Essays on Financial Risk Management

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To my family.

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by

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Abstract

This thesis comprises three essays on systemic risk using a computational approach for the first two chapters and statistical analysis for the third.

Chapter 1 uses an agent-based model to determine whether the stability of a financial system can be improved by incorporating BCVA into the pricing of OTC derivative contracts. The results illustrate that the adjustments of financial institutions credit can not only improve the stability of financial counter-parties in credit events but can also reduce systemic risk in the entire network. The scale of the benefit is dependent upon the leverage of institutions and is significantly affected by connectivity and the premium of derivative contracts.

Chapter 2 investigates systemic risk in an agent-based model with collateral commitments. Market prices of collateral are calculated by optimisation functions of financial institutions' efficiency. The experiments indicate that the value adjustments (xVA) is more effective at eliminating financial systemic risk than by incorporating only BCVA. However, this effect is unclear in systems of weak infrastructure. The benefit of xVA is also reduced by large exogenous shocks. Similarly, the market prices of collateral decline under high leverage or large premiums because the reserves for value adjustments limit financial funding of counter-parties. Asset traders can only offer lower bid-ask prices.

Chapter 3 tests the effectiveness of Basel III liquidity standards to enhance the stability of the banking sector. The analyses provide significant evidence that the long-term liquidity regulation of NSFR exacerbates bank profitability and fragility, especially for large banks. Short-term liquidity standard, also known as LCR, has a positive influence on ROAA but a negative impact on bank risk-taking. Nonetheless, these effects are economically insignificant. The Basel III regulations are therefore ineffective at improving bank strength; indeed they reduce bank performance.

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Thesis Introduction

The weaknesses of Basel II contributed to the financial crisis of 2007. Basel II focused on protecting banks by regulating through capital requirements, and it missed the default correlations between corporations and banks. Defaults of financial institutions can trigger contagion through connectivity within financial systems and reduce the stability of the banking sector, as in the case of Lehman Brothers. Lehman was one of the four largest investment banks in the US and was believed too big to fail. However, Lehman's bankruptcy filling in September 2008 triggered the global crisis from the US market to European economies. Investors were forced to re-examine risk-taking of all financial entities without exception. There was a lot of research which studied bank risk-taking in lending markets, but risk exposures in derivative markets receive less attention. The first chapter of this thesis, therefore, aims to investigate the situation where investors incorporate creditworthiness of financial counter-parties in pricing their derivative transactions, in such case the question is raised on whether the stability of each financial institution is enhanced. Consequently, the whole system is strengthened. We use computational methods to build an agent-based model simulating the 2007 financial network in which, financial counter-parties connect to one another by Interest Rate Swaps (IRS) transactions. Systemic risks are simulated by a Monte Carlo approach on identical networks with and without counter-party credit risk and its value adjustments. The effect of accounting for financial counter-parties' creditworthiness is measured by the difference between default numbers in the two scenarios. The outcomes of experiments indicate that the equity cushion provided by credit value adjustments (BCVA) shields financial participants against unexpected losses and contributes to the stability of the entire network. This benefit is affected by the leverage of institutions, connectivity of the network and premium of derivative contracts. In particular, BCVA is more effective in a system with higher leverage. A more complete financial network may alleviate systemic failures by propagating the negative impact of institutions' insolvencies on others. However, greater connectivity acts as an effective channel to transfer expose from the defaulted financial institution(s) to others and then exacerbate systemic risk. Experimental evidence also emphasizes that if the shock is caused by a small premium, BCVA could reduce systemic failures significantly.

Collateral was applied as a helpful mechanism against unanticipated credit events although researchers pointed out some potential risks related to collateral commitments. Gregory (2015) proposed that these risks consist of the collateral's impact outside OTC derivative markets, market risk and the risk related to margin period, operational risk, legal risk, liquidity and funding liquidity risk. The major concerns of counter-parties who hold collateral are transaction costs to liquidate collateral within a time frame required and its discounted prices in credit events. Additionally, another liquidity risk comes if investors simultaneously sell their collateral that generates a large supply of assets resulting in a significant decline in the market price of the collateral. The exposures of creditors are more extreme. Furthermore, another aspect of being considered is the demand for funding to fulfil collateral requirements, especially segregated collateral. The same is kept in a separate account without interest rate return, and it can not be re-posted in another transaction. A financial institution may go insolvent due to the constraint on funding to meet its obligations of collateral before it goes bankrupt by exogenous shocks. Gregory described some value adjustments which can be used as a buffer against collateral's financial risks in an expectation to contribute towards financial institutions' stability and the strengthening of the whole system. The value adjustments, which consists of CVA, ColVA (Collateral Value Adjustment) and FVA (Funding Value Adjustment) are denoted by a term called xVA in the second chapter. In this chapter, systemic risk is examined by a Monte Carlo approach on the agent-based model without xVA. The simulation is then repeated for the identical financial network of the same financial entities but with a buffer equivalent to xVA. The effect of xVA against systemic failures is evaluated by the gap between two Monte Carlo simulations. Furthermore, we estimate the fluctuations of collateral market prices by developing a function to optimise financial institutions' benefits if they have to liquidate their assets. The results of chapter 2 provide evidence that the additional equity equivalent substantially eliminates systemic risk to xVA. This benefit is however, ineffective if the network infrastructure is not strong enough, *i.e.* the financial system has a small number of derivatives transactions between entities. A very loose network even exacerbates the systems fragility. Besides, the benefits of xVA are also reduced by large premiums. Although xVA is shown as an effective determinant in improving the financial system's stability, its cost is the decline in the assets' market prices, the role of xVA is hence critical.

The Basel Committee on Banking Supervision (BCBS) responded to the global crisis by the introduction of Basel III. It requires a higher buffer in the capital and new liquidity standards. The implementation of Basel III is expected to reduce liquidity risk exposes and at the same time, enhance bank stability. However, the new requirements on long-term and short-term liquidity can put BCBS's members into the limitation of liquidity funding. And if they can fulfil the new liquidity standards, their performance might be negatively affected due to the constraints of sources for possible financial investments. The third chapter is based on a panel of the banking sector in developed European countries from 2011Q1 to 2018Q4 to analyse banks' performance and their stability after the announcement of Basel III. The impacts of liquidity standards which are Net Stable Funding Ratio (NSFR) for long-term capital and Liquidity Coverage Ratio (LCR) for short-term capital are examined with other determinants of bank efficiency and strength to avoid bias estimations. The statistical results of Chapter 3 indicate that long-term liquidity standards not only reduces bank performance but also reduce bank stability. Though the requirement of short-term liquidity may have positive impacts on the bank risk-taking, the improvement is trivial. If a bank is a member of BCBS, such a bank is more stable compared to a non-member of BCBS, although both apply Basel III requirements. This chapter also supports prior literature in the impacts of bank-specifics and macro-economics on the banking sector.

Chapter 1

An Agent-Based Model of BCVA and Systemic Risk

1.1 Introduction

The 2007-8 financial crisis highlighted significant weaknesses in Basel II's treatment of derivative contracts. Basel II regulated the capital requirements for all loans from banks to corporations, but it did not consider the default correlations between corporations and banks. Lehman Brothers was regarded as a risk-free financial institution by most of its counter-parties, but it was allowed to fail on the 15^{th} of September 2008. This financial institution's collapse impacted not only the US market but also the economy of the EU. The global credit crisis forced investors to carefully evaluate the default possibility of all financial institutions.

This paper aims to understand the response to this issue; if financial institutions consider the creditworthiness of their counter-parties when pricing their derivatives contracts, is there an improvement in their stability and does the entire network become more stable? Whilst there is a significant amount of research focusing on systemic risk in lending markets, there is little that examines the impact of the deterioration of counter-parties' credit rating on systemic risk in derivatives markets. The rapid development of Basel standards after the global credit crisis poses the question of whether Credit/Debit Value Adjustment play a role in improving the stability of financial systems and to what extent. This paper thus examines the relationship between interconnected architecture and systemic risk in a financial network.

To study this question, we construct an agent-based model of the financial system in which financial institutions are connected by a network of derivative contracts. Changes in the values of these contracts result in payments between institutions. If these changes in value are larger than the capital of the associated institutions, they may force defaults. The failure of institutions potentially results in the spread of losses as institutions are no longer able to make their required payments pushing losses onto their counterparties. We consider this system with and without CVA and DVA price adjustments in order to understand how they affect market stability.

1.2 Credit Risk and Value Adjustments

Counter-party credit risk is the risk that each party in a transaction could suffer in the form of a loss from its counter-parties' failures before the expiration of their contracts. In an Over-The-Counter (OTC) derivatives market, the issue of counter-party credit risk is potentially serious. For example, in an Interest Rate Swaps (IRS) transaction, one counter-party agrees to pay a fixed rate per annum on a notional principal, and in return, the other counter-party agrees to pay a floating rate which can be based on, for example, the London Interbank Offered Rate (LIBOR). The time intervals at which payments are exchanged are initially specified by both parties. At the points of exchange, one counter-party receives a payment from the other depending on the value of the contract. Exposure can be to either the fixed-rate payer or the floating-rate payer (bilateral exposure).

Since 1999, large banks have started to incorporate Credit Value Adjustments (CVA) in order to evaluate the cost of counter-party risk. If the default probability of an entity increases, its counter-party faces an equivalent increase in credit risk if the entity is unable to pay its contractual obligations. The counter-party, therefore, needs to evaluate its credit risk and factor this into the pricing of contracts. This adjustment is referred to a CVA and is calculated form the downgrade of the entity's credit rank. At the same time, counterparties will be evaluating the institutions rating and applying similar changes in value to reflect changes in default probabilities. These too must be reflected in the price as Debt Value Adjustment

(DVA). Thus, the dual component of CVA - DVA - should both be considered when calculating the value of an asset. Beyond this, there are further components that increase or decrease the market values of contracts such as collateral agreements, initial margins, required capital etc. These elements should also be included e.g. Collateral Value Adjustment (ColVA), Margin Value Adjustment (MVA) and Capital Value Adjustment (KVA) etc. The set of these adjustments are referred to as xVA; however, in this paper, we focus just on the first two CVA and DVA. Below we set out the mechanism by which CVA and DVA are calculated.

1.2.1 CVA/DVA

CVA is the price of counter-party risk, *i.e.* the expected loss due to counter-party default(s) in the future (Gregory, 2010; Crepey, 2014). The market value of a derivative should therefore be:

$$\text{Market price} = \text{Fair price - CVA}$$

Gregory (2010) derived the efficient formula to compute CVA in the assumption of no wrong-way risk as follows:

$$CVA \approx (1 - \overline{\delta}) \sum_{j=1}^{m} B(t_j) EE(t_j) q(t_{j-1}, t_j) \tag{1.1}$$

where:

Loss Given Default, $(1 - \overline{\delta})$, gives the proportion amount of expected loss in default event.

Discount Factor, $B(t_j)$, denotes the risk-free discount factor at time t_j.

Expected Exposure, $EE(t_j)$, is calculated for the relevant dates in the future given by (t_j) for $j = 0, n \to m$.

Default Probability, $q(t_{j-1}, t_j)$, is the marginal default probability in the interval between date t_{j-1} and t_j.

However, unlike lending markets where the exposure is usually one-way or unilateral, i.e. in where lenders face the risk that borrowers could default but not the opposite situation, transactions in derivatives markets are two-way or bilateral, so both counterparties have credit risk from the default possibilities of others. This is why DVA needs to be considered as the cost of institutions' own risk when financial firms fail before maturity.

DVA can be understood as the contrasting component of CVA and *vice versa* (Green, 2016). Thus, in a bilateral derivatives contract with two counterparties A and B, the below equation can be reached:

$$CVA_A = DVA_B;\ CVA_B = DVA_A$$

Market value of a counter-party in a derivatives transaction is now equal to:

Market price = Fair price - (CVA + DVA)

The consideration of DVA in this paper is due to the requirement of international accountancy standard such as The Statement of Financial Accounting Standard (FAS) No. 157 in 2006 or the International Financial Reporting Standards 13 (IFRS) in 2013. Even though DVA is generally ignored in the market practice that will be discussed in the next chapter, the record of CVA and DVA is useful to explain the symmetrical concern on both counter-parties' defaults.

1.2.2 BCVA

The combination of CVA and DVA in pricing a derivatives contract is known as Bilateral Credit Value Adjustment (BCVA). A simplified approach by Pallavicini et al. (2011) combines both components into one concept of BCVA equal to:

$$BCVA = CVA + DVA$$

Gregory (2010) argues, however, that the counter-party credit risk of one institution is only a concern if the institution survives after its counter-party default. Therefore, Gregory's adjusted BCVA is derived under one further assumption of no simultaneous defaults. Brigo et al. (2011) also details this as:

$$BCVA \approx (1-\overline{\delta}) \sum_{j=1} B(t_j)EE(t_j)S_I(t_{i-1})q(t_{j-1},t_j) + (1-\overline{\delta}_I) \sum_{j=1} B(t_j)NEE(t_j)S(t_{i-1})q_I(t_{j-1},t_j) \tag{1.2}$$

where:

$S(.)$ and $S_I(.)$ are the survival probabilities of institution and counter-party, respectively.

q_I and $\overline{\delta}_I$ represent the default probability and recovery of the institution.

$NEE(t_j)$ denotes the negative expected exposure. That is the EE from the perspective of the counter-party.

1.3 Literature Review

Systemic risk in derivative markets is received less attention than interbank lending markets. The majority of the work that has gone on has focused on the role of the credit derivatives market in the financial crisis and the benefits of Central Counterparty clearing house (CCP) in reducing financial distress.

Bliss and Kaufman (2004) examined whether protective characteristics of derivatives transactions, such as netting, collateral and close-out, can reduce systemic risk. They found that the positive impacts are unclear because netting and collateral can increase systemic risk by permitting the concentration of risk in dealers. However, they may also decrease distress by giving dealers an effective tool to manage their counter-party risk and reduce unanticipated defaults. Meanwhile, close-out can be a potential source of systemic risk since applying close-out increases the difficulty of managing major insolvent dealers. Conversely, Ali and Vause (2016), Singh (2010) and Hull (2010) agreed that the OTC derivatives market is a potential source of systemic risk, but financial institutions can effectively manage counter-party risk by using bilateral netting or collateralisation agreements.

Kiff et al. (2009) and Russo (2010) argued that the credit derivatives market can increase systemic risk and the inter-connectedness of large financial institutions. A CCP can help to reduce systemic risk, however, the effectiveness of multiple CCPs is arguable. This proposal is supported by Zigrand (2010), Wellink (2010), Yavorsky (2010), as well as Cont and Minca (2014) who used network-based measures of systemic risk and demonstrated that the default of an entity in the CDS market exposes losses for both its counter-parties and protection sellers. If financial institutions do not have enough reserves to fulfil their CDS liabilities, the credit event also causes the bankruptcy of protection sellers and widens the default contagion. Nonetheless, if all major dealers join multilateral clearing with a CCP, the stability of the market can increase. Whilst, Borovkova and Mouttalibi (2013) concludes that a CCP can reduce the network's fragility but only for a homogeneous financial system; a CCP's presence can exacerbate contagion defaults for non-homogeneous financial networks, especially small financial firms.

1.4 Model

We construct a model of a financial system that is statistically similar to the real network that was in place before the global credit crisis in 2008. There were at least 8,000 counter-parties working in the American derivatives market at this time. They were connected to one another by approximately 1 million derivatives transactions, including interest rate swaps, foreign exchange, and credit default swaps. The total notional outstanding was approximately $800 trillion. It is not feasible to engage in computational simulation with such a significant number of repetitions on a network of 8,000 counter-parties, involving over 1 million derivatives transaction. Hence, this paper attempts to develop a similar financial network on a smaller scale. Similarly, we focus on a single type of deviate contract - interest rate swaps (IRS). This is because these contracts account for approximately 80% of the derivatives market (BISb, 2015).

1.4.1 Financial Network

Consider a closed-economy which comprising n risk-neutral financial institutions. Each financial institution has a stylised balance sheet comprising derivative contracts at their fair value (Y), capital (E) and a balancing term Residual Assets (A). The value of the derivative position can be positive, negative or zero depending upon the value of each derivative contract being an asset or liability for the institution. If Y is negative, the derivatives are a net liability - the bank owes more than it is owed. The residual assets term represent all other assets and liabilities, including customer deposits, cash and loan position through. Note, as the derivative position, and A can be positive or negative depending on the balance or the non-equity and derivative asset and liability terms. The expression of the stylised balance sheet is illustrated in Figure 1.1.

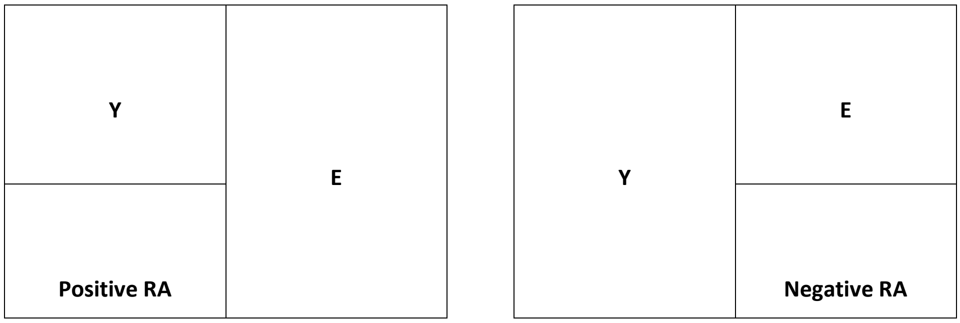

Figure 1.1: Stylised balance sheet

These figures are related through the following accounting equation:

$$E_i = Y_i + RA_i$$

The derivatives position of financial institution i, Y_i is comprised of the sum of its contracts with other financial institutions. The value of a contract between institution i and institution j is denoted by $y_{ij}^t = -y_{ji}^t$. If there is no contract between bank i and bank j then $y_{ij}^t = y_{ji}^t = 0$. The fair value of bank i's derivative position at time t is equal to $Y_i^t = \sum_{j=1, j \neq i}^n y_{ij}^t$. Note we do not specify that a given pair of banks have at most one derivative transaction connecting them, however, the sum of transactions between a pair of banks may be netted together to be considered as one single aggregate transaction. The set of derivatives contracts across all institutions forms a network in which nodes are financial institutions and edges are derivative positions.

1.4.2 Contracts and Payments

Each derivative contract has a floating rate and a fixed-rate payer. The fixed-rate is specified at the start of the simulation whilst the floating rate is determined in each time step. The net payment is the difference between these interest rates multiplied by the notional value of the contract. This value is transferred from the payer of the higher rate to that of the lower rate.

If one counter-party has a total amount of payables across all contracts which is larger than its sum of receivables, it has an excess obligation RA_i. If a financial institution has insufficient equity to cover the excess obligation, bank i is insolvent according to the default rule:

$$\text{Bank } i \text{ defaults when } E_i < RA_i \text{ where } RA_i = Payment - Receive$$

The loss from insolvency can negatively impact other financial institutions through the edges of the network leading to further insolvencies. Such insolvencies result in second round defaults. The chain of defaults from the first to the final failure is the financial contagion which is measured by the total number of insolvency.

1.4.3 Derivative Network

Define L_{ij}^t as the nominal liability of node i to node j at time t. Liabilities are non-negative and no counter-party has a claim against itself. Let p_i^t represent the total payment by counter-party i to other counter-parties at time t and define

$$p_i^t = \sum_{j=1}^{n} L_{ij}^t$$

The vector $p^t = \{p_1^t, p_2^t, ..., p_n^t\}$ represents the liabilities at time t of all financial institutions respectively.

Let Π^t denote the relative liability matrix which captures the proportion of the nominal liabilities by counter-party i to be paid to counter-party j , therefore:

$$\Pi_{ij}^t = \begin{cases} \dfrac{L_{ij}^t}{p_i^t} & \text{if } p_i^t > 0 \\ 0 & \text{otherwise} \end{cases}$$

Under equal priority of payments, the payment by counter-party i to counter-party j is $p_i^t \Pi_{ij}^t$. Thus the total payments received by node i are equal to $\sum_{j=1}^{n} \Pi_{ij}^t p_j^t$.

The fair value, or residual capital, of node i is the difference between the total payments from creditors and total payments from creditors which is equivalent to:

$$Y_i^t = \sum_{j=1}^{n} \Pi_{ij}^t p_j - p_i^t \tag{1.4}$$

Given the above, the fair value of each node is used to evaluate the stability of each counter-party and the system as a whole via the algorithm of Eisenberg and Noe (2001).

1.4.4 BCVA

We analyse the model with and without BCVA. In the presence of BCVA, the market value of the derivatives contract is equal to the price of a risk-free derivative minus BCVA.

$$\text{Market price} = \text{Fair price - BCVA}$$

$BCVA_i$ of financial institution i is the sum of the $bcva_i$ for all its transactions:

$$BCVA_i^t = \sum_{j=1, j\neq i}^{n} bcva_{ij}^t$$

In a derivative transaction between bank i and bank j, if bank j defaults, bank i suffers a loss which is equivalent to the payment from bank j to bank i. Conversely, if bank i is insolvent, bank j could not gain from bank i as its initial commitment. Therefore, the $bcva_{ij}$ is estimated by:

$$bcva_{ij}^t = \overline{\delta}_I \times receive_{ij}^t \times PD_j^t \times PS_i^t - \overline{\delta}_I \times payment_{ij}^t \times PD_i^t \times PS_j^t \qquad (1.5)$$

where: $\overline{\delta}_I$ is the recovery rate; $receive_{ij}$ is the receivable which bank i gains from bank j; $payment_{ij}$ denotes the payable which bank i pays to bank j. PD and PS are the respective probability of default and survival. The discounted interest rate in the original formula (1.2.2) is ignored because we focus on the determination of insolvency at a single point in time.

1.4.5 Parameters

In order to understand the effect of BCVA on market stability, we simulate the model. Parameters are assigned based on data prior to the last financial crisis in the period 2003 to 2007.

Exit price and duration

The notional values of the IRS contracts are randomly drawn from a uniform distribution with range 10,000 to 15 million currency units. Similarly, transaction durations are randomly drawn with uniform probability from a discrete distribution with intervals at three months ranging from six months to five years.

Fixed rate and floating rate

Fixed rates are randomly assigned from a continuous uniform distribution spanning 3.734% to 6.007% which is the range of average three-month LIBOR in the data window. Meanwhile, floating rates are drawn randomly from the uniform distribution with range 3.391% and 6.904%, reflecting the minimum and maximum LIBOR in the same period.

Credit spread and the probability of default

Credit spreads of financial institutions are assumed to be positive values which are normally distributed with a mean of 330 and a standard deviation of 500. The conditional probability of default in calculating CVA/DVA is then:

$$\bar{\lambda} = \frac{s(t)}{1 - \bar{\delta}_I} \tag{1.6}$$

where:

$s(T)$ is the credit spread for the maturity of T

$\bar{\delta}_I$ denotes the recovery rate which is assumed to be 40% for all financial institutions

$\bar{\lambda}$ is the the probability of first default between time 0 and time t of one counter-party. Later probabilities of default are calculated based on the first default probability.

Equity

Equity is randomly drawn from a continuous distribution with range 10,000 to 1 million currency units. However, the equity value of each counter-party is relevant to its credit spread. The formula (1.6) indicates that a higher credit spread implies a higher probability of default. An institution with a high default probability should not be endowed a large amount of equity. The connection between the probability of default and equity is a monotonic relationship.

1.5 Results

In order to estimate the impact of BCVA on systemic risk, we simulate systemic risk on the identical networks with and without BCVA. The difference between the numbers of defaults in the two scenarios is the effect of BCVA on systemic risk.

We use a Monte Carlo approach to evaluate how systemic risk happens in the without-BCVA condition. Contagion is triggered by a shock of interest rates. We draw a value of the floating rate interest rate from the distribution described above. Institutions face difficulties in fulfilling their obligations if their payables are larger than their own capital. Consequently, one or more insolvencies may occur. These are considered first-round insolvencies. After that, any financial institutions which are connected to the first defaulting institution are negatively influenced due to credit losses. These losses are equal in value to the payments not received from the defaulting institutions. Systemic risk is evaluated as the number of defaults from the second round until no more defaults occur.

The experiment is then repeated for the same financial network with the same financial institutions but with the addition of BCVA. The capital of financial institutions to cover credit risk can be either higher if CVA is larger than DVA or lower if CVA is less than DVA. The processes of applying the default rule and determining systemic risk are the same as with the non-BCVA simulation. The effect of accounting for BCVA in pricing derivatives on systemic risk is illustrated by the difference in default numbers between two Monte Carlo simulations.

1.5.1 Systemic Risk vs Leverage

The effect of the introduction of BCVA on systemic risk is demonstrated in Figure 1.2 across three levels of derivatives contract sizes: 15 million (Panel a), 30 million (Panel b) and 40 million (Panel c). Each case has the same level of equity. This configuration allows the effect of BCVA to be estimated across different levels of potential risk.

The results indicate that the stability of the financial network is improved by accounting for counter-party credit risk in pricing derivatives. The level of improvement is dependent upon the differences between the total notional principals of derivative contracts and the equity levels of financial institutions. The increased equity available within the system protects institutions against the failure of their counterparties. Larger exposures reduce the scale of this protection. Formally we test the hypothesis:

H_{0a}: Higher leverage results in a more fragile network

H_{1a}: Higher leverage does not result in a more fragile network

H_{0b}: Higher leverage reduces improvement of systemic risk caused by BCVA

H_{1b}: Higher leverage does not reduce the improvement of systemic risk caused by BCVA

Connectivity v.s. Systemic Risk in a network with differing levels of notional outstanding

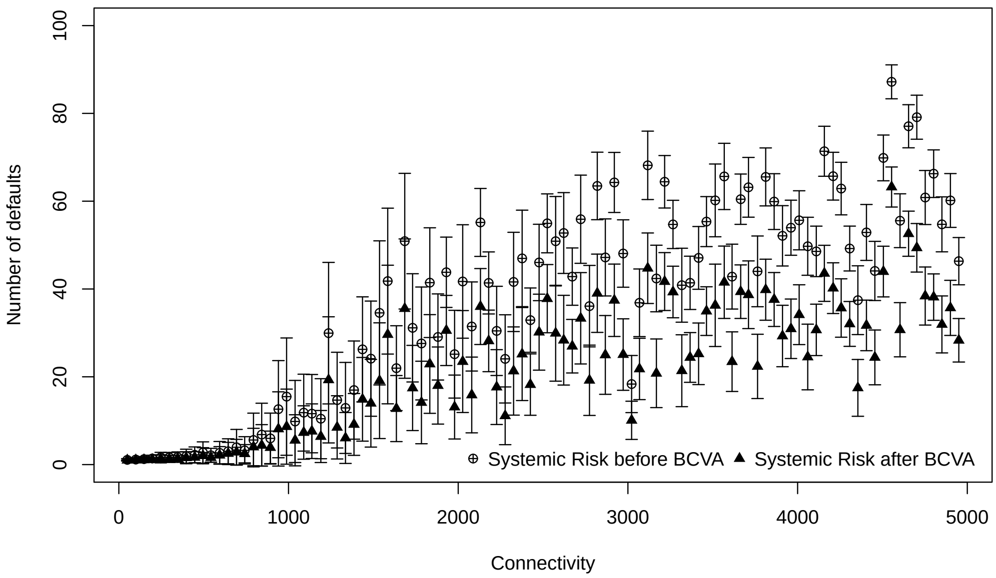

Figure 1.2a: Contract size from 10 thousand to 15 million currency unit

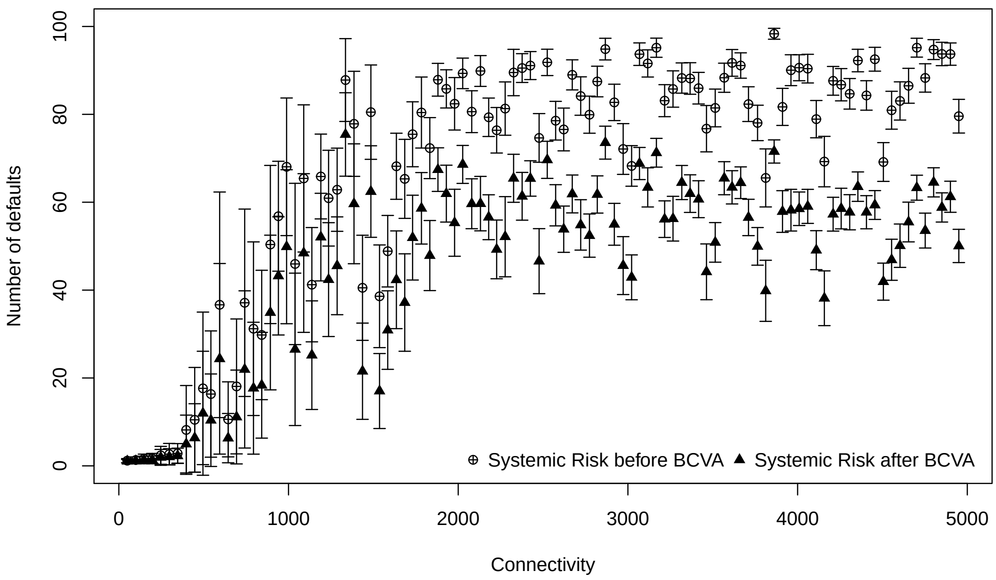

Figure 1.2b: Contract size from 10 thousand to 30 million currency unit

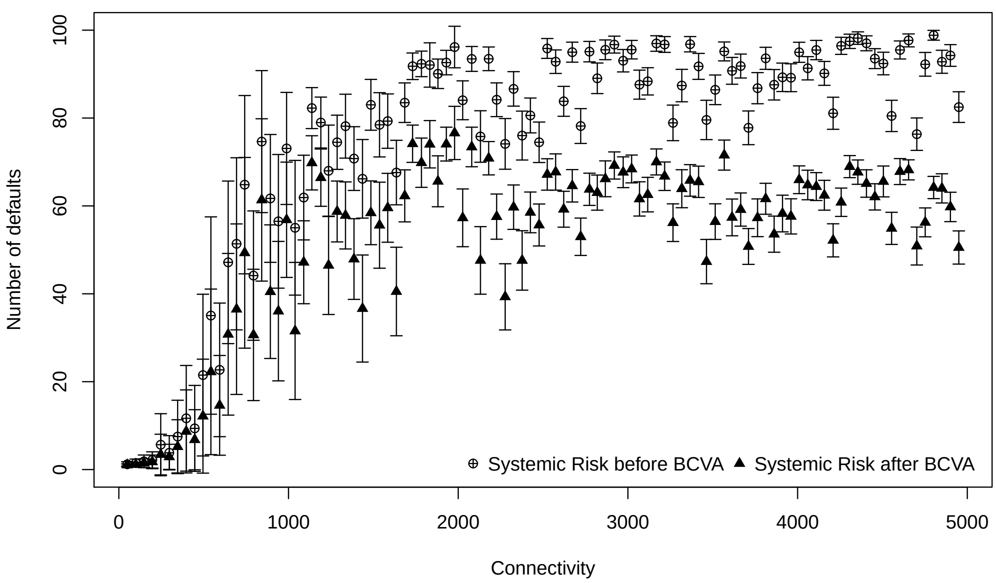

Figure 1.2c: Contract size from 10 thousand to 40 million currency unit

In both cases, the alternative hypotheses of H_{1a} and H_{1b} are rejected at the 1% significance level. Larger leverage leads to a more fragile system. Additionally, higher leverage reduces the role of BCVA in enhancing the stability of the system.

Whilst the effect of leverage was perhaps intuitive, we further investigate the impact on systemic risk caused by network structure (also known as connectivity) and premium (understood as the additional rate which floating-rate payers agree to commit with fixed-rate payers).

1.5.2 Systemic Risk vs Connectivity

Connectivity has been shown in numerous papers to affect systemic risk, e.g. Ladley (2013). We, therefore, examine the impact of connectivity associated with notional principals of derivatives contracts. Figures 1.2 and 1.3 display the effect of connectivity on systemic risk with two conditions for notional outstanding. The first, Figure 1.2 increases notional outstanding as the number of connections increases, in essence, adding more contracts to the market. The second fixes the notional outstanding as connections increase, in effect, dispersing or reducing the per connection contract size (Figure 1.3).

Connectivity v.s Systemic Risk in a network with fixed notional outstanding

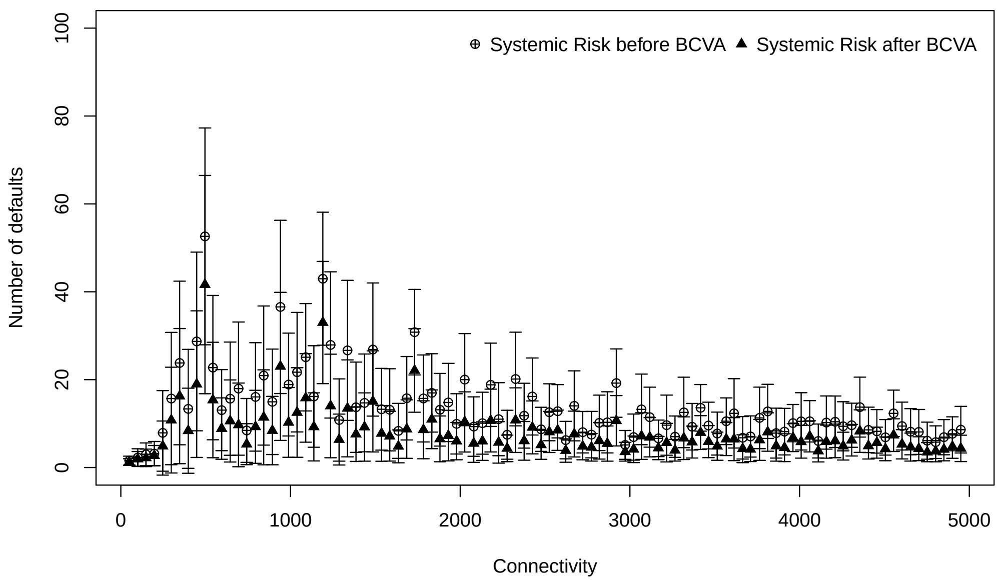

Figure 1.3a: Total notional outstanding of 2 million for entire network

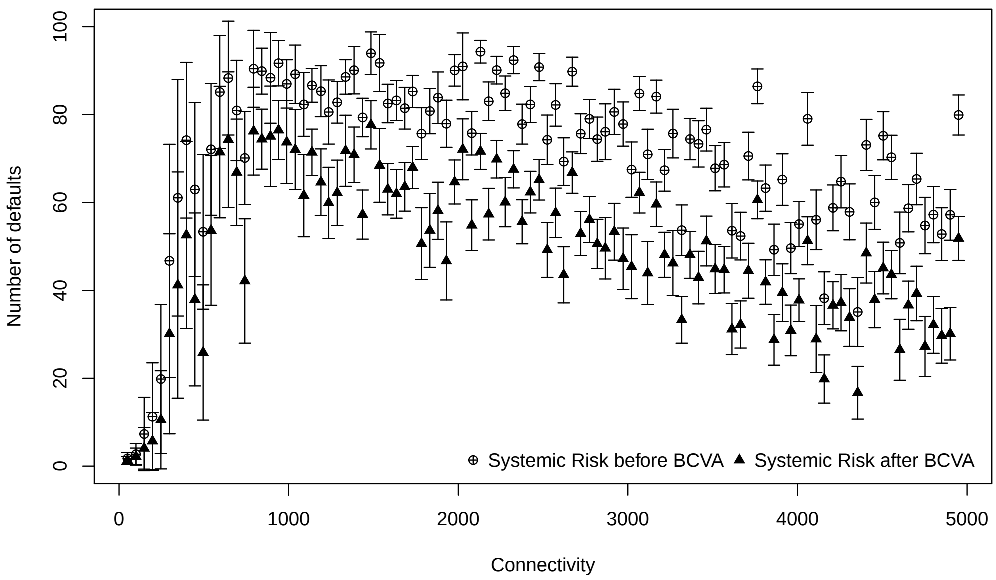

Figure 1.3b: Total notional outstanding of 15 million for entire network

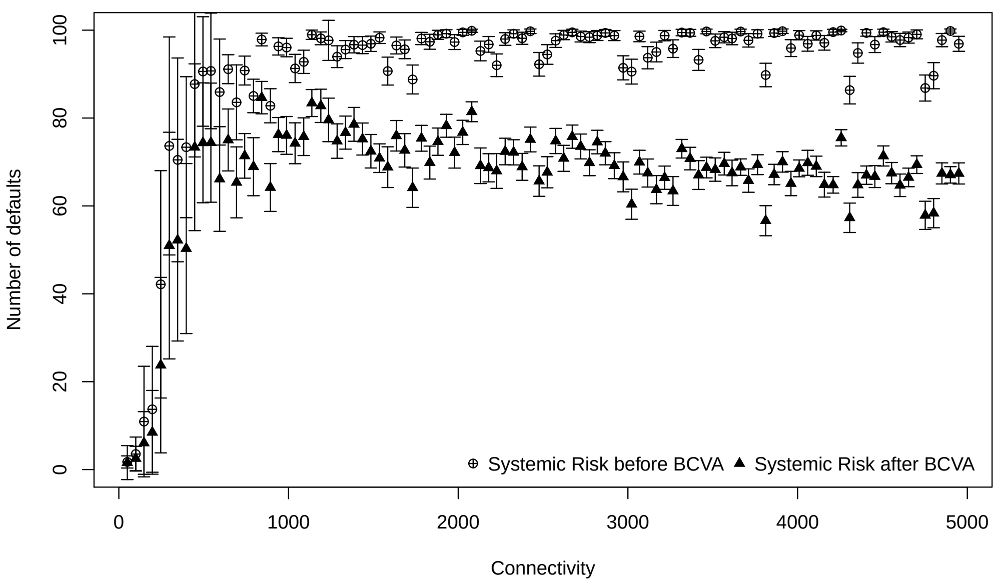

Figure 1.3c: Total notional outstanding of 100 million for entire network

Figure 1.2 a-c indicate that more connections lead to higher systemic risk. This finding supports work done by Blume et al. (2011) and Blume (2013). The shape of the relationship between connectivity and systemic risk changes, however, with the strength of connections between institutions. For relatively small contract sizes, systemic risk increases for the full range of connectivity's all the way up to a fully connected network. Each additional connection increases the risk of the spread of failures by bringing more capacity to spread shocks into the system. Increasing the levels of the contract size, however, changes the shape of this relationship. Figures 1.2b shows that the network saturates at approximately 2,500 connections, whereas for Figure 1.3 is saturated at a lower level. In these cases, larger contract sizes suggest that banks are more likely to fail and therefore spread further failures. As contract size increases the point at which all banks that can fail occurs with fewer connections due to the larger losses associated with each connection.

Although the above result is intuitive and speaks to the growth of these markets, it is also interesting to consider the effect of changing the structure of the market whilst holding the value of contracts constant. Such a change has often been discussed by regulators and commentators. These results are presented in Figure 1.3 and have a markedly different shape. The positive monotonic relationship between connectivity and systemic risk observed previously is no longer uniformly present. Whilst it is still the case that higher value contracts increase the number of failures observed connectivity also plays a role. For small contracts, failures are maximised for relatively small numbers of contracts; however, as contract size increases the maxima also increases. Notably, for intermediate size contracts, the relationship between connectivity and defaults is n-shaped. This pattern somewhat mirrors the results observed in Ladley (2013) and Acemoglu et al. (2015). Effectively, as shock size increases the network changes from being risk-spreading to failure-spreading. For small contract sizes, and therefore small shocks, the network spreads risk - as the network becomes better connected fewer institutions fail. As the contracts get larger, this relationship is replaced by the network acting to spread failures resulting in the peak in the distribution moving rightwards.

Both Figure 1.2 and 1.3 indicate that as the size of constricts increases, BCVA has a greater positive effect. In the case of higher notional principals of derivative contracts, a financial institution has to reserve more capital for its counter-party credit risk (BCVA). As a result the default probability of each financial entity decreases and the stability of the network is enhanced as it has greater loss-absorbing capacity.

1.5.3 Systemic Risk vs Premiums

In addition to the effect of leverage and connectivity, premiums also have a substantial impact on systemic risk. We consider and evaluate three levels of premium: 0.5%, 1% and 3%. The level of premium dictates the size of the payment owed from one counter-party to the other. Larger premiums equate to a larger gap - effectively a larger payment shock. Figure 1.4 illustrates the changes in systemic due to BCVA for different levels of premiums.

The results suggest that BCVA is more effective for smaller premiums. For markets with low connectivity, BCVA has little effect. It only starts to have an impact on greater numbers of connections. The higher connectivity results in shocks from failures being better spread, therefore allowing the BCVA to more effectively absorb the shock. More connections effectively lead to more BCVA reserves being available to absorb the failure. This benefit of BCVA, however, decreases as the strength of connections increases. Stronger connections limit the ability of BCVA to absorb the failures.

Premium v.s Systemic Risk

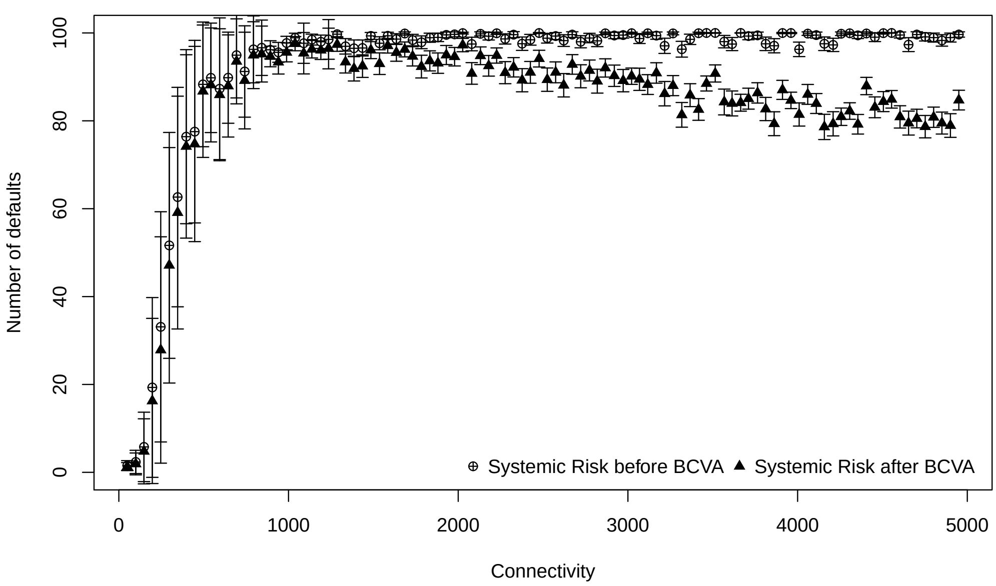

Figure 1.4a: 0.5% premium

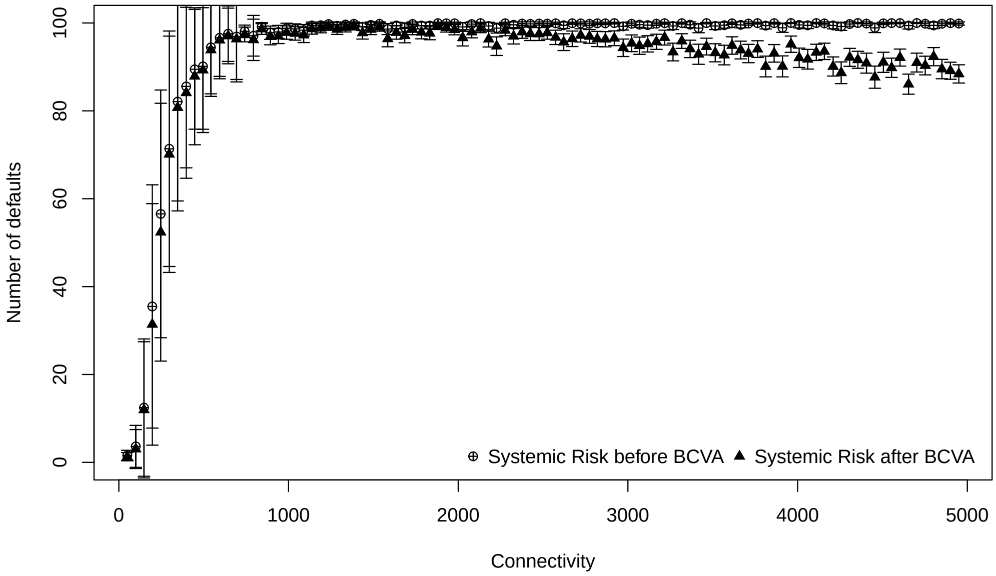

Figure 1.4b: 1% premium

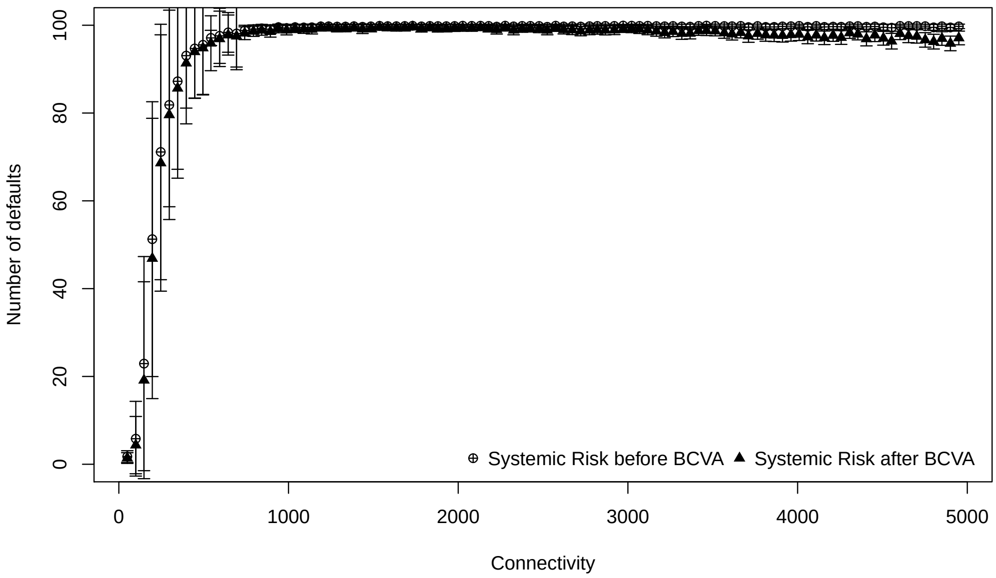

Figure 1.4c: 3% premium

1.6 Conclusion

Our paper is the first to analyse systemic risk in derivatives markets under the effect of xVA. This paper numerically analyses the fragility of a financial network before and after accounting for bilateral credit valued adjustments. The results illustrate that BCVA indeed has a positive influence on systemic risk of financial networks although its effect is dependent upon the leverage ratio in the network. In particular, the higher the leverage, the more effective the BCVA's impact. This paper provides evidence supporting the perspective that a more complete system which can propagate negative effects from one or more defaulting counter-parties to other entities reduces systemic failures. If shocks exceed a certain value, however, more interconnections do not reduce contagion but instead act to transfer effectively negative shocks from the financial institution(s) to others and widen systemic risk. Our results also highlight the possible improvement of systemic risk by BCVA if the variation of the premium is small enough.

In investors' perspective, applying bilateral credit value adjustment could be accepted since it is useful to enhance financial institutions' stability. However, this benefit might be not enough for policy-makers who care about the entire network's fragile because the risk of systemic failures is not completely eliminated. Thus, we examine more value adjustments by widening the financial network with collateral instruments in the next chapter.

Chapter 2

Systemic risk and collateral's market prices under xVA's treatment

2.1 Introduction

The previous chapter examined whether concern about a counter-party's creditworthiness can help improve the stability of the financial system. However, the financial network was built without collateral, which is a useful mechanism to mitigate counter-party credit risk, although there are some potential risks related to collateralisation. Collateral agreements actually convert counter-party credit risk to into other financial risks, for example, liquidity risk and funding liquidity risk (Gregory, 2015). If a counter-party is insolvent, the creditor will liquidate the collateral to cover the exposure. The creditor's main considerations are bid-offer prices and the volatility of the collateral's market price at that time. If the market price of the collateral is low and transaction costs are high, the creditor could not get enough to cover the loss. Additionally, if a significant amount of collateral is traded because of simultaneous bankruptcies, the supply of collateral in the market rapidly increases, which will substantially decrease asset values. Hence financial counter-parties suffer not only the loss because of high transaction costs to liquidate collateral but also the loss due to the decrease in market prices of collateral. Apart from the liquidity risk in the case of defaults, another financial risk is presented when a financial institution survives but does not have enough funding to meet collateral obligations. This is funding liquidity risk because the counter-party would borrow financial funds from financial markets. The costs of their loans might negatively affect their solvencies. This risk is more serious if the collateral is held separately and/or cannot be re-used in another financial transaction. This type of collateral raises a concern of funding limitations, which forces counter-parties into insolvencies due to their failures to meet collateral requirements. Similar to BCVA which is used to account for counter-party credit risk, the financial risks related to collateral agreements can be measured by some value adjustments such as Collateral Value Adjustment (ColVA) or Funding Value Adjustment (FVA). We used a term called xVA to describe the family of BCVA, ColVA and FVA.

This chapter aims to understand the impact of xVA on systemic failure in a derivatives market with the involvement of collateral agreements. The collateral's value adjustments are expected to improve the financial system's stability. However, the disadvantage of xVA is the shortage of capital funding, which either forces institutions into insolvencies or decreases their efficiency because funding for value adjustments is used as equity reserves instead of being invested in positive financial portfolios. The development of Basel III from BCVA to a family of xVA raises the first question of compared to BCVA, whether xVA provides financial institutions more positive protections and enhances the entire system. Furthermore, if contagion happens, a significant amount of collateral liquidated simultaneously will decline the collateral's market prices. The second question posed is how to determine the market volatility of asset prices during stress periods.

To solve the first question, we use a Monte Carlo approach to simulate systemic risks in a financial network based on an agent-based model in which connections between financial entities are derivatives transactions with collateral agreements. In each experiment, a counter-party goes bankrupt if it fails to pay its contractual commitments. The failures can be spread through the connectivity within the network. The simulations are repeated with and without the equity buffer provided by xVA. The difference between two Monte Carlo simulation represents the effect of xVA on network stability. We answer the second question of determining collateral's market prices during liquidation by determining the equilibrium of asset supply and demand. Suppliers are financial counter-parties who need to sell assets to meet their liabilities. Other institutions that pass their payment requirements will trade assets to maximise their benefits. We calculate the seller's needs and derive optimisation functions for buyers, then balance the supply and demand to determine the asset prices in the market.

2.2 Value Adjustment Family (xVA)

Apart from CVA/DVA, which are the terms used to evaluate the downgrade of a counter-party's credit rating, there are value adjustments in collateral agreements. Financial market participants apply three main types of collateral: initial margin, maintenance margin and variation margin. Initial margin (IM) is the amount of collateral required to open a position in a financial instrument. Maintenance margin (MM) is the minimum collateral required to keep the position open; the level of MM is usually less than the level of IM required. Because both IM and MM are segregated meaning that collateral receivers hold these deposits in separate accounts without paying interest, depositors face a cost to post these types of collateral. The terms to estimate these costs are called Margin Value Adjustment (MVA) and Collateral Value Adjustment (ColVA). If the requirements of IM and MM are the same, MVA and ColVA are duplicated. We, therefore, only apply MVA in our model. In contrast, the variation margin (VA) can be rehypothecated, which means that the collateral can be used by the creditor in another transaction. The rehypothecation provides benefits against funding cost. The collateral holders either suffer losses if they borrow funds with interest rates higher than the interest rate returns on his loans or gain benefits if the borrowing interest rates are less than the interest rates on the lending. Funding Value Adjustment (FVA) is used to estimate such costs/benefits.

2.2.1 Magin Value Adjustment (MVA)

The MVA of financial institution i at time t is calculated using the equation below. The value of MVA is always negative (-) because this is the cost of each financial institution for its deposit.

$$MVA_i^t = -\sum_{k=1}^{m} EIM_{i,k} \times [FC_{i,k}^t - s_{i,k}^{t,IM}] \times [d^t - d^{t-1}] \times S^t \tag{2.1}$$

where:

EIM_i^t is the expected IM of bank i in transaction k

$FC_{i,k}^t$ is the funding cost of posting the IM at time t

$s_{i,k}^{IM}$ is the remuneration of the IM at time t

$[d^t - d^{t-1}]$ is the duration that collateral is held

S^t is the joint survival probability of bank i and its counter-party (i.e., the probability that neither the party nor their counter-party defaults).

2.2.2 Funding Value Adjustment (FVA)

FVA includes Funding Cost Adjustment (FCA) and Funding Benefit Adjustment (FBA) as follows:

$$\begin{aligned} FVA_i^t &= -\sum_{k=1}^{m} EE_{i,k}^t \times FS_B^t \times [d^t - d^{t-1}] + \sum_{k=1}^{m} NEE_{i,k}^t \times FS_L^t \times [d^t - d^{t-1}] \\ &= FCA_i^t + FBA_i^t \end{aligned} \tag{2.2}$$

where:

$EE_{i,k}^t$ and $NEE_{i,k}^t$ are respectively expected exposure and negative expected exposure of financial institution i in the transaction k at time t

FS_B and FS_L represent the funding spreads for borrowing and lending at time t respectively.

Funding value adjustment can be either negative if the cost is higher than the benefit or positive if the cost is lower than the benefit.

2.2.3 DVA v.s FBA in derivatives

Recall the formula of DVA from Chapter 1:

$$
\begin{aligned}
DVA_i^t &= -CVA_i^t \\
&\approx (1-\overline{\delta}) \sum_{k=1}^{m} B^t \times NEE_i^t \times q_i^t
\end{aligned}
\tag{2.3}
$$

where:

Loss Given Default, $(1-\overline{\delta})$, gives the proportion amount of expected loss in a default event.

Discount Factor, B^t, denotes the risk-free discount factor at time t_j.

Negative Expected Exposure, NEE_i^t, is the payment which bank i could not pay to bank j in the transaction k if i defaults.

Default Probability, q_i^t, is the marginal default probability of bank i at time t.

Debit Value Adjustment is recognised as a benefit against the cost that bank i paid for its counterparty credit risk. The calculations of DVA and FBA both have the same term of NEE. Additionally, the multiplication of $(1-\overline{\delta}) \times q_i^t$ in the DVA estimation is equivalent to FS_L^t in the formula of FBA. Thus DVA and FBA are counted twice in the calculation of capital charge (Yi and Williams, 2010). Hence, we chose to remove the term of DVA to avoid the issue. Gregory (2015) agreed that DVA should not be counted as a part of CVA capital charge because first, DVA cannot be monetised when bank i defaults; if it is, financial institutions are motivated to make claims by going bankrupt, which is a moral hazard. Second, if a transaction is unwound which can be understood as closing a large or complex transaction out, two transactions with a counter-party are executed in which the values are equal but opposite; the DVA benefit from the unwound transaction is ignored in calculating the CVA charged of the replacements. Third, if investors attempt to exploit the benefits of DVA by hedging, they could make a long hedge on their own credit by selling Credit Default Swaps on themselves, which is impossible.

We, therefore, consider three main types of value adjustment included CVA, MVA and FVA to examine the effect of xVA in the financial system with collateralisation:

$$
xVA_i^t = CVA_i^t + MVA_i^t + FVA_i^t
$$

2.3 Literature Review

The role of collateralisation in reducing systemic risk in derivatives markets is debated. The work of Singh (2009) in a derivative system with Central Clearing Counterparties (CCPs) proposed that to mitigate systemic risk, financial firms should be required to post collateral regardless of the sizes of the banks and whether the collateral is rehypothecated or not. Raykov (2019) extended his research on US and Canadian futures markets during the credit crisis; his results illustrate that adequate collateralisation can enhance the stability of financial systems, and large financial institutions pay less for posting collateral than others.

However, instead of mitigating risk, the practical use of collateral can be the reason for more risks because firstly, not all assets posted as collateral are risk-free, even government bonds, which might lead to an unanticipated decrease in the market value of the collateral, reducing its utility. Secondly, collateralisation introduces the risk of moral hazard for creditors who transfer their emphasis from debtors' creditworthiness to collateral and then ease their requirements on loans' approval. Thirdly, the application of collateral in derivatives faces noticeable operational and legal risk which affect the collateral market's liquidity. Bliss and Kaufman (2005) conclude that it is unclear whether collateral has a positive effect in reducing systemic risk in the US derivatives markets. Schwarcz (2015) agrees that collateral is not useful protection against systemic risk. In the case of increasing concentrations of connectedness, collateralisation even exacerbates network fragility.

2.4 Model

A model of financial institutions connected by derivatives transactions is constructed. We simulate the model according to the real American financial market before the 2007-8 financial crisis. However, it is not practicable to apply computational approach on a financial system with approximately 8,000 counter-parties and more than 1 million derivatives transactions. We, therefore, reduce the size of the system and complicate the derivatives instruments by adding collateral agreements.

Obligations of financial institutions consist of contractual payments and collateral requirements. We use the value adjustments to measure the risk exposure related to counter-party credit risk and collateral, but there are other financial risks which are not accounted for. We, therefore, apply Value-At-Risk (VaR) to control other risk exposure of each institution's portfolio over the 3-month interval. Investors are confident that under stress markets for three months, they could not lose more than VaRs at given probabilities. The amount of VaR is used to calculate the reserve needed to cover other potential exposure besides the losses caused by collateral commitments. Therefore, at time $(t-1)$, each financial entity needs to prepare a reserve for time t, which is equivalent to the contractual payments plus VaR. If financial institution i lacks cash for its liabilities, the institution is forced to sell their assets until they reach adequate reserves. If they still face difficulties to fulfil their financial obligations after selling all their assets, they go bankrupt. In contrast, counter-parties who meet their liabilities may buy more assets to maximise their returns.

The failure(s) of insolvent institution(s) can trigger contagion within the network. We simulate the model by a Monte Carlo approach to determine how systemic risk happens without collateralisation. We then repeat the simulation but with the addition of collateral's value adjustment (xVA) to understand the response of the financial system. The difference between two simulations is the effect of xVA on systemic failures.

At each time t, the market prices of assets used as collateral change because of the different demands and supplies. We estimate the fluctuation of asset prices by deriving two equations. The first equation calculates the total amount of assets sold by counter-parties who need to meet their collateral's obligations. The second is an optimisation function to maximise the benefit of institutions that want to buy more assets. The balance between the assets' supply and demand is the market price of the collateral.

2.4.1 Contractual payments

A closed economy of one hundred risk neutral financial institutions denoted by $i = \{1, 2, ...100\}$ is considered. They connect to each other by IRS transactions with quarterly contractual payments. Let P_k denote the notional principal of an IRS contract between bank i and bank j. If bank i is a fixed-rate payer or floating-rate receiver, the payable and receivable of bank i at time t are respectively:

$$p_i^t = P_k \times r_0 \times T$$

and

$$r_i^t = P_k \times r_f \times T$$

where:

r_0 and r_f are fixed rate and floating rate respectively

$T = 0.25$ is the 3-month period k denotes the k^{th} contract

Denote $l_i^t = p_i^t - r_i^t$, bank i loses an amount of $(p_i^t - r_i^t)$ if $p_i^t > r_i^t$ and *vice versa.* Financial institution i has m IRS contracts with m other financial counter-parties $(m < n)$. Hence, if bank i is a fixed-rate payer, the total amount of bank i's losses or gains is:

$$L_i^t = \sum_{k=1}^{m} l_i^t = \sum_{k=1}^{m} P_k \times (r_0 - r_f) \times T \tag{2.4}$$

If bank i is a floating-rate payer, the total amount of bank i's gains or losses is:

$$L_i^t = \sum_{k=1}^{m} l_i^t = \sum_{k=1}^{m} P_k \times (r_f - r_0) \times T \tag{2.5}$$

If $L_i^t < 0$, financial institution i expects to gain an amount of L_i^t. Conversely, i has to prepare cash to pay its contractual payment of L_i^t if $L_i^t > 0$. Moreover, bank i also reserves more high liquid assets like cash for VaR, which is estimated in the next section.

2.4.2 Value At Risk (VaR)

Value-at-Risk is the loss level at which investors are X% confident that it will not be exceeded in a given period (Hull, 2008). Value-at-Risk is estimated based on the distribution of losses of bank i with the assumption that its losses are normally distributed with mean μ_i and standard deviation σ_i. Because each bank i trades a portfolio of m derivatives transactions, we first determine mean and standard deviation of institution i's losses in each transaction m. Then the portfolio's mean and volatility are estimated with each contract's weight.

The mean and standard deviation of losses in a single contract m are respectively calculated by:

$$\mu_{i,m} = \frac{\sum_{t=1}^{d_m} l_{i,m}^t}{d_m}$$

and

$$\sigma_{i,m} = \sqrt{\frac{\sum_{t=1}^{d_m}(l_{i,m}^t - \mu_{i,m})^2}{d_m}}$$

where d_m is the number of 3-month periods of contract m.

The mean and the standard deviation of bank i's portfolio loses are respectively determined by:

$$\mu_i = \sum_{m=1} w_{i,m}\mu_{i,m} \tag{2.6}$$

and

$$\sigma_i = \sqrt{\sum_{m=1} w_{i,m}^2\sigma_{i,m}^2 + \sum_{m=1}\sum_{h=1,h\neq m} w_{i,m}w_{i,h}cov(i_m, i_h)} \tag{2.7}$$

where:

$w_{i,m}$ and $w_{i,h}$ are the respective proportions of bank i's m^{th} and h^{th} positions in the portfolio

$\sigma_{i,m}^2$ is the variance of bank i's payments during contract m

$cov(i_m, i_h)$ is the covariance between the payments of bank i's contract m and contract h

With the standard normal percentiles and critical values, the 3-month VaR of bank i at $X\%$ is estimated by:

$$VaR_i = \mu_i + z_{X\%} \times \sigma_i \tag{2.8}$$

The above equation calculates the loss level VaR_i of bank i for a 3-month period that will not be exceeded with X percent probability.

2.4.3 Asset price without-XVA in a stress market

Each financial institution is endowed amounts of risk-less asset M_i^t and risky assets A_i^t initially. These amounts are uniformly distributed from a range of 10,000 to 1,000,000 currency units. Interest rates of risk-less assets and risky assets are r_C and r_A, respectively. At each time t, bank i can either face a loss if $E(L^{t+1}) > 0$ or receive a gain if $E(L^{t+1}) \leq 0$.

Positive expected loss $E(L^{t+1}) > 0$

A positive loss $E(L^{t+1}) > 0$ is the payable which institution i must pay at time $(t+1)$. Moreover, i needs to prepare a reserve of VaR against potential risks during stress markets. The total amount of cash required is:

$$C_i^t = E(L_i^{t+1}) + VaR_i \tag{2.9}$$

Compared to the amount of current risk-less asset M_i^t, there are two situations: (1) bank i lacks enough money M_i^t to cover the next payment $M_i^t < C_i^t$ and (2) bank i has sufficient reserves $M_i^t \geq C_i^t$.

Scenario 1 If $M_{i_1}^t < C_{i_1}^t$, bank i_1 will sell more risky assets to reserve more cash for the next payment. The amount of risky assets q_{A,i_1}^t should be sold at time t is:

$$q_{A,i_1}^t = \frac{C_{i_1}^t - M_{i_1}^t}{P_A^t}$$

or

$$q_{A,i_1}^t = \frac{[E(L_i^{t+1}) + VaR_i] - M_{i_1}^t}{P_A^t} \tag{2.10}$$

Bank i_1 is a supplier trading risky assets in the market. There are s_l bank i_1 providing asset A into the risky asset market. The total supply of risky asset S_1 in the first scenario is:

$$S_1 = \sum_{i_1=0}^{s_l} q_{A,i_1}^t = \sum_{i_1=0}^{s_l} \frac{[E(L_{i_1}^{t+1}) + VaR_{i_1}] - M_{i_1}^t}{P_A^t} \tag{2.11}$$

Scenario 2 If $M_{i_2}^t \geq C_{i_2}^t$, bank i_2 has enough cash to cover the next payment. Bank i_2 could consider to buy more risky assets to maximise its benefit assuming the interest return of a risky asset is higher than the value of the risk-less assets. The unit of risky assets which should be bought is determined by:

$$q^t_{A,i_2} = \frac{M^t_{i_2} - C^t_{i_2}}{P^t_A}$$

or

$$q^t_{A,i_2} = \frac{M^t_{i_2} - [E(L^{t+1}_{i_2}) + VaR_{i_2}]}{P^t_A} \tag{2.12}$$

Bank i_2 buys q^t_{A,i_2} risky asset to maximise its benefit R_{i_2}. With the assumption of no transaction cost, the return on bank i_2's assets is calculated based on the interest returns of risky assets and risk-less assets as follows:

$$max[R_{i_2}] = max\{r_A \times q^t_{A,i_2}; r_C \times [M^t_{i_2} - (E(L^{t+1}_{i_2}) + VaR_{i_2})]\} \tag{2.13}$$

where r_A and r_C are interest returns on risky assets and on risk-less assets, *i.e.* cash. If r_A ¿ r_C, i will use all exceed amount of cash to buy risky asset and *vice versa*.

There are d_l bank i_2 that are buyers in the market of risky asset, the total demand of risky assets will be:

$$D_1 = \sum_{i_2=0}^{d_l} q^t_{A,i_2} \tag{2.14}$$

Negative expected loss $E(L^{t+1}) < 0$

Negative expected loss means that bank j expects to receive an amount of $E(L^{t+1}_j)$ at time $t+1$; the expected risk-less asset of bank j's at time $t+1$ increases to the amount of $[M^t_j - E(L^{t+1}_j)]$. It needs to reserve cash only for the next VaR:

$$C^t_j = VaR_j \tag{2.15}$$

Similar to the case of positive expected loss, the situation is now that either (3) bank j does not have sufficient reserve $[M^t_j - E(L^{t+1}_j)] < |C^t_j|$ or (4) bank j has enough cash to cover the future payment $[M^t_j - E(L^{t+1}_j)] \geq C^t_j$

Scenario 3 If $[M^t_{j_1} - E(L^{t+1}_{j_1})] < C^t_{j_1}$, bank j_1 should sell more of risky asset A to reserve enough cash for its next payment. The amount of asset A sold by bank j_1 is:

$$q^t_{A,j_1} = \frac{C^t_{j_1} - [M^t_{j_1} - E(L^{t+1}_{j_1})]}{P^t_A}$$

The total supply of risky asset, which is sold by s_2 bank j_1 is:

$$S_2 = \sum_{j_1=0}^{s_2} q^t_{A,j_1} = \sum_{j_1=0}^{s_2} \frac{VaR_{j_1} - [M^t_{j_1} - E(L^{t+1}_{j_1})]}{P^t_A} \tag{2.16}$$

Scenario 4 If $[M^t_{j_1} - E(L^{t+1}_{j_1})] \geq C^t_{j_1}$, bank j_2 could buy $q^t_{j_2}$ units of the risky assets to maximise its benefit. The amount of risky asset and the function of maximising its benefit are respectively determined by the below equations:

$$q^t_{A,j_2} = \frac{[M^t_{j_2} - E(L^{t+1}_{j_2})] - C^t_{j_2}}{P^t_A}$$

or

$$q^t_{A,j_2} = \frac{[M^t_{j_2} - E(L^{t+1}_{j_2})] - VaR_{j_2}}{P^t_A} \tag{2.17}$$

Bank j_2 chooses to buy an amount of risky asset q^t_{A,j_2} to its maximise benefits or:

$$max[R_{i_2}] = max\{r_A \times q^t_{A,j_2}; r_C \times [(M^t_{j_2} - E(L^{t+1}_{j_2})) - VaR_{j_2}]\} \tag{2.18}$$

The total demand of the risky asset by d_2 bank j_2 is:

$$D_2 = \sum_{j_2=0}^{d_2} q^t_{A,j_2} \tag{2.19}$$

The market price of risky asset P^t_A is the price at which the total supply equals total demand:

$$S_1 + S_2 = D_1 + D_2$$

or:

$$\sum_{i_1=0}^{s_l}\frac{[E(L_{i_1}^{t+1})+VaR_{i_1}]-M_{i_1}^t}{P_A^t}+\sum_{j_1=0}^{s_2}\frac{VaR_{j_1}-[M_{j_1}^t-E(L_{j_1}^{t+1})]}{P_A^t}=\sum_{i_2=0}^{d_l}q_{A,i_2}^t+\sum_{j_2=0}^{d_2}q_{A,j_2}^t \tag{2.20}$$

Therefore, the price of risky asset P_A^t is determined by the equation below:

$$P_A^t=\frac{\sum_{i_1=0}^{s_l}[(E(L_{i_1}^{t+1})+VaR_{i_1})-M_{i_1}^t]+\sum_{j_1=0}^{s_2}[VaR_{j_1}-(M_{j_1}^t-E(L_{j_1}^{t+1}))]}{\sum_{i_2=0}^{d_l}q_{A,i_2}^t+\sum_{j_2=0}^{d_2}q_{A,j_2}^t} \tag{2.21}$$

where q_{A,i_2}^t and q_{A,j_2}^t are the results of the maximisation functions (2.13) and (2.18) with the constraints that q_{A,i_2}^t and q_{A,j_2}^t are integers and satisfy the equations of (2.12) and (2.17).

2.4.4 xVA

As explained in Section 2, the value adjustment family of each financial institution i is estimated by:

$$xVA_i^t=CVA_i^t+MVA_i^t+FVA_i^t \tag{2.22}$$

2.4.5 Credit Value Adjustment (CVA)

CVA of bank i at time t is estimated by:

$$CVA_i^t=\sum_{k=1}^{m}CVA_{i,k}^t=\sum_{k=1}^{m}LGD_{j,k}^t\times EPE_i^t\times PD_j^t\times PS_i^t \tag{2.23}$$

where $LGD_{j,k}^t$ is equal to 60%, and EPE_i^t is the payment from bank j to bank i. Bank j's probability of default PD_j^t at time t is:

$$PD_j^t=\frac{s_j^t}{LGD_j^t} \tag{2.24}$$

where s_j^t is bank j's 3-month credit spread. After the systemic failures during 2007-2009, investors seriously considered the role of value adjustments against the fragility of financial systems. Hence our objective is to test the hypothesis if the value adjustments are incorporated in pricing institutions' portfolios, whether the systemic risk happens and to what extent. We defined the form of credit spreads' distribution as well as the values of mean and volatility according to a histogram of the real 5-year credit spreads of US financial institutions during 2003-2007. Credit spreads are proposed to be positive values which are randomly drawn from a right-skewed distribution with a mean of 330 and a standard deviation of 500. Bank i's probability of survival PS_i^t will be equal to $(1 - PD_i^t)$.

Margin Value Adjustment (MVA)

The MVA of financial institution i at time t is estimated by:

$$MVA_i^t = \sum_{k=1}^{m} MVA_{i,k}^t = -\sum_{k=1}^{m} EIM_{i,k} \times [FC_{i,k}^t - s_{i,k}^{t,IM}] \times [d^t - d^{t-1}] \times S_k^t \quad (2.25)$$

The levels of Expected Initial Margin (EIM) are defined by BCBS (2013):

Duration	0-2 years	2-5 years	5+ years
Interest Rate Swaps	1%	2%	4%

Table 2.1: Standardised initial margin shedule

The remuneration of the IM $s_{i,k}^{t,IM}$ is randomly drawn from a continuous uniform distribution spanning from 3.734% to 6.007%. This is the range of average 3-month LIBOR from 2003 to 2007. The funding cost $FC_{i,k}^t$ is uniformly distributed based on the ranges of [3.391% and 6.904%] which is the minimum and maximum values of the same LIBOR data. Meanwhile, the joint survival probability of bank i and bank j is $S_k^t = 1 - PD_i^t \times PD_j^t$ where $PD^t(.)$ is estimated by formula 2.24.

Funding Value Adjustment (FVA)

The FVA of financial institution i at time t is determined by formula 2.26:

$$FVA_i^t = \sum_{k=1}^{m} FVA_{i,k}^t = \sum_{k=1}^{m} EE_{i,k}^t \times FS_B^t \times T - \sum_{k=1}^{m} NEE_{i,k}^t \times FS_L^t \times T \quad (2.26)$$

FS_B^t and FS_L^t are uniformly distributed based on the respective ranges of [3.391%

and 6.904%] and [3.734% to 6.007%]. The first range reflects the minimum and maximum values of 3-month LIBOR in the US market from 2003 to 2007, while the second is the average range of 3-month LIBOR in the data window.

2.4.6 Asset price with XVA in a stress market

The derivation is similar to the case of determining asset price without XVA in a stressed market, but the requirement of a cash reserve is now increased by the amount of XVA_i^t estimated by formula (2.22).

Positive expected loss $E(L^{t+1}) > 0$

The total cash required is now equal to:

$$C_i^{'t} = E(L_i^{t+1}) + VaR_i + XVA_i^t \tag{2.27}$$

Scenario 1 If $M_{i_1}^{'t} < C_{i_1}^{'t}$: bank i_1 should sell q_{A,i_1}^t units of risky asset A at time t:

$$q_{A,i_1}^{'t} = \frac{C_{i_1}^{'t} - M_{i_1}^{'t}}{P_A^{'t}} \tag{2.28}$$

The total supply of risky asset $S_1^{'}$ in the first scenario is:

$$S_1^{'} = \sum_{i_1=0}^{s_l^{'}} q_{A,i_1}^{'t} = \sum_{i_1=0}^{s_l^{'}} \frac{[E(L_{i_1}^{t+1}) + VaR_{i_1} + XVA_i^t] - M_{i_1}^{'t}}{P_A^{'t}} \tag{2.29}$$

Scenario 2 If $M_{i_2}^{'t} > C_{i_2}^{'t}$, bank i_2 should buy the amount of risky asset which is determined by:

$$q_{A,i_2}^{'t} = \frac{M_{i_2}^{'t} - C_{i_2}^{'t}}{P_A^{'t}} \tag{2.30}$$

where $q_{A,i_2}^{'t}$ is the result of a maximisation function of bank i_2's benefit:

$$max[R_{i_2}] = max[r_A \times q_{A,i_2}^{'t}; r_C \times (M_{i_2}^{'t} - (E(L_{i_2}^{t+1}) + VaR_{i_2} + XVA_{i_2}^t))] \tag{2.31}$$

The total demand $D_1^{'}$ of risky assets is:

$$D_1^{'} = \sum_{i_2=0}^{d_l^{'}} q_{A,i_2}^{'t} \tag{2.32}$$

Negative expected loss $E(L^{t+1}) < 0$

Financial institution i must now reserve cash for loss level and value adjustments:

$$C_j^{'t} = VaR_j + XVA_i^t \tag{2.33}$$

Scenario 3 If $[M_{j_1}^{'t} - E(L_{j_1}^{t+1})] < C_{j_1}^{'t}$, the unit of asset A which should be sold by bank j_1 is:

$$q_{A,j_1}^{'t} = \frac{C_{j_1}^{'t} - [M_{j_1}^{'t} - E(L_{j_1}^{t+1})]}{P_A^{'t}} \tag{2.34}$$

The total supply $S_2^{'}$ of the risky asset is:

$$S_2^{'} = \sum_{j_1=0}^{s_2^{'}} q_{A,j_1}^{'t} = \sum_{j_1=0}^{s_2^{'}} \frac{(VaR_{j_1} + XVA_{j1}^t) - [M_{j_1}^{'t} - E(L_{j_1}^{t+1})]}{P_A^{'t}} \tag{2.35}$$

Scenario 4 If $[M_{j_2}^{'t} - E(L_{j_2}^{t+1})] > C_{j_2}^{'t}$, $q_{j_2}^{'t}$ units of risky asset are bought:

$$q_{A,j_2}^{'t} = \frac{[M_{j_2}^{'t} - E(L_{j_2}^{t+1})] - C_{j_2}^{'t}}{P_A^{'t}} \tag{2.36}$$

where $q_{A,j_2}^{'t}$ is determined from the maximisation function of bank j_2's return:

$$max[R_{j_2}] = max[r_A \times q_{A,j_2}^{'t}; r_C \times ((M_{j_2}^{'t} - E(L_{j_2}^{t+1})) - (VaR_{j_2} + XVA_{j_2}^t)] \tag{2.37}$$

The total demand $D_2^{'}$ of risky asset is:

$$D_2^{'} = \sum_{j_2=0}^{d_2^{'}} q_{A,j_2}^{'t} \tag{2.38}$$

The market price of risky asset A at equilibrium is:

$$
\sum_{i_1=0}^{s_l^{'}} \frac{[E(L_{i_1}^{t+1}) + VaR_{i_1} + XVA_i^t] - M_{i_1}^{'t}}{P_A^{'t}} + \sum_{j_1=0}^{s_2^{'}} \frac{(VaR_{j_1} + XVA_{j1}^t) - [M_{j_1}^{'t} - E(L_{j_1}^{t+1})]}{P_A^{'t}}
$$
$$
= \sum_{i_2=0}^{d_l^{'}} q_{A,i_2}^{'t} + \sum_{j_2=0}^{d_2^{'}} q_{A,j_2}^{'t} \tag{2.39}
$$

Therefore, the price of risky asset with xVA under a stress market is:

$$
P_A^{'t} = \frac{[(E(L_{i_1}^{t+1}) + VaR_{i_1} + XVA_i^t) - M_{i_1}^{'t}] + [(VaR_{j_1} + XVA_{j1}^t) - (M_{j_1}^{'t} - E(L_{j_1}^{t+1})]}{\sum_{i_2=0}^{d_l^{'}} q_{A,i_2}^{'t} + \sum_{j_2=0}^{d_2^{'}} q_{A,j_2}^{'t}} \tag{2.40}
$$

where $q_{A,i_2}^{'t}$ and $q_{A,j_2}^{'t}$ are respectively the results of maximisation functions (2.31) and (2.37) with the constraints that $q_{A,i_2}^{'t}$ and $q_{A,j_2}^{'t}$ are integers and satisfy the equations of (2.30) and (2.36).

2.5 Results

To understand the role of xVA in enhancing a financial system's stability, we simulate systemic risk before and after applying the xVA capital requirement. The difference between default numbers in the two scenarios is the effect of xVA on systemic risk. Furthermore, we investigate the role of leverage, network infrastructure and premium in improving systemic risk by changing their levels in each simulation. Additionally, we estimate the risky asset's prices under stress markets to determine how the price of the asset fluctuates with and without collateral's value adjustments.

Simulation of systemic risk without xVA We trigger the contagion by the first failure of a financial institution which is randomly assigned. The institution's capital is inadequate to meet obligations. Financial entities that connect to the insolvent institution are negatively affected due to the lacks of repayments from their counter-parties. The consequence is one or some failure(s) in the first round. The contagion is widened due to more defaults of financial entities that connect to the insolvent institutions in the first round. The chain of failures may spread through the network connectivity until no more defaults occur.

Simulation of systemic risk with xVA The experiment is repeated in an identical system but with the involvement of collateral commitments. The financial institutions' equities are added amounts equivalent to their value adjustments. This additional capital is expected to provide counter-parties a greater buffer against potential losses. As such, we consider a upper bound for the effectiveness of xVA, systemic risk is simulated by the same Monte Carlo approach to evaluate how the system reacts to the same difficulties.

Both Monte Carlo simulations are repeated one thousand times at each point of time and at each level of connectivity. The final result is the average of the thousand outcomes. The range of connectivity is from a minimum of 30 derivatives and a maximum of 4,950 contracts between 100 financial counter-parties. We also change the level of leverage between the notional principal and equity of each financial counter-party and the gap between fixed rate and floating rate to determine how they affect systemic risk in both cases with and without the family of xVA.

2.5.1 Effect of xVA on Systemic Risk

The effects of xVA on the financial system's stability and the market prices of collateral are tested under the changes of three determinants, namely leverage, network infrastructure and premiums. This chapter determines the leverage as the ratio between the notional outstanding of each institution's derivatives and its equity. The number of derivative contracts measures the concentration of network infrastructure. The premium is understood as an additional gap between fixed rates and floating rates.

Leverage

Figure 2.1 illustrates the same level of equity but with three levels of total notional principal for each financial institution. The ratios between equities and notional outstanding are considered at three levels: 1:10 (Panel a), 1:20 (Panel b) and 1:40 million (Panel c).

The graphs demonstrate that the system becomes more fragile under the treatment of higher leverage, but accounting for xVA capital requirements is effective to eliminate the systemic failures in all scenarios. The higher leverage generates greater exposure if unexpected events happen. The exposure spreads through the connectivity between financial institutions and makes them unstable. The additional equity equivalent to collateral's value adjustments now works as a cushion against higher contractual payments, so contagion is cut off.

Systemic Risk in a network with differing levels of notional outstanding

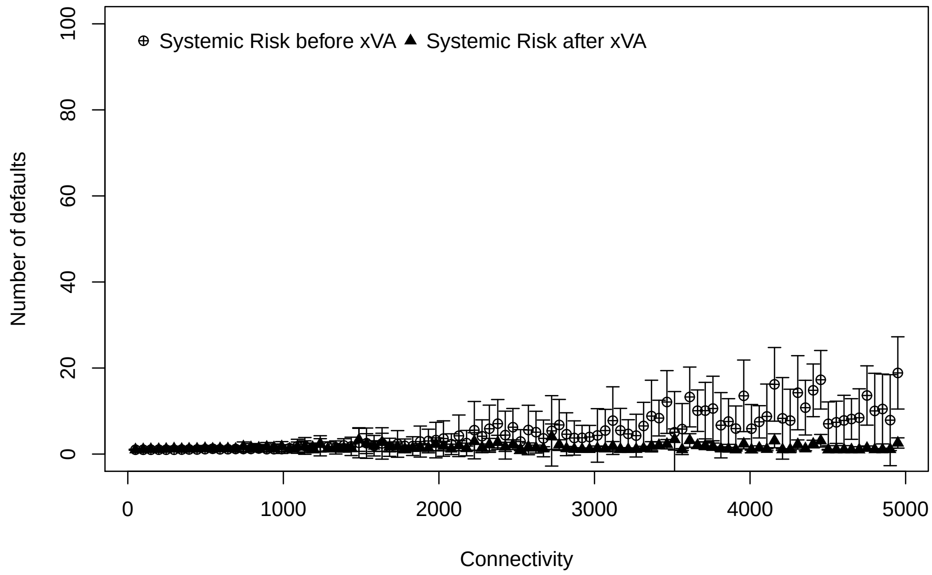

Figure 2.1a: Leverage 1. Contract size from 10 thousand to 10 million currency unit

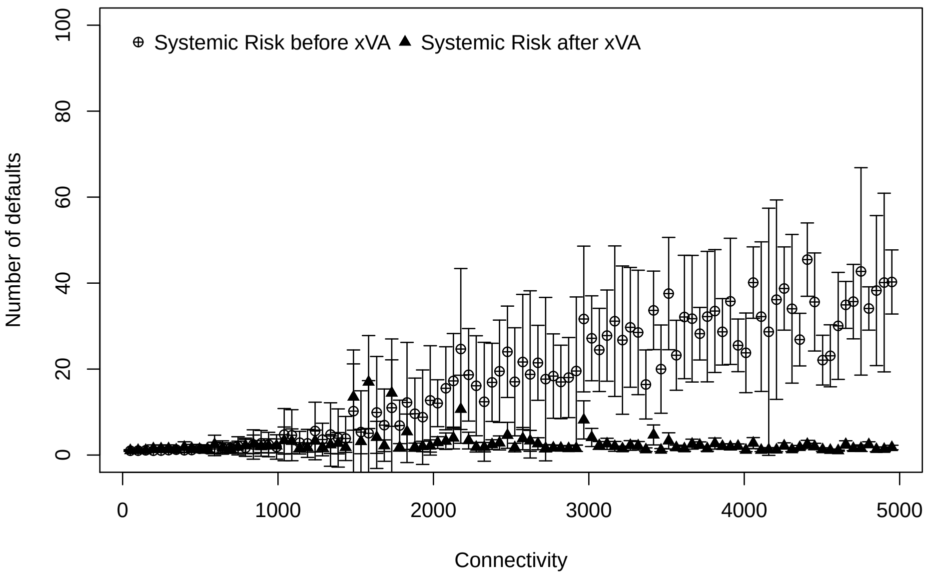

Figure 2.1b: Leverage 2. Contract size from 10 thousand to 20 million currency unit

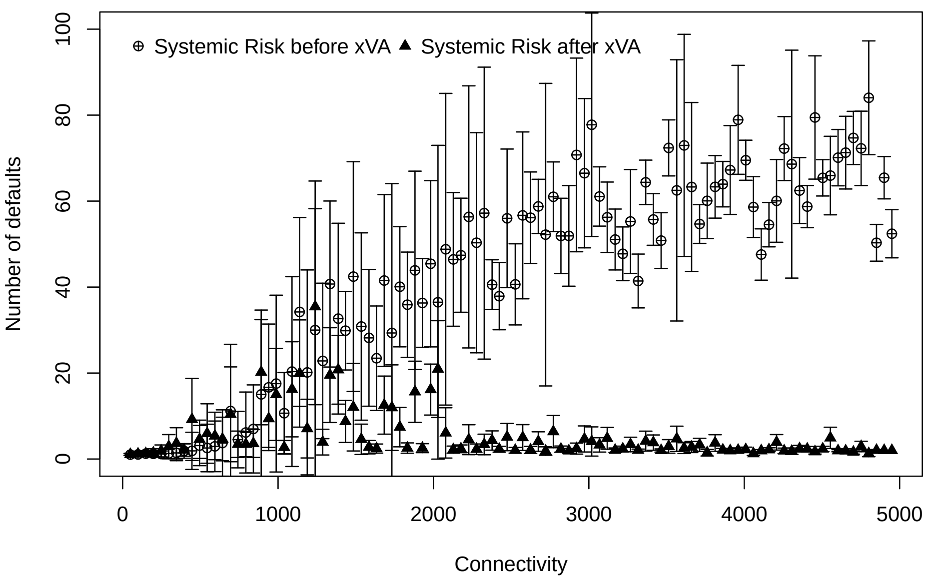

Figure 2.1c: Leverage 3. Contract size from 10 thousand to 40 million currency unit

Nevertheless, the ability of the xVA family to reduce systemic failures is only transparent if the network infrastructure is strong enough. Panel b and c of Figure 2.1 indicate that at some levels of weak connectivity, *i.e.* the total number of derivatives transactions in the systems is small; the systemic risk is more serious although the value adjustments are incorporated. Particularly, the opaque effectiveness of xVA is recognised in the range from approximately 1,000 to 2,000 transactions at leverage two and lower than 1,000 at leverage 3.

The reason why we need to carefully examine the effectiveness of the xVA family in improving networks' stability is that systemic risk is considered as a risk with (very) low frequency but (very) high severity. Investors should be worried if there is any small chance of contagion. Nonetheless, counter-parties who apply the value adjustments into their reserves have to pay greater costs which decrease not only their performance but also their stability, which also deteriorates financial networks. Therefore we focus on the details of the systemic risk before and after xVA for the first 3,000 connections of each leverage level in Figure 2.2, Figure 2.3 and Figure 2.4. Panels a, b and c respectively represent the numbers of defaults in the system from 0 to 1,000, from 1,000 to 2,000 and from 2,000 to 3,000 derivatives.

Systemic Risk in a network of 10-thousand-to-10-million notional outstanding

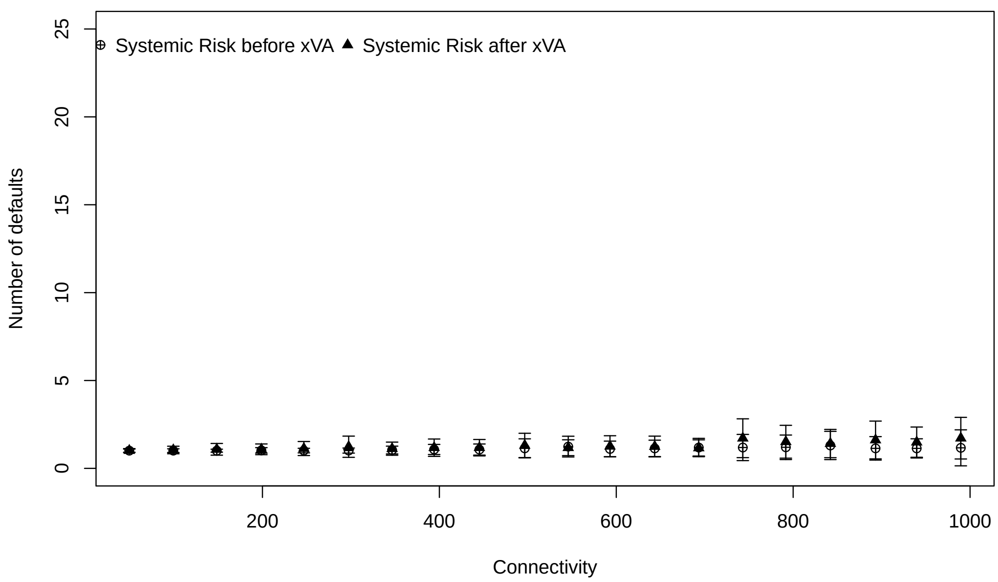

Figure 2.2a: First 1000 connections at leverage 1

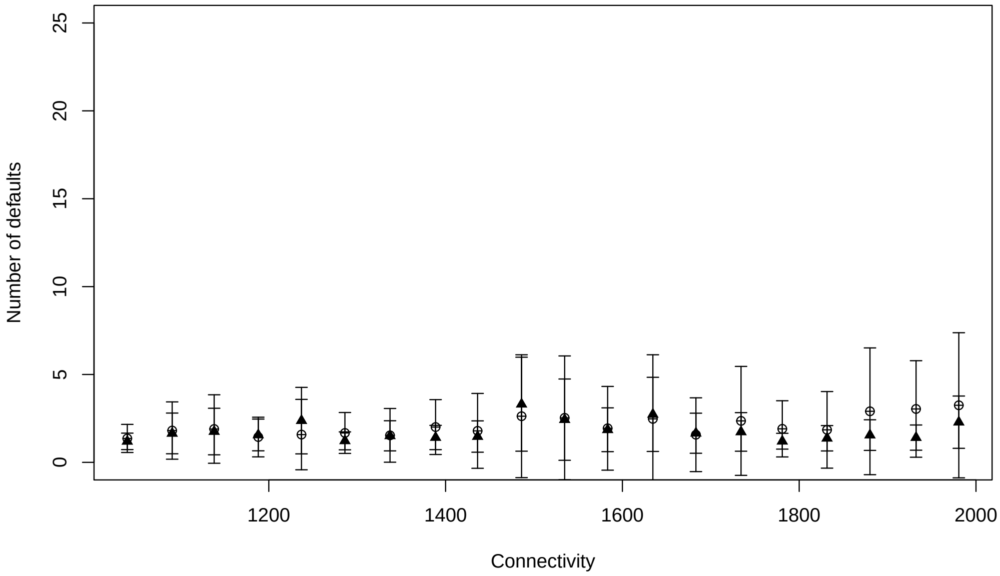

Figure 2.2b: Second 1000 connections at leverage 1

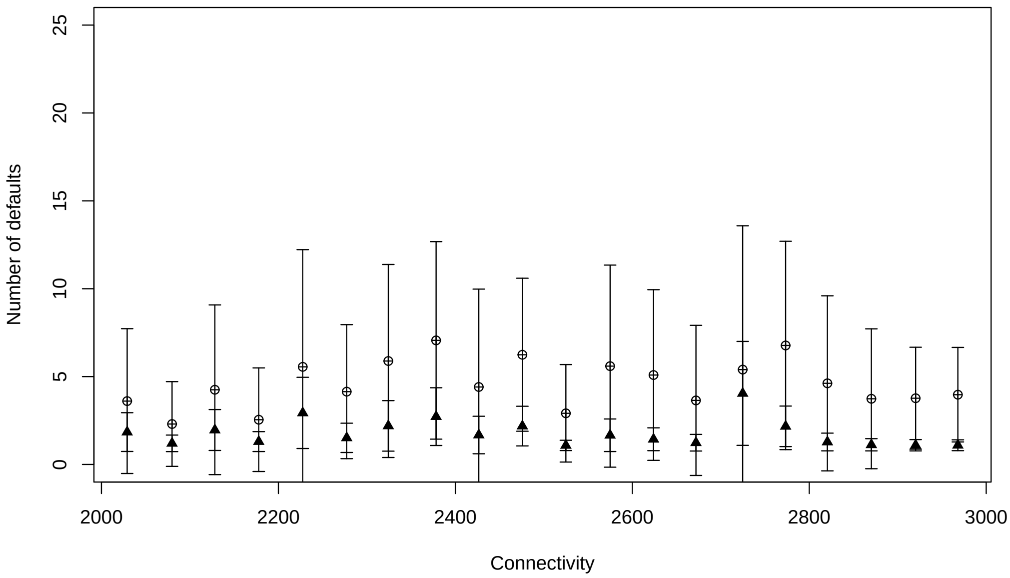

Figure 2.2c: Third 1000 connections at leverage 1

Systemic Risk in a network of 10-thousand-to-20-million notional outstanding

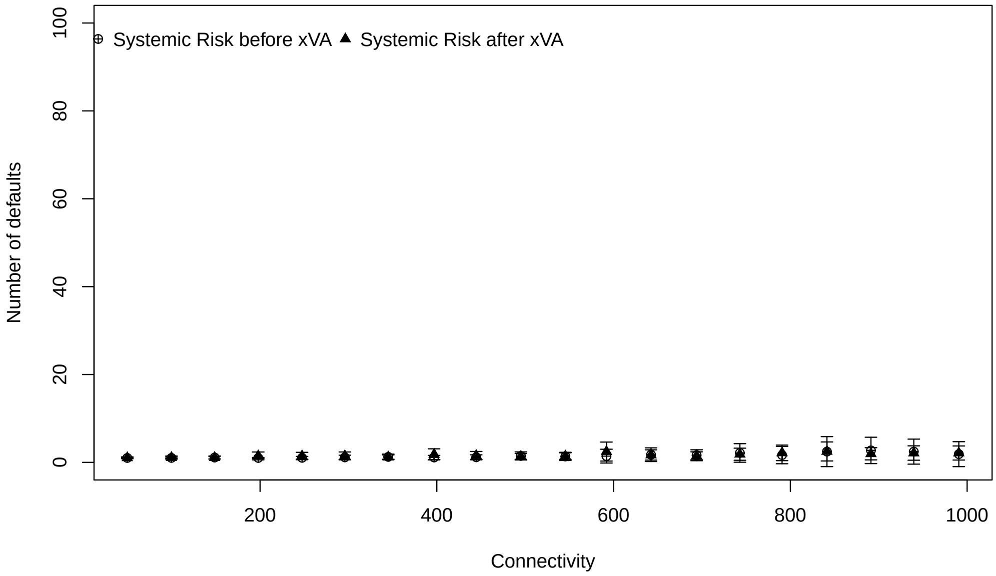

Figure 2.3a: First 1000 connections at leverage 2

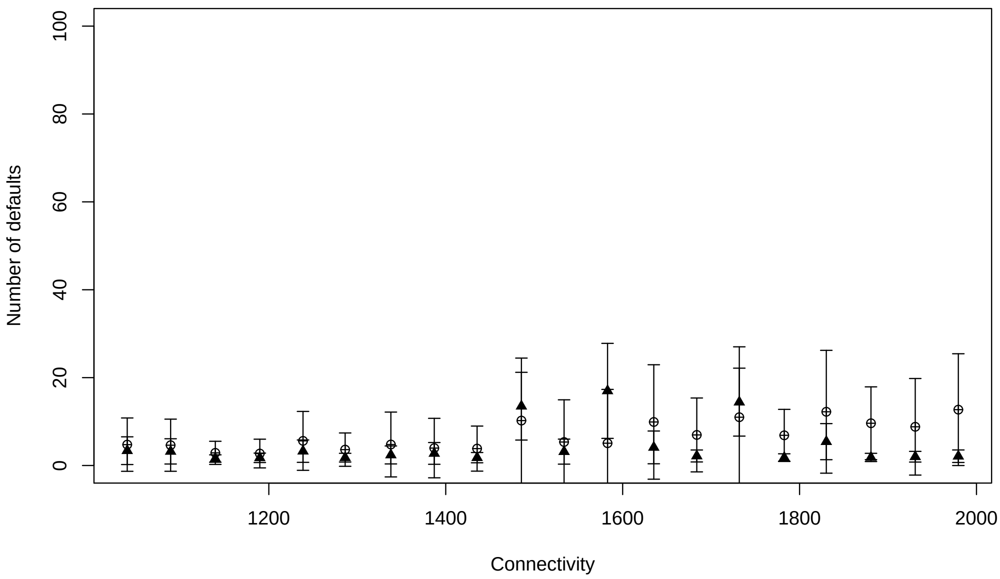

Figure 2.3b: Second 1000 connections at leverage 2

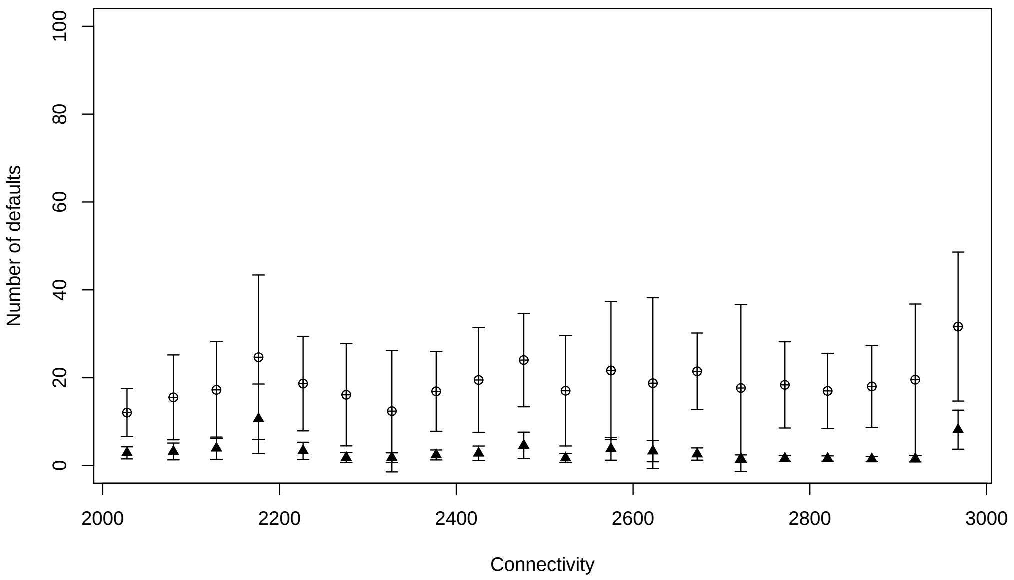

Figure 2.3c: Third 1000 connections at leverage 2

Systemic Risk in a network of 10-thousand-to-40-million notional outstanding

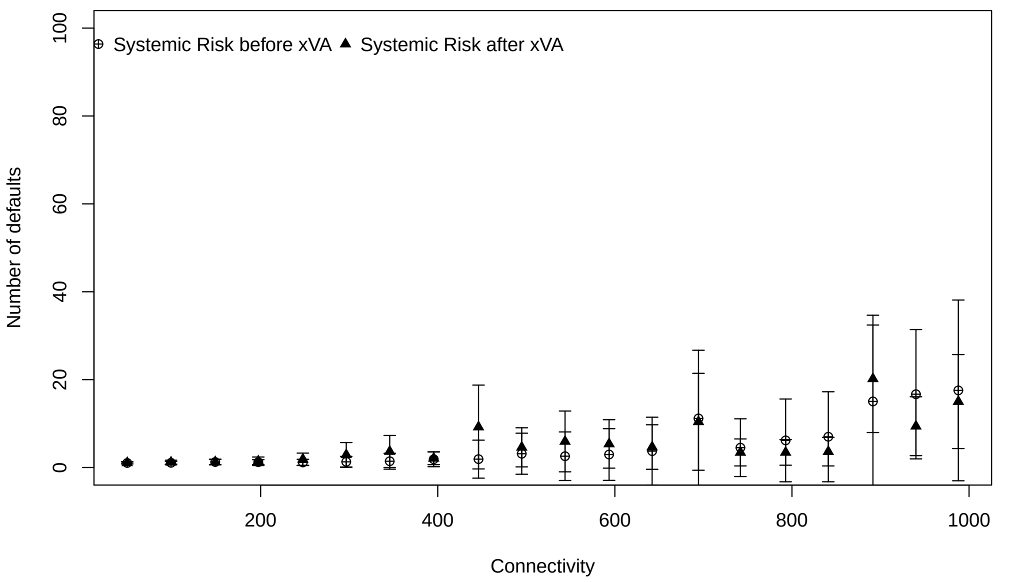

Figure 2.4a: First 1000 connections at leverage 3

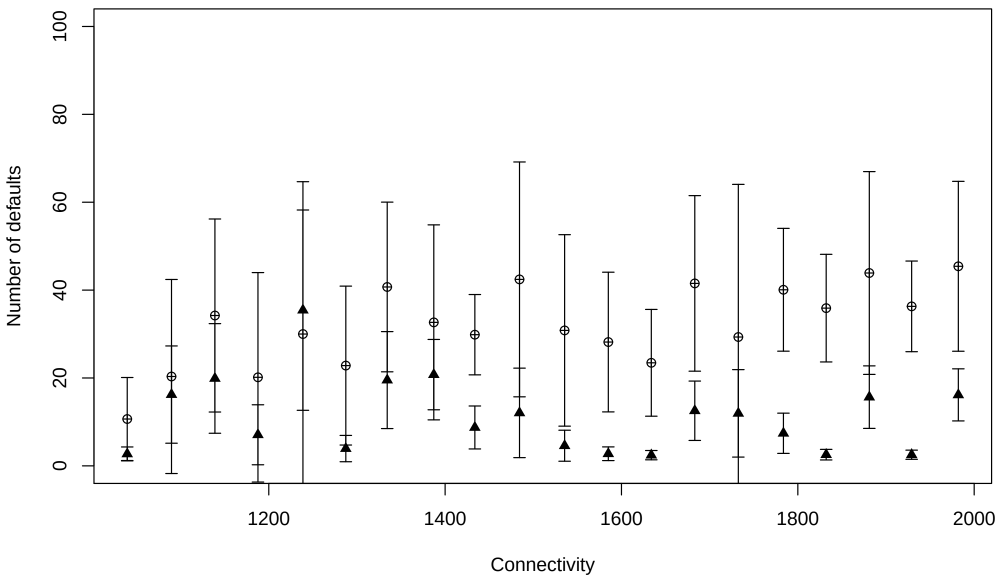

Figure 2.4b: Second 1000 connections at leverage 3

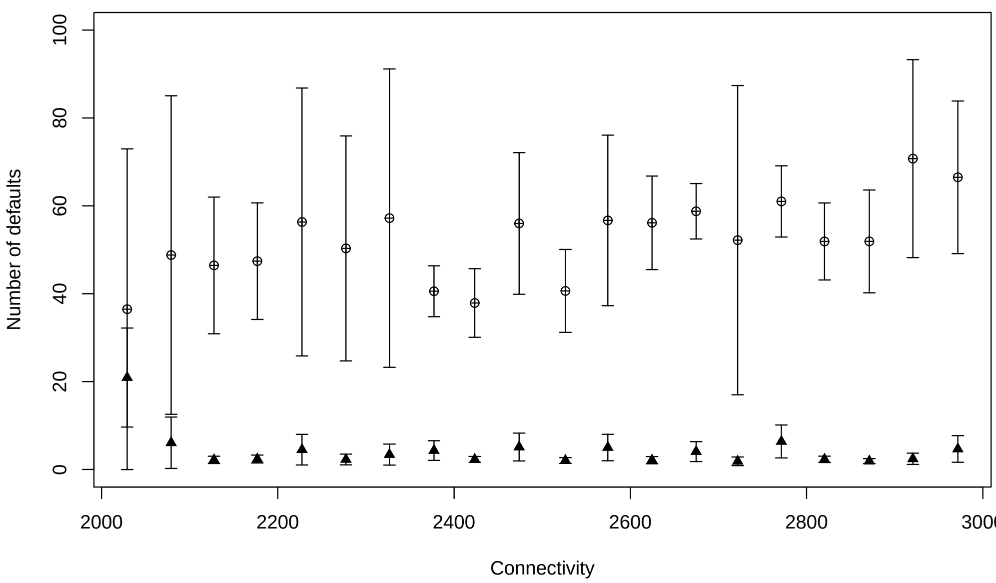

Figure 2.4c: Third 1000 connections at leverage 3

The graphs indicate that the buffers provided by the value adjustments do not completely protect the entire network from contagion. In some loose systems, more failures occur because of incorporating the xVA family. Its protection gradually increases parallel to the increase in the concentration of network infrastructure. In other words, the role of xVA in improving the stability of a derivative network is only effective if the network infrastructure reaches a certain level. Two reasons can explain it; first, the network is discrete, and if the xVA reserve is effective, it only protects counter-parties within particular transactions; this protection could not be spread to other institutions. Second, financial counter-parties that do not join any transactions can be overloaded by the additional capital requirements of xVA; they become more insolvent. Panels a and b of each figure below illustrate that the capacity of xVA for institutions against systemic failures is not guaranteed during the range of first 2,000 transactions. Additionally, at the same level of network infrastructure, the family of the value adjustments is more effective under higher leverage.

Connectivity

Systemic risk is continuously examined under the conditions of fixing total notional outstanding for the entire system whilst increasing the number of transactions between financial institutions. These conditions allow us to make the financial system stronger. We then put the same exogenous shock on each level of connectivity and evaluate how the network responded to the shock. Additionally, three levels of total notional outstanding such as 25 million, 50 million and 100 million currency units were applied to generate three different levels of exposures respectively presented by Figure 2.5a, b and c as follows.

The outcomes illustrate that a larger total notional outstanding implies higher systemic risk. This because with the same level of connectivity, the larger total outstanding is equivalent to higher leverage. Thus if unanticipated events happen, the losses are more serious.

Systemic Risk in a network with three fixed levels of notional outstanding

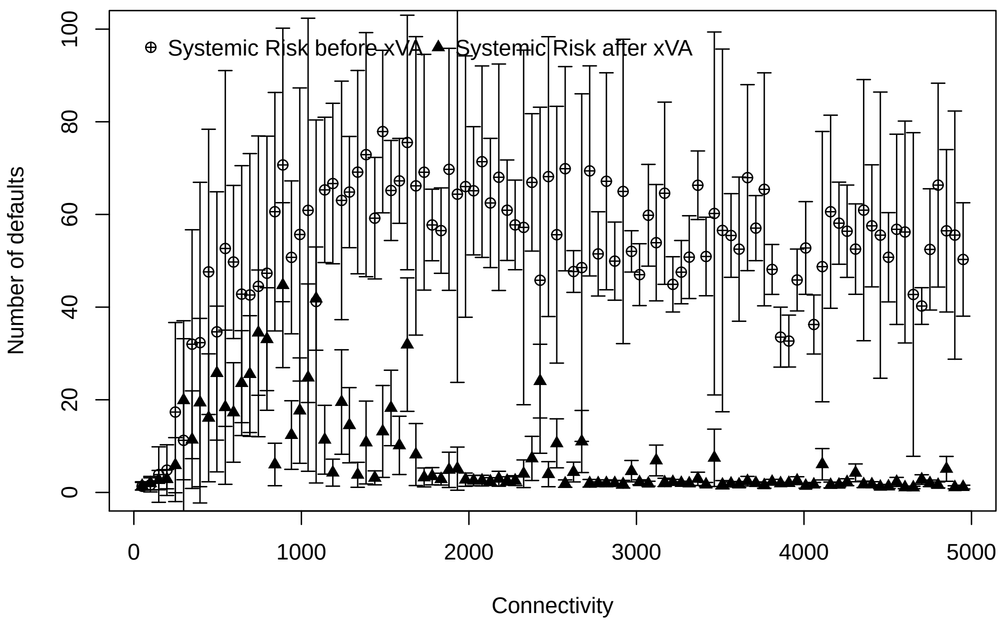

Figure 2.5a: Level 1 of notional outstanding. 25 million currency unit

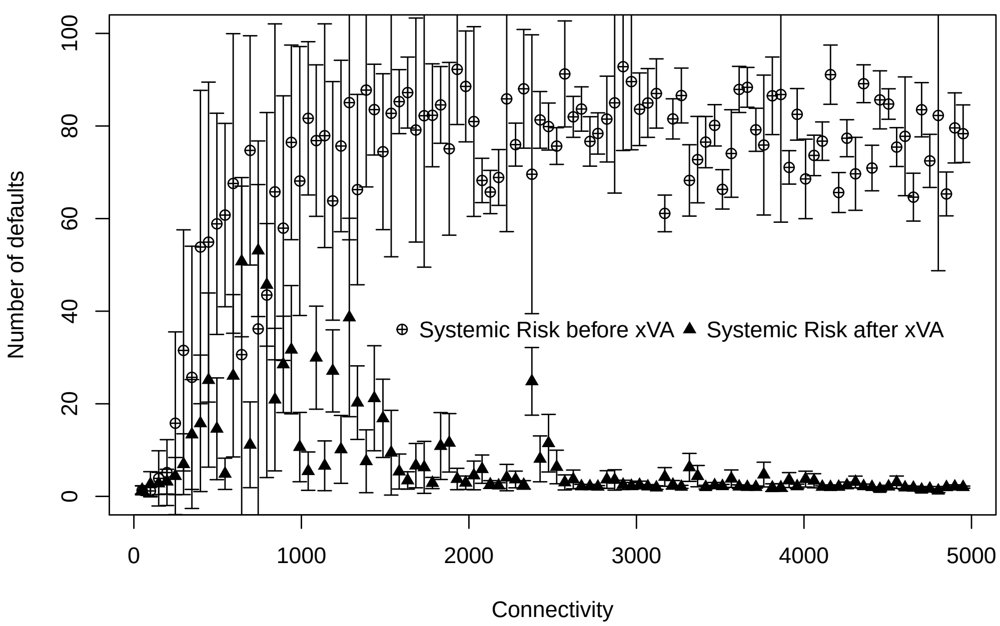

Figure 2.5b: Level 2 of notional outstanding. 50 million currency unit

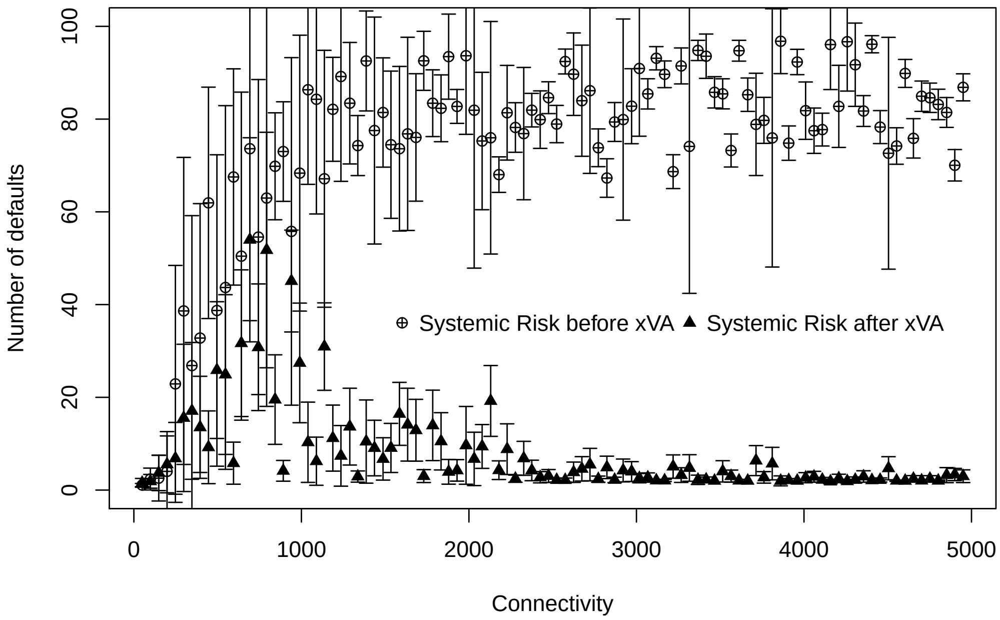

Figure 2.5c: Level 3 of notional outstanding. 100 million currency unit

Although network infrastructure was proved to play an essential role in improving systemic risk, our results support the proposal of Ladley (2013) that a strong network exacerbates the system stability if the shock is large enough because more internal connections act as bridges to spread the exposure to more counter-parties.

Moreover, incorporating the xVA family is likely to eliminate the systemic risk. If financial entities reserve more equity capital equivalent to the value adjustments, their capacities are widened to cover unexpected exposure. However, this benefit is reduced in loose financial systems. In a weak infrastructure, financial institutions are not closely connected; the positive impact of the value adjustment is only effective in one or a small number of derivatives. The connectivity is not complex enough to spread xVA's effectiveness within the system.

Comparing the effects of BCVA and xVA, BCVA can absorb a part of systemic exposure, but xVA is likely to eliminate systemic failures. This is because BCVA is used for a concern of counter-party credit risk whilst financial systems can face other potential risks related to collateral. Therefore, accounting for BCVA only protects the network from credit events, whereas the xVA family provides institutions greater ability to cover the damages caused by other financial risks and enhance the entire network.

Although the gaps between systemic risks before and after applying xVA are easily recognised, there are some ranges which are difficult to see in Figure 2.5. We, therefore, present systemic risk in the first 1000 connections at each level of notional outstanding in Figure 2.6. The graphs present several situations in which there are more defaults under the treatment of xVA. The protection of xVA is ineffective for loose networks. This is because besides the spread of exposures through derivative transactions, some financial individuals who are not in any position lack sufficient equity to fulfil the capital requirements of xVA. Their insolvencies contribute to the system's fragility. Meanwhile, counter-parties can more easily reserve the lower capital required for BCVA; the systemic risk is clearly improved. Therefore, the decision of whether applying BCVA or xVA against systemic risk is critical, especially in financial networks with low levels of connectivity. The family of xVA requires a higher cost for funding but still does not guarantee to entirely remove systemic risk in weak network infrastructure whilst the benefit of BCVA is lower costs and give an improvement in contagion for all levels of network connectivity, BCVA however could not completely eliminate the systemic exposure.

First 1000 connections at three different levels of notional outstanding

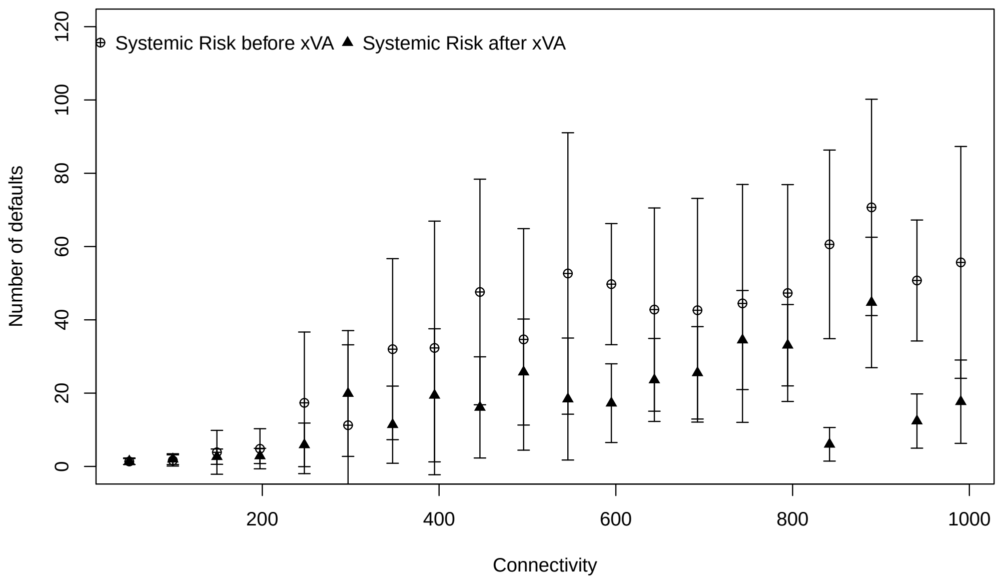

Figure 2.6a: First 1000 connections at level 1 of notional outstanding

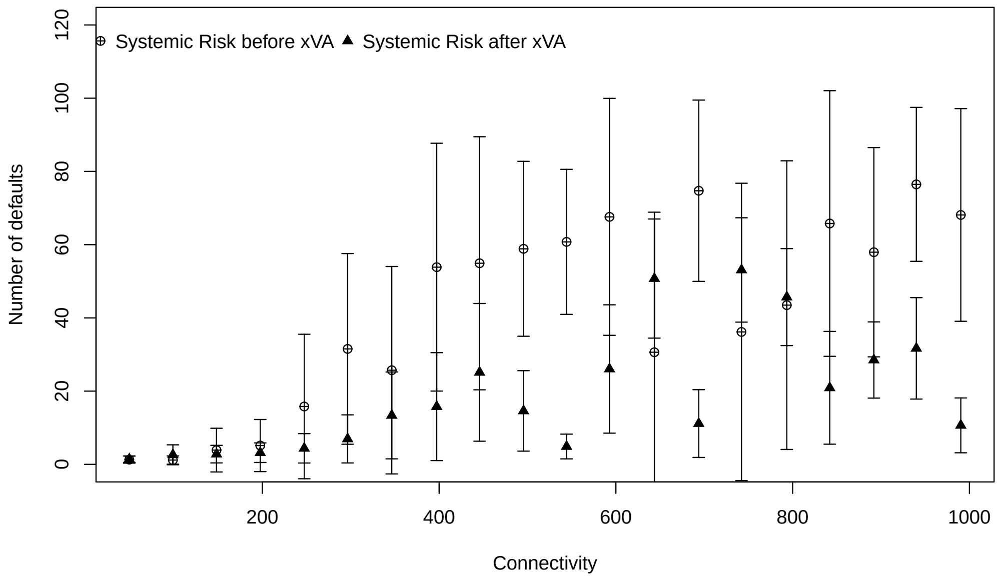

Figure 2.6b: First 1000 connections at level 2 of notional outstanding

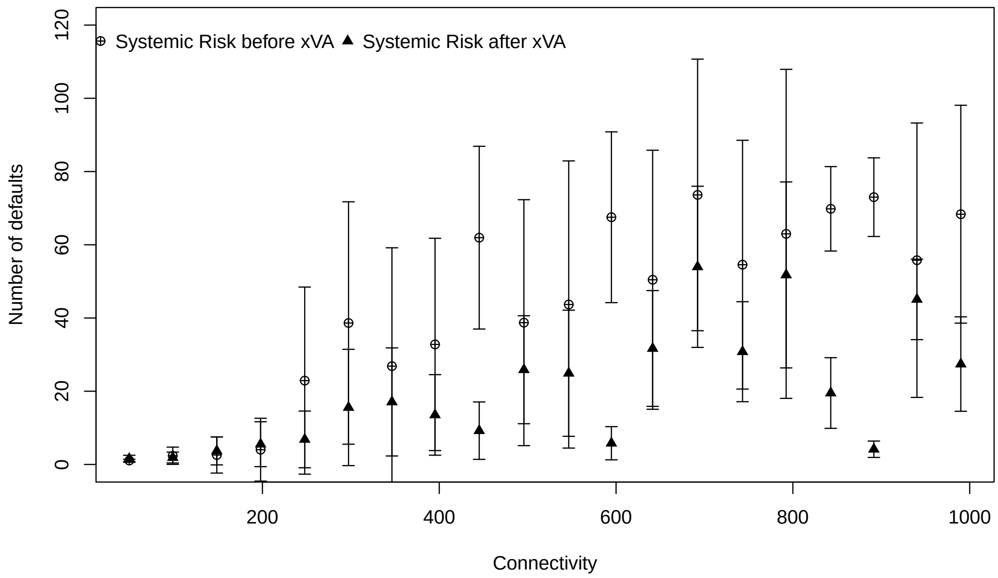

Figure 2.6c: First 1000 connections at level 3 of notional outstanding

Premium

Our next concern is the role of the value adjustments in maintaining the financial system under the shock created by premiums. We generate three levels of premiums, 0.1%, 0.3%, 0.5%, which are the distances between fixed rates and floating rates in derivatives markets. These premiums are small but combine of the large notional principals; they produce the large shocks to counter-parties whose commitments are based on floating rates.

Figure 2.7 indicates how systemic risk happens with and without the additional cushions of value adjustments. The larger premiums imply more extreme exposure. Because of the positive effect of xVA under the shocks of leverage and connectivity, it is also expected to eliminate systemic failures caused by premium shocks. However, the xVA's protection is limited under the stresses of premiums. BCVA and xVA have similar characteristics under the same configuration of premiums. Larger shocks of premiums reduce the positive effects of xVA.

The value adjustments are considered for the downgrade of credit rating and the risk exposure of collateral. However, the difficulties generated by premiums are contractual liabilities; they are not the potential exposure covered by xVA. Hence, the additional capital can cover an entire liability (Panel a) or a part of it (Panels b and c) depending on the level of obligations.

Systemic risk at three different levels of premiums

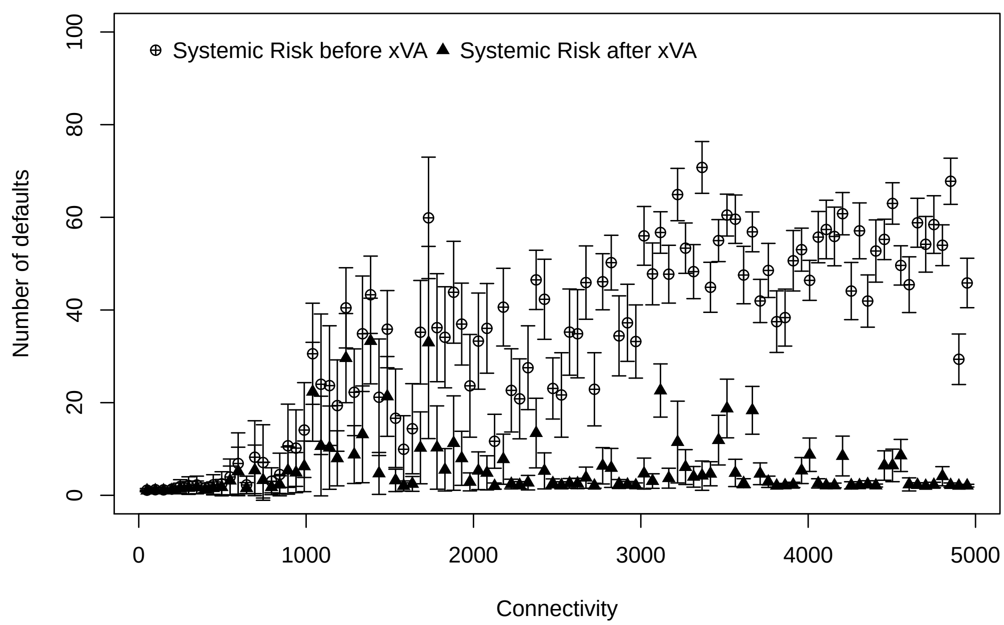

Figure 2.7a: Premium 1. 0.1%

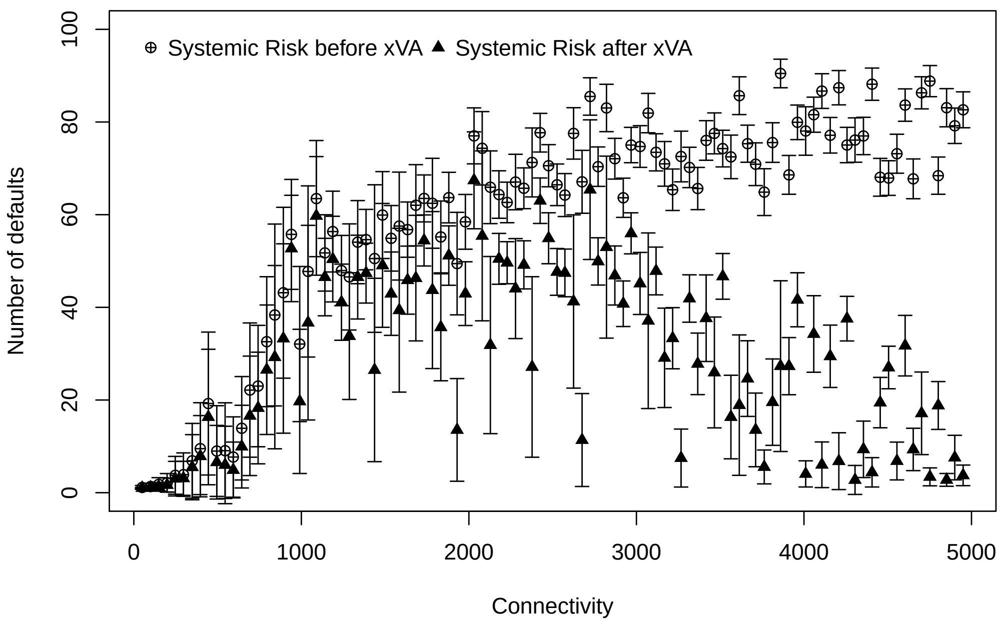

Figure 2.7b: Premium 2. 0.3%

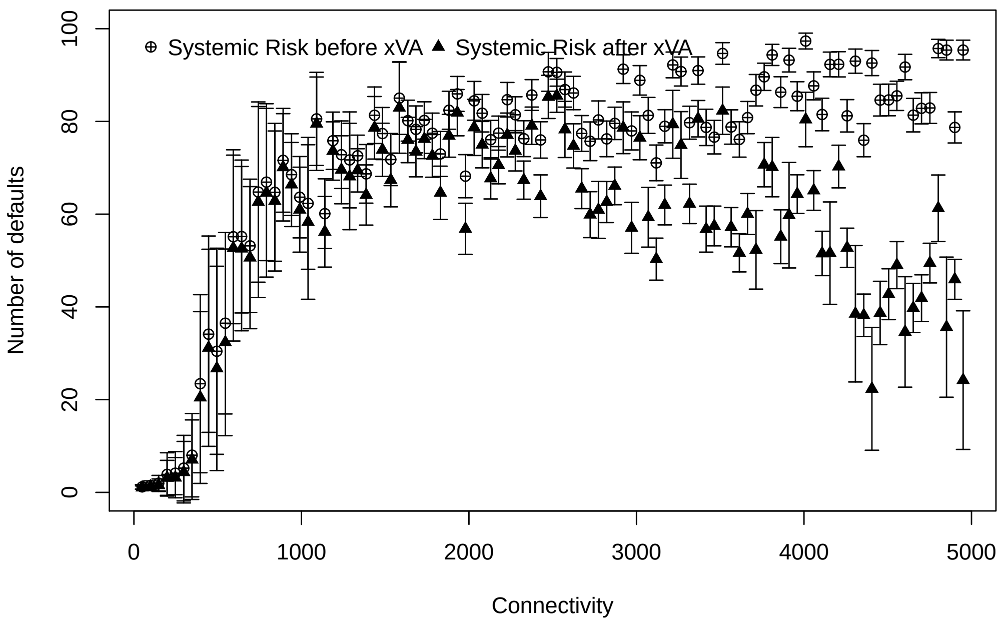

Figure 2.7c: Premium 3. 0.5%

We draw more graphs for the invisible ranges of weak connectivity. Figure 2.8 presents the first 1,000 connections at level 1 (Panel a), level 2 (Panel b) and level

3 of premiums (Panel c).

First 1000 connections at three levels of premiums

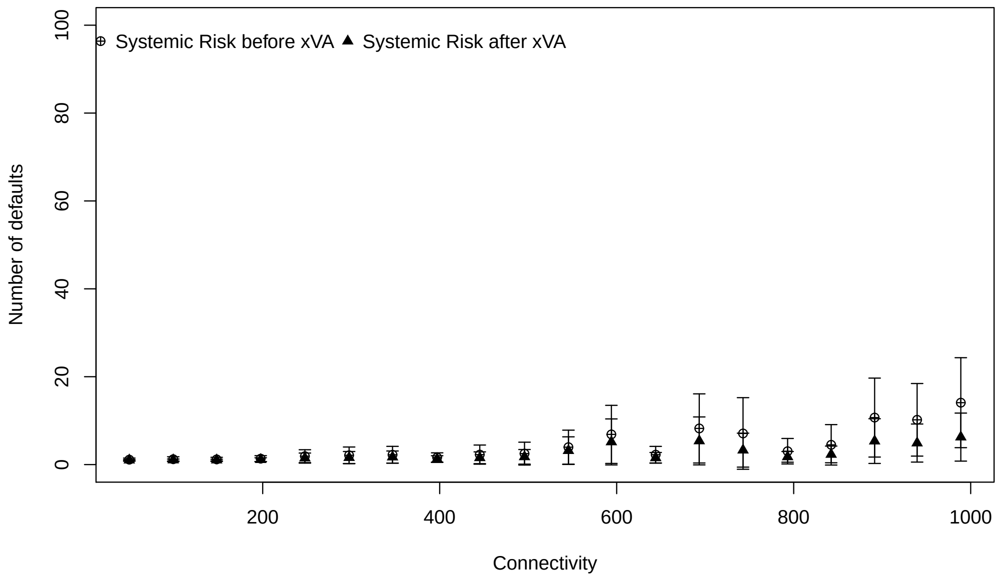

Figure 2.8a: First 1000 connections at level 1 of premium

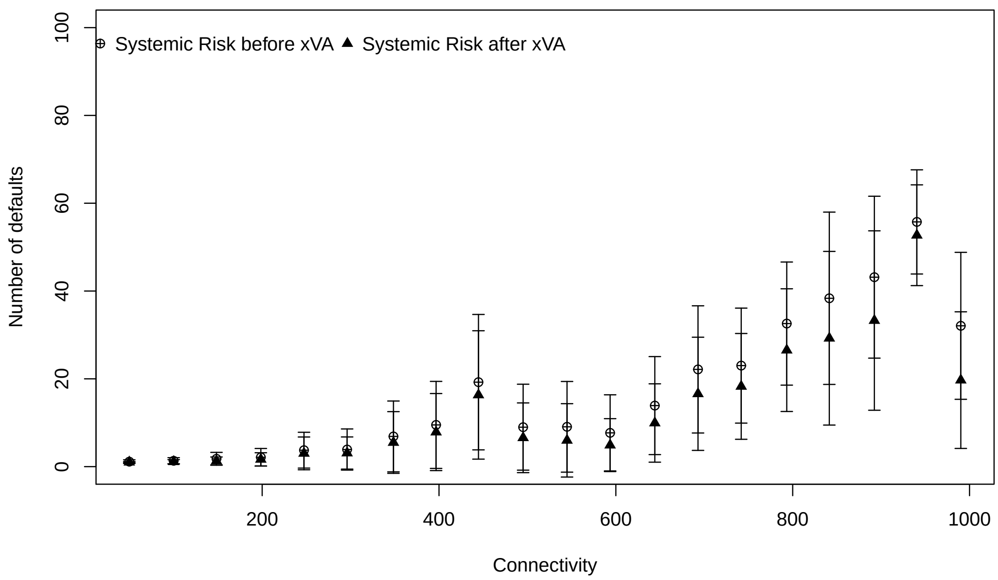

Figure 2.8b: First 1000 connections at level 2 of premium

Under the shocks of leverage and connectivity, the simulations illustrated that the shield of the value adjustments are restricted. Unlike those situations, the ability

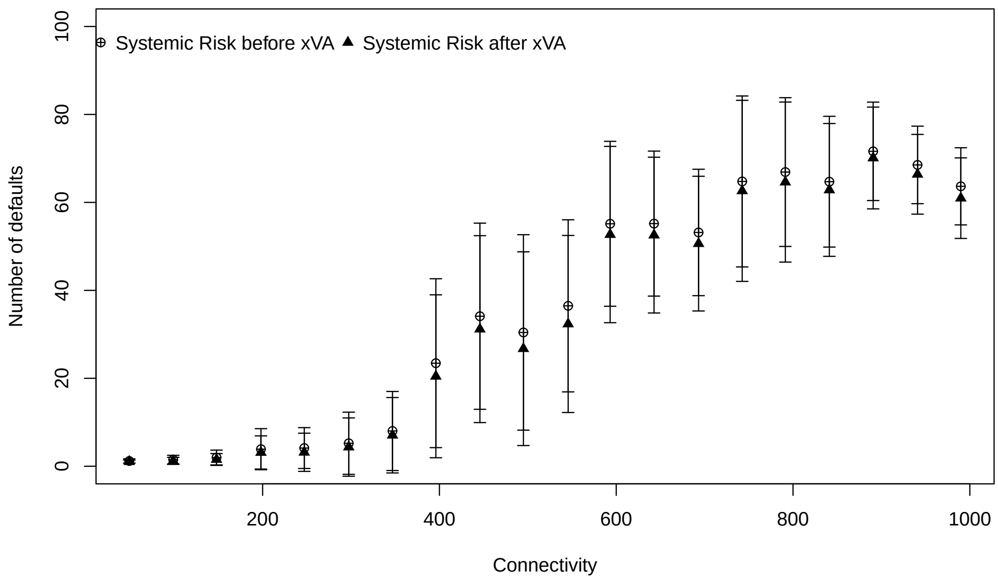

Figure 2.8c: First 1000 connections at level 3 of premium

of xVA to enhance system stability is consistent regardless of the level of network infrastructure.

2.5.2 Effect of xVA on market prices of collateral

At each contractual time, financial counter-parties either have to sell risky assets to meet their obligations or buy more to maximise their benefits. The balances between supply and demand fluctuate at each time that leads to different market prices for risky assets. The risky asset price is re-determined as long as there are one seller and one buyer in the market. Hence the level of connectivity is not considered in this part, but the durations of the derivatives contracts are. The market prices of risky assets are examined under the treatment of leverage and premiums.

Leverage

The leverage between equity and notional outstanding of each counter-party is considered at three levels: 1:10, 1:20 and 1:30 in Figure 2.9a, b and c, respectively. These graphs allow us to examine the trends of risky assets under a larger potential risk.

Market prices of risky assets at three levels of leverage

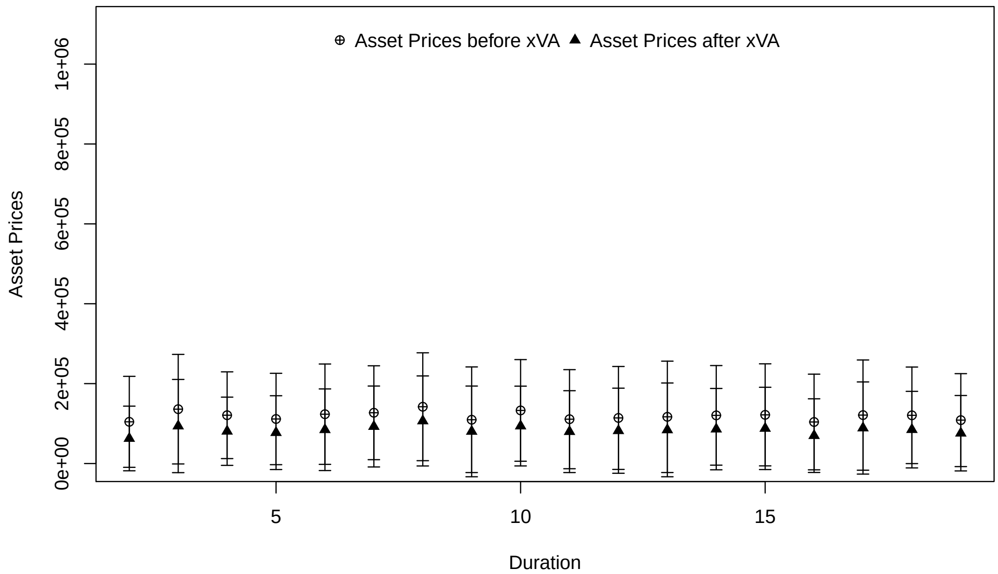

Figure 2.9a: Leverage 1. Equity:Notional Outstanding = 1:10

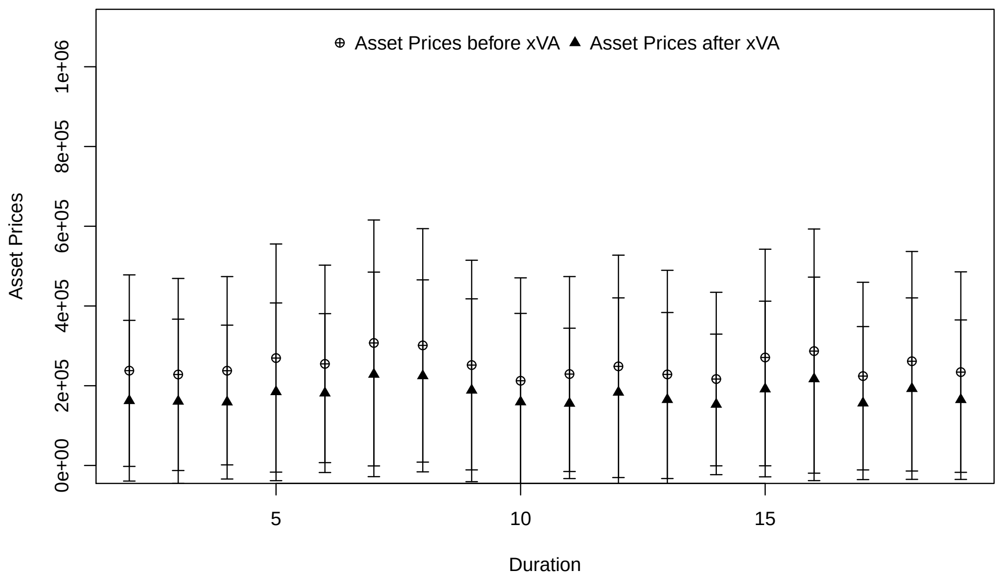

Figure 2.9b: Leverage 2. Equity:Notional Outstanding = 1:20

Figure 2.9 demonstrates that greater leverage imposes greater market volatility of asset prices. The distances between asset prices before and after accounting xVA expands associated with the leverage levels. This is because greater leverage causes

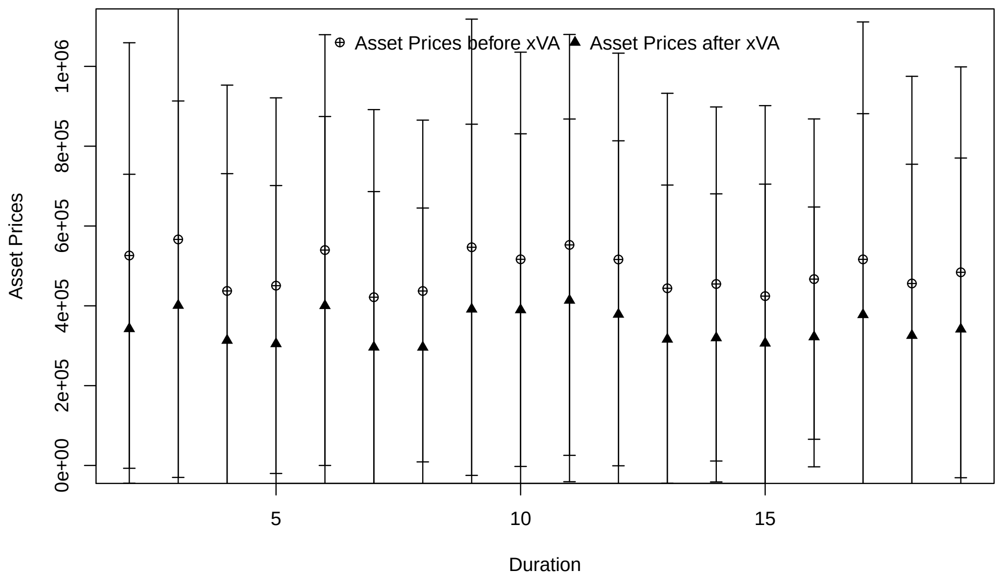

Figure 2.9c: Leverage 3. Equity:Notional Outstanding = 1:40

more difficulties for financial entities in unanticipated events. The large exposure forces more counter-parties to sell more assets. Hence the supplies and demands of collateral vary considerably. The value adjustments are unlikely to reduce the fluctuations of assets' prices.

Moreover, xVA declines the market values of risky assets. Because financial institutions have to reserve more equity for the additional capital requirements of xVA, their financial sources for investments is limited. In a market with the same amount of assets but less capital, the market price of the assets is driven down.

Premium

We continuously investigate the changes in assets' prices caused by the expansion of premiums. Figure 2.10 presents the values of risky assets under the treatment of the premiums included 0.5% (Panel a), 1.5% (Panel b) and 5% (Panel c).

Market prices of risky assets at three levels of premium

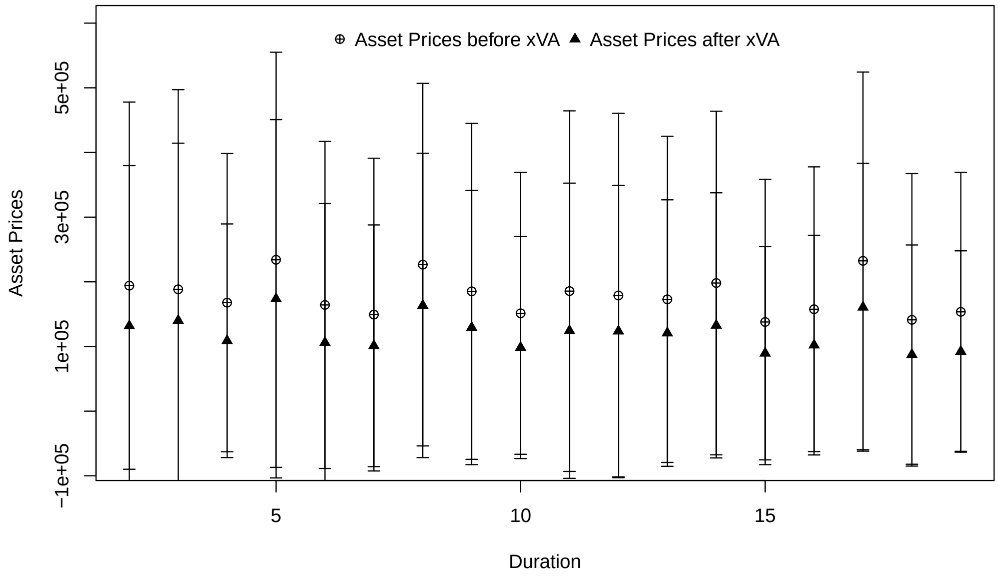

Figure 2.10a: Premium 1. 0.5%

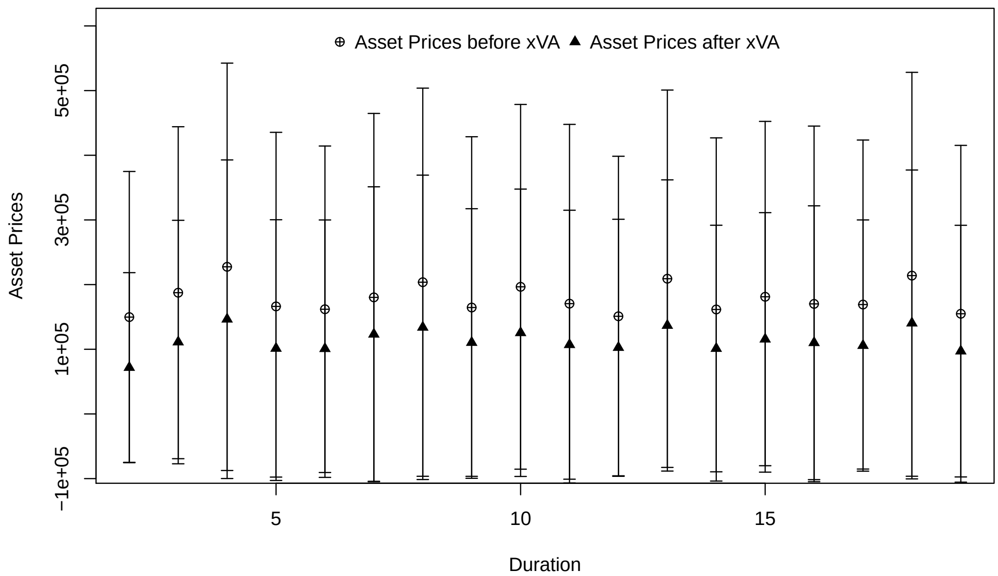

Figure 2.10b: Premium 2. 1.5%

It seems that xVA has no effect on the market prices, but it increases the gaps between the market prices with and without the value adjustments. The reductions in the market prices after xVA is applied can be explained by the same reason with

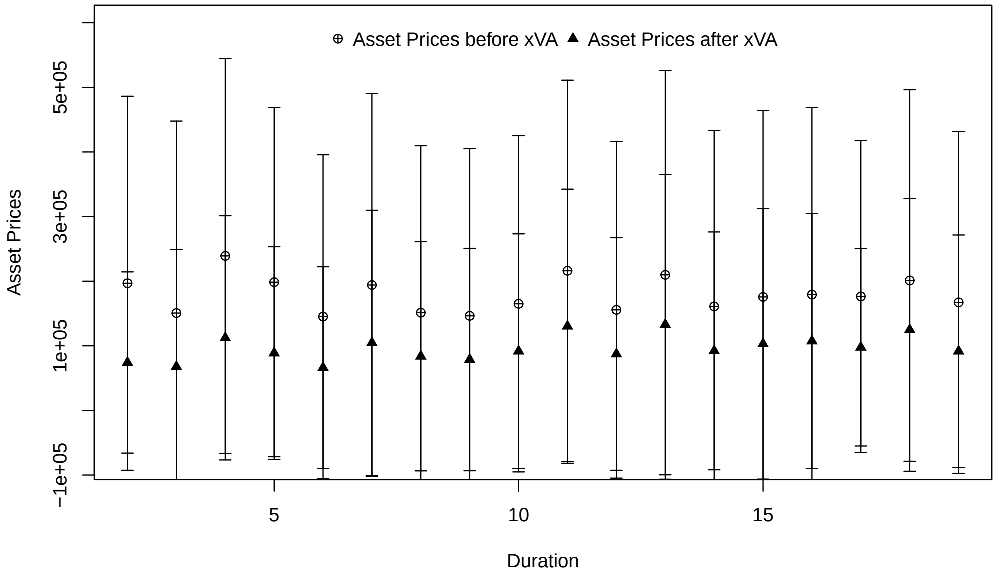

Figure 2.10c: Premium 3. 5%

the configuration of leverage. The reserves for the Basel III capital standards reduce the financial funding in the market, but the amount of assets traded in the market is unchanged. Buyers propose lower bid prices while sellers are forced to sell their assets. The sellers have to accept lower values for risky assets. Counter-parties suffer the lost value in their risky assets. This is considered a cost of incorporating the value adjustments to improve the stability of financial markets.

2.6 Conclusion

In this chapter, we attempt to mimic the real financial market by adding collateral agreements. Apart from BCVA, the value adjustments related to collateral include ColVA and FVA. We use a Monte Carlo approach to investigate how systemic risk happens when incorporating the value adjustment family into counter-parties' capitals. Moreover, the demands and supplies of collateral vary at each time of contractual commitments. This results in market volatility of assets' prices. We derive functions from estimating these collateral changes.

The experimental outcomes prove that xVA effectively eliminate systemic risk in derivative markets. However, this effect is opaque in networks with low connectivity. The consideration of xVA exacerbates the network's fragility because more financial counter-parties fail to meet the higher capital requirements. Furthermore, after applying the value adjustments, market prices of collateral are declined under higher leverage or larger gaps between fixed rates and floating rates.

Therefore, the application of xVA is critical because of two reasons. First, there is still the possibility of systemic risk in the weak financial systems. Second, xVA decreases the market values of assets, so financial institutions suffer greater losses in their assets.

The results of this chapter put investors in a situation to consider sacrifice between their stability and market values. However, if the highest priority of policy-makers is the stability of the whole financial system, they are interested in accounting for not only BCVA but also xVA to entirely remove systemic risk. However, more capital reserve could limit available funding sources for potential investments. Hence, we examine the practical usefulness of capital reserve under the treatment of Basel III liquidity standards in chapter 3, if such liquidity standards have any influence on bank profitability and stability.

Chapter 3

Do Basel III Liquidity Standards Improve Banks' Performance and Stability?

3.1 Introduction

In 2010, the Basel Committee on Banking Supervision (BCBS) responded to the global credit crisis by announcing higher global capital standards for commercial banks, also known as 'Basel III'. These regulations proposed new requirements to control liquidity risk: Liquidity Coverage Ratio (LCR) and Net Stable Funding Ratio (NSFR). Bank for International Settlements (BIS, 2018) defined such two liquidity standards as follows:

"The LCR is designed to ensure that banks hold a sufficient reserve of high-quality liquid assets (HQLA) to allow them to survive a period of significant liquidity stress lasting 30 calendar days".

"The NSFR aims to promote resilience over a longer time horizon by creating incentives for banks to fund their activities with more stable sources of funding on an ongoing basis"

BCBS approved Basel III with an expectation that it would mitigate counterparty risk of system entities and thus enhance the stability of financial markets. However, under the new standards of capital requirements, by 2019 the European banking system is estimated to need more approximately €1.1 trillion of Tier 1 capital and about €1.3 trillion (€2.3 trillion) of short-term (long-term) liquidity. The pressure of funding needs can negatively influence bank performance and safety. Additionally, Jones (2000) indicated that an application of the Basel Capital Accord (Basel I) leads to opportunities of "regulatory arbitrage". Calem and LaCour-Little (2004) highlighted that this intensive problem also happened under the treatment of Basel II. Banks were motivated to re-arrange their asset portfolios to reduce capital reserved for high-risk weighted assets. This raises a concern of whether the new Basel III liquidity requirements encourage banks to arbitrate liquidity regulation for short-term and long-term capital.

The objective of this chapter is to examine the impact of Basel III liquidity requirements on financial institutions' profitability and their possibilities of default. The impacts are evaluated along with the influences of bank-specific determinants and macroeconomic factors. This work provides a statistical analysis of costs and profits of Basel III liquidity standards, particularly LCR and NSFR. Banks' performance is measured by their Return on Assets (ROA), and Return on Equity (ROE) whilst their probabilities of default or distance-to-default are represented by Z-scores. The relationships between Basel III liquidity ratios and financial institutions' health are estimated by linear regressions according to a panel of developed European banks from 2011Q1 to 2018Q4.

3.2 Literature Reviews

This chapter focuses on the new liquidity requirements of NSFR and LCR, which were introduced in Basel III. This part hence reviews papers related to the effect of Basel III on bank efficiency and stability. Besides, the performance and safety of the banking sector are not only influenced by the implementation of Basel III but also by internal factors, understood as bank-specific determinants and external factors, also called macroeconomic conditions, which are reviewed as follows.

3.2.1 Effects of Basel III, internal and external determinants on Bank Performance

Hrle et al. (2010) proposed that Basel III has a significant effect on the European banking sector. Fulfiling the new capital requirements will reduce an average of 4% Return on Equity (ROE) on European banks, whereas Wagner (2007) implied that liquidity of banks' assets is negatively related to bank's probability of default. Furthermore, Lindblom and Willesson (2013) and Maria and Eleftheria (2016) agreed that the introduction of Basel III substantially affects both bank efficiency and risk exposure. However, the results of Ayadi et al. (2019)'s work related to Basel compliance and bank performance indicated that there is no relationship between them.

Apart from the impact of the new Basel capital standards, internal factors such as bank size, leverage, capital strength, loans and deposits, asset management and asset quality, operating efficiency, bank ownership were confirmed to statistically significant affect banks' profitability by Saunders and Schumacher (2013); Athanasoglou et al. (2006); Pasiouras and Kosmidou (2007); Flamini et al. (2009); Dietricha and Wanzenriedb (2014); Shehzada and Scholtensa (2013); Menicucci and Paolucci (2015); Narwal and Pathneja (2016); Goddard et al. (2004); Almaqtari et al. (2018). Meanwhile, the external factors of tax rate, inflation, interest-rate volatility, GDP growth, market concentration, financial crisis and ownership were examined to have remarkable influences on banks' performance (Saunders and Schumacher, 2013; Micco et al., 2007; Pasiouras and Kosmidou, 2007; Flamini et al., 2009; Dietricha and Wanzenriedb, 2014; Almaqtari et al., 2018). The research find mixed negative and positive effects of bank-specific and macroeconomic conditions based on different backgrounds, e.g. different countries such as Europe, US, Africa or China; and different periods, for example before, during and/or after global crisis.

3.2.2 Effects of Basel III, internal and external determinants on bank Distance-to-Default

Merrouche and Nier (2010) indicated that inadequate supervision and regulations are key reasons for financial imbalances before the global credit crisis. Cihak et al. (2013) supported the result that bank regulations may harm the stability of a financial system. However, research on cooperative banks by Fiordelisi and Mare (2013) proposed that the Basel III capital agreement had a significant positive association with banks' probabilities of defaults because of higher capital buffers equivalent to stronger loss-absorb ability (Giordana and Schumacher, 2017; Abugamea, 2018).

The probabilities of banks' defaults were also affected by changes of internal factors such as CAMEL (capital, asset quality, management, earnings and liquidity), capital strength and deposit, operating efficiency and non-performing loans (Canicio and Blessing, 2014; Leung et al., 2014; Schenck, 2014; Menicucci and Paolucci, 2015; Abugamea, 2018; Makinen and Solanko, 2016; Jabra et al., 2017; Ali and Puah, 2019). External factors also significantly influence bank stability, including GDP growth rate, capitalisation and interbank offered rate (Canicio and Blessing, 2014; Diaconu and Oanea, 2014; Jabra et al., 2017), market competition measured by the proportion of foreign banks and wholesale funded banks (Degryse et al., 2013). Even though prior research attempted to study different countries and different regions, the effects of internal and external factors are still ambiguous. We could not find any research which studies the effects of the Basel III liquidity requirements along with bank-specific in macroeconomics conditions.

Accordingly, this chapter aims to evaluate the impacts of NSFR and LCR alongside the internal and external determinants on bank profitability and stability. In the next section, we describe the measurements of banks' performance and their probabilities of default as well as the explanatory variables related to bank-specific and macroeconomic factors.

3.3 Determinants of developed European banks' profitability and risk taking

3.3.1 Dependent variables

We use two measures of banks' profitability which are Return-On-Average-Asset (ROAA) and Return-On-Average-Equity (ROAE) following recent studies of Narwal and Pathneja (2016); Garcia and Trindade (2018); Xu et al. (2019). The reason for using ROAA and ROAE instead of ROA and ROE is that ROA and ROE are calculated by dividing net income by the final total assets or shareholders' equity, respectively. The end values of total assets or shareholders' equity can include last-minute stock sales or dividend payments. Hence ROA and ROE calculated at one time might not be accurate indicators of actual returns over a while. Meanwhile, ROAA and ROAE are ratios of net income divided by the average total assets and the average shareholders' equity during a period. They allow investors to correctly analyse the profitability of a financial institution over a period.

Probability of a bank's default is estimated by the Z-score which has been extensively used in prior research (Hesse and Cihak, 2007; Mercieca et al., 2007; Laeven and Levine, 2009; Diaconu and Oanea, 2014). This indicator calculates the distance to a bank's insolvency, which happens when its loss is beyond equity (Loss > Equity = - Return > Equity). Comparing these values to total bank assets, these are equivalent to negative ROAA (- ROAA = - Return/Total Average Asset) and Capital Asset Ratio (CAR = Equity/Total Average Asset). The probability of default is, hence, the probability of (-ROAA > CAR). The inverse of this probability if returns are normally distributed, is the distance-to-default Z-score. The advantage of this measure that it is easily calculated, but it does not account for the correlation between bank defaults (Diaconu and Oanea, 2014).

3.3.2 Independent variables

This section describes three categories of explanatory variables, namely liquidity capital standards, bank-specific and macroeconomic conditions. Liquidity capital requirements are measured by NSFR and LCR. Bank-specific variables include bank size, capital strength, leverage, deposits, asset management, operational efficiency and asset quality ratio. The final category of macroeconomic determinants consists of GDP growth and inflation.

Basel III liquidity ratios

The objective of the Basel III liquidity standards is to maintain stability and liquidity profiles of banks' balance sheets. Particularly, NSFR requires a bank to hold a minimum reserve of stable funding according to its assets and activities over one year. LCR is the minimum amount of high liquidity assets for a bank's survival during 30-day stress scenarios.

A working paper of Hoerova et al. (2018) showed that full compliance with liquidity regulation could reduce European bank insolvency during the global financial crisis. This result was consistent with the outcomes of Fiordelisi and Mare (2013); Giordana and Schumacher (2017); Abugamea (2018). However, an application of the Basel III liquidity standards can also reduce an average bank performance (Maria and Eleftheria, 2016; Flotynski, 2017; Giordana and Schumacher, 2017).

BCBS's members are strictly required to implement the Basel III requirements. However, in financial markets there are non-members of BCBS who also follow the new capital standards. The difference in the Basel III applications between members and non-members is that members have to meet the minimum liquidity ratios whilst non-members can be flexible dependent upon their capital ability. It leads to the fact that although the standards may harm profitability and stability of the members, they have no options to avoid. In contrast, the non-members can decide not to pay the costs if their financial strength are threatened. We, therefore, use a dummy variable of MEM to see how the differences in performance and risk-taking between a member and a non-member of BCBS.

Bank-specific factors

Bank size (BAS). The proxy of bank size is the natural logarithm of total assets which was commonly used in prior research. Terraza (2015) analysed data of 1270 European banks from 2005 to 2012 and proposed that there was no significant evidence of a relationship between bank size and profitability. Nonetheless,Goddard et al. (2004) stated that bank performance is affected by bank size, but this effect is quite weak. Additionally, Regehr and Sengupta (2016) implied that although higher returns are associated with larger banks, increasing bank size does not necessarily lead to better performance. Adelopo et al. (2017); Abugamea (2018) also supported the positive relationship between bank scale and profitability. The reasons to believe bank size positively related to bank efficiency is that large banks take advantage of the economic scale to reduce average fixed costs and operation costs between branches, product lines or sectors (Mester, 2010; Hughes and Mester, 2015) whereas some researchers propose a negative correlation between bank size and bank performance (Aladwan, 2015). Moreover, large banks become riskier because they usually have lower capital, less-stable funding (Laeven et al., 2014). Indeed, a study by Athanasoglou et al. (2008) from a panel data of Greek banks covering a period from 1985 to 2001 stated that bank size does not influence bank performance.

In this chapter, we distinguish the effect of NSFR and LCR on small, medium and large banks by dummy variables D1 and D2 and interaction variables NSFR*D1, NSFR*D2, LCR*D1 and LCR*D2 where:

$$D1_i = \begin{cases} 1 & \text{if bank } i \text{ is a large bank} \\ 0 & \text{if others} \end{cases}$$

$$D2_i = \begin{cases} 1 & \text{if bank } i \text{ is a medium bank} \\ 0 & \text{if others} \end{cases}$$

Small banks and large banks are defined by their total assets which belong to the first and the last 25% of quantiles.

Capital adequacy (CAA). Capital adequacy is estimated by a ratio of bank equity to its total assets. It represents the capacity to cover losses from its portfolio. Goddard et al. (2004) and Lee and Hsieh (2013) based on bank-level data of European and Asian regions found that capital has a positive effect on bank profitability but negative relationship on bank risk-taking. These impacts are different between investment banks and commercial banks, and between lower-middle-income to higher-income countries. Altunbas et al. (2007) look at European countries from 1992 to 2000 and show that banks holding higher capitals were inefficient and took less risk. Agoraki et al. (2011) agreed that capital generally reduces bank fragility, but this benefit is significantly less for banks with market power. However, Rime (2001) showed evidence that an increase in bank capital does not have any effect on bank risk.

Leverage (LEV). Leverage is measured by the ratio of total liabilities to total assets. It is used as a tax shield to reduce income tax and hence increase revenue. Alshatti (2015) showed evidence that higher leverage reduces the bank's profitability because of a higher cost to cover larger liabilities. Moreover, Switzer and Wang (2013) proved that banks with higher leverage are more likely to default.

Asset Management (ASM). Asset management is calculated as operating income divided by total assets. This ratio indicates an amount of revenue which is generated from one unit of asset. Masood and Ashraf (2012); Almaqtari et al. (2018) revealed a positive effect of asset management on bank efficiency.

Operating Efficiency (OPE). Operating efficiency is estimated by the ratio of total operating expense to total operating income (revenue). It represents how a bank manages to maintain low cost with high revenue. The relationship between bank risk and operating efficiency is arguable. Although an efficient bank is expected to have larger capacity to restrain itself from insolvency, it is more flexible to involve more risky activities for higher returns and then take more risk (Kwan and Eisenbeis, 1997). Fiordelisi et al. (2011) supported the negative correlation between bank risk and its operating efficiency whilst Maudos et al. (2002) implied strong effects of cost efficiency on low levels of profit.

Asset Quality (ASQ). A bad quality loan can become a non-performing loan which is unable to repay. Banks need to reserve capital for the loan losses which is called loan loss. A ratio of loan loss to total loans is used as a proxy of asset quality. If this ratio is high, the bank has a large amount of bad loans, bank creditworthiness can be downgraded. Impact of asset quality on bank profit is unpredictable because higher risk loans equivalent to higher returns but poorer asset quality raises more funding costs and then reduces bank efficiency (Iannotta et al., 2007).

Macroeconomic determinants

GDP growth (ΔGDP) and **inflation rate (INF)** are used as two proxies of macroeconomics factors (Naceur and Omran, 2011). Both factors were expected to affect bank profit (Athanasoglou et al., 2008) positively. Higher growth of economies motivates banks to lend more for more returns. However, Pasiouras and Kosmidou (2007) showed that ΔGDP and INF significantly impact bank returns but with opposite directions for domestic and foreign banks. It was explained that local banks were more sensitive to inflation changes than foreign banks; they hence adjusted their lending interest rates to earn higher benefits. Moreover, financial investments had higher probabilities of getting expected returns under good economic conditions; thus, the credit risk of banks was reduced (Kashyap et al., 1996).

A short description of all dependent and independent variables is in Table 3.1.

Table 3.1: Description of Dependent and Independent Variables

Variable Name	Notation	Measure	Expectation on Performance/Default
Dependent Variables			
Return-On-Average-Assets (%)	ROAA	Net Income / Average Total Assets	
Return-On-Average-Equity (%)	ROAE	Net Income / Avergae Total Equity	
Distance-To-Default	Z-score	(ROAA + CAR)/σ(ROAA)	
Independent Variables			
Liquidity standards			
Net Stable Funding Ratio (%)	NSFR	Available Stable Funding / Required Stable Funding	±/±
Liquidity Coverage Ratio (%)	LCR	High quality Liquid Asset Amount / Total Net Cashflow Amount	±/±
Member of BCBS	MEM	1/0 = BCBS's member/not BCBS's member	±/±
Bank-specifics determinants			
Bank size	BAS	LN(Total Assets)	±/-
Capital Adequacy	CAA	Total Equity/Total Assets	+/-
Leverage	LEV	Total Debts/Total Assets	-/+
Asset management ratio (%)	ASM	Operating Income/Total Assets	+/+
Operating Efficiency (%)	OPE	Operating Expenses/Total Income	±/±
Assets Quality (%)	ASQ	Loan Loss/Total Loans	±/±
Macro-economics determinants			
GDP Growth	ΔGDP	(Recent GDP - Last GDP)/Last GDP	±/±
Inflation (%)	INF	(Current CPI - Initial CPI)*100/Initial CPI	±/±

Note. The variables of ROAA, ROAE, NSFR, LCR, ASM, OPE, ASQ, INF are extracted from the S&P Global's website: www.spglobal.com. The term of CPI is Consumer Price Index.

3.4 Methodology and Data

3.4.1 Empirical Methodology

Although some research has used the Generalized Moments Method (GMM) to examine determinants of bank profitability and risk-taking (Goddard et al., 2004; Athanasoglou et al., 2008; Lee and Hsieh, 2013), GMM approach can impose possible correlations between independent variables (Athanasoglou et al., 2008). The problem of multicollinearity between explanatory variables is that the variance of a coefficient is increased, then either the statistical significance of an independent variable is reduced, or the signs of coefficients can be switched. Moreover, a serious problem of GMM estimators is that estimations can be subject to large finite sample biases when the instruments available are weak or when the moment conditions use weak identification of parameters (Bond:2002). Therefore, this paper applies linear regression models with pooled, fixed and random effects on a panel data following Iannotta et al. (2007); Cihak et al. (2013); Almaqtari et al. (2018). Linear regressions not only control the problem of multicollinearity but also deal with heterogeneity which is caused by the inconstant variances of error terms. Furthermore, the main advantage of linear regressions is that it is helpful to obtain more consistent and comparable estimations (Almaqtari et al., 2018).

The general model can be expressed as follows:

$$\pi_{i,t} = f(liquidity_{it}, bank - specific_{i,t}, macroeconomics_{i,t}) \tag{3.1}$$

where $\pi_{i,t}$ represents bank profitability and their distance-to-default measured by ROAA/ROAE and Z-score respectively. The expansion of the general model is:

$$\begin{aligned}
\pi_{i,t} =& \beta_0 + \beta_1 NSFR_{i,t} + \beta_2 LCR_{i,t} + \beta_3 NSFR_{i,t} * D1_{i,t} + \beta_4 NSFR_{i,t} * D2_{i,t} \\
&+ \beta_5 LCR_{i,t} * D1_{i,t} + \beta_6 LCR_{i,t} * D2_{i,t} + \beta_7 D1 + \beta_8 D2 \\
&+ \beta_9 MEM_{i,t} + \beta_{10} BAS_{i,t} + \beta_{11} CAA_{i,t} + \beta_{12} LEV_{i,t} + \beta_{13} ASM_{i,t} \\
&+ \beta_{14} OPE_{i,t} + \beta_{15} ASQ_{i,t} + \beta_{16} \Delta GDP_{i,t} + \beta_{17} INF_{i,t} + \gamma_{i,t}
\end{aligned} \tag{3.2}$$

where t denotes quarterly data, $\gamma_{i,t}$ is the model residual.

Models with fixed effect are unbiased under an assumption that the idiosyncratic error $\gamma_{i,t}$ is uncorrelated with the dependent variables across all periods (Wooldridge:2013). Hence explanatory variables which are constant over time for a bank i should be removed from the fixed-effect regressions, *i.e.* D1, D2, MEM will be dropped from the data.

We base on Adj-R^2 to determine whether pooled OLS model or fixed/random effect is suitable. A higher Adj-R^2 represents a higher ability to explain the variation of bank performance and stability. Between fixed and random effect, the Hausman test is applied to identify the best estimation. The null hypothesis of the Hausman test is that the model with random effects is preferred. If p-value of the Hausman test is less than 0.01, 0.05 or 0.1, the null hypothesis can be rejected at 1%, 5% or 10% respectively. It can be concluded that the fixed effect is more suitable.

3.4.2 Data Sample

The original data of 594 developed European banks throughout 2011Q1 to 2018Q4 was exploited from the S&P Global website based on a quarterly basis. Banks were excluded if they lack either NSFR or LCR information. The data which is much smaller than the original includes 89 banks with 855 observations. Moreover, there is a lack of data in some periods that makes the panel data unbalanced. Table 3.2 provides a brief overview of the data which is used in our analysis.

3.5 Empirical Results

3.5.1 Descriptive Statistics

Table 3.3 presents the summary statistic with percentiles of dependent and independent variables in the data set. Although the Basel III was introduced in 2010, BCBS's members are required to apply the minimum levels of liquidity requirements at 60% on 1 January 2015. The ratios are gradually increased annually until 100% on 1 January 2019. We, therefore, provide some comparisons of bank performance and risk-taking before and after the implementation of the Basel III liquidity standards.

Table 3.2: Data Sample

Number	Country	Number of banks	Number of observations	Proportion of observations Performance/Default (%)
1	Austria	6	37	4.18
2	Belgium	1	25	2.82
3	Cyrus	1	17	1.92
4	Czech	2	34	3.84
5	Denmark	3	32	3.61
6	Finland	4	45	5.08
7	Germany	3	26	2.94
8	Greece	1	3	0.34
9	Iceland	3	40	4.52
10	Italy	8	92	10.40
11	Netherlands	2	9	1.02
12	Norway	26	180	20.34
13	Portugal	4	71	8.02
14	Slovenia	1	3	0.34
15	Spain	12	106	11.98
15	Sweden	8	115	13.00
16	Switzerland	1	2	0.23
17	United Kingdom	3	48	5.42
	Total	**89**	**885**	**100**

Note. Data covers the period from 2011Q1 to 2018Q4. Banks are counted into the data including commercial banks and investment banks.

Table 3.3: Summary Statistics

Variable	Mean	Std	Min	0.25	Median	0.75	Max
Dependent Variables							
ROAA	0.5085	1.1816	-9.9700	-8.41	0.50	4.18	9.6100
ROAE	5.2224	17.2218	-270.37	-125.21	6.90	32.36	51.5700
Z-score	2.8887	3.2242	-5.4196	-3.5575	2.0802	13.4704	15.2929
Independent Variables							
NSFR	117.9967	22.4641	50	50	116.02	217	384
LCR	199.4422	117.7649	0	48.70	163.40	790.37	946.7400
BAS	18.0786	1.8445	13.7227	13.7915	17.9028	21.8146	21.8657
CAA	0.0820	0.0358	0.0212	0.0314	0.0728	0.2040	0.2261
LEV	0.2341	0.2116	0	0	0.1771	0.9131	0.9153
ASM	0.7891	1.6163	-0.1182	-0.0323	0.5706	15.9958	16.5847
OPE	59.0627	22.2295	5.3300	7.09	55.95	178.87	224.1000
ASQ	3.6293	4.5466	0	0	1.99	24.82	25.2300
ΔGDP	2.1618	1.4311	-2.9800	-2.03	1.98	8.78	9.2600
INF	0.3522	0.4143	-2.5840	-1.2019	0.3610	1.2152	2.2602

Note. ROAA is Return-On-Average-Assets (%), ROAE is Return-On-Average-Equity (%), Z-score is Distance-to-default, NSFR is Net Stable Funding Ratio (%), LCR is Liquidity Coverage Ratio (%), BAS is bank size, measured by LN(Total Assets), CAA is Capital Adequacy, estimated by the ratio of Total Equity toTotal Assets, LEV is leverage, calculated by the ratio of Total Debts to Total Assets, ASM is Asset Management Ratio, measured by Operating Income divided by Total Assets (%), OPE is Operating Efficiency, calculated by the ratio of Operating Expenses to Total Income (%), ASQ is Asset Quality, proxied by Total Loan Loss divided by Total Loans, ΔGDP is GDP growth, estimated by the difference in GDP of a period divided by the former GDP, INF is the difference in CPI over a period divided by the inital CPI.

Using data of the top 35 European commercial banks from 2009 through 2013, Menicucci and Paolucci (2015) summarised average ROA and ROE of 0.0792% and 0.3031% respectively. It can be seen that bank performance was much better than the prior period, although banks had to deal with more liquidity regulations of Basel III. Another data set of Goddard et al. (2004) analysed 665 commercial and saving banks in six European countries showing the average ROE in 1998 was 8.90%. Hence it can be expected that the banking sector has higher efficiency before the application of Basel III. Ristolainen (2016) showed a large negative distance-to-default of -12 according to monthly data of 37 large European banks from January 2006 to December 2013 compared to our positive value of +2.89 imply that the stability of the banks is enhanced after the introduction of Basel III.

3.5.2 Correlation Analysis

Table 3.4 reports the correlation matrix between all variables in the models. Apart from the correlation of 0.8439 between ROAA and ROAE, none of the correlations is beyond the threshold of high correlation which is defined by a value of 0.8 (Kennedy:2008). ROAA and ROAE are highly correlated due to the same return in the calculations of ROAA and ROAE. However, this issue does not have any negative effect because both proxies are dependent variables which are separately predicted in different regressions. According to the positive correlations between liquidity ratios and bank efficiency/distance-to-default, we predict that bank performance and stability are improved by the liquidity regulations. However, the small values of correlation imply that Basel III's influences are not noticeable. Particularly, the correlations between LCR and ROAA, ROAE and Z-score are tiny, at 0.0605, 0.0277 and 0.0324 respectively. In other words, a bank with better liquidity position might not have better efficiency and a larger distance-to-default. We can expect that the effects of short-term liquidity ratio are invisible. Although we expect that each explanatory variable consistently impacts bank profitability (ROAA/ROAE), bank sizes are oppositely correlated to ROAA and ROAE. Moreover, large banks with higher leverage are likely to have larger distance-to-defaults, whereas high operating efficiency and asset quality are useful to strongly reduce Z-scores by the values of -0.3961 and -0.4365, respectively. Notwithstanding, an increase in asset quality, surprisingly exacerbates bank performance. The correlation matrix eliminates any concern about multicollinearity in the models.

Table 3.4: Correlation Matrix

	ROAA	ROAE	Z-score	NSFR	LCR	BAS	CAA	DEP	ASM	OPE	ASQ	ΔGDP	INF
ROAA	1.0000												
ROAE	0.8439	1.0000											
Z-score	0.4736	0.4308	1.0000										
NSFR	0.1572	0.1257	0.0993	1.0000									
LCR	0.0605	0.0277	0.0324	0.1958	1.0000								
BAS	-0.0931	0.0100	0.2738	-0.1076	-0.0752	1.0000							
CAA	0.3185	0.1179	0.0388	0.0106	-0.0343	-0.5894	1.0000						
LEV	0.0108	0.0724	0.2251	-0.1014	0.1499	0.1870	-0.2646	1.0000					
ASM	0.0766	0.0422	-0.0492	0.0540	-0.0318	-0.1673	0.1092	0.2274	1.0000				
OPE	-0.2970	-0.2728	-0.3961	0.0050	-0.0801	-0.0782	-0.0797	0.2896	-0.0636	1.0000			
ASQ	-0.3857	-0.4053	-0.4365	-0.2590	-0.0986	-0.0972	0.1014	0.3456	0.1248	0.1861	1.0000		
ΔGDP	0.1250	0.0445	0.0642	0.0659	0.0996	-0.1822	0.3785	0.0282	-0.0331	-0.0132	-0.0224	1.0000	
INF	0.2347	0.1545	0.1528	0.1255	-0.0193	-0.0128	0.1041	-0.1099	-0.0201	-0.1016	-0.2466	0.0510	1.0000

Note. ROAA is Return-On-Average-Assets (%), ROAE is Return-On-Average-Equity (%), Z-score is Distance-to-default, NSFR is Net Stable Funding Ratio (%), LCR is Liquidity Coverage Ratio (%), BAS is bank size, measured by LN(Total Assets), CAA is Capital Adequacy, estimated by the ratio of Total Equity toTotal Assets, LEV is leverage, calculated by the ratio of Total Debts to Total Assets, ASM is Asset Management Ratio, measured by Operating Income divided by Total Assets (%), OPE is Operating Efficiency, calculated by the ratio of Operating Expenses to Total Income (%), ASQ is Asset Quality, proxied by Total Loan Loss divided by Total Loans, ΔGDP is GDP growth, estimated by the difference in GDP of a period divided by the former GDP, INF is the difference in CPI over a period divided by the inital CPI.

3.5.3 Regression Results

The three tables below show the results of Ordinary Least Squares (OLS) regressions with pooled, fixed and random effects for the determinants of ROAA (Table 3.5), ROAE (Table 3.6) and Z-score (Table 3.7). Following is the discussions on each proxy.

Bank performance

Return On Average Assets (ROAA)

ROAA represents bank performance by returns on a unit of its asset. According to the Adj-R^2, the regressions with pooled and random effects have a similar ability to explain approximate 39% of banks' performance variations. The p-value of the Hausman test is less than 1%, the fixed effect is more suitable than the random effect, although it only explains 2.61% of ROAA's changes.

The regressions with fixed and random effects indicate that liquidity regulations have no statistically significant impact on ROAA. Meanwhile the pooled regression shows that bank profitability is affected by long-term and short-term liquidity requirements at the 10% significant level although their influences are economically insignificant and opposite to each other. An increase of 1% in NSFR reduces 0.0035% ROAA whilst it will be increased by 0.0011% by a 1% increase in LCR. A reason for this opposite effect could be the different time horizons between NSFR and LCR. Banks have to pay higher costs of NSFR to fund one-year or longer stress episodes than costs of LCR which are for only 30-day stresses. The higher costs in long term put more pressure on demands of available sources for effective investments and reduced bank efficiency. Whereas the costs of short-term funding are classified as an expenditure, it is not large enough to reduce the bank's profitability. Additionally, the significant levels at 1% and 5% of the interaction variable NSFR*D1 and dummy variable D1 respectively in the pooled model imply that the negative impact of the long-term liquidity requirement is stronger on large banks. If bank size belongs to the top 25% quantile, bank size is equal to or larger than a value of $e^2 1.8657$ which is equivalent to EUR3,134,388,700. Banks' performance is reduced by an amount of (1.5639% - 0.0176%) or 1.5463%. Nevertheless, this exacerbation is not confirmed with the fixed effect in which the positive effect of the NSFR*D1 interaction is significant at 10%.

Table 3.5: Regression Results on ROAA

ROAA	Pooled OLS		Fixed Effect		Random Effect	
Variable	Co.eff.	t_{stat}	Co.eff.	t_{stat}	Co.eff.	t_{stat}
Liquidity Variables						
NSFR	-0.0035	-1.92***	-0.0058	-1.21	-0.00211	-1.00
LCR	0.0011	1.87***	0.0008	0.93	0.0009	1.42
NSFR*D1	0.0176	3.71*	0.0077	1.80***	0.0085	1.46
NSFR*D2	0.0027	0.69	0.0045	1.41	1.41	1.07
LCR*D1	-0.0009	-1.02	0.0045	-1.08	-0.0009	-0.98
LCR*D2	-0.0007	-0.97	0.0001	0.13	-0.0002	-0.30
Bank-specific Variables						
D1	-1.5639	-2.50**	.	.	-0.4600	-0.61
D2	-0.0870	-0.18	.	.	-0.3830	-0.66
MEM	-0.0412	-0.50	.	.	-0.0008	-0.01
BAS	-0.0058	-0.13	0.6367	1.78***	-0.0029	-0.05
CAA	8.8716	6.39*	18.1383	4.80*	10.3410	5.82*
LEV	-1.6073	-6.96*	-1.1521	-1.02	-1.4111	-4.86*
ASM	0.0374	1.77***	1.1018	6.01*	0.0500	1.75***
OPE	-0.0150	-8.80*	-0.0102	-4.78*	-0.0148	-8.11*
ASQ	-0.1208	-12.90*	-0.0133	-0.58	-0.1003	-8.39*
Macroeconomic Variables						
Δ GDP	0.0019	0.08	0.0131	0.47	.0075	0.30
INF	0.3343	4.14*	0.4494	5.59*	0.3653	4.61*
Adjusted-R^2		0.3861		0.0279		0.3892
F-statistic		33.71		12.08		323.50
Prob(F-statistic)		0.00		0.00		0.00
Hausman test				0.0000		

Note.
The model is described by: $\pi_{i,t} = f(liquidity_{it}, bank - specific_{i,t}, macroeconomics_{i,t})$.
*, **, *** Co-efficient is statistically significant at 1%, 5% or 10% respectively.

Furthermore, supporting prior literature, both regressions with pooled and random effects highlight the significant effects with the same directions of some bank-specific variables such as capital adequacy (CAA), leverage (LEV), asset management (ASM), operating efficiency (OPE) and macro-economic determinants namely inflation. In which, CAA can strongly increase ROAA by 8.87% whilst LEV reduces bank profitability by 1.61% Other determinants have influences on bank performance at small levels which are less than 0.12%. Nonetheless, the fixed-effect model does not recognise the statistical influence of leverage.

Return On Average Equity (ROAE)

The regression with random effect on ROAE is the model which has the greatest ability to explain ROAE's fluctuation. However, only the pooled model detects the significant negative effect of NSFR on bank performance; the decline in ROAE is 0.05% by an increase of 1% in NSFR. Unlike the analysis of ROAA, this negative effect of NSFR on ROAE is independent of sizes of a bank. Meanwhile, the positive impact of LCR is statistically insignificant. The models with pooled and random effects do not recognise the role of asset management in increasing banks' ROAE. Conversely, the fixed-effect model confirms the significant impact of asset management but declines the role of leverage in ROAE's variation.

Distance-to-default (Z-score)

According to the Adj-R^2 in Table 3.7, the pooled regression is the best model to explain bank risk-taking. The pooled model shows that the effects of liquidity ratios are dependent on bank size. In which, the long-term liquidity requirement (NSFR) plays a significant role in a large bank' s probability of default. Meanwhile, the short-term liquidity (LCR) negatively impacts only medium banks; the reductions in their Z-score are very small, approximately 0.004. Whereas, a large bank's Z-score is reduced by a meaningful distance of (7.8561 - 1*0.0293) equivalent to 7.8558. If the bank maintains sufficient amounts of highly liquid funding for NSFR, the bank may be short of financial funds for positive investments.

Surprisingly, if a bank is a member of BCBS, its distance to default increases by approximately 0.8 whilst this status is not helpful to improve bank performance (ROAA/ROAE). This fact can be explained by the process of Basel III's implementation. Members of the BCBS are requested to reach the minimum liquidity ratios which are increased annually, hence their capacities against unanticipated risks are also increased after each year. In opposite, non-members are flexible to maintain

Table 3.6: Regression Results on ROAE

ROAE	Pooled OLS		Fixed Effect		Random Effect	
Variable	Co.eff.	t_{stat}	Co.eff.	t_{stat}	Co.eff.	t_{stat}
Liquidity Variables						
NSFR	-0.0498	-1.68***	-.0057	-0.07	-0.0377	-1.22
LCR	0.0057	0.62	.0081	.57	0.0066	0.68
NSFR*D1	0.1018	1.34	.0345	0.48	0.0782	0.93
NSFR*D2	0.0677	1.07	.0082	0.15	0.0816	1.21
LCR*D1	-0.0010	-0.07	-.0130	-0.63	-0.0033	-0.22
LCR*D2	-0.0070	-0.62	-.0003	-0.02	-0.0060	-0.52
Bank-specific Variables						
D1	-7.7559	-0.77	.	.	-4.8621	-0.44
D2	-5.9096	-0.75	.	.	-7.7981	-0.92
MEM	-0.3347	-0.26	.	.	-0.0525	-0.04
BAS	-0.2681	-0.37	10.1821	1.71***	-.0973	-0.12
CAA	33.880	1.52	344.1244	5.42*	45.8644	1.87***
LEV	-22.4077	-6.05*	-12.7347	-0.67	-20.8861	-5.17***
ASM	0.3527	1.04	8.3046	2.73*	0.3756	1.00
OPE	-0.2151	-7.88*	-.1880	-5.24*	-.2104	-7.43*
ASQ	-1.7744	-11.79*	-.8600	-2.36**	-1.6682	-10.20*
Macroeconomic Variables						
Δ GDP	-0.0159	-0.04	-.1703	-0.37	-0.0367	-0.09
INF	2.2723	1.76***	4.5349	3.49*	2.6146	2.03**
Adjusted-R^2		0.2594		0.0579		0.2727
F-statistic		19.13		8.15		252.26
Prob(F-statistic)		0.00		0.00		0.00
Hausman test				0.0000		

Note.
The model is described by: $\pi_{i,t} = f(liquidity_{it}, bank - specific_{i,t}, macroeconomics_{i,t})$.
*, **, *** Co-efficient is statistically significant at 1%, 5% or 10% respectively.

the ratios, they do not want to apply the Basel III if it negatively affects their profitability. As a result, they might not be prepared in stress markets.

Table 3.7: Regression Results on Z-score

Z-score	Pooled OLS		Fixed Effect		Random Effect	
Variable	Co.eff.	t_{stat}	Co.eff.	t_{stat}	Co.eff.	t_{stat}
Liquidity Variables						
NSFR	-0.0013	-0.28	-0.0099	-1.93	-0.0079	-1.29
LCR	0.0018	1.24	0.0007	0.72	0.0004	0.45
NSFR*D1	0.0293	2.38**	0.0101	2.19**	0.0011	0.12
NSFR*D2	-0.0026	-0.26	0.0002	0.07	0.0037	0.45
LCR*D1	0.0009	0.41	-0.0027	-2.07**	-0.0024	-1.81***
LCR*D2	-0.0040	-2.23**	0.0006	0.57	0.0008	0.81
Bank-specific Variables						
D1	-7.8561	-4.82*	.	.	0.8022	0.67
D2	-1.4477	-1.13	.	.	-0.7147	-0.75
MEM	0.7962	3.75*	.	.	-0.0524	-0.09
BAS	1.3102	11.11*	0.3335	0.87	0.5125	2.57*
CAA	21.2735	5.89*	14.4331	3.56*	17.5577	4.58*
LEV	-1.5628	-2.61*	-2.1339	-1.76***	-0.7948	-0.82
ASM	-0.1210	-2.20**	0.6248	3.18*	0.2961	2.08**
OPE	-0.0486	-11.00*	-0.0190	-8.29*	-0.0214	-9.43*
ASQ	-0.2950	-12.12**	-0.0702	-2.86*	-0.0970	-4.08*
Macroeconomic Variables						
Δ GDP	.0440	0.69	.0483	1.62	.0448	1.50
INF	.2729	1.30	.3820	4.43*	.3787	4.35*
Adjusted-R^2		0.4429		0.0930		0.2768
F-statistic		42.34		12.97		196.03
Prob(F-statistic)		0.00		0.00		0.00
Hausman test				0.0000		

Note.
The model is described by: $\pi_{i,t} = f(liquidity_{it}, bank - specific_{i,t}, macroeconomics_{i,t})$.
*, **, *** Co-efficient is statistically significant at 1%, 5% or 10% respectively.

Furthermore, the pooled results confirm the significant effects of all bank-specifics on bank risk-taking. Beside bank size, capital strength is another independent variable which strongly improves bank stability, particularly a unit increase in CAA can increase a bank distance-to-default by 21.3 units. Other internal determinants such as leverage, asset management, operating efficiency and asset quality negatively impact bank stability. The external factors of macro-economics, meanwhile, have no significant effects on bank defaults.

3.6 Conclusion

This chapter analyses the effects of Basel III liquidity requirements on bank performance and stability. The data used is an unbalanced panel of 89 developed European banks during the period of 2011Q1 to 2018Q4. There are 885 observations which were reported on a quarterly basis. The variations of bank efficiency and risk-taking are measured by ROAA/ROAE and Z-score, respectively. They are examined by three categories of explanatory variables, namely liquidity regulations, bank-specifics and macro-economics. We also consider the interaction variables between NSFR and LCR with dummy variables of bank size. The models were run with pooled, fixed and random effects to determine the most suitable model to explain the fluctuations of bank profitability and distance-to-default.

The results show that the long-term liquidity standard (NSFR) reduces bank profitability and makes banks more fragile, especially large banks. Whereas the positive effects of the short-term funding ratio (LCR) on ROAA and its negative impact on Z-score are invisible. However, if a bank is a member of BCBS, it is more stable because of an improvement in default distance. Nonetheless, this benefit is eliminated by the strong negative impact of NSFR on large banks. These outcomes challenge the introduction of Basel III liquidity requirements which are expected to be helpful in reducing bank risk-taking. The Basel III standards not only decrease performance of banking sector but also shorten their distance-to-default. Furthermore, this chapter provides evidences to support the mixed impacts of internal and external determinants on bank performance and their strength.

Thesis Conclusion

Prior literature focuses on systemic risk in (internal) lending markets whilst derivatives markets have received less attention. In addition, investors usually use value adjustments to account for the costs of funding, credit risk and regulatory capital. These value adjustments may have an impact on the stability of the financial systems. The first chapter of this thesis contributes to the literature by investigating systemic risk in derivatives markets while incorporating the bilateral value adjustment. In the second chapter, we expand the model's sophistication by using collateral agreements. Systemic risk is examined before and after applying the value adjustments related to counter-party credit risk and collateral's financial risks. The market prices of collateral are also estimated using optimisation functions. Chapter 3 analyses bank performance and risk-taking under the implementation of the Basel III alongside bank-specific and macro-economic determinants.

In Chapter 1, an agent-based model is used to examine the effect of BCVA on systemic risk in derivatives markets. We apply a Monte Carlo approach to simulate the financial system before the 2007 global crisis. Systemic risk is examined before and after incorporating BCVA into pricing derivatives contracts. The results illustrate that the bilateral value adjustments effectively improve the stability of the entire network. The equity cushion provided by BCVA shields financial intuitions against unanticipated losses. This reduces the frequency and scale of systemic events and the spread of losses. This positive effect of BCVA is dependent on the leverage of institutions, connectivity and the premiums of derivatives contracts.

Chapter 2 examines the role of collateral's value adjustments in improving a financial system's stability. We compare the difference in the effects of xVA and BCVA on systemic risk. We also introduce optimisation functions of financial counter-parties benefit to estimate market prices of collateral during liquidation. The results show that the systemic risk in derivatives markets could be eliminated under the treatment of xVA. However, this positive effect is opaque in the networks with a weak infrastructure. This is first because the protection of xVA is effective within individual derivatives transactions; it could not spread within the loose connectivity. Secondly, more financial institutions who fail to meet higher capital requirements may become insolvent. Besides, collateral's market prices are reduced by higher leverage or larger gaps between fixed rates and floating rates. Therefore the introduction of xVA is critical in two aspects. Firstly, although the value adjustments can eliminate systemic risk, financial systems may become fragile if the network infrastructure is not strong enough. Secondly, the cost of xVA is the decrease in the collateral's market prices, that negatively affect the efficiency and stability of financial institutions.

Chapter 3 tests whether the application of Basel III liquidity standards has any impacts on bank performance and risk-taking. We analyse a panel of European banks during 2011Q1 to 2018Q4 by linear regressions with pooled, fixed and random effects. The outcomes indicate that the long-term liquidity ratio significantly reduces both bank profitability and distance-to-default. This negative effect is more serious for larger banks. Meanwhile, the impact of the short-term liquidity standard is economically insignificant. The outcomes highlight the benefit of being the BCBS's members in improving their stability, but the members' profitability is still reduced. These results challenge the implementation of the Basel III liquidity requirements, which are expected to affect banks' performance and fragility positively.

The contribution of value adjustments reserve to financial institutions' strength and the entire network's stability is proved through the Monte Carlo simulations in chapter 1 and 2. The more value adjustments are accounted for, the lower level of systemic risk is. However, the capital reserves equivalent to value adjustments unexpectedly decrease the market price of institutions' assets. Therefore, the application of value adjustments is critical. If investors only account for the bilateral value adjustment, they can reduce partial systemic defaults. In contrasts, financial decision-makers want to eliminate the threat of the entire network, they can apply extra value adjustments of collateral agreements, but it can reduce investors' asset values. Investors, hence, should balance their stability and market values. Meanwhile, the statistical evidence from chapter 3 fails the expectation of Basel III's implementation. Liquidity standards not only reduce bank profitability but also increase risk-taking. Policymakers should reconsider the scope of Basel III's application since members of BCBS have larger distances-to-default, but this benefit is limited to large financial institutions.

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