo method to generate the asset-price shocks, the liquidity risk of each bank is quantified by estimating four indicators, including the probability of cash shortage and the probability of default due to liquidity problem, the expected first cash shortage time (FCST) conditional on occurrences of cash shortage and the expected default time (DT) conditional on occurrences of default. A bank's FCST is defined as the first business day that the bank fails to meet its liquidity outflows by its cash balance, and DT is defined as the first business day that the banks fails to meet its liquidity outflows even after liquidating all its saleable financial assets. By definition, smaller values of FCST and DT imply higher liquidity risk. Figure 2 shows an illustrative example of the simulations of the FCST and DT, together with the simulated evolution of the market value of financial assets, the net cumulative cash outflow gap and the PD of a bank.

III. DATA SAMPLE AND SOURCES

The framework is applied to a group of 12 listed banks in Hong Kong. Data for banks' balance sheets, including the maturity profile of balance sheet items, and the compositions of financial investment, are mainly from their 2007 annual financial reports, except for the banks' exposures on structured financial assets of banks, including sub-prime mortgage-related securities, and corporate collateralised debt obligations, which are supplemented by Fitch (2008). Since the framework involves estimations of daily cash flows of banks and the maturity profile presented in banks' annual report only shows the time to maturity of balance sheet items by some selected time intervals[31], we need to derive a daily maturity profile of balance sheet items for individual banks. In this study, for any given amount of an balance sheet item that will mature in a given time interval, the amount of the item that will mature in any given business day within the time interval is derived by dividing the total amount of the item that will mature in the time interval by the number of business days within the time interval.[32] To facilitate the specification of stressed operating income in the stress scenarios, we calculate the return on assets (ROA) for each bank from the banks' annual reports.

To calculate the initial value of $L_{i,t}$ (i.e., $L_{i,0}$), we first obtain the daily time series of $D_{i,t}$ and $S_{i,t}$ for each bank[33] in the one-year period before the beginning

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[31] Banks usually present their liquidity profile with the following time intervals: Repayable on demand,one month or less, over one month but within three months, over three months but within one year, Over one year but within five years, over five years, and undated. In the framework, we treat "undated" items as "repayable on demand" items.

[32] For example, if a bank holds HK$2,100 million of AAA corporate debt securities in the time interval "over one month but within three months", then we assume that HK$50 million (i.e., HK$2,100 million/42) of AAA corporate debt securities will mature in every business day in the two-month period.

[33] Or the bank's holding company if the bank itself is not listed.

of the stress period[34]. $D_{i,t}$ is defined as the sum of total deposits, short-term debt and long-term debt, while $S_{i,t}$ is defined as the total market value of equity. We thus obtain a one-year time series of $L_{i,t} = \frac{D_{i,t}}{A_{i,t}} = \frac{D_{i,t}}{D_{i,t} + S_{i,t}}$ for each bank. The average value of the one-year time series of $L_{i,t}$ is set to be $L_{i,0}$. Regarding σ_i, we first obtain the time series of the daily standard deviation of equity returns, $\sigma_{i,t}^{s}$, for each bank in the one-year period using the exponentially weighted moving average method, with the decay factor being set as 0.94. We then calculate the corresponding annualised asset volatility by $\sqrt{250}(\frac{S_{i,t}}{D_{i,t} + S_{i,t}})\sigma_{i,t}^{s}$. We set σ_i as the average of the annualised asset volatility in the one-year period. With $L_{i,0}$ and σ_i for each bank, we can calculate the initial value of $PD_{i,t}$ (i.e., $PD_{i,0}$) for each bank using the Briys and de Varenne model.

For asset price data, r_t is proxied by the three-month US-dollar LIBOR. Credit spreads[35] of AAA, AA, A, and BBB non-financial corporate debt are proxied by the corresponding credit spreads of the JPMorgan US Liquid Index, while credit spreads of high-yield corporate debt is derived by the difference between the yield to maturity of the JPMorgan Global High-yield Index and the seven-year swap rate.[36] The Hang Seng Index (HSI) and the Morgan Stanley Capital International (MSCI) World Equity Index are selected as the price indices for the Hong Kong (P_t^{EHK}) and non-Hong Kong (P_t^{EW}) equities respectively. For simplicity, we assume that a majority of structured financial assets are related to US sub-prime mortgages. Therefore, the ABX index, which is a credit default swap index for sub-prime mortgage-backed securities, is selected as the price index for structured financial assets (P_t^{SFA}). The movements of the price index for other financial assets, P_t^{OFA}, are assumed to be similar to those of the equity prices. In the simulations, ΔP_t^{OFA} is calculated by the simple average of the ΔP_t^{EHK} and ΔP_t^{EW}. All data are obtained from Bloomberg, except for the credit spreads of corporate debt, which are obtained from JPMorgan.

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[34] From 1 January to the end of December 2007.

[35] Credit spreads over LIBOR.

[36] The seven-year swap rate is used, as the average value of years to maturity of the JPMorgan Global High-yield Index for the period January 2000 – June 2008 is about 7.2 years.

IV. SPECIFICATION OF STRESS SCENARIOS

Two stress scenarios, A and B, are considered in this study. The severity of major asset price shocks is assumed to be the same in these two scenarios, but Scenario B is more severe than Scenario A in other assumptions.

The asset-price shocks for credit spreads of corporate bonds, equities and structured financial assets are assumed to be the same in the two scenarios. The future paths of credit spreads of corporate bonds and prices of structured financial assets in the one-year stress horizon are simulated from the historical time series of the respective variables from July 2007 to June 2008. The period covers roughly from the onset of the sub-prime crisis to the latest development.[37] The future paths of prices of the Hong Kong and non-Hong Kong equities are simulated from the time series of the HSI and the MSCI World Equity Index respectively for the period mid-March 2000 to October 2002 (i.e., after the burst of the internet bubble). The simulated paths of the asset-price shocks are shown in Figures 3.

For the movement of the interest rate in the stress horizon, Scenario A assumes a neutral stance of the US monetary policy and thus interbank interest rates hover around the initial level in the stress horizon[38], while Scenario B assumes that interest-rate hikes occur due to US monetary policy tightening. The future paths of the interest rate in Scenarios A (see Figure 3(I)) and B (see Figure 3(J)) are simulated from the time series for the periods from August 2006 to July 2007, and from July 2004 to June 2006 respectively.

Scenario B is more severe than Scenario A in other assumptions. Specifically, Scenario A assumes that the asset-market disruptions adversely affect the operating environment of the banking sector[39], such that the ROA of each bank drops by 25% (i.e., $1-\beta$) and the non-performing loan ratio increases by 200 basis points. The factor α of a bank's undrawn credit lines related to SIVs is set to be 5%. In Scenario B,

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[37] By the time of conducting the analysis.

[38] We assume that interbank interest rates broadly follow the US monetary policy rate. This assumption can be modified by applying the interbank rates and short-term US Treasury yield to different assets.

[39] The financial-market disruptions would lead to a recession in the US that would have impact on the macroeconomic conditions in other economies.

the ROA of each bank decreases by 50% and the non-performing loan ratio increases by 500 basis points. α is assumed to be 10%.

V. SIMULATION RESULTS

For each scenario, we assume the balance-sheet conditions of the banks at the end of December 2007 as the initial state. We then simulate daily future paths of the asset-price shocks covering the entire year 2008 . The cash flows of each bank are calculated based on the simulated paths of the asset price shocks according to the system of equations in Section II. We repeat the process 1,000 times, from which the numbers of occurrences of cash shortage and default are calculated. We also calculate the expected FCST and DT conditional on occurrences of cash shortage and default respectively for each bank. The extent to which individual banks could withstand the stress scenarios is assessed by these liquidity risk indicators.

Based on the estimated probability of cash shortage and the probability of default, the stress-testing results suggest that liquidity risk of banks in Hong Kong would be contained in the face of a prolonged period of asset price shocks under Scenarios A, as all the 12 banks are estimated to have zero probability of cash shortage or default. However, a few banks would be vulnerable when such shocks coincide with interest rate hikes due to monetary tightening in Scenario B, despite that such tightening is, relatively unlikely in the context of such shocks. Table 2 shows that five banks are estimated to have positive probabilities of cash shortage in Scenario B, ranging from 0.7% to 84.7%. Among the five banks, four are estimated with positive probabilities of default due to liquidity problems in the one-year stress horizon, with the estimated probabilities ranging from 0.6% to 38.5%. Although five banks would be prone to liquidity problems in Scenario B, the estimated expected values of FCST and DT of individual banks are relatively large[40], indicating that the likelihood of sudden default of a bank in the early stage of the one-year stress horizon would be very low.

To assess the systemic liquidity risk for the Hong Kong banking system,

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[40] The conditional expected FCST and DT range from 228 to 249 and from 241 to 247 respectively.

the distribution of multiple defaults under Scenario B is calculated and shown in Table 3. There is more than a 60% chance that no bank would default in Scenario B. Under extreme conditions at the tail of the distribution, no more than three banks would default at the 99% confidence level.

VI. CONCLUSION

This framework highlights the potentially destabilising dynamics linking liquidity risk and default risk of financial institutions, but concludes that the likelihood of a self-perpetuating deterioration in liquidity and default risks in the Hong Kong banking system is minimal.[41]

As highlighted in the revised principles for liquidity risk management by the Basel Committee on Banking Supervision (2008), holding adequate liquidity cushion of unencumbered and high quality liquid assets is particularly important for banks to maintain sound liquidity risk management. In this connection, this study does highlight the importance of incorporating the interaction between market and credit risks in assessing the adequacy of liquidity cushions to withstand stress events. In particular, in addition to holding sufficient amount of high quality liquefiable assets, banks should also pay particular attention to the risk that declines in asset prices may likely coincide with high run-off of funds due to deterioration in the bank's balance sheet and increases in its default risk. With the proposed framework, the adequacy of the liquidity cushion of banks can be quantified by the expected cash shortage time and expected default time.

[41] The stress-testing result is consistent with the fact that during the sub-prime crisis, although some individual banks with higher leverage or lower asset quality may suffer from higher liquidity stress, the systemic risk of the banking sector in Hong Kong appears to be contained as indicated by strong capitalisation levels (i.e., the aggregate consolidated capital adequacy ratio of locally incorporated Authorized Institutions at the end of December 2008 was 14.8%, which remained well above the minimum international standard of 8%.).

Appendix A

Econometric estimation of the relationship between the probability of default (PD) and the monthly retail deposit outflow rate

To reveal the empirical relationship between PD and the monthly retail deposit outflow rate, the following panel data regression equation is estimated:

$$DG_{i,t} = \alpha_i + \beta_1 \ln(DR_{i,t}) + \beta_2 \ln(DR_{-i,t}) + \beta_3 PD_{i,t} + \beta_4 Y_t + \varepsilon_{i,t}, \qquad \text{(A1)}$$

where $DG_{i,t}$ is the monthly growth rate of Hong Kong dollar retail deposits of bank *i* at time *t*. $DR_{i,t}$ is the retail deposit rate offered by bank *i* at *t*, while $DR_{-i,t}$ is that offered by other banks in the market. The estimated coefficients of $DR_{i,t}$ and $DR_{-i,t}$ (i.e., β_1 and β_2 respectively) are expected to be positive and negative respectively. $PD_{i,t}$ is the default probability of bank *i* at *t*, which is calculated based on the Briys and de Varenne model. The empirical relationship between PD and the monthly retail deposit outflow rate is revealed by the estimated value of β_3, which is expected to be negative. Y_t is the year-on-year growth rate of GDP in Hong Kong, and the estimated coefficient of Y_t is expected to be positive, as the growth rate of retail deposits should be higher under good economic conditions.

We estimate Equation (A1) using its first difference form[42] with the generalised least squares method.[43] β_3 is estimated to be -0.2111, which is statistically significant at the five per cent level. This suggests that a bank with high default risk

[42] This is for several reasons. First, differencing the equation removes the individual effects (which are time invariant and cross-section specific), reducing the number of parameters to be estimated. Second, removing the individual effects also avoids complications arising from the possibility that they may be correlated with the explanatory variables. Third, differencing the equation avoids the omitted-variable bias stemming from the cross-sectional unobserved heterogeneities that are constant over time.

[43] To correct for the presence of cross-section heteroskedasticity, the cross-section weights are used in the estimation.

(i.e., $PD_{i,t}$ closer to 1) would lead to a monthly retail deposit outflow rate of about 21%.[44] The 95% confidence interval of β_3 is approximately between -0.42 and -0.01. In the stress-testing framework, instead of setting the monthly retail deposit outflow rate to be the point estimate (i.e., -0.2111), a more severe rate, which is the lower bound of the confidence interval, is assumed (i.e., monthly retail deposit outflow rate = -0.42 $PD_{i,t}$).

Other parameters, β_1, β_2 and β_4 are estimated to be 0.4738, -0.2748, and 1.2387 respectively, with β_1 and β_2 being statistically significant at the 1 per cent level and β_4 being statistically significant at the 10 per cent level. Overall, the estimation result is consistent with the economic intuitions in Equation (A1).[45]

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[44] The relatively low estimated value of the sensitivity of the monthly retail deposit outflow rate to PDs may partly reflect the adoption of the Deposit Protection Scheme in Hong Kong in September 2006.

[45] Details of the estimation result are available upon request.

Appendix B

The relationship between the probability of default (PD) and the interbank deposit outflow rate as revealed from the Bear Stearns debacle

Interbank deposit outflows of a bank are in general sensitive to the bank's default risk. Given that default risk of banks can change drastically even in a short period of time, high frequency data (e.g. daily data) on bank's PDs and their interbank deposits are crucial to obtain an accurate estimate of the sensitivity of the interbank deposits outflow rate to PD. However, high frequency data on banks' liquidity positions in general and interbank deposits in particular are not readily available. This means that applying standard econometric methods to estimate the empirical relationship may not be feasible. Nevertheless, a rough approximation could be obtained from the Bear Stearns event. In SEC (2008), daily data concerning the liquidity positions of Bear Stearns are given for the period 31 January 2008 to 13 March 2008. Together with the PDs of Bear Stearns for the corresponding period estimated using the Briys-de Varenne model, a simply analysis is conducted.[46] The following table shows the daily data of liquid assets of Bear Stearns from SEC (2008) and the PD estimates for the two–week period before it was acquired by JP Morgan Chase on 16 March 2008.

Date	Liquid asset (US$ billion)	1-year default probability (PD)
3 March 2008	20	0.0645
4 March 2008	20.1	0.0566
5 March 2008	21	0.0515
6 March 2008	21	0.0878

[46] An alternative way to conduct the analysis is by estimating the relationship between credit default swap (CDS) spreads (or CDS spread implied PDs) of Bear Stearns and its liquidity positions. However, the currently adopted approach is more consistent with our stress-testing framework. This is particularly so in view of that CDS data for banks in Hong Kong are not generally available. Technically, however, modifying the framework to use CDS data to represent default risk of banks rather than using PD estimated from structural models is feasible. In practice, only Equations (6), (7) and (8) in the framework are required to be re-specified.

Date	Liquid asset (US$ billion)	1-year default probability (PD)
7 March 2008	18	0.0783
10 March 2008	18.1	0.1594
11 March 2008	11.5	0.1474
12 March 2008	12.4	0.1385
13 March 2008	2	0.1639
14 March 2008	Not available	0.6936

As revealed in the table, the first significant drop in liquidity of Bear Stearns occurred on 7 March 2008 where its liquid assets declined from US$21 billion to USD 18 billion from 6 March 2008. Since then, the company's liquidity had trended downwards along with significant increases in PDs. The data reflects that the unwillingness of counterparties to provide liquidity to Bear Stearns may have begun as early as on 7 March 2008, where the PD of Bear Stearns was around 0.08. By the end of 14 March 2008, the last trading date before the acquisition by JP Morgan Chase on 16 March 2008, the PD of Bear Stearns reached to around 0.69. Based on the Bear Stearns event, we assume that when a bank's PD is higher than 0.08 under the liquidity stress-testing framework, the withdrawal of interbank deposits will begin and the outflow rate is assumed to be dependent on the bank's PD linearly, with the maximum outflow rate set as one when the PD is over 0.69.

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Figure 1: Impacts of asset price shocks on banks' liquidity through three channels

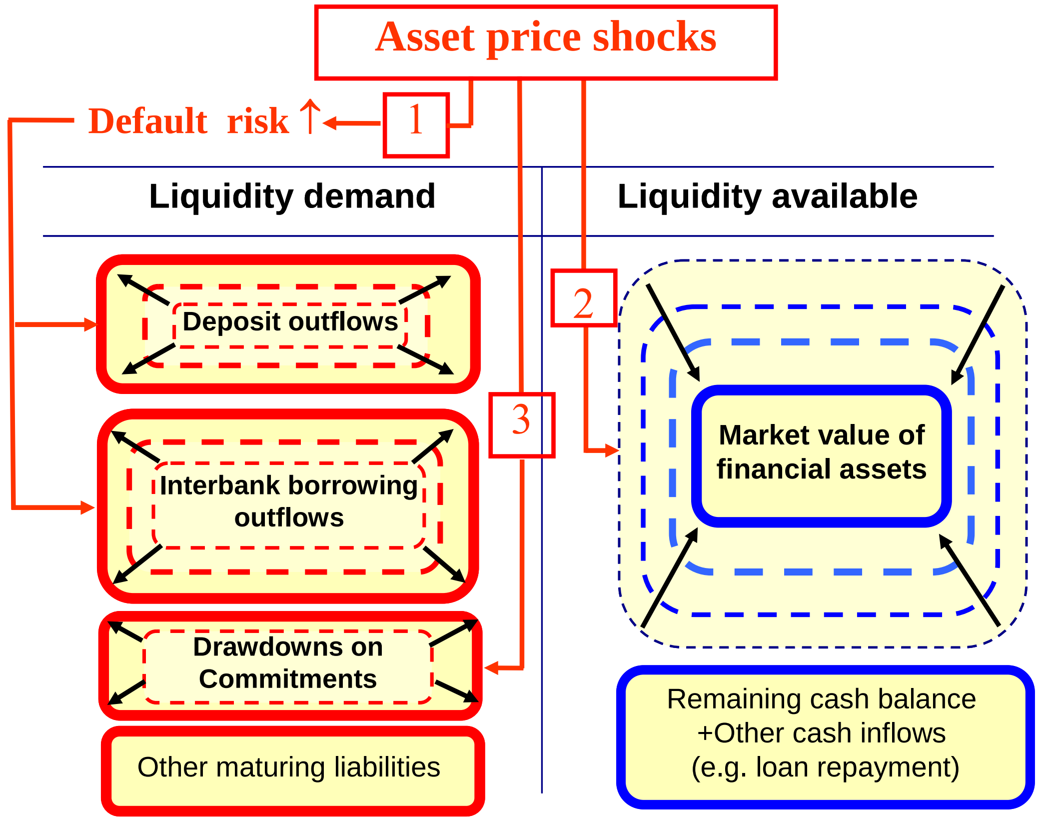


Figure 2: An illustrative example for simulations of the first cash shortage time and default time

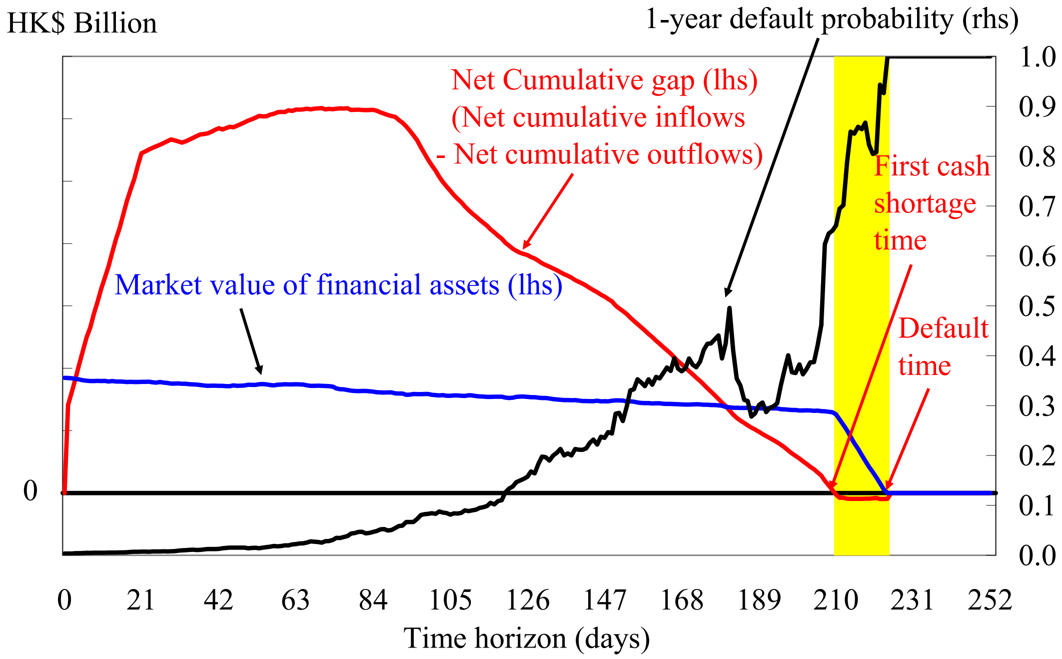
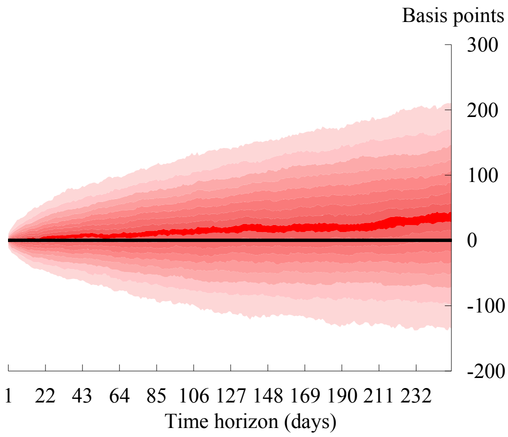
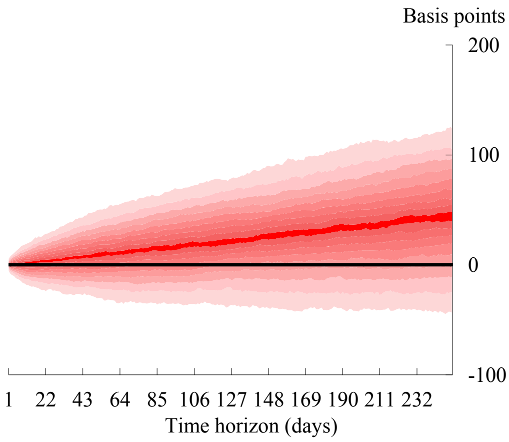


Figure 3: Simulated paths of exogenous asset price shocks

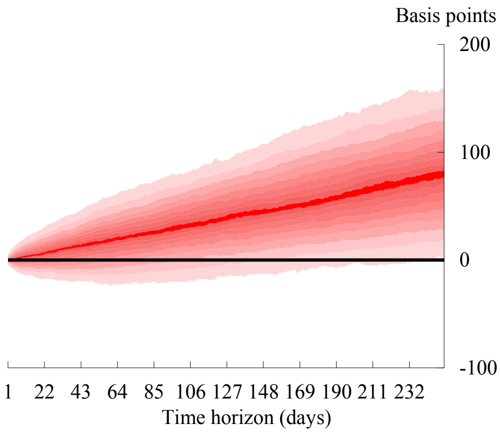
Panel A: Cumulative changes in credit spreads of non-financial corporate bonds with AAA credit rating



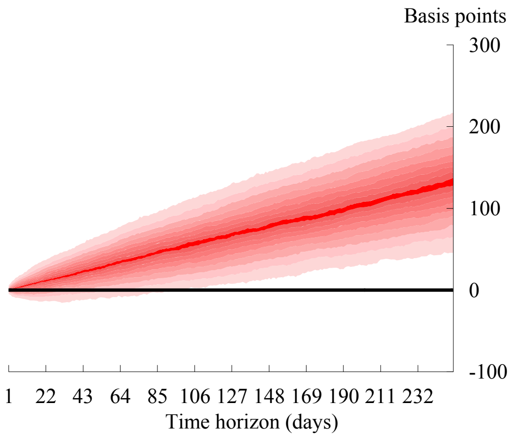
Panel B: Cumulative changes in credit spreads of non-financial corporate bonds with AA credit rating



Panel C: Cumulative changes in credit spreads of non-financial corporate bonds with A credit rating



Panel D: Cumulative changes in credit spreads of non-financial corporate bonds with BBB credit rating



Panel E: Cumulative changes in credit spreads of high-yield non-financial corporate bonds

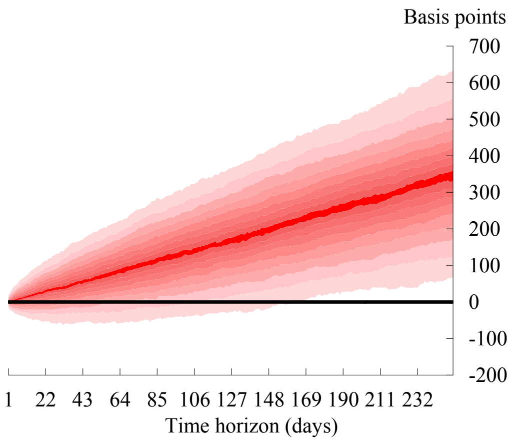
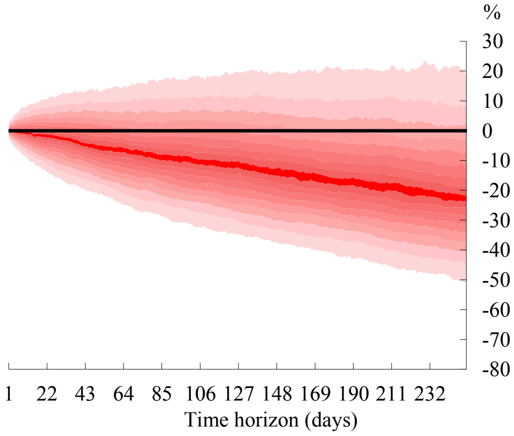
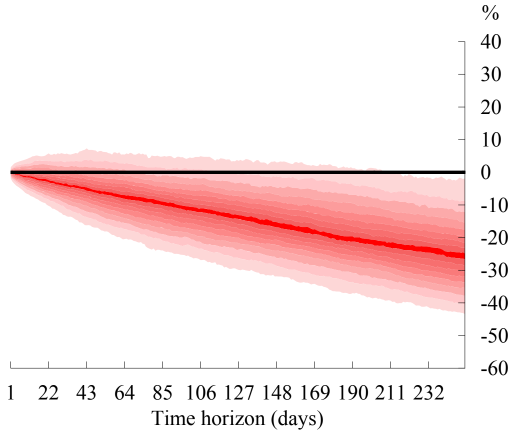


Figure 3: Simulated paths of exogenous asset price shocks (cont')

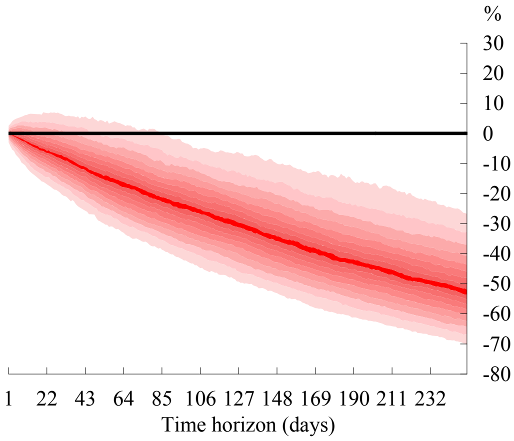
Panel F: Cumulative percentage changes in prices of Hong Kong equities.



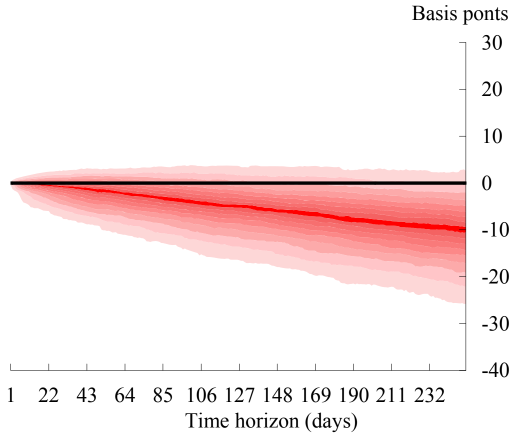
Panel G: Cumulative percentage changes in prices of non-Hong Kong equities.



Panel H: Cumulative percentage changes in prices of structured financial assets



Panel I: Cumulative changes in the interest rate in Scenario A.



Panel J: Cumulative changes in the interest rate in Scenario B.

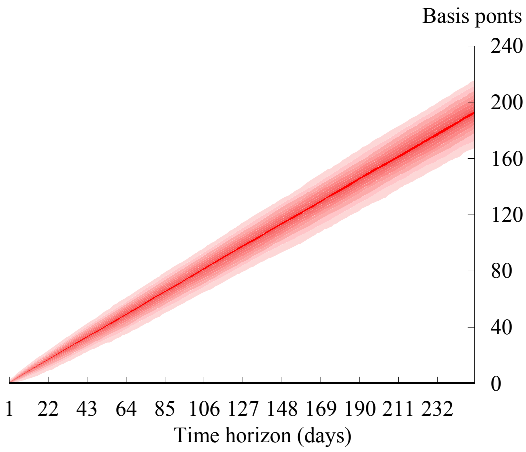


Table 1: Impacts of shocks on market value of banks' assets

Market value of assets ↓	Shocks	Proxies
1. Cash		--
2. Loans to customers ↓	PDs of customers↑	Classified loan ratio
3. Interbank lending ↓	PDs of other banks ↑	Endogenised banks' PDs
4. Financial assets		
(a) Debt securities issued by		
(i) Sovereigns ↓	Interest rate r_t ↑	USD LIBOR
(ii) Banks ↓	(a) Interest rate r_t ↑, (b) PDs of other banks ↑	(a) USD LIBOR (b) Endogenised banks' PDs
(iii) Corporate and others (by credit ratings) ↓	(a) Interest rate r_t ↑ (b) Expected default losses ↑ (el_t^{AAA}, el_t^{AA}, el_t^{A}, el_t^{BBB} and el_t^{HY})	(a) USD LIBOR (b) Credit spreads of corporate bonds (by credit ratings)
(b) Equities		
(i) Listed in Hong Kong ↓	P_t^{EHK} ↓	Hang Seng Index
(ii) Listed outside Hong Kong ↓	P_t^{EW} ↓	MSCI world equity index
(c) Structured financial assets ↓	P_t^{SFA} ↓	ABX index
(d) Others financial assets↓	P_t^{EHK} ↓ and P_t^{EW} ↓	Hang Seng and MSCI indices
5. Others		--

Table 2: Simulation results of Scenario B

Bank	Probability of cash shortage	Expected first cash shortage time[1] (days)	Probability of Default (due to liquidity problem)	Expected Default time[2] (days)
1	0.7%	249	--	--
2	5.4%	243	0.6%	247
3	51.3%	238	15.9%	244
4	53.7%	237	30.4%	241
5	84.7%	228	38.5%	242

Notes: (1) Conditional on an occurrence of cash shortage in simulations.
(2) Conditional on an occurrence of default in simulations.

Table 3: Simulated distribution of the number of bank defaults in Scenario B

Simulated number of bank defaults	Probability
= 0	61.1%
≤ 1	69.9%
≤ 2	84.2%
≤ 3	99.4%
≤ 4	100.0%