Credit market under the risk-based capital requirement

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Declaration

This dissertation is submitted to fulfill the requirements for a Doctor of Philosophy in the Department of Land Economy at the University of Cambridge. This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text. This thesis does not exceed the regulation length, including footnotes, references and appendices.

Wentao He

Cambridge, June, 2013

Dedicated to
My Family

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Abstract

This thesis studies the credit market under the Basel III banking regulation, which is in the process of being implemented following the 2007 global financial crisis. In the aftermath of the crisis, the stability of the banking system was an overriding consideration of central banks and Basel committee. A series of measures have been introduced to ensure the stability of the banking system, of which higher capital requirement is an important policy measure. The motivation of this thesis is to assess the impact of higher capital requirement on the credit supply decisions of banks.

Chapter 2 presents a discussion of the period leading up to the financial crisis, the key issues that relating to the credit market and the regulatory responses.

Chapter 3 presents a discussion of the relevant literature on credit market.

Chapter 4 empirically analyses of the UK credit market disequilibrium, based on a set of financial market data from 2000 to 2012, by adapting maximum likelihood method to estimate the effect of a number of macroeconomic variables on the supply of credit and the demand for credit. The results are generally in line with the expectation of disequilibrium in the credit market over the sample period with the credit demand exceeding the credit supply.

Chapter 5 formulates a credit market cobweb model to study the dynamics of the credit supply and demand. The dynamic equations for the expected lending rate, profit of a representative bank as well as the stability conditions for the market are derived under two different scenarios: unconstrained lending and capital constrained credit supply. The results lend support to the risk-based capital requirement policy: banks need to hold a specific amount of regulatory capital to ensure the stability of the banking industry. More specifically, the results suggest that it is necessary to have a countercyclical regulatory capital requirement.

Chapter 6 develops a credit supply model, as an alternative approach to the credit market cobweb model in chapter 5, based on a bank portfolio allocation approach. The optimality conditions are derived for a representative bank to select its asset portfolio. The results indicate that the optimal portfolio allocation decision of a representative bank vary depending on the risk weighted capital requirement and leverage, which provide some useful insights into the deleveraging decision and adjustments of portfolio weights from risky to safe assets. The model is then tested empirically, using a set of panel data on four major British banks over the time period from 1991 to 2010, to determine the effect of default rate and the risky loan size on bank lending.

Chapter 7 considers both the credit supply and credit demand to study the relationship between the capital requirement and the magnitude of credit rationing. In order to gain a better understanding of the effect of higher capital requirement on the credit market, it is important to consider both sides of the credit market. The result shows that both a poorly capitalised bank and a bank holding capital buffer react in the same manner to higher capital requirement by raising the lending rate on the loans and by shrinking loan portfolio. The result also lends support to the countercyclical capital policy. A number of possible scenarios are presented to explain how the higher capital requirement can affect the magnitude of credit rationing depending on the demand and supply conditions in credit market. The results indicate that both the higher lending rate and an increase in the magnitude of credit rationing have an adverse effect on the profitability of the bank.

Chapter 8 presents an overall conclusion of the thesis along with a discussion of the limitations of the study and some suggestions for future research.

List of notation

We list some important notations we will use throughout the thesis here:

Roman symbols

A^R	The total value of the risky assets in a typical bank's portfolio
A^S	The total value of the safe assets in a typical bank's portfolio
B	The amount of funding required by a typical borrower
$Bint$	Business investment
c	Regulatory minimum leverage ratio
C	Value of collateral
d	Regulatory minimum risk weighted capital ratio
D	A typical bank's total liabilities (include both deposits and debt)
E	A typical bank's equity value
i^e	Expected inflation
K	A typical bank's capital (include equity and other qualified assets)
L	The amount of loan
L^S	The quantity of credit supply
L^D	The quantity of credit demand
MV	Market value of the banks
p	Price of a good
Q	Observed quantity of outstanding loan
r^L	Lending interest rate
r^{LIBOR}	Three month LIBOR rate
r^D	Deposit interest rate
r^S	Interest rate of the risk-free securities
R	Return on a typical investment project
S	Safe asset
T	Time period
w_R	Risk weighting of the risky asset
w_S	Risk weighting of the safe asset
X_1	Observable macroeconomic factors that determine credit supply
X_2	Observable macroeconomic factors that determine credit demand
y^e	Expected industrial production output

Greek symbols

α	Constant of the production function in the cobweb model
β^S	Parameters for the credit supply equation
β^D	Parameters for the credit demand equation
δ	The probability of default for loans
ϵ	Error term in the model
Ω	Magnitude of credit rationing
ϕ	Probability density function of the standard normal distribution
Φ	Cumulative distribution function of the standard normal distribution
φ	A typical bank's capital ratio
γ	Adjustment speed
λ	Cost function for issuing equity
π	Expected return for a typical borrower
θ	Riskiness of a project
σ	Standard deviation of certain distribution (depends on the specific model)
ζ	Discounted factor

Contents

Chapter 1

Introduction

One of the most important considerations in ensuring the stability of the banking system is maintaining a balance between regulatory capital requirement and the volume of bank lending in the economy. The recent changes in banking regulation brought about by Basel III have complex and wide ranging effects on the supply of credit by banks depending on their effects on the bank capital holding, portfolio adjustments and leverage. The key changes in the Basel III capital regulation are the minimum tier 1 capital ratio that is raised from 3.5% to 4.5%, and banks are required to hold a 2.5% mandatory capital conservation buffer as well as another 2.5% countercyclical capital buffer by the end of 2019. Three main effects of these changes can be identified as being crucial in terms of their significance to the economic activity and the stability of the banking system. First, the supply of credit has been reduced significantly. When the risk-weighted capital requirement is raised, banks may either adjust their capital holding or reduce their risk-weighted assets[1]. If banks issue more equity in response to higher capital requirement, thereby keeping their assets holding constant, it will not shrink the supply of credit in the economy. If, however, banks adjust their asset allocation in favour of lower risk weighting, the availability of loans to risky borrowers will invariably contract. In the G3 (US, Euro Area and Japan), the Institute of International Finance estimated that the combined impact of new banking regulations may be to cut gross domestic product by $0.5 - 0.6\%$ per year

[1] We interchangeably use risk-weighted and risk-based throughout the thesis.

over five years and could cost some 7.5 million jobs in the process. According to IMF (2008), ‘The repricing has been triggered by tighter lending conditions across the major economies, making credit more difficult to access for corporates and households. Faced with the increasing probability of unintended balance sheet expansion and losses, banks have become increasingly reluctant to extend credit while securitization markets may remain impaired. Combined with widening spreads, this increases the risks to the economy of a credit crunch.’ In the recent times of the implementation of Basel III, it has been observed that most banks resorted to significant scaling down of their operation. Barclays, for example, sold Barclays Global Investor to Blackrock to raise \$6.6 billion cash in 2009, Lloyds sold A\$1.7 billion (November 2011) worth of distressed property loans to Morgan Stanley and Goldman Sachs Group Inc, UBS shut down its fixed income division in 2012 as part of a cost cutting program, and etc. One explanation is that the banks find the cost of issuing equity is too high, especially at the time when their share prices were low.

The second effect of higher regulatory capital requirement is different depending on whether a bank is well capitalised or not. Raising the level of capital can be valuable in turbulent times, however, it only affords partial protection to the banking system. To the extent that many of the major banks are still seriously under-capitalised, the presence of the risky assets creates an incentive to gamble for reclamation. For a clearly solvent bank, the decision to hang on to or dispose of the risky assets would be based on a profit maximising motive. For a bank that is close to insolvency, the incentive to remove the risk is much lower. If the assets lose value and drive the bank into insolvency, the inability to resolve such an institution could create a zombie bank.

Another main effect of higher capital requirement is on the profitability of banks and the returns to shareholders. Banks may resort to raise the lending rate or scale down the supply of credit in order to boost the returns to their shareholders. But, even with such actions, returns may not be sufficient to cover the cost of equity capital. In addition, if banks try to pass on the higher cost of capital to borrowers and increase the lending rate, it can inadvertently increase default risk.

Thus, faced with a combination of deteriorating economic conditions and unfavourable profit outlook, increased credit risk, and the steep cost of raising new capital, banks did not have any other choice but to curtail their portfolio and reduce new lending in order to meet the Basel III capital requirement.

In view of the recent evidence available on the effects of higher capital requirement, it is important to study these effects more formally within a theoretical model that can provide deeper insights into these effects. The main aim of this thesis is to theoretically analyse the effect of higher capital requirement on bank portfolio adjustment, the credit supply decisions of banks as well as the magnitude of credit rationing.

Over the past thirty years, credit rationing has attracted great focus in research following the seminal paper Stiglitz and Weiss (1981), which uses a simple static model to show two key results. First, firms borrow from the bank if and only if the riskiness of their projects are above a certain critical level. If the bank increases the lending rate or collateral, those low risk borrowers will withdraw from the credit market due to the negative expected return, and this will happen before the high risk borrowers do so. Hence, the expected return for bank will be reduced if only the high risk borrowers exist in the credit market. Second, the expected return on loans for bank will have a single peaked and the bank would set the interest rate to be below the market clearing level in order to maximise its expected return. This implies that some borrowers are rationed by the bank.

In the existing literature, there are a number of shortcomings that can be identified. First, they fail to model the portfolio selection process of a typical bank. Apart from the traditional function of lending out money to households, banks can also invest in safe government securities. As a result, the rate of return of the safe asset plays an important role in the portfolio selection process for bank. This will have a significant impact on the credit available in the market as well as the existence of credit rationing. Hence, we need to specify a mechanism for banks to choose between safe government securities and risky loan in order to study the credit rationing outcome. However, the existing credit rationing literature only focuses on the return of the risky loan to the banks and fails to consider the role of government securities. Second, the credit rationing literature only focuses on a small picture of the credit market, namely credit rationing, and the banking regulation is neglected in their theoretical models. After the introduction of Basel I back in 1988, banks were subject to capital regulation. In order to reach a definite conclusion on the existence of credit rationing, we need to integrate the existing credit rationing theory into the capital regulation framework. To our knowledge, Agur (2011) is the only paper considers the credit rationing under the risk-weighted capital requirement. But, there is a flaw in the modeling approach in Agur (2011), which is discussed in detail in section 3.2.4. Most of the existing literature on the effect of capital regulation solely focuses on the supply side of the credit market. This literature typically uses regression analysis to estimate the supply of credit with respect to various control variables such as bank capital, capital shock and other macro economics indicators. [See Bernanke et al. (1991), Hall (1993), Hancock and Wilcox (1994), Hancock et al. (1995) and Thakor (1996)] The common criticism of the above literature is that they do not have a structural model to identify the optimal level of credit supply.

By addressing the shortcoming in the existing literature outlined above, this thesis contributes to a better understanding of the effects of higher capital requirement on the supply of credit, the optimal portfolio adjustment of a typical bank, the profitability of the bank and the magnitude of credit rationing in the market. We develop a theoretical framework, identify some empirical tests, and carry out some numerical analysis to study the credit market under the risk-based capital requirement.

The key contributions of this thesis are: first, by modifying a number of factors in the standard cobweb approach in economics, we develop a dynamic credit market model that can quantify the multi-period optimal levels of credit supply given the current economic factors. To our knowledge, the cobweb approach in this thesis is the first attempt to study the dynamics of the credit market. By considering the probability of loan default and the risk-weighted capital requirement, we allow for bankruptcy and attempt to predict the future demand for credit as well as the loan default rate. This provides a useful basis from which to study the supply of credit under different economic conditions. One of the important areas where our credit market cobweb model is most useful is in the mortgage market to forecast the future supply of loans. The credit supply to housing market is crucial in both mature and developing economies. The availability of mortgage is an important parameter to forecast the house price. Our study provide a useful theoretical framework for empirical work in this field.

Second, we develop a multi-period structural model for a typical commercial bank to study its optimal portfolio allocation decision between the safe asset and the risky assets. This is another approach to model the supply of credit but does not rely on the assumption of competitive credit market, which is the key assumption in our cobweb approach. By introducing the safe asset in the asset portfolio of the bank, the model has a built in feedback route that allows the bank to switch between assets when the capital regulation change. This captures the more realistic setting of the credit market and provides useful results that can better explain the portfolio adjustment and the shrinkage of risky loan in the banking sector in response to Basel III. We can use this bank portfolio selection model to determine the optimal level of mortgage supply by banks. However, the risk characteristics of the land, houses, commercial properties and industrial properties are different, so banks apply different risk weightings to these assets according to the Basel regulation. The current version of our optimal bank portfolio model considers one type of risky asset solely, but a possible future research would be modified our model to incorporate different types of risky assets in order to gain insight into the credit supply to different real estate sub sectors.

Third, we incorporate the risk-based capital requirement into the model in Stiglitz and Weiss (1981) to study the effect of raising capital requirement on the magnitude of credit rationing. Based on the results of the credit supply models we develop, we study a credit rationing model includes the safe asset and considers both the asset and liabilities sides of the balance sheet for a typical bank. To capture the effect of the required rate of return by the shareholders, we set up an maximisation framework based on rate of return approach. Our result contributes to the existing credit rationing literature by providing a framework to quantify the magnitude of credit rationing given the changes in capital requirement. Our model would be most useful for regulator and policy makers interested the short run effect of raising capital requirement on mortgage market. Once they determine the required rate of return by the shareholders on mortgage asset held by banks, they can use our credit rationing model in this thesis to quantify the magnitude of credit rationing. Then the regulator and policy makers can take appropriate action according to their objectives.

The rest of the chapters in this thesis are as follow:

Chapter 2 presents a discussion of the financial innovation leading up to the 2007 global financial crisis and the regulatory responses that follow the crisis. As is widely known, the implementation of Basel II caused banks to seek new ways to avoid holding too much capital, which is expensive from the banks' point of view. Due to the loophole in the Basel II, and the accounting standard, the shadow banking system emerged at a rapid pace and the composition of balance sheets of large banks changed significantly. When the risk appetite started to drop after the 2007 global crisis, there was not enough liquidity in the market. Consequently, many banks suffered large losses on their off-balance sheet assets. To prevent the systemic collapse of the banking system, central banks were forced to step into the financial markets and take unprecedented measures to improve the liquidity as well as the stability of the banking system. These regulatory actions, in particular through the implementation of Basel III capital requirements, have significant impacts on the credit market. The discussion in this chapter helps us to highlight the necessity as well as the profound consequences of the new banking regulation.

Chapter 3 presents a discussion of the relevant literature on the credit market. This chapter together with chapter 2 lay the foundation for our theoretical and empirical analyses of the credit supply decision, portfolio allocations decision, profitability for a representative bank and the magnitude of credit rationing in the subsequent chapters.

Chapter 4 studies empirically the disequilibrium of the UK credit market. We adapt the maximum likelihood method to quantitatively estimate the magnitude of disequilibrium in the UK credit market, which is based on a set of financial market data from 2000 to 2012. We also identify the effects of a number of macroeconomic variables on the supply of credit and the demand for credit. We show that the credit demand exceeds the credit supply most of the time throughout the sample period, which is in line with our expectation. The results indicate that disequilibrium exists in the credit market and provide a useful basis for our theoretical analyses in the remaining chapters.

Chapter 5 adapts the well established cobweb approach in agricultural economy to study the dynamics of the credit supply and demand. Based on our result in chapter 4, we formulate the evolution equations for the expected lending rate, profit of a representative bank as well as the stability conditions for the market under two different scenarios: unconstrained lending and capital constrained credit supply. The results in line with the risk-based capital requirement policy: to improve the stability of the banking sector, banks should hold certain amount of regulatory capital. Moreover, the countercyclical regulatory capital requirement proposed in Basel III is a better policy tool than the risk-based capital requirement alone.

Chapter 6 develops a structural model of credit supply based on the bank portfolio allocation decision. This model is an alternative approach to the credit market cobweb model in chapter 5, but it is not based on the assumption of a competitive credit market. We introduce the safe asset to enrich the robustness of the portfolio selection of the bank. Our model builds on Furfine (2001). There are two distinguishing features of our model. First, it incorporates the expected probability of default, which is an essential factor in the bank lending process. Second, we specify a number of more realistic cost functions. The asset allocation optimality conditions for a representative bank are established. The results are illustrated with some numerical analysis. We calculate the optimal portfolio for the model bank under different regulatory requirements. We find that the changes in risk weighted capital requirement and leverage have different impacts on the optimal portfolio allocation decision. This helps to explain why most banks have been deleveraging and adjusting their portfolio weights from risky to safe assets following the 2007 global financial crisis.

Chapter 7 considers both the credit supply and credit demand to study the effects of the higher capital requirement on the lending rate, the magnitude of credit rationing and the profitability of a typical bank. We introduce the risk-based capital requirement in Stiglitz and Weiss (1981) and develop a model in which a bank may adjust the asset or liability side of its balance sheet. A distinguishing feature of this model is that the bank tries to maximise its rate of return to shareholders. We discuss the possible actions of the bank under binding and non-binding capital constraints. Our results indicate that both a poorly capitalised bank and a bank holding capital buffer react in the same manner to change in regulatory requirement by raising the lending rate on risky loans and by shrinking risky loan portfolio. This is in line with our expectation and empirical finding. Based on our results, we suggest that a countercyclical capital policy is more suitable than raising capital requirement when the economy is in a distressed environment. We present a number of possible scenarios to explain how the magnitude of credit rationing changes when the regulator raises capital requirement. Based on the effects of higher capital requirement on lending rate and on the change in magnitude of credit rationing, we deduce that the implementation of Basel III inadvertently reduced the profitability of bank.

Chapter 8 presents an overall conclusion of the thesis along with a discussion of the limitations of the study and some suggestions for future research.

Chapter 2

Debt, capital procyclicality, deleveraging and regulatory responses

We start this chapter by setting out the key issues relating to the credit market and the regulatory responses that have emerged since the 2007 global financial crisis. In the period leading up to sub-prime crisis, the composition of balance sheets of large banks had changed significantly, which had not been fully captured by disclosures or regulations. When dislocations in credit and funding markets surfaced, central banks were forced to take unprecedented measures to avert systemic collapse of the banking system. The emerging regulatory actions, especially through the implementation of Basel III capital requirements, have profound consequences for credit supply and credit rationing. There is a vast body of literature on credit rationing, but to our knowledge, not many studies have examined the impact of higher regulatory capital requirement on credit rationing. Chapter 3 will present a detail discussion of the existing literature on credit supply and credit rationing along with a review of some selective approaches to modelling disequilibrium in markets. These two chapters together lay the foundation for our analysis of banks' credit supply decision, portfolio allocations decision, profitability and credit rationing in later chapters.

2.1 Banks' on and off balance sheet leverage

In the run-up to the 2007 global crisis, the composition of balance sheets of large banks had changed significantly. The implementation of the Basel Capital Accord in the late 1980s and early 1990s changed the economic landscape of banking activities. Incentivized by domestic and international competition under the Basel I regulatory capital requirement, US banks devised asset backed commercial paper (ABCP) vehicles to reduce the exposure of their assets from a credit perspective and incur lower regulatory capital charges associated with related liquidity exposures of such vehicles. The most striking development of the regulation was a widening of the gap between risk-weighted assets and total assets. Many banks had significantly expanded their off balance sheet activities, largely by increasing their holdings of highly rated securities that carried low risk weightings for regulatory capital purposes. IMF (2008) report pointed out that 'This trend is evident in the 10 largest publicly listed banks from Europe and the United States, which doubled in aggregate assets in the last five years to 15 trillion euros, while risk-weighted assets, which drive the capital requirement, grew more moderately to reach about 5 trillion euros'. The growth in banks' total assets was engineered by innovative off-balance-sheet bank conduits and structured investment vehicles (SIVs) that allowed commercial banks to offer their corporate customers low-cost, off-balance-sheet funding. In addition to the significant management fees and trading income, SIVs had the added advantage of being able to sell the investment in the capital notes to their client base. More importantly, banks were able to record a lower or no risk weight under Basel I and Basel II for the associated assets and for backup credit lines extended to SIVs.

Inderst and Mueller (2008) model banks' optimal capital structure and show how competition for borrowers leads to an 'underinvestment problem', unless banks are levered up sufficiently. Based on 'functional approach', the authors argue that an important function of banks is to make risky loans in a competitive environment. To illustrate how more leverage was fostered under Basel I, Merton (1995) offered the following example (pp. 468-469): If a bank were managing and holding mortgages on houses, it would have to maintain a capital requirement of 4%. If, instead, it were to continue to operate in the mortgage market in terms of origination and servicing, but sells the mortgages and uses the proceeds to buy US government bonds, then under the BIS rules, US government bonds produce no capital requirement and the bank would thus have no capital maintenance.

SIVs and Conduits were set up mainly as off-balance-sheet entities that allowed banks to extend their lending without the pressure of regulatory capital requirements. Most SIVs and conduits had back-up liquidity facilities with banks. Along with SIVs and conduits, finance companies such as Countrywide, Thornburg Mortgage and Northern Rock borrowed short in ABCP markets to underwrite loans that they then sold to broker-dealers for securitisation. ABCP conduits and SIVs changed the way credit was intermediated and risk was transformed in the financial system. In a period of low interest rates, repackaging low-grade assets into investment-grade assets by using complex financial instruments such as CDOs, cash flow CDOs, and synthetic CDO were highly lucrative. The SIVs involved five groups of players: money market mutual funds (MMMF), institutional investors (pension funds, insurance companies, hedge fund), credit rating agencies, underwriters and traders (often both within the same banks). By pooling and tranching the cash flows from (seemingly) imperfectly correlated assets, CDOs allowed institutional investors to gain exposure to assets that, on their own, had been too risky, while banks looking to take more risk receive potentially higher returns by holding the most junior or 'equity' CDO tranches. For banks (Merril Lynch, Citigroup, Credit Suises, Goldman Sachs, Bear Stern, Deutsche Bank, etc.) and rating agencies, CDOs generated underwriting and rating fees, respectively. According to JPMorgan estimates, $6 trillion worth of credit was intermediated through the shadow banking system as of the second quarter of 2007 compared with the $10 trillion intermediated through regulated banks funded primarily by deposits. Astonishingly, some investment banks continued to market new CDOs (and synthetic CDOs) in 2007, even after RMBS securities lost value and mortgage delinquencies intensified.

The process of transformation of risk involved funding illiquid long term assets (CDOs, cash flow CDOs, CMO) with staggered, off balance sheet, short term ABCPs in the unregulated wholesale market rather than from the traditional retail deposits. The operational structure of conduits and SIVs was highly risky; it lacked the solid foundation of adequate capital and transparency. Moreover, SIVs often had multi layers of leverage because they owned leveraged vehicles (CDOs), particularly those backed by subprime and so-called Alt-A mortgages. Whilst most ABCP conduits had liquidity support to cover at least 100% of the value of ABCP issued, SIVs relied on capital and liquidity models, approved by ratings agencies, to manage liquidity risk. ABCPs ratings were contingent on liquidity support and the ratings of the credit so that a downgrade in the short-term or long-term debt ratings of any of the parties may result in a re-evaluation and possible downgrade of the ABCPs. As Dodd and Mills (2008) succinctly point out, 'The principal risk management strategy was to plan to trade rapidly out of a loss-making position. But such a strategy, which relies on markets remaining liquid, failed when markets rapidly became illiquid.' Indeed, the first signs of failure of this strategy surfaced on July 31, 2007, when two Bear Stearns's hedge funds filed for bankruptcy and a week later BNP Paribas halted withdrawals from its three investment funds.

The loophole in regulatory capital spurred banks to reconfigure their assets using credit risk transfer instruments such as Collateralised Debt Obligations (CDOs) and credit default swaps (CDS). This was done either by purchasing insurance against credit losses using CDSs (reducing the gross risk of a loan portfolio) or by removing the riskiest (first loss) portions of a loan portfolio using CDOs. Apart from regulatory arbitrage, the growth in off-balance sheet activity was driven by competition from (unregulated) money market mutual funds (MMMFs), which had diminished banks cost advantage in acquiring funds, and had eroded their profitability from traditional loan markets. Banks that had adopted aggressive off-balance sheet trading and investment activities became vulnerable to illiquidity in the wholesale money markets, earnings volatility from marked to-market assets, and illiquidity in structured finance markets. These concealed risks of their exposures to off-balance sheet vehicles, which had not been captured by disclosures or regulations, came under the spotlight when dislocations in credit and funding markets surfaced.

Bernanke (2006) in his speech on implementation of Basel II remarked 'Much more so than in the past, banks today are able to manage and control obliger and portfolio concentrations, maturities, and loan sizes, and to address and even eliminate problem assets before they create losses Basel II will make it easier for supervisors to identify banks whose capital is not commensurate with their risk levels and to evaluate emerging risks in the banking system as a whole. From the perspective of bank management and stockholders, the availability of advanced methods for managing interest rate risk leads to a more favorable risk-return trade-off. For supervisors, the benefit is a greater resilience of the banking system in the face of a risk that figured prominently in some past episodes of banking problems'. In hindsight, it is evident that financial institutions applied risk models in ways that significantly underestimated certain risk exposures, and consequently, their capital was not commensurate with exposures. Given the public and private sector costs of the credit crunch, the focus has shifted towards assessing the implications of Basel II and Basel III risk-management requirements and bank supervision.

In the aftermath of the 2007 financial crisis, a raft of unprecedented measures including liquidity support, extended deposit insurance, asset purchase programmes, and recapitalisation of banks were launched by central banks to rescue the global financial system from the contagion of bank failures. A confluence of rising interest rate [1], falling house prices, and uncertainty surrounding the values of complex structured mortgage and credit products, had fuelled credit and liquidity risk to spiral upwards.

Inevitably, as more and more information about the multi-layered complex structures became publicly available, banks that had adopted an off-balance sheet strategy most aggressively were heavily penalised in the equity markets. Between 2006 and 2009, the overall loss in market capitalization of the top-30 banks was 52 %, which includes a significant stock market recovery during 2009 (Laeven and Valencia (2010)).

The downward spiral of falling asset prices and deleveraging precipitated contraction of the supply of secured financing, particularly, to highly-leveraged market users. In IMF (2008) it is emphasised 'It is now clear that the current turmoil is more than simply a liquidity event, reflecting deep-seated balance sheet fragilities and weak capital bases, which means its effects are likely to be broader, deeper, and more protracted.' Because leveraged institutions suffer mark-to-

[1]Between 2004 and 2006, the Federal Reserve Board raised interest rates 17 times, increasing them from 1 % to 5.25 %.

market losses of x dollar have to reduce their position by x dollar times their leverage ratio, the ultimate impact on new lending to businesses and households was enormous. During August and December of 2008, Ivashina and Scharfstein (2010) estimate a 36% reduction in monthly loan origination by a bank with the median deposits-to-assets ratio relative to the previous year while the same ratio one standard deviation below the mean the reduction goes as high as 49%. Greenlaw et al. (2008) estimate shows '\$2.3 trillion contraction in intermediary balance sheets, of which roughly \$1 trillion would represent a decline in lending to households, businesses, and other non-levered entities.'

2.2 Procycical bank capital

It is widely accepted in the literature on financial intermediation (Bryant (1980), Diamond and Dybvig (1983), Diamond (1984), Diamond and Rajan (1999) and etc.) that the main function of a traditional commercial bank is to provide liquidity by issuing demand deposits and loans to borrowers. In fact, liquidity is driven by economic activities, so the supply of deposits and the demand for loans are positively correlated with macroeconomic cycles. This causes procyclical movement in credit supply and bank capital. In the up phase of an economic cycle, normally rising profits and asset values are associated with rising aggregate volume of lending. The rise in lending volume in turn accelerates investment and economic activity. Most notably bank profits, return on equity and capital for the bank rise due to the lower default rate and higher lending volume. The credit expansion and economic boom in the past have resulted into bubbles[1]. The recent house price bubble in the US that eroded bank capital and the subsequent global financial crisis. The rapid credit expansion and low interest rate after the dot come bubble in the early 2000s led to the house prices boom in many mature economies. According to the S&P/Case-Shiller national home-price index, the US house prices rose by 124% between 1997 and 2006, in the UK house prices went up by 194%, in Ireland by 253% over the same period.

[1]Allen and Gale have proposed a number of models to study the formation of asset price bubbles and financial crises. See Allen and Gale (1998), Allen and Gale (2000a), Allen and Gale (1999) and etc.

The net worth of banks increased significantly during this period. According to the balance sheet data of Barclays Bank Plc, its total asset value and equity value rose 3.36 folds and 2.44 folds, respetively. When the 2007 bubble bust, both house prices and bank capital collapsed as would be the case given the procyclical nature of the housing and banking sectors.

There is a great deal of evidence accumulated in the academic literature on procyclicality of the banking sector. Ayuso et al. (2004), using a set of Spanish banks' panel data, find that the bank capital and the phase of business cycle has a significant statistical positive relationship. Goodhart, Hofmann and Segoviano (2004) suggest that there are three main factors are responsible for the procyclicality in the banking sector. First, the financial liberalisation in 1970s enabled the large companies, which had traditionally borrowed from banks, to raise fund from the capital market. As a result, banks began to lend to small and medium businesses (SME) and individuals, which in general have higher risk and cost of obtaining information. Apart from lending to SME, banks also started to expand their mortgage business. All of these new lending activities are cyclical in nature compared to the traditional large businesses borrowers. Hence, the developments in the banking sector since 1970s have increased the procyclicality of the capital (net worth) of the banks. Second, the interaction between capital regulation and economic cycles. In 1988, the Basel Committee on Banking Supervision (BCBS) formalised a set of minimum capital requirements in order to systematically rationalise international banking supervision and improve stability of the banking system. This is known as Basel I. This regulation change to a certain extent achieves its target but had given rise to capital arbitrage. More importantly, Basel I has been widely criticised for exacerbating the procyclicality in the banking sector and even the whole economy. The literature on the fire sale provides ample evidence on this subject. It can be argued that in a downturn equity market, the existence of minimum capital requirement can force a capital constraint bank either liquidate its illiquid assets or raise capital. More recently, during the financial crisis, it was very difficult for the banks to raise equity because their share prices were collapse[1], hence, the capital constrained banks chose to sell off their risky assets and used the proceeds to buy government bonds. This incured

[1]Some examples can be found at page 2 of the Introduction chapter of this thesis.

significant losses to banks due to adverse market conditions. Furthermore, this exacerbated the downward market trend in the equity market and the upward market trend in the government bond market. This is because government bonds tend to become a safe haven during a crisis, so the government bonds market had an upward trend. In 2012, the government bond market reached such a high level that the two years German government bunds were traded in a negative interest rate. This provided an opportunity to the speculators in the market to profits from the trends in the equity and bond markets. Evidently, the minimum capital requirement increased the extent of procyclicality in the banking sector. Third, capital regulation itself is procyclical. More specifically, Basel II, which adopts internal rating approach and mark to market accounting, gives rise to procyclicality. The empirical literature (Acharya et al. (2003), Kashyap and Stein (2004) and Altman et al. (2005)) suggests that the Probability of Default (PD) and Loss Given Default (LGD) parameters in the internal rating models are highly cyclical. Hence, using these parameters to set minimum capital requirement increases the procyclicality in the banking sector. Furthermore, mark to market accounting also causes procyclicality of minimum capital requirement. This is because both asset values and bank profits tend to be lower in down phase of the cycle. Even though the regulatory minimum capital ratio remains the same, the capital burden for banks effectively increase during the crisis.

There are several other studies that support the view that the procyclicality in the banking sector arising from the regulatory minimum capital. Blum and Hellwig (1995) study the procyclical nature of the banking sector by using a reduced-form specification of macroeconomic variables. The authors suggest that macroeconomic fluctuations may be amplified under the Basel I fixed capital requirements. Estrella (2004) develops a dynamic model to consider costs associated with bankruptcy and capital in an infinite time horizon setting. The author uses simulations to show that the risk-based capital requirement does have procyclical effects. Covas and Fujita (2010) formulate a general equilibrium model to quantify the procyclical effects of bank capital requirements. The result shows that the standard deviation of output fluctuations is increased by around 5 basis points and 10 basis points due to Basel I and Basel II, respectively.

A number of policies/regulation that have been suggested to mitigate the procyclical effects in the banking sector. Pennacchi (2005) suggests using a form of risk-based deposit insurance to reduce the procyclical effects. Pederzoli and Torricelli (2005) propose to use ex post observations instead of ex ante expectation of altered risks to calculate risk weighted assets. The authors use a set of US data from 1971 to 2000 to show that the procyclical nature of the capital requirement is significantly smaller. The implementation of Basel III began in 2013, proposes a countercyclical capital policy [1] to mitigate the procyclicality problem in the previous version of banking regulation. The countercyclical capital policy requires the banks to build up additional capital buffer on top of tier 1, tier 2 and mandatory capital conservation buffer in an economic upturn. This will be the first resource for banks to absorb losses during the downturn phase of an economic cycles. In Chapter 5 and Chapter 7 of this thesis, we propose two theoretical models to study the impact of Basel III on credit supply and the magnitude of credit rationing. Both credit supply and the magnitude of credit rationing are closely related to above discussion on cyclical nature of the banking sector. More specifically, the magnitude of credit rationing is one of the key policy issues that needs to be carefully analysed when examining the trade off between banking stability and the economic costs of Basel III capital requirement.

2.3 The 2007 global crisis and deleveraging

By necessity, banks are highly geared. However, in the run-up to the 2007 crisis many banks had taken on excessive on and off balance sheet leverage. When the sub-prime problem surfaces, these banks were highly vulnerable as they were exposed to excessive risk taking. The crisis in the US sub-prime mortgage market picked up pace in the summer of 2007. In mid July 2007, Standard & Poor's (S & P) and Moody's each downgraded over 400 or more residential mortgage backed security (RMBS). On August 29, 2007, Standard & Poor's downgraded the ratings of the short-term notes issued by Cheyne Finance by six notches, which just two weeks before it had declared those same notes to be the highest investment grade. Cheyne Finance become the first SIV to default on its ABCP debt after the administrator of the troubled fund won court backing to declare it

[1] See Gordy and Howells (2006) for a simulation study on a countercyclical capital policy.

in breach of insolvency tests. The first sale of the assets of SIV Cheyne Finance was described as 'fire sale' by Moody's Investors Service.

Mass downgrades by Moody's and S & P sent shock waves through the financial markets and led investors to speculate about the next investment vehicle to fall. The speed at which the downgrades occurred was an indication of how quickly RMBS prices and values of assets in CDOs had deteriorated. In January 2008, S & P again shocked the markets by its actions on over 6,300 RMBS and 1,900 CDOs (including downgrading and placing securities on credit watch with negative implications) and triggered sales of assets that had lost investment grade status. Investors like pension funds, insurance companies, and banks were suddenly forced to reduce their exposures to RMBS and CDO holdings because they had lost their investment grade status. New securitisations were unable to find investors since RMBS and CDO securities held by financial firms lost much of their value. Plunging asset prices meant market-value thresholds embedded in the SIVs started to be hit. By early 2009 the total value assets SIVs' was virtually close to zero from the peak of $400bn in July 2007; of the total 29 SIVs, 7 defaulted, 18 were restructured or were consolidated onto the sponsoring banks' balance sheets. The sub-prime RMBS market initially froze and then collapsed and CDO investors and underwriters.

The frantic exodus by money market funds from ABCP market proved to be catastrophic for the off balance sheet credit supply. Rapidly shrinking ABCP market on one side and plummeting values of illiquid assets on the other side meant that the whole process of issuing, underwriting and marketing high risk, low quality assets suddenly sent the banking system into a tailspin. Banks that had sponsored SIVs came under heavy pressure to take their assets onto their own balance sheets and/or fire sale those assets.

A full blown liquidity and credit crunch hit banks' balance sheets that precipitated deleveraging and wiped significant chunks off their equity. CRS Report for Congress described 'By September (2007), not a single 'bulge bracket' investment bank remained standing: they had either failed (Lehman Brothers), merged (Merrill Lynch and Bear Stearns), or converted themselves into commercial bank holding companies (Goldman Sachs and Morgan Stanley)' [1]. FDIC insured banks

[1] CRS Report for Congress, Containing Financial Crisis, Updated November 24, 2008.

fell by 568 from June 2007 to April 2010 [1].

2.4 The central banks' response

Coordinated central bank actions were taken to support troubled banks aimed at both asset side and liability side of banks' balance sheets. Liquidity support and extended deposit insurance were the first to be instigated to contain the panic in the ABCP market. In the wake of the demise of Northern Rock, HBOS, Bear Stern, Countrywide, Lehman Brothers, Merrill Lynch, and many other banks, money market fund and conduits, liquidity needs rose sharply across markets. On the asset side, liquidity was provided through purchase of illiquid assets outright or by accepting for the purposes of collateralised lending. In August 2007, a series of emergency actions by the European Central Bank (ECB) injected a further US$85 billion in liquidity through various mechanisms, highlighting the seriousness of the crisis. The Federal Reserve introduced three programs with varying degrees of success. The Commercial Paper Funding Facility (CPFF) and the Asset-Backed Commercial Paper Money Market Fund Liquidity Facility (AMLF) lending programs were created to enhance liquidity by reducing extension risk and by reducing the risk of suspension of redemptions at money market mutual funds that hold commercial paper. The Treasury, in an effort to assure investors during a run on money market funds, then a $3 trillion industry, that future suspension of redemptions would not occur, also offered insurance for the value of MMMF shares held to funds. Central banks managed to avert run on deposits by guarantees of deposit and non-deposit liabilities in a number of different forms. Guarantees in respect of non-deposit liabilities in the UK were restricted to 'new' borrowing and granted only under certain conditions, such as a defined quantum of recapitalization. A blanket guarantee of liabilities was put in place in Ireland while in Italy guarantee or support was offered to a particular class of non-deposit liabilities, such as inter-bank claims. Central banks, both inside and outside the Euro area offered emergency liquidity assistance to individual banks under such terms as they choose, with the credit risk remaining at national level.

[1] http://www.fdic.gov/bank/individual/failed/banklist.html

The asset purchase programmes [1] of troubled assets (and high-quality assets) eased the pressure of deleveraging, fire sale, haircuts by distressed banks inflicting losses on other institutions. The first signs of distress emerged in 2006 when HSBC, the world's third-largest bank, disclosed its bad-debt provisions soar to $10.8 billion as a result of defaults in its sub-prime portfolio. As asset valuation uncertainties increased, troubled banks began to offload their assets at distressed prices. In deteriorating market conditions, fire sales intensified and capital losses of leveraged institutions went up, credit terms became tighter with higher haircuts/initial margins on assets. Problems intensified with the bailout of Bear Stearns, and later in the year with the collapse of investment bank Lehman Brothers, and the government bailouts of insurer AIG and mortgage lenders Freddie Mac and Fannie Mae. The Troubled Asset Relief Program (TARP), 'the bailout legislation' as it has come to known, was established to buy troubled assets from ailing banks and other financial institutions and then dispose of them. Some 707 financial institutions received $204.9 billion as part of the Capital Purchase Program, and as of March 31 2009, 351 regional and community banks were still in the program. Another 83 financial institutions were in the TARP Community Development Capital Initiative, bringing the total number of institutions still in TARP to 434. The Capital Purchase Program (CPP) was set up to Infuse capital into troubled financial institutions, had the obvious positive effect of increasing banks' available capital.

As part of the co-ordinated Action plan, various EU governments on a national level pledged a total of 1,873 billion euros to guarantee their banking sectors. In February 2008, the UK Government nationalised Northern Rock Bank plc, which was the first UK bank failure of the 2007-2009 financial crisis. The government also took controlling interest in Royal Bank of Scotland Group Plc and Lloyds Banking Group plc and injected £500 billion ($750 billion) in the eight largest banks and building societies. Barclays also raised £ 5.8 billion of new capital in 2008 from the state investment funds and royal families of Qatar and Abu Dhabi. In July 2007, the German government and financial regulators were granted approval by the EU Commission to bailout 9 billion euros ($11.7 billion) of IKB.

[1] The Emergency Economic Stabilization Act of 2008 authorized Troubled Asset Relief Program to restore liquidity and stability to the US financial.

The Financial Market Stabilization Supplementary Act was passed April 2009 that paved the way for the nationalisation of Hypo Real Estate Holding AG. The law extended the financial market stabilization law agreed in 2008, giving the government powers to seize control of banks whose failure would pose a risk to the stability of the financial system. The Bad Bank Act, passed July 2009, provided private banks relief on holdings of illiquid assets by allowing them to transfer assets to a special entity and receive government-guaranteed bonds issued by this special entity in exchange.

The actions of central banks and governments in coping with the global financial crisis has raised many issues. There is no doubt that the exceptional rescue measures and monetary policy reaction to the crisis has helped to stabilise the banking system. Raising the level of banks capital can be valuable in turbulent times; however, it only affords partial protection to the banking system. Faced with a combination of deteriorating economic conditions and unfavourable profit outlook, increased credit risk, and the steep cost of raising new capital, banks did not have any other choice than to curtail their portfolio and drastically reduce new lending. Indeed, between 2008 and 2010, commercial bank lending was reduced by 25% and M1 money multiplier was reduced by almost half. The most recent rules allow a 10 times gearing ratio, which implies that a 10% write off of its loan portfolio could wipe out its capital and no bank geared at such level could withstand a run on its deposits whatever its level of capital.

Chapter 3

Literature review

The purpose of this chapter is to distil the key features of the literature on credit supply and credit rationing. This literature review is organised in four sections. In section 3.1, we examine the portfolio allocation decisions of banks. The role of the risk free asset (default free) is of paramount importance in bank's portfolio allocation decisions. Our focus in this section is to highlight how banks choose between safe and risky assets. In section 3.2, we introduce Stiglitz and Weiss (1981) seminal paper, which lay the foundation for a formal analysis of credit rationing due to adverse selection. We begin with an outline of the Stiglitz and Weiss (1981) model and discuss the key results. We then focus on the recent developments in the credit rationing literature. Naturally, the credit markets are in disequilibrium when banks resort to credit rationing. In a normal economic environment, the demand for credit usually exceeds supply. Thus it is necessary for any empirical analysis of the credit market to employ the relevant models of market disequilibrium. The early work on the analysis of disequilibrium in goods market they back to early 1950s. In recent years, a number of studies have attempted to analyse empirically the disequilibrium in credit markets. In the section 3.3, we review the econometric techniques to study the disequilibrium models. We outline the key models in this field and focus on the maximum likelihood estimation method. We will use these techniques to examine the extent of credit market disequilibrium empirically in chapter 4. In the section 3.4, we outline the classical cobweb approach to model multi-periods demand and supply imbalances in commodities markets. This approach can also shed some light on the stability conditions of credit market. We begin with the seminal work presented in Ezekiel (1938) and then discuss the subsequent refinements of the cobweb approach. In chapter 5 we use the cobweb approach to study the credit supply by first deriving the stability conditions and then, using appropriate initial parameters values, we carry out some numerical analysis of credit market. In the section 3.5, we review some important literature on the stability of the financial system. The stability of the banking sector is related to a number of results in this thesis. We will discuss them in the relevant chapters.

3.1 Bank Portfolio Allocation

Dewatripont and Tirole (1994) provides a very good survey of the existing literature on banking regulation. The authors analyse the banks under the prudential regulation and suggest that banking regulation deviates from the aim to protect 'ordinary uninformed, free-riding depositors' may subject to a problem of collective action. Freixas et al. (1997) also summarise the relavent microeconomics theory and models related to banking regulation. The more recent survey on the effect of bank capital regulation on bank lending is provided by VanHoose (2007). Based on these surveys, we can classify the existing research on bank portfolio selection into four categories, namely the portfolio-based approach, an adverse selection approach, the effects of changes in regulation on the bank, and the effects of financial innovations on bank lending.

Kahane (1977) and Koehn and Santomero (1980) use a mean variance portfolio selection model to show that a tighter leverage requirement may cause a representative bank cannot achieve efficient allocation of its assets and the bank may change the asset composition according to its coefficient of relative risk aversion. So non-risk-averse bank will choose a riskier portfolio if the capital requirement is raised, which implies capital requirement encourage risk taking. Based on this result, Kahane (1977) further suggests the use of risk weighted capital requirement instead of simple leverage requirement as a policy tool, which is in line with Basel I.

The above research is useful to understand the asset allocation decision for a representative bank, it does, however, fail to consider the possibility of behaviour distorting. Thus, another strand of literature emerges to focus on the adverse selection problem of the bank. A representative study is Thakor (1996), which specifies a conditional probability model that bank may screen the prospect borrowers. The author uses the cases of a monopoly bank as well as multiple representative banks to demonstrate the asset portfolio selection strategies for these banks. The result shows that higher capital requirement can cause higher probability of a loan applicant to be rationed. Another seminal paper is Stiglitz and Weiss (1981), which will be discussed in detail in section 3.2. Morrison and White (2005) extend this adverse selection approach to the case that the depositors and bank regulators screen banks. The authors examine a closed economy with many identical agents with diverse interest to show that the monitoring cost can determine whether banking regulation is necessary.

A common criticism of the portfolio optimisation approach and the adverse selection approach is that their models are based on short time horizon and fail to consider the multi-period impact. Thus, another strand of literature focuses on using historical data to identify the main factors that affect the bank lending. Bernanke et al. (1991) show a relationship between bank lending and bank capital by using regression analysis to study the US state-level data on individual banks. The authors show that there is a negative relationship between bank capital and lending. Hall (1993) uses regression analysis based on bank level data to determine the relationship between capital ratios and portfolio shifts, and he finds that the risk-based capital standards have significantly affected bank portfolios. Hancock and Wilcox (1994) uses quarterly data of individual banks to estimate the dynamic responses to capital shocks and finds that large banks adjust each component of their portfolios faster than small banks. Hancock et al. (1995) examine the bank asset allocation decisions between trading asset and risky loans. The authors find that banks which have less capital than what is required by the risk-weighted standard appear to have shifted away from the assets with low risk weights (securities and single-family mortgages) and to have shifted towards assets with higher risk weights (commercial real estate and commercial and industrial loans). The main contribution of these empirical studies is to identify the key factors that drive the bank lending. But, they lack a structural model to determine the optimal asset allocation for bank. This limitation makes it difficult to obtain robust result of the estimate of the impact of the changing capital regulation.

Another strand of literature is related to financial innovations. More specifically, this refers to the off-balance sheet activities of banks such as letters of credit, loan commitments and securitisation that affect portfolios selection. Loutskina (2005) shows that securitisation causes the banks to increase the size of their loan portfolios significantly while decrease their liquid assets holding. As discussed in chapter 2, these off-balance sheet activities were one of the main drivers of the 2007 global financial crisis and a number of policies have been proposed or implemented to address this issue. Thus, these off-balance sheet activities should not affect the assets composition for banks to a great extent in the future and we do not discuss these literatures in detail here.

Given the limitations in the existing literature outlined above, we specify a multi-period bank assets allocation model that considers both asset and liabilities sides of the balance sheet in Chapter 6. Our work is more close to Furfine (2001). In Furfine (2001), the bank is assumed to maximise the present value of its future profits:

$$max \quad \mathbb{E}\sum_{t=1}^{\infty}\zeta^t[r_t^R A_t^R + r_t^S A_t^S - r_t^D D_t + E_t\lambda(e_t) - G_t - H_t - J_t] \tag{3.1.1}$$

where $\mathbb{E}$ represents expectation, the ζ is a discounted factor, A^R is risky assets, A^S is safe asset, D is the deposits, r_t^R, r_t^S, and r_t^D are the rate of returns from risky assets, safe asset and deposits, E is the equity, λ is the equity cost function, and G, H and J are different cost functions.

The first-order conditions for the maximisation problem shows that after netting of all the current cost, the current marginal return on risky asset need to be equal to the discounted future marginal adjustment cost.

Due to the complexity of the model, Furfine (2001) needs to make further assumptions on the functional forms of the above cost functions to continue the analysis. In this specification the bank is assumed to incur a decreasing per dollar cost to build up its capital cushion. This assumption makes the bank capital cost function a log linear decreasing function. In reality, this implies that the cost to a bank will decrease continuously if it holds more and more capital. This implies that the cost will be minimised at 100% equity financing, which contradict the traditional corporate finance theory. The adjustment cost and the cost of issuing equity are assumed to be second order increasing functions in Furfine (2001). Additional simplifying assumptions are: $w_R = 1$, $w_S = 0$ and there are unlimited supply of safe asset. Furfine (2001) uses these assumptions and U.S. commercial banks data to show that the introduction of Basel II will increase the incentive of the banks to lend more to those safe borrowers. In Chapter 6 we will examine the limitations of the Furfine (2001) model in more detail and propose an alternative specification of the bank portfolio allocation model.

3.2 Credit Rationing

The following concept of credit rationing introduced in Baltensperger (1978) will be used throughout this thesis:

> *"whenever some borrowers' demand for credit is turned down although this borrower is willing to pay all the price and non-price elements of the loan contract."*

There are two types of credit rationing in the literature:

- Type I rationing occurs when there is a partial or complete rationing of all the borrowers within a given group.

- Type II rationing has another name called redlining, which concerns the problem that the bank can perfectly distinguish between the different types of borrowers according to some criteria and certain identifiable groups of borrowers are unable to obtain loans at any interest rate given certain credit supply level.

We focus solely on Type I credit rationing in this thesis. Stiglitz and Weiss (1981)(henceforth Stigltitz-Weiss) study the equilibrium of credit rationing in markets with imperfect information. The model can be summarised as follows:

There are N firms (borrowers), each has one and only one investment project θ, which requires funding B from a bank. For each borrower there is a probability distribution of return R. Without loss of generality, these borrowers/projects can be rearranged in numerical order, which represents their riskiness. i.e. $\theta \in 1, 2, 3, \ldots, N$, and the bigger the θ, the greater the volatility of project returns, which implies greater risk of the project. However, these θ are only observable privately and the bank cannot observe them. As a result, the bank is facing a group of borrowers having the same mean return but different variance. We call these borrowers are observably identical in the sense of mean preserving spreads. If we let $f(R, \theta)$ be the density function of R, and $F(R, \theta)$ be the distribution function of returns, the mean preserving spread can be interpreted mathematically as follows.

For any $\theta_1 > \theta_2$, if

$$\int_0^\infty Rf(R, \theta_1)dR = \int_0^\infty Rf(R, \theta_2)dR$$

then for any $y \geq 0$,

$$\int_0^y F(R, \theta_1)dR \geq \int_0^y F(R, \theta_2)dR$$

Only standard debt contract is used here: the bank requires collateral C and interest pay (with interest rate r_L) from the borrowers. So an individual borrower defaults on his loan if the return R plus the collateral C is insufficient to pay back the promised amount, i.e., if

$$C + R \leq B(1 + r_L)$$

Hence, the net return to the borrower ($\pi(R, r_L)$) is a convex function of the return on the project:

$$\pi(R, r_L) = max(R - (1 + r_L)B; -C) \tag{3.2.1}$$

There are many identical banks in the credit market and all of them are risk neutral. The return to a typical bank ($\rho(R, r)$) is a concave function of the return on the project:

$$\rho(R,r) = min(R + C; (1 + r)B) \tag{3.2.2}$$

There are two key results of the Stigltitz-Weiss model.

The first result related to the problem of adverse selection. Firms would borrow from the bank if and only if the riskiness of their projects θ is above a certain critical level $\hat{\theta}$. If the bank increase the lending rate r_L or collateral C, those low risk borrowers will withdraw from the credit market due to the negative expected return, and this will happen before the high risk borrowers do so. Hence, the bank's expected return will be reduced if only the high risk borrowers exist in the credit market.

This result follows immediately by observing that the net return to a borrower $\rho(R,r)$ is a convex function of R. The expected net return (expected profits) can be expressed as:

$$\Pi(r_L, \theta) = \int_0^\infty max[R - (1 + r_L)B; -C]dF(R, \theta) \tag{3.2.3}$$

Hence the expected profits increase as the risk θ increases. In another words, firms would borrow from the bank if and only if the riskiness of their projects θ is above a certain critical level $\hat{\theta}$. By differentiating (3.2.3) with respect to r_L, we can get:

$$\frac{d\theta}{dr_L} = \frac{-B\int_{(1+r_L)B-C}^{\infty} dF(R,\theta)}{\partial\Pi/\partial\theta} > 0$$

As a result, if the bank increases its lending rate r_L, the risk of the pool of borrowers will increase. This is adverse selection and we reach the first result in Stigltitz-Weiss.

The second result of the Stigltitz-Weiss model is Type I credit rationing: For some distribution of θ, the bank's expected return on loans will have a single peaked. Hence the bank would set the interest rate to be below the market clearing level in order to maximise its expected return. This implies type I credit rationing.

This result is represented in Figure 3.1. Stigltitz-Weiss argue that the adverse selection effect together with competition among banks will lead to a backward bending credit supply curve. The reason is that as the lending rate r_L increases, those low risk borrowers will withdraw from the market first, and the return to the banks will fall. As a result, high lending rate will reduce credit supply. If this supply curve only has a single peak as Figure 3.1 shows, we know that banks will not charge the market clearing lending rate r_L. They will charge a rate $\hat{r_L}$, which is lower than the market clearing level, to maximise their return. This causes the demand for credit excess the supply, which is credit rationing.

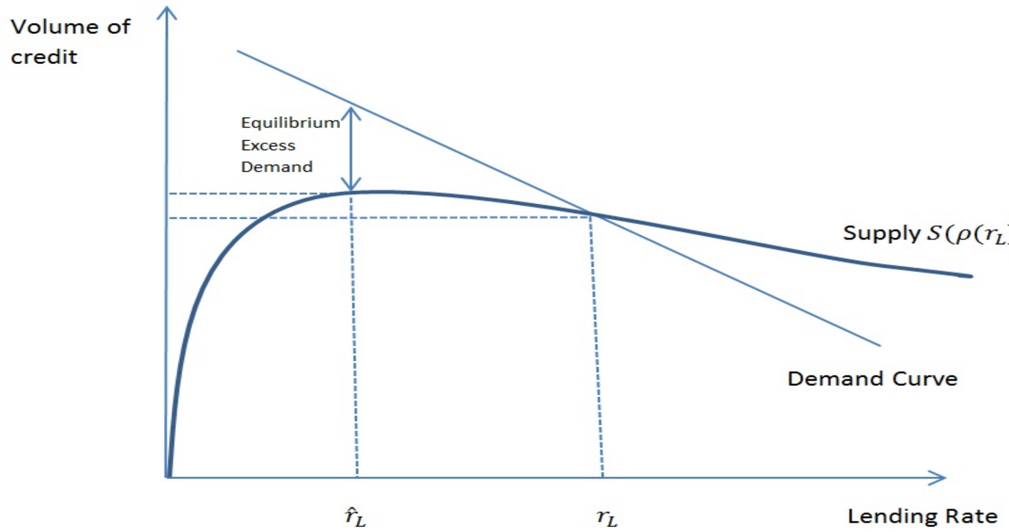


Figure 3.1: Market Equilibrium

Following the Stigltitz-Weiss formulation, a number of strands of research have evolved in this field. We can classify four main streams: (i) using an optimum loan contract (i.e. analyse the effect on rationing by considering the change in the interest rate charged, the collateral requirement, the loan maturity and the loan size) to support or question the rationing outcome. The relevant studies include Stiglitz and Weiss (1983), Stiglitz and Weiss (1987a), Stiglitz and Weiss (1987b), Stiglitz (1989), Stiglitz and Weiss (1992), Bester (1985), Bester (1987), Besanko and Thakor (1987), Riley (1987), Milde and Riley (1988), Innes (1990a), Innes (1991), Innes (1990b), Innes (1993), Ardeni and Messori (1996), etc. (ii) introducing equity to examine the interaction between the credit rationing and the equity rationing. This includes Cho (1986), DeMeza and Webb (1987), Hellmann and Stiglitz (2000), etc. (iii) using a dynamic model to analyse the credit market. This includes the studies of Webb (1991), Webb (1992), Mason (1998), Lensink and Sterken (2002), and Patel and Zavodov (2011). (iv) more recent researches Arnold (2007), Arnold et al. (2009), Arnold (2005), Reeder and Trepl (2009) focus on the credit supply function in the Stigltitz-Weiss model. Based on the above classification, we will present some important research results from the literature in the following section.

3.2.1 Optimum loan contract on credit rationing

By applying a more realistic assumption that banks consider interest rate charge and the level of collateral simultaneously rather than separately as Stigltitz-Weiss did, Bester (1985) showed that a loan contract, which employs collateral as a self-selection and incentive mechanism, is able to eliminate the problem of adverse selection and obtain the separating equilibria. However, Stiglitz and Weiss (1986) argued that, when collateral is limited, there may be equilibria in which some or all borrowers post all of their assets as collateral, but still do not have enough assets to achieve separation. With no further scope for lowering fail-state income, the only way to combat moral hazard, or influence the composition of borrowers, is by adjusting the repayment in the event of solvency (the interest rate). Hence, random credit rationing may arise. In response, Bester (1987) reassures the importance of collateral in reducing the adverse selection effect as well as the moral hazard effect. He extends his model to many types of borrowers and the insufficient desired collateral case. He shows that credit rationing only occurs when the borrowers' initial wealth is too small to put down the desired level of collateral and as a result the perfect sorting cannot be achieved. Once the desired level of collateral has been put down, perfect sorting will be achieved, credit rationing will not exist. To summarise, Bester argues that in an ideal market, banks can use collateral to eliminate the adverse selection effect as well as the moral hazard effect. A similar study is by Chan and Kanatas (1985), who discuss different types of collateral.

Since Bester only considered the interest rate and collateral in the loan contract as the screening and incentive devices, a natural extension of his work is to incorporate more screening and incentive devices into the model to see whether the rationing outcome will change. Besanko and Thakor (1987) proposed a more general model that incorporates collateral, interest rate and the probability of getting the loan. The model is used to analyse the rationing outcome in two different market structures. First, they assume that a bank acts as a price-setting monopolist in the loan market. They show that the optimum outcome is no collateral is required, all low risk borrowers obtain loans and high risk borrowers will not apply for loan if the interest rate is too high. This is because under their monopolist model, bank extracts all the surplus from borrowers, and high risk borrowers have a smaller surplus, so if the interest rate charged by the bank is too high, then these high risk borrowers will withdraw from the credit market. Second, a perfectly competitive market is analysed. In this case, they assume a bank faces a perfectly elastic deposit supply schedule and that banks compete for loans as well as deposits. Competition for loans results in every borrower being offered a contract that maximises its expected utility subject to the constraint that the bank break even. The key result is similar to Bester. By designing credit contracts with inversely related interest rates and collateral requirements, banks can sort borrowers into different risk class. If borrowers initial wealth is sufficient for the optimal collateral requirement, then all of them will get credit from the banks. If a borrower's initial wealth is insufficient for the collateral requirement, then he/she will face a none zero probability of being denied credit. Hence, credit rationing does exist in a competitive lending market.

However, it is important to know that Besanko and Thakor use a different assumption about project return from that of Stigltitz-Weiss. They assume that the return is the same across all the projects if they are successful, but the probability of success differs from project to project. This assumption about project return gives rise to the result being fundamental difference in the two models. Besanko and Thakor also implicitly assume the banks know borrower's type and this is 100% accurate. In reality, banks do classify borrowers into different categories or rating class. The accuracy of the rating system banks currently use in order to estimate the probability of default is, however, questionable.

In contrast to results described earlier, Stiglitz and Weiss (1992) extend their work by considering simultaneously both interest rate and collateral in the loan contract. Stigltitz-Weiss examine the problem by assuming that moral hazard exists[1] such that once the borrowers receive the loan, they can use two different techniques to invest the fund and the lenders cannot observe which technique a borrower is using. The project is either successful, yielding a return of R^s or R^r depending on the technique used, with $R^s < R^r$, or is unsuccessful yielding a return of zero. They also assume the probability of success of the safer technique is greater than that of the riskier technique. Again, this is a mean-preserving spread of the distribution of return. Through the analysis of the borrowers' payoff, Stigltitz-Weiss show that the bank indirectly control the technique used by borrowers by specifying interest rate and collateral. In addition, they consider the case that borrowers with different initial wealth, which implies the level of collateral borrower can put down is subject to certain constrain. This is the same condition as in Besanko and Thakor (1987). The result they obtained is that there exists equilibrium with or without rationing, which depends on the banks' payoff function and the supply of fund. If the supply of fund is at the Walrasian equilibria, and the banks' payoff function satisfies certain condition, then credit rationing exists. This contradicts Bester's result that collateral can eliminate adverse selection and moral hazard effect. In addition, Stiglitz-Weiss also explore the macroeconomic implication of their model for the case when the probability of project success is changed and for the changes monetary policy.

The major criticism of Stiglitz and Weiss (1992) is the assumption that borrowers can use two different techniques to invest and banks cannot observe directly which technique a borrower is using. In reality, term loans are often used for capital expenditure. For example, the purchase of land, factory and equipment can be easily monitored by the bank. In some cases like home mortgage loan, the banks even know which property the borrower would like to buy before they make the decision on whether to approve the loan. Therefore, the key assumption of Stiglitz and Weiss (1992) does not hold in real world.

Another criticism of the above analysis is the assumption that all the borrowers face the same borrowing requirement. In reality, different borrowers have

[1] Williamson (1987) used the model developed by Gale and Hellwig (1985) to show that banks cannot observe project revenues of firms without a cost, and therefore moral hazard does exists.

different borrowing need. For example, the borrowing requirement of an individual will be significantly less than that of a public trading company. As a result, Milde and Riley (1988)(Milde-Riley) introduce variable loan size into the analysis. This means banks can offer loans of different sizes at different interest rates. In their model, each firm has a production function, which is an increasing function of loan size and a firm specific quality parameter. Under the asymmetric setting, the banks cannot observe the firm specific quality parameter. Milde-Riley showed that borrowers can use loan size to signal their type as follows. In the model presented in Milde-Riley, when the production function is multiplicative in terms of the quality parameter, the firm's quality parameter is an increasing function of loan size, which means the higher quality firms can signal their type by demanding larger loans. When the production function is additive in term of the quality parameter, the loan size is invariant to quality, and hence higher quality firms can signal their type by accepting smaller loans. Thus, self-selection and separating equilibria exist. Hence, credit rationing will be reduced. Based on the assumption that banks can distinguish different classes of borrowers, Riley (1987) shows that credit rationing cannot occur in more than one of these classes and concludes that the extent of rationing generated by the Stiglitz-Weiss model is not likely to be empirically important. In reply, Stiglitz and Weiss (1987b) point out four reasons that make the conclusion reached by Riley (1987) is misleading. Stiglitz-Weiss also summarise a series of their previous papers Stiglitz and Weiss (1983), Stiglitz and Weiss (1987a) to argue that with many observationally distinguishable groups there might be rationing of several, or even of all group. The effect of loan size as pointed out by Milde-Riley is still not addressed in Stiglitz and Weiss (1983) and Stiglitz and Weiss (1987a). Consequently, more recent papers have also considered the effect of loan size on credit rationing. For example, Innes (1991) consider the role of the government and obtain the pooling equilibria. He shows that signalling and separating equilibria weakens the occurrence of credit rationing. Ardeni and Messori (1996)(Ardeni-Messori) extend the Milde-Riley model by assuming apart from the quality factor, also the technological factor can influence the project return. This technological factor depends on how firms organise their production activities. Ardeni-Messori obtains a similar but more general result compared to the one in Milde-Riley model.

The introduction of the loan size factor into the credit rationing model enables the above authors to derive a more robust result. This approach relies on the assumption that the return for bank is an increasing function of loan size and the quality factor is, however, questionable. A large loan size and a higher quality factor do not guarantee a better return. We need to consider the probability of default. In the Milde-Riley model, the authors have a random realisation parameter in the return function. This can be analogous to probability of default. But, in their additive production function model, the quality factor does not depend on the random realisation parameter, and the loan size is only partially affected by the random realisation parameter. This implies that any increase in either the loan size or the quality factor will increase bank's return. Obviously, this assumption is not realistic. Moreover, the work by Milde-Riley and Ardeni-Messori purely focus on the loan size instead of considering the loan to value ratio, which is a very important parameter in the modern lending decision process.

Up until now, we have seen a line of research that shows whether credit rationing exists by considering complicated financial contracts. One issue with this approach is that the structure of optimal contracts is very sensitive to the specific nature of asymmetric information and the particular instruments available to banks. This approach argues that banks can separate most or all types of borrowers by loan contracts. However, it may be too complex for banks to implement this strategy in practice. In addition, a general criticism of the theory of designing optimum loan contract is that they ignore the equity financing option available to firms. Hence, there is another stream of research parallel to that discussed above.

3.2.2 Credit and equity rationing

When a firm has a financing need, it can either issue debt or raise equity capital. As a result, equity rationing has attracted attention in the literature. Myers and Majluf (1984) and Greenwald and Stiglitz (1990) show that if the expected return, but not the risk, is the parameter of asymmetric information, equity investors interpret firms' action randomly and equity markets could have rationing. Cho (1986) argues that adverse selection would disappear in the Stigltitz-Weiss model if the equity method of financing is used instead of debt. In contrast to Stiglitz-Weiss, DeMeza and Webb (1987)(DeMeza-Webb) obtain different results about credit rationing and equity rationing under a different assumption on the asymmetric information parameter. They show that if there is asymmetric information about expected returns then debt is the optimal financial contract and credit rationing will not exist. But, if there is asymmetric information about risk instead of expected return, which is the same assumption as the Stiglitz-Weiss model, DeMeza-Webb show that equity rather than debt would be the optimal method of financing, and there cannot be any equity rationing. An implication of the DeMeza-Webb result is that once firms choose the appropriate method to finance their project, no rationing will exist. Since DeMeza-Webb only consider the asymmetric information about expected return and risk separately, Hellmann and Stiglitz (2000)(Hellmann-Stiglitz) extend their work to a model that allows asymmetric information on both expected return and risk. Their model assumes that there are private equity investors, who compete to finance the investment projects, and the firms can apply for equity financing and debt financing at the same time, but they cannot combine debt and equity. Hellmann-Stiglitz show that in such a model there may be credit rationing, equity rationing or even simultaneous credit and equity rationing.

One of the limitations of the Hellmann-Stiglitz model is that they only study the effect on credit and equity rationing when the firms can only choose either equity or debt but not both. As the modern corporate finance theory suggests, however, there is an optimal capital structure which minimises the firm's cost of capital. This implies even a firm that has sufficient equity capital to finance its investment, the project will be normally financed by both debt and equity capital in order to maintain their optimal capital structure. Therefore, it is important to consider both equity and debt finance jointly.

Furthermore, all of the models discussed above are a single period model, which ignores the subsequent changes in the economic and lending environments. We know that the future state of the economy, however, directly affects the project return and the value of collateral. For instance, if the economy is in recession, the probability of project success is different from that when the economy is in boom. Generally, we should expect the project return to depend on the economic cycle. Therefore, a multi-period model with a dynamics return functions has been proposed in more recent literature.

3.2.3 Multi-period and dynamic models

Stiglitz and Weiss (1983) allow banks and borrowers to have multi-period relationships and show that the market equilibrium can have rationing. This is the first attempt to introduce multi-period into the Stiglitz-Weiss model. Diamond (1991) also considers the effect of borrower reputation in a multi-period setting. Webb (1991) proposes a two-periods model to argue that a sequence of debt contracts, whose terms are contingent on the repayment in the previous period, may mitigate the adverse selection effect. The intuition is as follow. All firms are initially offered the same loan contract. If they repay the loan on time in the first period, then they will be offered a loan contract with better term (i.e. lower interest or collateral requirement) when they apply for loan the next time (second period). If, however, firms default in the first period, they will get the same contract as they had in the first period. This will create an incentive for firms to use safe technique to invest and repay loan on time. As a result, banks will be able to separate borrowers' types, and hence asymmetric information as well as the credit rationing may be reduced.

An important drawback of the Webb model is that it fails to capture the dynamics of the return function. In order to overcome this limitation, Mason (1998) integrates the option pricing theory and Stiglitz-Weiss model. Mason assumes the project return follows the same stochastic differential equation as Black and Scholes (1973) to model the stock price in their option-pricing framework. In this case, the payoffs to the firms and banks for a loan contract are equivalent to long an American call option and writing an American put option, respectively. Mason shows that all of the Stigltitz-Weiss results hold under a one period model and discusses how this work can be extended to a multi-period model. Mason also uses a stochastic volatility option pricing approach to model asymmetric information and uses a simulated example to show that credit rationing is unlikely to be empirically significant in the US and UK small commercial loans markets.

Based on the idea of option pricing, Lensink and Sterken (2002) (Lensink-

Sterken) extended the Stigltitz-Weiss model by incorporating the value of option to wait to invest. This approach implies the firm has the right but not the obligation to defer its investment decision. They show that the value of the option to wait is greater for more risky borrowers, and therefore, an increase in the interest rate will induce them to delay investment. Hence, the effect of increasing the interest rate is to drive bad rather than good firms out of the credit market, which contradicts Stigltitz-Weiss result. Demeza and Webb (2006) use a different approach that considers the interaction of loan size and interest rate, and the incentive for borrowers to cut their borrowing requirement, to show much weaker conditions for the non-existence of rationing than does Lensink-Sterken.

In Patel and Zavodov (2011) (Patel-Zavodov), extend Lensink-Sterken work by introducing borrowers' option to default. The option to default enables a borrower to sell the project to the lender in exchange for the notional value of the outstanding debt. Patel-Zavodov consider the joint effect of the value of option to default and option to wait on the total value of an investment project, and show that the Stigltitz-Weiss result only hold when the loan to value ratio is higher than some critical value.

There is another branch of literature that studies credit rationing in general equilibrium setting with overlapping generations. Bernanke and Gertler (1989) is a classic overlapping generations model that study the moral hazard effect on bank lending. The authors extend the two-periods model in Diamond (1965) to allow for shocks in production. Infinite time horizon is assumed in overlapping generation model. There are two types of agents, namely entrepreneurs and lenders, live for two periods. There are two types of goods in the economy, a capital good and output good. Entrepreneurs have different production technologies to produce output, and they borrow from the lenders to start production. This two-periods production process is subject to exogenous shocks. The assumption of realised return of production are only observable costly implies that it will cost the lenders time and effort to obtain this information. This asymmetric information leads to the moral hazard problem. The aggregate wealth of entrepreneurs is initially in a static state and then in a dynamic setting. Under this setting, the authors derive the optimal consumption and investment decisions for the entrepreneurs and suggest that bank lending has 'accelerator effects' on business cycles. Although not explicitly mentioned in this paper, one can deduce that one of the implications of Bernanke and Gertler (1989) is that credit rationing does exists due to asymmetric information between borrowers and lenders.

According to Suarez and Sussman (1997), one of the shortcomings of Bernanke and Gertler (1989) is that the external production shock is not anticipated by agents. Therefore, entrepreneurs may fail to predict repeated shocks. Hence, it raises the issue of irrationality of the agents. To overcome this shortcoming, Suarez and Sussman (1997) propose a pure reversion mechanism to study an economy similar to the one in Stiglitz-Weiss but focus on the effect of moral hazard. The model proposed in Suarez and Sussman (1997) is a dynamic extension of Stiglitz-Weiss with two-periods overlapping generations. Similar to Bernanke and Gertler (1989), Suarez and Sussman (1997) consider an infinite time horizon, discrete time economy with two goods (capital and output goods) and two types of agents (entrepreneurs and lenders). Lenders are identical and live forever. A typical lender has an objective function:

$$max \quad \mathbb{E}\sum_{t=0}^{\infty}(\frac{1}{1+r})^s[x_{t+s} + u(c_{t+s})] \tag{3.2.4}$$

where x_{t+s} and c_{t+s} are the consumption of the capital and output goods, respectively, at time $t+s$; $u(c)$ is a concave increasing utility function. The budget constraint for a typical lender is:

$$x_t + p_t c_t + a_t = e + \tilde{R}_{T-1} a_{t-1} \tag{3.2.5}$$

where p_t is the price of the output good, a_t is the amount of external finance, e is the amount of endowment and $\tilde{R}_{T-1}$ is a random gross rate of return per unit of finance extended.

Entrepreneurs are assumed to be born at each period and live for three periods. Each of them has one and only one investment project to produce output. Entrepreneurs borrow from lenders to activate their projects. Once the project is initiated, it has two production periods. In the first period the output is constant $Y > 0$ units of output, which is not subject to production shock. Entrepreneurs can obtain another Y units of good in the second period with probability π. This is called the 'success' state. Otherwise, the project will not produce anything in the second period, which is called 'failure' state. The probability of success is independent across projects. But, this probability will depend on the amount of effort spent by the entrepreneur. This gives rise to the problem of moral hazard. The disutility of effort is denoted by an increasing convex function $\Psi(\pi)$. As a result, entrepreneurs may increase their second period income $(p_{t+1}Y - \Psi(\pi))$ by adjusting their effort π. Hence, the objective function of a typical entrepreneur is:

$$max \quad 1 + \frac{1}{1+r} p_t Y + (\frac{1}{1+r})^2 [\pi p_{t+1} Y - \Psi(\pi)] \tag{3.2.6}$$

The fact that the amount of effort spent by the entrepreneur is assumed to be not observable by lenders causes moral hazard issue. The authors impose a number of constraints in order to derive analytically the optimal conditions. The key results are as follows. First, for equilibria without credit rationing to exist, any pair of consecutive prices of the output need to satisfy certain conditions that depend on the specific shape of the demand curve. This implicitly requires the possibility of credit rationing in this economy. Second, the moral hazard issue in this economy does not only cause the 'accelerator effects' on business and credit cycles, but also may itself be a source of endogenous fluctuations. Intuitively, this can be explained as follows: when the production activity is high, the quantity of output increases and price falls. This will cause the entrepreneurs to demand greater amount of external finance and consequently excessive risk taking. This results in high failure rate, which will cause the output quantities to decrease, price increases and profits increase. The presence of profits will in turn cause production activity to increase, thus setting emotion of the next cycle. The authors believe that this countercyclity of the net worth of entrepreneurs is the main driver of the business and credit cycles, and therefore suggest that there exists a stabilising policy that can produce a net positive surplus in the economy.

Gu and Wright (2011) and Matsuyama (2004) also use a general equilibrium approach to study the moral hazard issue. They obtain similar result that macroeconomic instability can be driven by moral hazard in certain sectors in the absence of exogenous shocks. Myerson (2012) extends this type of overlapping generations model to more than two-periods and suggests that the credit cycles do exist although long term relationship between lenders and borrowers efficiently solve the moral hazard problem.

There is another strand of overlapping generations models that consider the adverse selection effect. Martin (2008) is a representative study in this field. The author models a close economy where lenders use screening techniques such as the amount of investment and the entrepreneurial net worth to select borrowers. By allowing regime switching in financial contacts, the author shows that the fluctuation in the credit cycles are driven by the presence of perfect competition in credit market and suggests that the financial system may dampen the exogenous shocks by itself. A similar result is obtained in Figueroa et al. (2008).

There is some literature that considers the effect of moral hazard and adverse selection jointly. Similar to Suarez and Sussman (1997), Reichlin and Siconolfi (2004) extend Stiglitz-Weiss static credit rationing model to a general equilibrium framework. The key difference between these two studies is the assumption of the net worth of the entrepreneurs. In Suarez and Sussman (1997), the results are based on the assumption that the entrepreneurial net worth is countercyclical, which implies that when output is high, the price for the good is low and the entrepreneurial net worth falls. As Reichlin and Siconolfi (2004) argue, however, empirical evidence suggests procyclicality of asset prices, net worth, investment and loanable funds, lower reliance on bank financing during boom periods. As a result, one of the important assumptions in Suarez and Sussman (1997) does not hold in reality. By assuming the entrepreneurial net worth is procyclical and using an overlapping generations model, Reichlin and Siconolfi (2004) show that there are multiple steady states and endogenous fluctuations in the economy.

In summary, the use of overlapping generations approach to study credit market has significantly enriched the result of credit rationing. It also provides a very useful way to explain the multi-period impact of asymmetric information on credit rationing. Most of the literature using this approach, however, mainly focus on studying the production process of the borrowers rather than examine the credit market from the lender's prospective. The credit rationing in Suarez and Sussman (1997) is demand driven and lenders in their model act passively. They do not model the regulatory capital requirement and the portfolio selection process of the banks which is the supply side of credit rationing. As a result, this makes their contribution is limited. Moreover, Suarez and Sussman (1997) studies the credit rationing under the moral hazard which can be addressed by relationship lending in practice. The asymmetric information is in terms of the amount of effort borrowers put into the project and the maximum return is fixed. As a result, this is closer to Stiglitz and Weiss (1992) rather than the classic Stiglitz-Weiss model, where asymmetric information is in terms of the variance of project returns. Our credit rationing model in Chapter 7 of this thesis will focus on the magnitude of credit rationing under the Stiglitz-Weiss model. Due to this significant difference in approach in this thesis, Suarez and Sussman (1997) is not directly relevant. It is, however, important to acknowledge the contribution of the dynamic overlapping generations modelling approach in Suarez and Sussman (1997) that can provide useful insight into credit rationing, which is a potential future extension of the models proposed in this thesis.

Tsomocos (2003), Goodhart, Sunirand and Tsomocos (2004) and Goodhart et al. (2006) study financial fragility and contagious effect in incomplete markets. The main focus of this general equilibrium literature is on the stability of the financial system instead of credit rationing, and we review them in section 3.5.

3.2.4 Credit supply function models

One of the Stigltitz-Weiss results is that credit rationing can only occur if the return function of banks (i.e. that is equivalent to the loanable fund supply function if the credit market is assumed to be perfectly competitive) is hump-shaped. Bhattacharya and Thakor (1993) emphasis this by noting that the key result in Stigltitz-Weiss is the expected return for bank could peak at an interior loan interest rate. However, Arnold (2005) pointed out that the expected return function for bank cannot be hump-shaped as Stigltitz-Weiss suggest. Arnold also showed that the expected return function for bank is not necessarily monotonic, but it attains its global maximum at the upper limit of the interest rate beyond which there is no demand for credit. Therefore, the capital supply function is not the same as the one in the Stigltitz-Weiss model and many other studies. Under the return function for bank proposed by the Arnold model, they show that there are a two price equilibria, in which only safe firms are rationed. Reeder and Trepl (2009) further introduce the dependent project revenues into the Arnold model. The intuition is that in an economic downturn, the default correlation tends to be higher, while in a rapid growth economy, the default correlation tends to be lower. They show that there could be an equilibrium with credit rationing when project revenues are dependent. In such a situation, loans are given at single market interest rate, but some risky and some safe firms are denied credit. At that rate, safe firms have zero expected profits while risky firms miss a strictly positive expected profit. Similar to the Stigltitz-Weiss result, the safe firms will withdraw from the credit market first, and therefore, there is no incentive for banks to increase the interest rate.

One of the limitations of the Arnold as well as the Reeder and Trepl study is that despite the development of credit rationing models and banking practice, they still use the simple Stigltitz-Weiss model. This limits the usefulness of their models to explain the modern credit market. Hence, an obvious extension of their work is to include more parameters such as loan size, the probability of getting the loan, etc, under the new return function for bank as Arnold suggests. In Reeder and Trepl (2009), the dependent project revenues assumption is a more realistic extension. However, in their model, the probability of success of safe projects and the number of the successful projects are the same under both good and bad states. A more realistic model may need to introduce stochastic success probability and an introduction of stochastic probability will certainly enrich the model, however, at a cost of greater complexity. This is a possible extension for future research.

3.2.5 Credit rationing and capital requirement

Since the magnitude of credit rationing is determined by both supply of credit and by the demand for credit, we can expect that the latest Basel Accord will have a significant impact on the outcome of credit rationing. There was no capital requirement in place for the banking sector at the time when the Stiglitz-Weiss seminal model on credit rationing was published. This is a major shortcoming in the existing literature on credit rationing as well. Agur (2011) provides the first attempt to use a formal framework to study the relationship between capital requirement and credit rationing. In this section, we will summarise the Agur model and discuss its limitations.

The set up of the Agur model is similar to that of the Stiglitz-Weiss. The main difference is that the Agur model considers the capital structure of the bank. In Agur (2011), there are M identical banks in the market and the funding of a typical bank come from two sources: equity, E, and debt, D. Let A represents the total value of the assets of a typical bank. Then we can write

$$A = E + D \tag{3.2.7}$$

The interest rate on the debt for bank is r^d, so the bank need to pay $(1+r^d)D$ after one period of operation. The amount of equity is given, and is a constant over time, and the cost of equity is not modelled specifically. As a result, the bank can only change its capital structure by adjusting its debt level.

Agur (2011) also assumes that the capital requirement for the banks is always binding, and define the the capital ratio for a typical bank as $\frac{E}{A}$. Consequently, there is a maximum level of debt D^{max} the bank can issue.

The magnitude of credit rationing is defined as

$$\Omega = B(N - \hat{\theta}) - MA \tag{3.2.8}$$

where $B(N-\hat{\theta})$ is total loan demanded by a group of observationally identical borrowers in the sense of mean preserving spread and MA is the total credit supply.

Based on this set up, Agur uses an option approach to derive a key result in his paper:

Higher capital requirements imply more credit rationing: $\frac{\partial\Omega}{\partial A/E} > 0$.

The other results in Agur (2011) are all based on this result.

However, the use of standard option pricing approach here is incorrect for two reasons. First, the standard call option payoff function as specified in the paper is incorrect. Second, there is no theoretical or empirical basis that suggests a higher strike price imply a higher volatility of the underlying asset. This is a major flaw of this model and it leads to a wrong conclusion that higher capital requirement implies more credit rationing.

Moreover, the Agur result is based on the premise that a 'smaller balance sheet reduces the amount of credit that bank can supply'. In fact Agur focuses only on the liability side of the balance sheet for bank and does not consider the significance of the asset allocation between safe and risky assets for bank. Basel Accord sets zero-risk weighting for safe assets (government securities), which implies holding an extra unit of government security does not require bank to hold more capital. In this sense, bank can either change its asset composition that is shift from risky loan to government securities or to raise equity in order to meet the higher capital requirement. A more appropriate approach is to include an internal mechanism that allows banks to adjust their asset side of the balance sheets.

In this thesis, we address the flaws in the Agur model. Chapter 6 will present a bank portfolio allocation model that considers both asset and liabilities sides of the bank balance sheet. Chapter 7 will demonstrate the relationship between credit rationing and capital requirement by specifically considering the significance of the safe asset as well as the important probability of default in the risky assets.

Having reviewed the recent developments in the credit rationing literature, it is essential to empirically estimate the magnitude of credit rationing. Given that this is one of the aims of this thesis, the next section attempts to identify the appropriate econometric techniques to assess the extent of the difference between the quantities of credit supply and credit demand.

3.3 Disequilibrium econometrics

It is an established practice in macro-econometric models to estimate the relevant parameters using log-likelihood function when the ex ante demand is not equal to the supply in the markets. In this section, we present the maximum likelihood approach that will form the basis for the empirical analysis of the credit market disequilibrium in chapter 4. We focus on the Maddala and Nelson (1974) model and show the intermediate steps to derive the log-likelihood, which is omitted in the paper. Then, we outline an algorithm by Hurlin (2012) to identify the initial values for the maximum likelihood estimators, which will be used in chapter 4 to study the disequilibrium in the UK credit market.

In practice, it is often difficult to measure the exact quantities of demand and supply in some markets. Although an actual quantity of the smaller of the demand and supply can be observed ex post, we do not know whether this quantity is demand or supply. Credit market is one example. The flow of credit is affected by both supply side factors and demand side factors, so there is an identification problem in the sense that it is difficult to know the change in the observed outstanding loan is caused by credit supply, credit demand or both. This limits the usefulness of some economic policies. In particular, if the business investment activities are low due to low consumer confidence, then there is no point to increase the credit supply, which may increase the disequilibrium in the market.

In recent years a number of studies have attempted to develop econometric techniques to quantify the magnitude of disequilibrium. Fair and Jaffee (1972) is the first paper to study the disequilibrium problem. The authors propose four different methods to estimate the ex ante quantities of demand and supply. One of the methods is the maximum likelihood approach. The authors use a set of housing market data to access the usefulness of the econometric methods. A number of studies have subsequently focused on econometric methods for disequilibrium markets in different markets. Quandt (1972) suggests methods based on switching regression to deal with the disequilibrium problem; Fair and Kelejian (1974) extend the maximum likelihood method proposed in Fair and Jaffee (1972) in three different ways. However, as suggested by Maddala and Nelson (1974), these methods suffer a common shortcoming: we cannot use the model to estimate the probabilities for the quantity of supply and demand to be the observed quantity. As a result, some information is ignored in these models and their likelihood functions do not capture the full picture. Hence, instead of focusing on these mis-specified models, we will outline the model presented in Maddala and Nelson (1974), which is the econometric method we will use in chapter 4.

The Maddala and Nelson (1974) model is specified by three different equations:

$$L_t^S = X_{1t}'\beta_1 + \epsilon_{1t} \tag{3.3.1}$$

$$L_t^D = X_{2t}'\beta_2 + \epsilon_{2t} \tag{3.3.2}$$

$$Q_t = min(L_t^S, L_t^D) \tag{3.3.3}$$

where L_t^S and L_t^D are the unobservable quantities of supply and demand at time period t, respectively; X_{1t}' and X_{2t}' include all the observable variables that influence the quantity of supply and demand, respectively; β_1 and β_2 are the parameters for X_{1t}' and X_{2t}', respectively; ϵ_{1t} and ϵ_{2t} are residual terms; Q_t is the quantity observed in the market. So L_t^S and L_t^D are scalar, X_{1t}' and X_{2t}' are matrices, β_1 and β_2 are vectors.

Maddala and Nelson (1974) further assume ϵ_{1t} and ϵ_{2t} are independent identical normal variables with zero mean. Let σ_1^2 and σ_2^2 denote the variances for ϵ_{1t} and ϵ_{2t}, respectively. As a result, the variable $\frac{\epsilon_{1t}-\epsilon_{2t}}{\sqrt{\sigma_1^2+\sigma_2^2}}$ is a standard normal variable.

We can calculate the probability that the observation Q_t belongs to the demand regime as:

$$pr(L_t^D < L_t^S) = \Phi(h_t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{h_t} exp(-\frac{u^2}{2})du \tag{3.3.4}$$

where $h_t = (X_{1t}' - X_{2t}')/\sqrt{\sigma_1^2 + \sigma_2^2}$, and Φ is the cumulative distribution function of the standard normal distribution.

Similarly, we can obtain the probability of the observation Q_t belongs to the supply regime as:

$$pr(L_t^S < L_t^D) = 1 - \Phi(h_t) \tag{3.3.5}$$

By definition, we can write the marginal density, say $f(Q_t)$, of Q_t as

$$f(Q_t) = f_{Q_t|L_t^D<L_t^S}(Q_t) + f_{Q_t|L_t^S<L_t^D}(Q_t) \tag{3.3.6}$$

So we need to deduce $f_{Q_t|L_t^D<L_t^S}(Q_t)$ and $f_{Q_t|L_t^S<L_t^D}(Q_t)$ in order to obtain the marginal density of the observation Q_t. Next, we consider the joint density of L_t^D and L_t^S, say $g(d_t, s_t)$.

By definition,

$$f_{Q_t|L_t^D<L_t^S}(Q_t) = \int_{Q_t=L_t^D}^{\infty} g(d_t, z)dz$$

and

$$f_{Q_t|L_t^S<L_t^D}(Q_t) = \int_{Q_t=L_t^S}^{\infty} g(z, s_t)dz$$

Now, let us try to work out $\int_{Q_t=L_t^D}^{\infty} g(d_t, z)dz$ and $\int_{Q_t=L_t^S}^{\infty} g(z, s_t)dz$. Since ϵ_{1t} and ϵ_{2t} are independent identical normal variables, we can calculate the joint density $g(d_t, s_t)$ as:

$$g(d_t, s_t) = \frac{1}{\sqrt{2\pi\sigma_1^2}} exp[-\frac{1}{2}(\frac{s_t - X_{1t}'\beta_1}{\sigma_1})^2] \times \frac{1}{\sqrt{2\pi\sigma_2^2}} exp[-\frac{1}{2}(\frac{d_t - X_{2t}'\beta_2}{\sigma_2})^2] \quad (3.3.7)$$

Let us consider the case that $L_t^D < L_t^S$, so $Q_t = L_t^D$. We can express the marginal density of Q_t as:

$$\int_{Q_t}^{\infty} g(Q_t, z)dz = \frac{1}{\sqrt{2\pi\sigma_1^2}} exp[-\frac{1}{2}(\frac{Q_t - X_{1t}'\beta_1}{\sigma_1})^2] \times \frac{1}{\sqrt{2\pi\sigma_2^2}} \int_{Q_t}^{\infty} exp[-\frac{1}{2}(\frac{z - X_{2t}'\beta_2}{\sigma_2})^2]dz \quad (3.3.8)$$

Similar expression can be obtained for the case $L_t^D > L_t^S$.

Maddala and Nelson (1974) then shows that the unconditional density function of Q_t can be expressed as follows:

$$f(Q_t) = \frac{1}{\sigma_1}\phi(\frac{X_{1,t}'\beta_1 - Q_t}{\sigma_1})\Phi(\frac{X_{2,t}'\beta_2 - Q_t}{\sigma_2}) + \frac{1}{\sigma_2}\phi(\frac{X_{2,t}'\beta_2 - Q_t}{\sigma_2})\Phi(\frac{X_{1,t}'\beta_1 - Q_t}{\sigma_1}) \quad (3.3.9)$$

where ϕ is the standard normal probability density function.

Let $\theta = (\beta_1\beta_2\sigma_1\sigma_2)'$. We can then write the log-likelihood for this model as:

$$L(Q_t, \theta) = \sum_{t=1}^{n} log(f(Q_t)) \quad (3.3.10)$$

Maddala and Nelson (1974) also derive the closed form solution for the first and second derivatives of the log-likelihood 3.3.9. We are not reproducing these derivatives here. Once we know these derivatives as well as the log-likelihood, we can use Newton-Raphson procedure to calculate the maximum likelihood estimators for θ based on the data of Q_t, X'_{1t}, and X'_{1t}.

There is a large body of empirical literature that uses this maximum likelihood method to estimate the quantities of supply and demand in different markets. Laffont and Garcia (1977) use a set of monthly data to study the Canadian business loan market. Sneessens and Dreze (1986) examine the Belgian labour market by using similar maximum likelihood method. Pazarbaşioğlu (1997) use this approach to test whether there was a credit crunch in Finland in early 1990s. In the theoretical literature, Ito (1980) extends the approach proposed in Maddala and Nelson (1974) to a two markets setting and generalise to n-market case. Gourieroux et al. (1980) use a different approach to study n-market disequilibrium and provide a theoretical framework to link this type of disequilibrium approach to the traditional economic theory.

We know that the result of the Newton-Raphson method as well as other iteration methods will depend on the initial values of the estimated parameters. We may obtain local maximum or even non-convergent result if we start the iteration from some inappropriate values. There are various methods to overcome this limitation in the maximum likelihood approach. In particular, Laird (1978) proposes a grid search method to identify the initial values for the maximum likelihood iteration. However, this search method itself may have slow convergence problem. Karlis and Xekalaki (2003) gives a good review of different methods to select initial values for the Expectation-Maximisation (EM) algorithm, which can be used in Maddala and Nelson (1974) method with some modification.

In this thesis, we use a recent approach proposed in Hurlin (2012). It is a two stages OLS procedure. In stage one, he uses linear regression method to estimate the relationship among the observable variables Q_t, X'_{1t}, and X'_{2t}. In this stage, he suggests that we should use Q_t as the dependent variable to construct two different linear regression equations, say $Q_t = X'_{it}\hat{\tau}_i + \mu_{i,t}$ $(i = 1, 2)$. After we obtain the values for $\hat{\tau}_1$ and $\hat{\tau}_2$, we can obtain our first guess for supply and demand: $\tilde{L}_t^S = X'_{1t}\hat{\tau}_1$ and $\tilde{L}_t^D = X'_{2t}\hat{\tau}_2$. Next, we separate these initial guess of supply and demand into two subgroups as follow. The first subgroup contains all the observations Q_t, X'_{1t}, and X'_{2t} that $\tilde{L}_t^D \leq \tilde{L}_t^S$. In this case, $Q_t = L_t^D$, so that can denote this subgroup by d. Similarly, the second subgroup contains the observations Q_t, X'_{1t}, and X'_{2t} that $\tilde{L}_t^D > \tilde{L}_t^S$. This subgroup can be denoted by

s since $Q_t = L_t^S$. Once we identify these two different subgroups of observations, we can use linear regression method again for both subgroups:

$$Q_t^d = X_{1t}^d \hat{\beta}_1 + \tilde{\mu}_{1,t} \tag{3.3.11}$$

$$Q_t^s = X_{2t}^s \hat{\beta}_2 + \tilde{\mu}_{2,t} \tag{3.3.12}$$

The coefficients $\hat{\beta}_1$ and $\hat{\beta}_2$ obtained in these regression equations are our initial values for β_1 and β_2 in our maximum likelihood estimation. The initial values for σ_1 and σ_2 can be obtained via calculating the mean of $\tilde{\mu}_{1,t}$ and $\tilde{\mu}_{2,t}$. i.e.

$$\sigma_1 = \frac{1}{n^d} \sum_{k=1}^{n_1} \tilde{\mu}_{1,k} \tag{3.3.13}$$

$$\sigma_2 = \frac{1}{n^s} \sum_{k=1}^{n_2} \tilde{\mu}_{2,k} \tag{3.3.14}$$

where n^d and n^s are the total number of observation for subgroup d and subgroup s, respectively.

In chapter 4, we will combine the methodologies proposed in Maddala and Nelson (1974) and Hurlin (2012) to study the macro credit market disequilibrium. The next essential step is to estimate at the micro level supply of credit by individual banks. To this end, we consider the well established cobweb approach that can provide a useful basis for estimating the stability conditions for the credit market.

3.4 Cobweb approach

The cobweb models are widely used to explain the price dynamics in vary markets including agricultural market and labour market. The existing literature in this field can be classified by their modelling approaches: linear cobweb models and non-linear dynamics model. In the later case, it can be further divide into two strands, namely non-linear cobweb models and heterogeneous agent models, according to Gouel (2012). Based on these classifications, we will present the relevant literature below.

3.4.1 Linear cobweb models

Ezekiel (1938) offers one of the most important contributions in the development of cobweb model. His model assumes a competitive market and there is a time lag between the production decision and the profit realisation, which implies a short-run inelastic supply. Producers need to predict the next period price based on the current available information. They will choose an optimal level of production according to their expectation. They will realise the market clearing price for their products after they produce the goods.

The rest of the mechanism can be illustrated by Figure 3.2 or Figure 3.3. In both Figures, the horizontal axes represent the quantity of good and the vertical axes correspond to the price of the good. The intersection of the supply and demand curves gives the equilibrium price. If the supply quantity is $Q1$, which could be caused by the producers' wrong expectation or other external factors such as bad weather for agriculture market and government policies for credit market, and then the prices will increase to $P1$. Based on the current high price, the producers may forecast a relative high price for next period and produce a quantity larger than $Q1$, say $Q2$. As can be seen from the Figure 3.2, the price will fall to $P2$ in the second period. This will lead to another adjustment in the quantity of goods supply. As this process continue for a number of periods, the price fluctuation can end up with two cases: convergent (Figure 3.2) or divergent (Figure 3.3).

Ezekiel (1938) shows that whether the price can converge or not will depend on the elasticities of the supply and demand curves. The result can be summarised as: If $\frac{dL^S/Q}{dP^S/P} < |\frac{dL^D/Q}{dP^D/P}|$, then the market price converges; If $\frac{dL^S/Q}{dP^S/P} > |\frac{dL^D/Q}{dP^D/P}|$, then the market price diverges (P, Q are the equilibrium price and quantity of goods, respectively). That means the elastic of the demand curve should be greater than that of the supply curve if it is a convergent case. The opposite is true for the divergent case. Ezekiel (1938) also shows that it is possible to achieve another two outcomes, namely constant magnitude price fluctuations and converge to limit cycles, which will depend on the elasticities of the supply and demand curves.

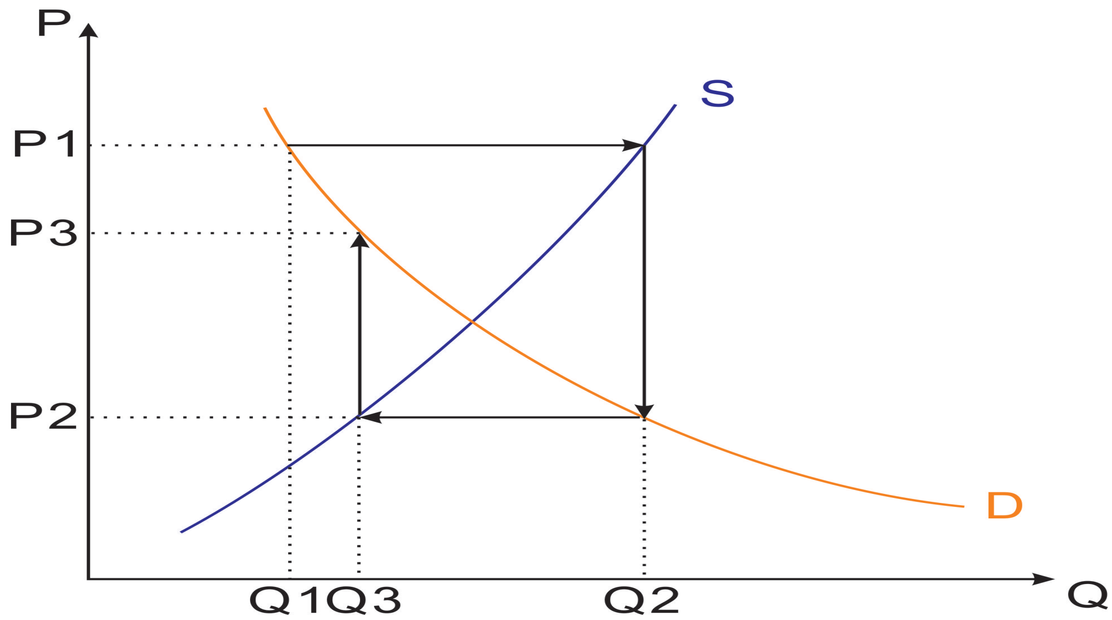


Figure 3.2: Cobweb theory convergent case

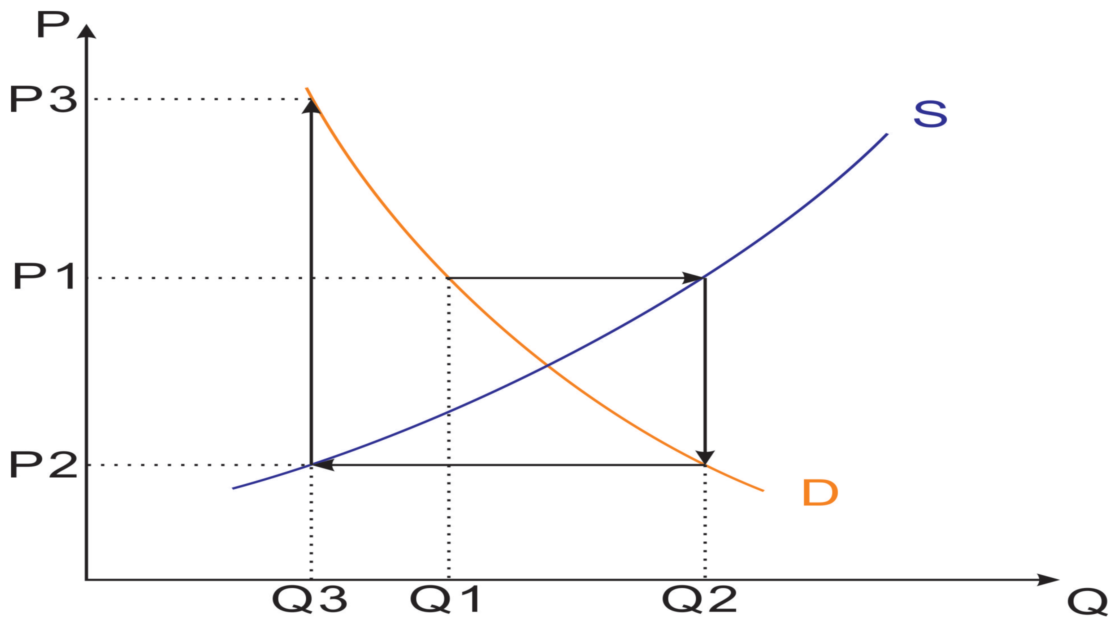


Figure 3.3: Cobweb theory divergent case

Buchanan (1939) criticises this model as it can be only valid under a special assumption that new entrances in the industry on the supply side is always possible. He shows that otherwise the losses to the producers will inevitably exceed the profits over a number of production cycles, which implies some of the producers may go bankrupt. However, the assumption that new entrances to an industry that is not profitable and some firms go bankrupt is itself problematic since it implies irrational behaviour of the economic agents. Buchanan (1939) also argues that the assumptions made in Ezekiel (1938) are too strong and may not be useful in real life.

The subsequent literature focuses on studying the elasticities of the demand and supply curve and tries to extend the stability range proposed in Ezekiel (1938). Akerman (1957) introduces speculators into the cobweb analysis of Ezekiel (1938). He argues that the supply curve will become more elastic in the short run in the presence of the speculators. Akerman (1957) also questions the adjustment speed of the producers that proposed in Ezekiel (1938). For example, it may take time for the farmers to update their production schedules in response to a sudden change in the price of the commodities they produce. Nerlove (1958a) develops this idea further and proposes the adaptive expectation process as:

$$p_t^e = p_{t-1}^e + \gamma(p_{t-1} - p_{t-1}^e)$$

where γ is the adjustment speed, p^e is the expected price and p is the market clearing price of the good.

This method enriches the complexity of the original cobweb model significantly. It can also include both short run and long run supply curves in the cobweb process. After the introduction of the adaptive expectation, the cobweb model has been widely used in economics to study market stability. However, the criticism proposed in Buchanan (1939) has not been addressed in this literature. More importantly, this research suffers from a common drawback in that there are some significant forecasting errors in the model. This has led to the development of non-linear models. The next section review the non-linear dynamics cobweb models.

3.4.2 Non-linear dynamics models

Meadows et al. (1971) review pork production in the United States and point out that it is necessary to develop a non-linear cobweb model. We know that the outcomes of the linear cobweb models are limited to four different cases: convergence to steady state, divergence, constant magnitude price fluctuations and converge to limit cycles. But if the linear cobweb models are extended to allow for the non-linear feature, the results will be more robust.

The dynamical system has its root back to the Newtonian mechanics. In a dynamical system, all the parameters are specified by a set of non-linear equations and their evolution is determined by these equations. We can start with certain initial values and use iteration procedure to derive all of the future values for the parameters in the system. As a result, small changes in parameters could lead to significantly different results or even chaotic dynamics. In fact, there are three characteristics that often come with chaos theory. [1] The first one is that the evolution patterns of parameters are very sensitive to the initial conditions as we mentioned earlier. The second one is that although the results can appear to be random, the chaotic systems are actually deterministic since they are determined by those non-linear equations that specify the dynamical system. The final one is that the system looks similar at different levels of magnification and we call this as "self-similarity". This is different from the linear cobweb model, in which small changes in parameters can only change the results through the magnitude of elasticities.

In the cobweb models, the supply and demand curves are monotonic functions. Artstein (1983) is the first paper that introduces non-monotonic curves and shows that chaotic dynamics is possible. Jensen and Urban (1984) uses backward bending supply curves and multi-valued demand curves to reach similar conclusion. Instead of using the non-monotonic curves, Chiarella (1988) analyses some more general non-linear supply functions in a cobweb setting. There are two regions in the result: a stable region, in which dynamic behaviour is similar to that predicted by linear cobweb models; an unstable region where price becomes chaotic. This is indeed the pattern we commonly observe in economic time series. Hommes

[1] Chaos theory is proposed by Lorenz (1963)

(1991) and Hommes (1994) further confirm this result with adaptive expectation and a non-linear, S-shaped increasing supply function.

These non-linear cobweb models partially solve the systematic forecasting errors problem in the linear cobweb models. They, however, fail to address the survival of producers problem suggested in Buchanan (1939), so their models are subject to internal inconsistency. It is interesting that only a limited literature has addressed this criticism that was outlined back in 1930s. Commendatore and Currie (2008) is one of the recent studies that look at how producers finance their production activities and the possibility of bankruptcy. In this model, a firm is bankrupt if and only if it has a financial debt that is not diminishing. The credit rationing phenomenon is also taken into consideration in the model to assess the availability of credit to producers. They show that the profitability and probability of bankruptcy of the producers are very sensitive to the credit market. More significantly, their result also demonstrates that unconstrained borrowing could lead to bankruptcies and financial crisis.

Another strand of research focuses on the assumption regarding expectations. The rational expectation assumption made in the above literature has been criticised by behavioral economists. The rational expectation assumption requires that all of the producers are capable of thinking through all possible outcomes and choosing the action that will result in the best possible outcome. Following the theory of bounded rationality proposed by Simon (1957), behavioral finance challenges the rational expectations assumption. Simon (1957) introduces the concept that economic agents may only make sub-optimal decision based on the available information and past experience and knowledge. Kahneman and Tversky (1979) introduce the prospect theory to support the idea of bounded rationality. It describes how prospects are perceived by individuals based on their framing, how gains and losses are evaluated and how uncertain outcomes are weighted. Brock and Hommes (1997) applies the bounded rationality concept in the cobweb model. They discuss the concept of adaptively rational equilibrium and use a simple example to show how irregular equilibrium price occurs. There are a number of extensions of this work, known as heterogeneous agent models. The bounded rationality theory and prospect theory is beyond the scope of this thesis, so we do not discuss this strand of literature here.

Having discussed relevant aspects of linear and non-linear cobweb models, we have identified a potential avenue of their application to analyse the disequilibrium in the credit market. In chapter 5, we will apply the cobweb model based on adaptive expectation about the lending rate of banks and the probability of default of loans.

3.5 Stability of the banking system

The stability of the financial system has become one of the key objectives for most central banks and regulators because of reoccurring credit booms and crashes. According the European Central Bank, a stable financial system should have the following three key characteristics. First, the financial system should be able to efficiently and smoothly transfer resources from savers to investors. Second, financial risks should be assessed and priced reasonably accurately and should also be relatively well managed. Third, the financial system should be in such a condition that it can comfortably absorb financial and real economic surprises and shocks. [1]

The traditional economic theory (Arrow-Debreu) assumes complete markets while the financial markets are incomplete and there exists asymmetric information as well as other financial frictions. Numerous studies in recent years have focused on the optimal design of the banking system. Bardsen et al. (2006) provides a very good review of the macroeconomic models on financial stability based on their modelling approach, namely Real business cycle (RBC) models, Dynamic stochastic general equilibrium (DSGE) models, Overlapping generation (OLG) models, Finite horizon general equilibrium (FHGE) models, Dynamic aggregative estimated (DAE) models and Structural vector autoregressive (SVAR) models. We can also classify this literature according to their main objectives in this section: the important role of banks, financial accelerator and contagion.

[1] For a detail analysis of financial stability, see Bardsen et al. (2006).

3.5.1 The important role of banks

The modern literature on the significant of the banking system began in 1980s. Most of these studies focus on the provision of liquidity and monitoring services by banks. In terms of liquidity provision, two classic papers in this field are Bryant (1980) and Diamond and Dybvig (1983). Although they use different models, they come to the same conclusion that the existence of banks improves the efficiency of the financial markets by issuing demand deposits and providing liquidity. Banks can to some extent solve the asymmetric information problem in the credit market better than individual agents. The demand deposits, however, lead to a financial instability (undesirable equilibrium) such as run on banks. Hence, deposit insurance is essential for banking stability. Banks provide useful monitoring services as well. Diamond (1984) uses an ex-post asymmetric information model that suggests the existence of banks can help the economy to avoid duplicate monitoring costs. The basic idea is that it costs the investors time and effort to obtain the information about the projects of the borrowers. From the point of view of the economy, the welfare of the society can be improved if all the investors provide funding to a bank through the form of deposits or equity investment and delegate monitoring to the bank. This structure of the banking system is, however, prone to bank run. Following Diamond (1984), a number of models (Gorton and Pennacchi (1990), Myers and Rajan (1998) and Qi (1998)) have examined the synergies between deposits and loans. One of the shortcomings of these studies is that the absence of exogenous shocks in their models. There is also no consideration of intertemporal smoothing. To address this limitation Allen and Gale (1997) propose an overlapping generations model with incomplete financial markets. The authors compare the optimal conditions from an economy with banks and one without banks. The result shows that there is an underinvestment in the economy without banks and the ex ante expected utility will be lower for all generations in such an economy. This further confirms the important role banks play in the economy. However, Allen and Gale (1997) argue that the competition in the banking sector inevitably create instability because of excessive risk taking. In another paper, Allen and Gale (2003) further discuss the point that greater competition may be good for (static) efficiency, but bad for financial stability.

Diamond and Rajan (1999) demonstrate the existence of instability in the banking system by using a model where both investors and borrowers have preference for liquidity. Subsequent research by these authors (Diamond and Rajan (2000), Diamond and Rajan (2001), Diamond and Rajan (2005), Diamond and Rajan (2009a) and Diamond and Rajan (2009b)) focus on the liquidity issue and instability in the banking sector. This strand of literature on financial stability, however, suffers from too short time horizon in the models. Although overlapping generations is modelled in this literature, the analysis is still limited to a single production cycle. As we discussed in section 2.2, there is procyclicality of bank net worth in practice and the credit cycles booms and busts occur frequently. This has motivated another strand of research that uses multi-period models to study the interaction in credit market as summarised in section 3.5.2.

3.5.2 Financial accelerator

There is a burgeoning literature (Kiyotaki and Moore (1995), Bernanke et al. (1999), and etc.) on financial accelerator that studies the mechanism of how the financial friction may amplify the adverse shock to the economy. In bank lending collateral plays an important role in practice and the market values of the net worth of the borrowers become an essential consideration in the loan sanction process. Naturally, this follows from credit rationing literature discussed earlier. Following our discussion on procyclicality in section 2.2, it is not surprising that a negative shock to the borrowers or banks will be amplified by the current structure of the banking system. A credit cycle that is initiated by a small shock will produce a large change in economic conditions. The literature on financial accelerator has directly link to business cycles literature. In this section, we review a few important studies in this field.

Kiyotaki and Moore (1995) propose a cyclical mechanism to explain the transmission and amplification of a small shock. The authors developed a dynamic model of credit chains with an emphasis on the role of durable goods (e.g. land), which can be used as collateral for loans. The value of these durable goods can determine the total amount of money firms can borrow. The amount of credit a firm can obtain will have a strong impact on their assets value. Thus, there is an interaction between the asset values and bank lending can form a transmission channel of shock. The authors show that even temporary liquidity shocks to some firms can cause a chain reaction in which other firms get into financial difficulties. Hence, the banking system is therefore called the financial accelerator.

Bernanke et al. (1999) is another well known study in this field. The authors use a dynamic general equilibrium model to show that endogenous developments in credit markets can amplify and propagate shocks to the wider economy. The approach is a form of new Keynesian model with monopolistic competition, sticky prices and asymmetric information on the realisation of the investment project return. Following the literature on credit rationing and Diamond (1984), the authors assume that banks cannot monitor borrowers without costs and have to use loan contract to align the interest of borrowers. Moreover, they define a premium on external financing as: 'the difference between the cost of funds raised externally and the opportunity cost of funds internal to the firm'. It is assumed that this premium is inversely related to the net worth of the borrowers. Under this definition, the cost of fund raised externally will be higher in the recession due to the high agency cost and aggregate uncertainty and the reverse also true. Hence, the premium is countercyclical. A financial accelerator exists since the net worth of the borrowers is procyclical (as discussed in section 2.2) while the premium is countercyclical. The shortcomings of this approach are that it does not allow the possibility for banks to go bankrupt, genuine heterogeneity is not taken into account and equilibrium outcomes are second best (Bardsen et al. (2006)). Given that the focus in this thesis is on the dynamics of credit supply side and the magnitude of credit rationing, we do not review the literature on financial accelerator in further detail.

3.5.3 Financial contagion

There is another branch of research that focuses on the interbank market and how financial contagion affects the stability of the banking sector. Allen and Gale published a series of papers in this field. Allen and Gale (2000b) use a two-periods model to study how liquidity preference shocks affect banks across regions.

The economy in this model includes many regions. Consumers are assumed to have different liquidity preference in each region while the aggregate demand for liquidity is constant. As a result, banks operate in different region can have different liquidity needs. An interbank market in deposits will allow banks to obtain liquidity. This interbank market can work well if there is enough liquidity in the banking sector as a whole. If the aggregate demand for liquidity of the consumers exceed that in the banking sector, this interbank market will produce contagion in the banking sector. This contagion is a part of the equilibrium in the model of Allen and Gale (2000b). The linkage in the banking system can lead to instability. In Allen and Gale (2000b), the contagion arises from the assumption that banks are linked ex ante. Diamond and Rajan (2005) further suggest that contagion in banking sector is possible even without any explicit ex ante linkage between banks. This is because of the 'negative real spill over effect of bank failure on the available liquidity'. Allen and Gale generalise this contagion effect to 'financial fragility', which implies '...small shocks (in the banking system) have disproportionately large effects'. The subsequent work of Allen and Gale such as Allen and Gale (2004) and Allen et al. (2009) mainly focuses on studying financial fragility caused by inefficiency in the interbank market.

A general conclusion of this work is that contagion causes instability in the banking sector. Studying the banking sector and banking supervision in a system context has generated a great deal of interest (Furfine (2003), Elsinger et al. (2006), Tsomocos (2003), Tsomocos (2004), Goodhart, Sunirand and Tsomocos (2004), Goodhart et al. (2005) and Goodhart et al. (2006)) Here, we review Goodhart et al. (2006) as this is a generalisation of other models published by these authors. Within a general equilibrium model with incomplete credit market and heterogeneous agents, the authors study the behaviour of individual bank, the possible contagious effects between banks and the optimal design of banking regulation. The introduction of heterogeneous agents significantly increases the complexity of the model compared to the earlier models based on homogeneous agents. The heterogeneous agents approach is more representative of the banking system in practice, where banks have different levels of capital, leverage and risk/return preference. Banks inevitably have different level of risk. When one of the highest risk banks fails, contagion in the banking system will spread through the interbank market as suggested in Allen and Gale (2000b) or the liquidity link as suggested in Diamond and Rajan (2005). The heterogeneous agents approach can capture the contagious effect, however, at the expense of increase complexity. In the model proposed in Goodhart et al. (2006), there are multiple markets for deposits and loans that give rise to multiple interest rates. Banks operating in this environment are aiming to maximise their utilities by choosing optimal asset portfolios according their individual risk preference. Deposits may not be sufficient for some individual banks to fund their asset portfolios, so they rely on the interbank market to raise additional funds. Default is assumed to be endogenous in the model. In equilibrium, the marginal utility of default is equal to the marginal disutility of bankruptcy penalty. A regulator and a central bank are also included in the model. They cooperate with each other if necessary to ensure the stability of the economy via setting penalties on bankruptcy and minimum capital requirement. Under this setting, the authors define a monetary equilibrium with commercial banks and default (MECBD) and derive the conditions to achieve such equilibria. Based on their result, the authors also study the channels of contagion (default in specific sectors and collapse of the equity market), liquidity trap and the possible regulatory policies. They show that if the penalties on bankruptcy are sufficiently high, default and violations of capital requirement will vanish in equilibrium. This implies that capital requirement can improve financial stability. The opportunity cost for this improvement in financial stability is higher interest rates and lower efficient trade. Goodhart et al. (2006) extend the study of banking regulation to another dimension by focusing on the banking system as a whole. In this approach, systemic importance of assets is demonstrated, which was the case in the 2007 global financial crisis. As we discussed earlier in chapter 2, failure of one financial institutions has spill over effects on the whole banking system and an optimal action for an individual bank (fire sales) may not be optimal from the point of view of the economy as a whole. This view is also discussed in great detail in Morris and Shin (2008).

Using heterogeneous agents to study the interaction in the banking system is important. This approach captures the correlation between bank failures. The default correlations were not considered adequately in the period leading up to the 2007 global financial crisis. The assumption of log normal distribution of default risk or asset value is not entirely representative in reality. Default correlations are much higher during crisis than that in normal economic conditions. Studying the linkage and interaction between banks will produce some useful insight. Such an approach, however, increases the complexity of the model. In this thesis, we therefore use the traditional ‘representative bank’ approach to obtain tractable results at a cost of more realistic complex models. The extension of our models to heterogeneous setting is a possible area of future research.

Having reviewed the relevant literature on financial stability, we propose a series of models in this thesis to study the impact of Basel III banking regulation on credit supply and credit rationing. Although financial stability is not explicitly addressed in our models, we discuss the policy implication of financial stability in our cobweb credit supply model in chapter 5.

Chapter 4

A disequilibrium analysis of the credit market

In chapter 3, we discussed a number of strands of the literature relevant to the credit market. The recent experience of the financial crisis discussed in chapter 2 combined with the literature on disequilibrium econometrics gives us a useful basis for the analysis of credit market disequilibrium in this chapter. The empirical analysis in this chapter lays the foundations of our analysis of the credit supply decision by banks and their portfolio allocations decision, as well as their profitability and credit rationing in later chapters. This chapter is organised as follows. Section 4.1 set out a general introduction. Section 4.2 outlines our model and the data used in this study. Section 4.3 presents the results. Section 4.4 concludes.

4.1 Introduction

Deleveraging and capital requirement have been the main driving forces behind the recent changes in the supply of the credit market. Based on the discussion in the previous chapters, the level of credit supply and the magnitude of credit rationing are important consideration for the stability of the credit market. In other words, it is essential to study the credit market disequilibrium.

The empirical studies of credit market disequilibrium use mainly balance sheet data and surveys data. Berger and Udell (1992) use generalised linear models and the Federal Reserve's survey in terms of bank lending data set to estimate the magnitude of credit rationing (i.e. credit market disequilibrium in the broader sense). Harhoff and Körting (1998) uses a set of survey data and use regression analysis to study the credit availability to the German SME firms. However, these type of studies are subject to common drawbacks such as data measurement errors or biases. To overcome these limitations, we propose a disequilibrium model that consists a system of equations for the credit supply as well as credit demand in this section.

There are a number of studies similar to our work. For example, Hurlin and Kierzenkowski (2003) study the Polish credit market in 1990s. The authors use maximum likelihood method to estimate the parameters in their model, which is adapted in this chapter. Their results are very sensitive to the sample period, which limits the usefulness of this study. Atanasova and Wilson (2004) use the disequilibrium model similar to Maddala and Nelson (1974) to investigate the British monetary transmission mechanism and its impact on SME businesses in 1990s. The authors find that the demand for credit by the SME businesses in the UK increases during periods of tight monetary conditions. We also study the UK credit market in this chapter, but our model is more general since it considers the demand for credit for both corporate and households. Pazarbaşioğlu (1997) is also close to our work. He proposes a disequilibrium model of credit market and uses a set of Finnish banking sector data from 1981-95 to show that the significant reduction in Finnish bank lending in 1990s was caused by a cyclical decline in credit demand rather than the credit supply. In his model, there are eight factors that affect the quantity of credit supply. These include bank funding source (represented by total deposits plus book value of capital), the banking sector share price relative to the market average, lending rate, market capitalisation of corporate equity, cyclical risk premium (the difference between the lending rate and the money market rate), expected inflation rate, expected industrial production and variance of bank share price. This empirical specification of the model, however, suffers from the problem of multicollinearity. In particular, we would expect a high correlation between the bank's funding source, the banking sector share price relative to the market average, market capitalisation of corporate equity and bank share price. Surprisingly, the author did not address this problem. Multicollinearity can distort the standard errors of the estimate parameters and the coefficient standard errors of the whole model, and t-tests for the significant of the parameters (i.e. a Type II error). As a result, in the absence of robust multicollinearity checks and stepwise regression procedure, the result in Pazarbaşioğlu (1997) is not reliable. Apart from the multicollinearity problem, Pazarbaşioğlu (1997) analysis also may have a mis-specification problem of the functional form in his credit supply equation. The most important factor, namely probability of default, is omitted in the model. There are internal risk rating models in place in the banking industry, and probability of default is a key part of these models. The output of these risk models is a risk rating for a borrower, which determine whether the borrower can obtain the loan or not. As a result, we can say that the lending decisions for banks are based on expected default rate and the credit supply model has to capture this aspect.

We propose an alternative specification of the disequilibrium model to study the credit market in the UK. Our model addresses the weaknesses in Pazarbaşioğlu (1997). We use a maximum likelihood method proposed in Maddala and Nelson (1974) to estimate the quantity of credit supply and credit demand in the UK based on a set of quarterly data from 2000 to 2012. This is a particularly important time period for the credit market in the UK, which comprises the dot com bubble in the early 2000s, and the credit boom leading up to 2007 global crisis. Our result suggests that credit disequilibrium and credit rationing do exist and the credit demand exceed credit supply in 41 out of the total 51 observations.

4.2 The empirical model of the credit market disequilibrium

In this section, we begin with a description of the dependent and independent variables in the model. This is followed by a discussion of the dataset used in this chapter. A system of equations including credit supply, credit demand and observable outstanding credit in the market are outlined below.

The supply of bank loan can be modelled in a number of ways. Here, we mainly focus on the macroeconomic variables that affect credit supply.[1]

The funding sources of a typical bank are equity and debt, which form the right hand side of the balance sheet of bank. Bank loan is one of the key components on the asset side. Hence, we use the total market value of all the listed banks in the UK to capture the effects of these sources of funding.[2] We expect that the market value of the banks will be positively correlated to credit supply.

From the economic theory, we also expect the lending rate to play an important role in the determinant of credit supply. This is the price element of the loan contract, so we expect this has a positive effect on the credit supply.

We also include a cyclical risk premium in our model to capture the agency costs, which are those costs related to adverse selection and moral hazard. As Bernanke and Gertler (1989) suggests, these costs fluctuate across business cycles due to the net worth of borrowers: the agency costs will increase in the downturn when there is a shock to the net worth of borrowers and decrease in the good time when those borrowers have higher net worth. Hence, we expect higher agency costs (i.e. economic downturn) to reduce credit supply.

There are several other macroeconomic variables that reflect the overall health of the economy. These include the expected change in inflation rate and expected industrial production growth rate. The inflation rate is negatively correlated with the return on fixed income securities. Given that bank loans are generally fixed income instrument, inflation is expected to have a negative impact on the supply of bank loan.

As pointed out earlier, bank lending crucially depends on the expected default rate, so we also include a parameter to capture the effect of expected default in our model. We expect a negative relationship between bank lending and the expected default rate.

Next, we will present some discussions about the data used in this chapter.

[1] For microeconomic approach to model credit supply, please see Chapter 5 and Chapter 6 for two different credit supply models.

[2] We included total deposits outstanding in our original model, but only obtained non-convergent result in our algorithm. This could be caused by the correlation between market value of banks and the total deposits outstanding.

4.2.1 Description of the data

The data used in this empirical analysis is obtained from Thomson Reuters Datastream over the sample period Q1 2000 to Q3 2012 except for the expected loan default rate, which is estimated from the balance sheets of the major UK banks. All the data is quarterly apart from the data on expected loan default rate, which is semi-annual.

Total loan outstanding in the UK (Q_t)

The Q_t series is domestic currency and foreign currency lending to the business sector and households. The lending figure is provided by three main types of lenders: UK-resident banks, UK-resident building societies and other specialist lenders such as non-bank, non-building society UK credit grantors, specialist mortgage lenders, retailers, central and local government, public corporations, insurance companies and pension funds. These lenders report lending data directly to the Bank of England. The data is available in two different forms: seasonally adjusted and non seasonally adjusted. As explained in our discussion in Chapter 2, we expect to observe procyclical movement in the credit market. Hence, we do not use seasonally adjusted data here. We take the log-transformation of this time series.

Market value for the UK banks (MV_t)

The MV_t series is market capitalisation of the listed UK banks. The market value of banks available on Datastream is their share prices multiplied by the number of ordinary shares outstanding. The amount of outstanding share is updated whenever new tranches of stock are issued or after a capital change. We transform the data to log series. We appreciate that using the data for listed banks underestimate the market value of the lenders in the UK, however, given the size of listed banks the approximation is very close.

Lending interest rate (r_t^L)

The r_t^L series is the weighted average of the lending rate by UK banks. This rate is calculated as follows: each new loan amount is multiplied by the annualised interest rate for each loan; next the new loans in the UK are aggregated, which then divided by the sum of new loans during the quarter. Compared to other interest rate measures such as base rate and LIBOR, this weighted average of the lending rate can give us better indication of the interest burden for borrowers.

Cyclical risk premium ($r_t^L - r_t^{LIBOR}$)

The $r_t^L - r_t^{LIBOR}$ series is the difference between the lending rate and three month LIBOR rate. LIBOR stands for London Inter Bank Offer Rate, which is the interest rate that the banks charge each other for loans with 3-month maturity. It is a standard practice in the literature (e.g. Pazarbaşioğlu (1997) and Hurlin and Kierzenkowski (2003)) to use three month LIBOR to capture the cyclical risk premium.

Expected change in inflation rate (i_t^e)

The data about inflation expectation is normally available in the form of survey data. Financial data providers such as Thomson Reuters and Bloomberg conduct survey among economists to obtain a median forecast for inflation rate. Ideally, we would like to have all the historical forecast series over our sample period. Unfortunately, only forward looking inflation forecasts are available. We therefore use the actual consumer price index (CPI) data here and calculate the percentage change in inflation for each quarter. We can justify the use of CPI on the basis of rational expectation hypothesis. One potential drawback of using CPI index is that the components of the index change over time, which is common for other inflation measures.

Expected industrial production growth rate (y_t^e)

The y_t^e series is the expected industrial production growth rate. For same reason outlined above, we use the actual figure on Index of Production (IoP) from Office for National Statistics (Datastream). The IoP measures the gross value added in the manufacturing (the largest component of production), mining & quarrying, energy supply and water supply & waste management sectors.

Business investment ($Bint_t$)

$Bint_t$ series is business investment. The definition of business investment from Datastream is 'Gross fixed capital formation consists of resident producers' acquisitions less disposals of fixed assets during a given period plus certain additions to the value of non-produced assets realized by the productive activity of producer or institutional units. Fixed assets are tangible or intangible assets produced as outputs from processes of production that are themselves used repeatedly, or continuously, in processes of production for more than one year.' Since bank loan is one of the major funding sources for business investment, we assume this figure can have a direct positive impact on the credit demand. We use non seasonally adjusted figure here for the same reason as explained earlier in the case of total loans outstanding. Log-transformation is applied to the data.

Expected loan default rate (δ_t)

The δ_t series is calculated by dividing the loan provision data from the total loan outstanding in the major British banks' balance sheets (HSBC, Barclays, RBS and Lloyds banking group), which are obtained from Bloomberg. All of the data are adjusted for mergers and acquisitions. The data for loan provision and total loans outstanding are reported according the international accounting standards. We are only interested in the expected default rates in bank loans rather than the actual default rates. Due to confidentiality, we cannot obtain the expected default rate from banks directly so we can use a proxy here. The reserve for losses on loan account on the balance sheet of a bank is good indication of the expectation of the bank's expected losses given default. Hence, this reserve for losses divided by total loans is the best possible data we can obtain to represent the expected default rate. We should point out that the accounting figures are discretionary and can be questionable. The semi-annual data is interpolated to obtain quarterly rates, which introduce downward biased on the correlations and standard deviation of the sample data. We know that the results have to be interpreted with some caution.

4.2.2 The empirical model

Our credit supply function is specified as follows[1]:

$$L_t^S = \beta_0^S + \beta_1^S MV_t + \beta_2^S r_t^L + \beta_3^S (r_t^L - r_t^{LIBOR}) + \beta_4^S i_t^e + \beta_5^S y_t^e + \beta_6^S \delta_t + \epsilon_{1t} \quad (4.2.1)$$

where L_t^S is the quantity of credit supply, MV_t is the market value of the UK banks, r_t^L is the weighted average of the lending rate by the UK banks, $r_t^L - r_t^{LIBOR}$

[1] House price index and corporate profitability are also considered in our original model, but the estimation results show that they are not significant different from zero in 95% confidence level, so we drop them in our specification here

is the cyclical risk premium, which is the difference between the lending rate and three month LIBOR rate, i_t^e is the change in expected inflation rate, y_t^e is the expected industrial production growth rate, δ_t is the expected default rate [1], ϵ_{1t} is the error term, and $\beta_0^S, \beta_1^S \dots \beta_6^S$ are coefficients.

Following the discussion in Pazarbaşioğlu (1997), our credit demand function includes four variables, namely lending rate, business investment, expected change in inflation rate and expected industrial production growth rate. Our credit demand function is specified as follows:

$$L_t^D = \beta_0^D + \beta_1^D r_t^L + \beta_2^D Bint_t + \beta_3^D i_t^e + \beta_4^D y_t^e + \epsilon_{2t} \tag{4.2.2}$$

where L_t^D is the quantity of credit demand, $Bint_t$ is the business investment, ϵ_{2t} is the error term, and $\beta_0^D, \dots, \beta_4^D$ are coefficients.

We cannot use the standard linear regression technique here since the quantity of credit demand and the quantity of credit supply are not observable. The actual quantity of bank credit we observe is the smaller of the two, hence we specify another variable as

$$Q_t = min(L_t^S, L_t^D) \tag{4.2.3}$$

where Q_t is total loan outstanding in the UK.

We use the maximum likelihood method proposed in section 3.3, which is the combination of the methods in Maddala and Nelson (1974) and Hurlin (2012), to estimate the parameters β_i^S and β_i^D. The log-likelihood equation is as given in equation 3.3.10 in section 3.3, and we use Newton-Raphson iterative procedure to obtain the maximum likelihood estimators. The computational work here is done in Matlab and the main code is adapted from Hurlin (2012). The result of three different specifications of the model are presented according to their goodness of fit in section 4.3.

[1] it is calculated by diving the the loan provision data from the total loan outstanding in the major British banks' balance sheets

4.3 Estimation results

We begin with the full model as presented in section 4.2. We refer to this model as Model 1.

$$\begin{aligned}
&\text{Model 1 :}\\
&L_t^S = \beta_0^S + \beta_1^S MV_t + \beta_2^S r_t^L + \beta_3^S (r_t^L - r_t^{LIBOR}) + \beta_4^S i_t^e + \beta_5^S y_t^e + \beta_6^S \delta_t + \epsilon_{1t}\\
&L_t^D = \beta_0^D + \beta_1^D r_t^L + \beta_2^D Bint_t + \beta_3^D i_t^e + \beta_4^D y_t^e + \epsilon_{2t}\\
&Q_t = min(L_t^S, L_t^D)
\end{aligned} \tag{4.3.1}$$

The estimation results of Model 1 is shown in Table 4.1.[1] The adjusted R^2 of the model is 0.82, which is a fairly good fit.

AIC Criterion	-278.71	Schwarz Criterion	-251.66
R^2	0.86	Adjusted R^2	0.82
Log-Likelihood	-85.00		

β^S	$t-stats$	β^D	$t-stats$	σ_1	$t-stats$
5.28**	(7.59)	-0.38*	(-0.15)	0.02**	(73.45)
0.40**	(3.25)	-4.22**	(-4.29)		
-10.10**	(-20.41)	1.52**	(2.65)		
-31.26**	(-6.87)	6.78**	(2.19)		
-1.62	(-1.06)	-0.01	(-0.92)		
0.02*	(1.92)			σ_2	$t-stats$
-22.74**	(-8.19)			0.07**	(30.84)

Table 4.1: Estimation results of Model 1

As can be seen in Table 4.1, the estimated parameters of the change in expected inflation rate and expected industrial production growth rate in the credit supply function is not significantly different from zero at the 5% confidence level. Also, the estimated parameter of the expected industrial production growth rate in the credit demand function is not significantly different from zero at the 5% confidence level. We therefore drop these parameters in Model 1 and change

[1] We use one asterisk to indicate a confidence level of 90% and two asterisks denote 95% confidence interval throughout this thesis.

the specification of the model as follow:

$$\begin{aligned}&\text{Model 2}:\\&L_t^S=\beta_0^S+\beta_1^S MV_t+\beta_2^S r_t^L+\beta_3^S(r_t^L-r_t^{LIBOR})+\beta_4^S\delta_t+\epsilon_{1t}\\&L_t^D=\beta_0^D+\beta_1^D r_t^L+\beta_2^D Bint_t+\beta_3^D i_t^e+\epsilon_{2t}\\&Q_t=min(L_t^S,L_t^D)\end{aligned}\tag{4.3.2}$$

The result is summarised in Table 4.2.

AIC Criterion	-282.10	Schwarz Criterion	-260.85
R^2	0.86	Adjusted R^2	0.83
Log-likelihood	-91.45		

β^S	$t-stats$	β^D	$t-stats$	σ_1	$t-stats$
5.69**	(11.74)	-1.75	(-0.83)	0.01**	(148.42)
0.33**	(4.07)	-4.97**	(-6.06)		
-10.19**	(-26.12)	1.84**	(3.85)		
-29.13**	(-9.40)	3.88*	(1.49)	σ_2	$t-stats$
-24.98**	(-9.73)			0.07**	(30.85)

Table 4.2: Estimation results of Model 2

The adjusted R^2 is slightly higher in model 2. Both Akaike Information Criterion (AIC Criterion) and Schwarz Criterion become smaller compared to model 1, which indicate that Model 2 is a better specification than Model 1. The parameter of changing expected inflation rate in the credit demand equation is, however, only significantly different from zero at the 10% confidence level. We therefore estimate yet another specification as set out in Model 3.

$$\begin{aligned}&\text{Model 3}:\\&L_t^S=\beta_0^S+\beta_1^S MV_t+\beta_2^S r_t^L+\beta_3^S(r_t^L-r_t^{LIBOR})+\beta_4^S\delta_t+\epsilon_{1t}\\&L_t^D=\beta_0^D+\beta_1^D r_t^L+\beta_2^D Bint_t+\epsilon_{2t}\\&Q_t=min(L_t^S,L_t^D)\end{aligned}\tag{4.3.3}$$

Stage one OLS result is shown in Table 4.3.

$\hat{\beta^S}$	$\hat{\beta^D}$	σ_1	σ_2
2.82	-1.04	0.06	0.06
0.77	-5.59		
-8.36	1.69		
-10.60			
-11.11			

Table 4.3: Initial estimators

Using these βs and σs as our starting point of our Newton-Raphson iteration, we obtain the result presented in Table 4.4.

AIC Criterion	-271.45		Schwarz Criterion	-252.14	
R^2	0.81		Adjusted R^2	0.78	
Log-likelihood	-91.93				
β^S	$t-stats$	β^D	$t-stats$	σ_1	$t-stats$
3.00**	(23.35)	-1.28	(-0.78)	0.001**	(552.90)
0.77**	(37.02)	-4.72**	(-7.05)		
-8.17**	(-78.61)	1.73**	(4.68)		
-29.59**	(-84.55)			σ_2	$t-stats$
-11.97**	(-18.57)			0.07**	(33.71)

Table 4.4: Estimation results of Model 3

In the credit supply equation, the parameter of market value of banks is statistically significant at the 5% level and has the correct positive sign. The parameters of the lending rate, cyclical risk premium and default rate are also statistical significant and have the correct negative sign (See discussion in section 4.2).

In the credit demand equation, the parameter of the lending rate is statistical significant and has the correct negative sign and the parameter of the business investment is also statistically significant and has a correct positive sign. Since lending rate represents the price element in the loan contract, the higher lending rate the lower demand. The business investment is a measure of the activity in the corporate sector. When the investment is high, there is a higher probability that firms require bank funding. Hence increase in business investment increases the demand for credit.

Next, we will present the test of the robustness of our model.

4.3.1 Specification concerns

Since R. A Fisher founded modern statistic inference in 1922, there have been numerous developments in statistic methods and techniques. Despite these developments, specification of the statistical model remains as a fundamental problem. In this section, we discuss the model specification problem with multicollinearity and endogeneity concerns.

Multicollinearity

We use variance inflation factor (VIF) to detect whether multicollinearity problem is present. The variance inflation factor can be calculated by

$$VIF = \frac{1}{1 - tolerance}$$

where $tolerance = 1 - R_j^2$ and R_j^2 is the coefficient of determination of an independent variable j on all the other independent variables.

A general rule is that if the tolerance is less than 0.20 or a VIF greater than 5 indicates multicollinearity. We calculate the tolerances and VIFs for our data in Table 4.5 and Table 4.6. As can be seen on the tables, all the VIFs are less than 5, which indicate multicollinearity is not present in our dependent variables.

	MV	r^L	$r^L - r^{LIBOR}$	i^e
tolerance	0.71	0.46	0.92	0.47
VIF	1.41	2.18	1.08	2.14

Table 4.5: Variance Inflation Factor: Supply side

r^L	$Bint$
0.999	0.999
1.00	1.00

Table 4.6: Variance Inflation Factor: Demand side

Endogeneity concerns

Following Roberts and Whited (2012), we classify the sources of endogeneity into three categories: omitted variables, simultaneity, and measurement error.

We discuss the first two categories here. Measurement error arises mainly due to definition of variables and collection. Given that the main objective of this thesis on the theoretical credit market model, we do not discuss the measurement error.

The problem of omitted variables occurs when there are some variables that should be included in the independent variables, but for various reasons they are not included in the empirical specification. This can cause the estimated parameters to be either overestimated or underestimated. This can be easily detected by a RESET test in an ordinary linear regression (OLS). This kind of test can not be easily performed in the model presented in this chapter since we cannot observe the variables L^S and L^D and we are using maximum likelihood estimation technique rather than OLS. To begin with, we include a number of relevant factors based on the justification of their economic relationships and use AIC criterion as well as Schwarz criterion to select the best fitted model. Apart from the empirical specifications presented in this chapter, we included total deposits outstanding, house price index and corporate profitability in our full model, but we encountered the problem of non-convergence. This problem is most likely due to correlation between market value of banks and the total deposits outstanding. Based on AIC criterion and Schwarz criterion, we can conclude that model 3 is the best specification we tested.

Simultaneity bias is a well known problem in estimating demand or supply curves. In our model presented in this chapter, one may argue that the quantities of credit supply and demand have some effect on a number of independent variables. It is difficult to predict whether the simultaneity bias produces overestimation or underestimation of coefficients since the direction of the bias depends on the relative magnitudes of different parameters. In some special cases, this bias can be cancel out. There are advanced statistical techniques such as Difference-in-Differences Estimators and Instrumental Variables to mitigate the simultaneity bias. We do not explore this problem further since our objective is on developing a theoretical framework rather than on testing different econometric methods. This is a potential future research area.

4.3.2 A discussion of the results

Next, we will discuss the results of Model 3. The plot of fitted value of Q and the observed quantity of Q is presented in Figure 1 on page 156. As can be seen the fitted value of Q has the same trend as the actual observed quantity, which indicates a good fit. This also confirms the accuracy of the estimated R^2. The plot the estimated quantity of credit supply and credit demand is presented in Figure 2 on page 157. The estimated quantity of credit demand (blue line) is above the estimated value of credit supply (red line) in most of the time periods, and they are only equal to each other in a small number of cases (9 times over the sample period). This indicates that the UK credit market is in disequilibrium most of the time. In fact, the Matlab program also estimate that the probability is 82% for the quantity of credit demand is greater than the quantity of credit supply. Figure 3 on page 157 plots the difference between the quantity of credit demand and the quantity of credit supply. This difference has a significant jump between period 35 and 38, which correspond to the Q3 2008 to Q2 2009. This observation can be explained by the uncertainty in the financial market during this time period. The Lehman Brothers, which was the fourth largest investment bank in the US, declared bankruptcy on 15 September 2008. This had a contagious effect across the global financial market: freezing credit, historically low interest rates, fire sales and low investors' risk appetite for risk taking. In the late 2008, central banks embarked upon an unpresented quantitative easing programme to stablise the financial market. In a speech given by Miles (2009), who was a member of the MPC in the Bank of England, mentions that the Bank of England had purchased around £165 billion of assets by September 2009 to increase liquidity in the market and encourage banks to lend. It is not surprise that there was indeed a disequilibrium in the credit market during the period of Q3 2008 to Q2 2009. The actual level of disequilibrium, however, might be less than that suggested by our result. Due to linear specification of our model, when the interest rate suddenly falls, there is expected to be a big jump in the estimated demand, which is not necessarily always the case in reality. A stochastic jump model would be a better specification during this period, but such analysis is beyond the scope of this thesis. Nonetheless, the existing of credit market disequilibrium indicated by our result provides a useful insight into the nature of the credit market during this sample period.

The result also indicates the existence of procyclicality in the credit market. Our empirical estimate quantities of credit supply and credit demand (Figure 2 on page 157) vary directly with economic activities and are therefore procyclical in nature. This result is in line with our expectations and with other relevant academic research as discussed in section 2.2. When the economic cycle is in an upturn phase, high production activities, profits, asset values and aggregate lending volume are expected. The rise in bank profits further accelerate lending and investment. The excess credit supply can produce asset bubbles, which will go bust eventually. This starts the down phase and the reverse is the case. Moreover, our finding on fluctuation in credit supply over the sample period also provides an empirical support for some of the theoretical literature in credit cycles (section 3.2.3) and financial stability (section 3.5).

4.4 Concluding remarks

In recent years, there has been a great deal of interest in analysing the disequilibrium in credit markets. This chapter contributes to this emerging literature by adapting maximum likelihood method to estimate the effect of a number of macroeconomic variables on the supply of credit by banks and the demand for credit. The data used in our empirical analysis include the UK macroeconomic data on the market capitalisation of the banks, lending rate, cyclical risk premium, and probability of default. For the supply of credit equation, all our parameters estimated have the correct signs and are statistically significant. In particular, our model identifies the credit supply is positively correlated to the total market value of all the banks, and inversely related to lending rate, cyclical risk premium and expected inflation. For the demand side, our result indicates that the credit demand is positively correlated with business investment and negatively correlated with lending rate. We also find that the quantity of credit demand tends to be greater than the quantity of credit supply with a probability of 82%, which is in line with our expectation. Moreover, our result in this chapter indicates the existence of procyclicality in the credit market, which is in line with the existing literature and lends support to the countercyclical capital policy. This disequilibrium model of the credit market can provide a useful tool for central banks in identifying the cause of credit market disequilibrium. Furthermore, the model we proposed in this chapter can be used to study the credit supply for different real estate or environmental investment projects that require external finance. We can identify different factors that affect credit supply and demand in these particular fields and estimate the magnitude of disequilibrium. This can be very useful for investors to make investment decisions on these projects.

Based on the historical analysis of the UK credit market in this chapter along with the lessons learnt from the recent global financial crisis, it is useful to investigate the impact of the recent changes in regulatory capital requirement on the credit market. In chapter 5, we develop a credit market cobweb model to analyse the dynamics of credit supply given the higher regulatory capital requirement.

Chapter 5

Supply Side: An Optimal Bank Lending Decision Based On Cobweb Model

In chapter 4, we empirically analysed the disequilibrium in the UK credit market. Our results indicate that the probability is 82% for the quantity of credit demand is greater than the quantity of credit supply. Given this evidence of disequilibrium in the credit market, we now focus on developing a dynamic credit market model based on the standard cobweb approach in economics. This chapter is organised as follows. Section 5.1 set out a general introduction. Section 5.2 presents a cobweb model that studies the credit market. Section 5.3 analyses the expected adjustment and stability conditions for the unconstrained credit market. Section 5.4 investigates the multi-periods effect of risk-based capital requirement on credit market. Section 5.5 concludes.

5.1 Introduction

The cobweb process illustrates how the demand and supply adjustment take place in a given market to establish an equilibrium price. In the cobweb process introduced by Kaldor (1934) and Ezekiel (1938)[1] the expectations of the produc-

[1] We discuss the cobweb literature in detail in section 3.4.

ers about prices are assumed to be based on the observations of previous prices, and this could be naive (static) expectation, adaptive expectation and rational expectation. The suppliers are assumed to be operating in a competitive industry, producing a homogeneous good and subject to the same well defined cost function. Once the suppliers choose an optimal level of production, the market clearing price will be established based on the quantities of demand and supply. So the suppliers' expectation on price could turn out to be right or wrong, which will affect their expectation for next period. This starts the iteration mechanism. Under certain stability conditions on the demand and supply curves, the market price will achieve a stable equilibrium. However, if any of these stability conditions is violated, the equilibrium will be unstable. Agricultural market is a typical market that fulfils most of the assumptions made in the classic cobweb model. There is a time lag between harvesting and planting in the agricultural market, and therefore the farmers need to make the decision about how much to produce based on their expectation about the future price. There are a number application of the cobweb models ranging from the agriculture (Harlow (1960), Mackey (1989)), labour market (Freeman (1976), Diebolt and El Murr (2004)), and etc.

To our knowledge, there has been no attempt to apply the cobweb approach to study the dynamics of credit supply and credit demand. As discussed in chapter 3, Commendatore and Currie (2008) consider the financing options for the producers in the cobweb model. But the market they study is still the agricultural market and bank credit only comes into the model as an external factor. Following this study, in this chapter we attempt to model the optimal credit supply by banks given the regulatory capital requirement. In the credit market banks supply credit and they need to go through similar 'production' cycle as the farmers in the agricultural market. The reasons are threefold. First, there is a significant time lag involved when banks need to raise either equity or deposits to fund their operation. As in the case of farmers, banks have to forecast the main factors including the future demand for credit, the lending rate and the probability of default of loans in order to determine both the capital structure and the optimal quantity of credit supply. Banks normally fund their assets by raising deposits and equity[1] [2], which involves significant time and effort. Although banks can increase deposits by raising interest rate, it does take time before they reach the target level of deposits. Moreover, liquidity in the market is affected by central banks policies and individual bank has limited influence. As a result, the amount of deposits banks can raise in the short term is limited. More importantly, raising deposits alone do not overcome the funding problem due to the regulatory capital requirement. There is a minimum capital ratio banks have to maintain. Even if a capital constrained bank can raise enough deposits, it cannot issue new loans without raising new equity. In practice, equity is more difficult to raise than deposits as amply demonstrated during the recent financial crisis. Three out of four major British banks required new equity, but only Barclays managed to raise the required equity through the market. Since both the deposits and equity are costly in terms of time and effort, banks have to determine the optimal quantity of deposits and equity they require at the beginning of the each period. This target are governed by their expectation of the future credit market. As pointed out earlier as in the agricultural market, there is a significant time lag involved in banks' response to the expected demand for credit.

Second, the cost of raising new funds for banks is an increasing function of the amount of equity and deposits as is the case of farmers in the cobweb model. Modigliani and Miller (1958) show how a firm can increase its value and reduce its weighted average cost of capital by introducing debt into its capital structure under a perfect capital market with tax. The authors also suggest that the cost of equity for firm is an increasing function, which is widely accepted in the literature.

Third, there is a time lag between issuing loan and realising profits for bank. Note that we need to take default risk into account when measuring bank profits. The profits of a bank are measured as the interest income minus the losses given default on loans. As a result, we cannot simply take the interest income as the profits. Default is a stochastic event. Borrowers can default simply due to lack of

[1]The major funding source is the deposits for most banks. For those rely heavily on wholesale funding historically either went bust or change their funding source after the 2007 global financial crisis.

[2]On average, those 4 major British banks, namely Barclays, HSBC, Lloyds banking group and RBS, have an equity to total asset ratio of 4% over the time period 2000 to 2012. Source: Bloomberg

luck or choose to default strategically. Although banks can setup early warning systems to detect potentially risky borrowers, it takes time for them to obtain this information. Hence, it takes time for banks to realise their actual profits in practice.

After its operation in the first period, banks will observe the actual market factors like credit demand, lending rate as well as default rate. They will update their expectation each period based on this new information. One example of this is that most of the credit risk models used in banking practice are based on or partially based on historical information. For example, one important step in the default probability estimation of Moody's KMV is to scale the distance to default to actual probabilities of default, which requires a default database. After banks update their expectation, they start to determine the optimal capital structure for the next operation period. Thus, we can apply the cobweb approach to model the multi-period credit supply decision by banks based on their expected and actual market information.

We modify a number of key factors in standard cobweb model. First, we can represent the risk adjusted rate of return (or default adjusted rate of return) as the price. We define the default adjusted rate of return as the interest rate charged to the borrowers net of the default rate. Comparing to the normal production goods, we cannot simply say the interest on the loan is the price since this interest rate also contain the premium for the default option to the borrowers, and therefore, from the banks' point of view the default adjusted rate of return will be a more appropriate measure that is equivalent to the price of a normal production good. The bank needs to sanction the loan application based on the expectation of the default adjusted rate of return. Moreover, the traditional cobweb theory implicit assumes that the producers can borrow or lend as much as they wish at a given price. For banks as the producers, this assumption does not strictly hold since the banks are subject to risk-based capital requirement, which set an upper limit to their total lending. We extend the traditional cobweb model to incorporate the minimum capital requirement.

Our main contribution in this chapter is to provide a theoretical framework for the regulator to forecast the banks' behaviour over a multi-period horizon under different market conditions as well as the impact of higher capital requirement.

The key result in this chapter is the stability conditions we derive in our model. We shows that for credit market to be stable, the capital ratio for all the banks have to stay within a given boundaries. These boundaries will depend on the expected default rate, adjustment speed for the expected lending rate and the marginal cost of deposits. We also provide three different numerical examples to illustrate our results.

All of the mathematical equations and results derived in this chapter are the own work of the author of this thesis. The fixed point definition is based on Border (1989).

5.2 The credit market cobweb model

In this model we assume there are N banks in the market, all are price takers and identical. Hence, we will consider a case of representative bank. We appreciate that if the banks are price takers, the banking sector will have to be competitive. However, empirical evidence suggests that the banking industry is highly competitive in some countries. Claessens and Laeven (2004) uses the methodology proposed in Panzar and Rosse (1987) to study the banking sectors in 50 countries. They find that some countries such as Costa Rica, South Africa and Luxembourg have H-statistics over 0.8, which indicates a highly competitive banking sector. Casu and Girardone (2006) uses balance sheet data for the major EU country to calculate the H-statistics for them. The banking sectors in some countries such as Finland, Belgium and Luxembourg are observed to be close to perfect competition. Hence, we can justify using the assumption of competitive market in the credit market cobweb model developed here.[1]

In reality, the banks have certain degree of flexibility in terms of the interest rate they charge on the loan. However, the default rate is not easily under the control of banks. Hence, the bank is assumed to only have control on its total lending level in our model. The funding of the bank comes from two sources: equity and debt. The equity portion represents the fixed amount of money the bank can lend out, which can be viewed as fixed cost in the production function of

[1]In Chapter 6, we develop an alternative credit supply model for banks that are not price takers.

the standard cobweb model. For simplicity, we only consider deposits as the sole form of debt the bank has, so the deposits portion can be viewed as the variable input in the standard cobweb production function. In this case, the output of a representative bank (total lending) at any given time period t is:

$$q_t = q_f + q_{v,t} \tag{5.2.1}$$

where q_t is the total among of money the bank lends out at time t, $q_f > 0$ is the lending at time period t that would result from using the bank's equity solely, and $q_{v,t} \geq 0$ is the variable output quantity, which is achieved by issuing deposit or in other word using leverage.

We further assume the cost of issuing deposits follows a specific cost function:

$$r_{d,t} = (\frac{q_{v,t}}{\beta})^\alpha \tag{5.2.2}$$

where α and β are constants and greater than one. We can see that when $q_{v,t} = 0$, then $r_{d,t} = 0$, and the first and second derivatives of the cost function is greater than zero, which satisfies the characteristics proposed in Blum (1999).

Our definition of the cost of deposits is equivalent to assume the supply function of deposits is $q_{v,t} = \beta(r_{d,t})^\alpha$. By this definition, we observe that the total deposits the bank can take is an increasing function of the cost, and the marginal cost of raising deposits is increasing since $\alpha > 1$.

To begin with, we consider the case that the bank can choose any level of leverage, and then we apply the capital requirement on the capital structure of the bank.

The main objective of the bank is to maximise the wealth of shareholders, which is equivalent to the maximisation of the expected profit in each period. Given an expected price (default adjusted rate of return) $r^e_{l,t} - \delta^e_t$, we can write the representative bank's expected profit function at time t as:

$$\pi^e_t = r^e_{l,t}(1 - \delta^e_t)q_t - (\frac{q_{v,t}}{\beta})^\alpha q_{v,t} \tag{5.2.3}$$

The expected default in this model is assumed to be exogenous for simplicity. We do not attempt to use an endogenous default model here since it will significantly increase the complexity of the model. Some of the endogenous credit models such as Suarez and Sussman (1997) assume exogenous shock on the production side. This is similar to the model of exogenous shock to borrowers that takes into account the possibility of default. It is questionable that whether this type of approach can give a better estimation of default rather than a model that takes into account the structure of credit as in extended model of Black-Scholes-Merton, Moody KMV and etc. Given that this concern and the fact that our main model focuses on the effect of higher capital requirement, we believe that the assumption of exogenous shock to probability of default, which is estimated from other more sophisticated structural credit risk models, can give us tractable result. As a result, we use the assumption of exogenous default in all the models in this thesis.

We normalise the risk free rate to 0, and therefore we do not consider the time value for the cost of raising deposits.

Following Nerlove (1958b) and Commendatore and Currie (2008), we assume the expected lending rate and default rate are based on adaptive expectations:

$$r^e_{l,t} = r^e_{l,t-1} + \gamma_1(r_{l,t-1} - r^e_{l,t-1}) \tag{5.2.4}$$

$$\delta^e_t = \delta^e_{t-1} + \gamma_2(\delta_{t-1} - \delta^e_{t-1}) \tag{5.2.5}$$

where $0 < \gamma_1, \gamma_2 \leq 1$ are the adjustment speed of the expected to actual lending rate and the adjustment speed of the expected to actual default rate, respectively, with $\gamma = 1$ corresponding to naive expectations.

We further assume that the credit demand (L^D_t) in the market is:

$$L^D_t = b_0 r_{l,t} + b_1 M'_{1,t} + u_{1,t} \tag{5.2.6}$$

where b_0, b_1 are the coefficients, $M_{1,t}$ are the macro-economics variable that affect credit demand (e.g. business investment, expected inflation, capital market efficiency, etc) and $u_{1,t}$ is a residual term that is assumed to be a normal random variable with zero mean and standard deviation σ_1.

Next, we define the market-clearing price, $r_{l,t}$, in the credit market as:

$$r_{l,t} = R_t / L_t \tag{5.2.7}$$

where R_t is the total revenue of the banks and $L_t = min(L_t^D, Nq_t)$. Our result in Chapter 4 shows that the credit demand is greater than credit supply with a probability of 82%. Hence, we can assume that the credit demand is generally greater than credit supply, so L_t can be written as $L_t = Nq_t$. The total revenue of the banks are determined by the macro-economic conditions, say $M_{2,t}$, and is subject to a stochastic shock, say $u_{2,t}$. We assume the macro-economic shock $u_{2,t}$ is a normal random variable with mean zero and standard deviation σ_2. Thus,

$$R_t = a_0 + a_1 M_{2,t} + u_{2,t} \tag{5.2.8}$$

We do not estimate the coefficients of the above parameters a_0, a_1, b_0, b_1, but assume them as given.[1] Although we model L_t^d, R_t in a way that they are linear relationships with the macro-economics variables, it does not make much difference if we model them as stochastic Brownian processes.

5.3 Unconstrained credit market

If the bank can raise any level of deposits as it desires, then it can choose the level where the marginal cost equal the marginal benefit (i.e. expected default adjusted rate of return):

$$\alpha(\frac{q_{v,t}}{\beta})^{\alpha-1} = r_{l,t}^e - \delta_t^e \tag{5.3.1}$$

Substituting (5.3.1) into (5.2.1), we have:

$$q_t = q_f + q_{v,t} = q_f + \beta(\frac{r_{l,t}^e - \delta_t^e}{\alpha})^{\frac{1}{\alpha-1}} \tag{5.3.2}$$

So q_t is the optimal quantity of credit supply for a typical bank in the credit

[1] R_t and its parameters can be estimated by using linear regression. L_t^D and its parameters require sophisticated econometric techniques to estimate since it is difficult to observe credit demand directly. An example of these kind of techniques is presented in chapter 4.

market.

We can substitute (5.2.7) and (5.3.2) into (5.2.4) to get an expression for $r^e_{l,t}$ in terms of $r^e_{l,t-1}$:

$$\begin{aligned} r^e_{l,t} &= f(r^e_{l,t-1}) \\ &= (1-\gamma_1)r^e_{l,t-1} + \gamma_1 r_{l,t-1} \\ &= (1-\gamma_1)r^e_{l,t-1} + \gamma_1 R_{t-1}/L_{t-1} \\ &= (1-\gamma_1)r^e_{l,t-1} + \gamma_1 \frac{a_0 + a_1 M_{2,t-1} + u_{2,t-1}}{N q_{t-1}} \\ &= (1-\gamma_1)r^e_{l,t-1} + \gamma_1 \frac{a_0 + a_1 M_{2,t-1} + u_{2,t-1}}{N(q_f + \beta(\frac{r^e_{l,t-1} - \delta^e_{t-1}}{\alpha})^{\frac{1}{\alpha-1}})} \end{aligned} \tag{5.3.3}$$

Hence, starting with some appropriate initial values about the default adjusted rate of return $r^e_{l,0}$ and δ^e_0, we can calculate all the future expected lending rate $r^e_{l,t}$. Once we know the expected lending rate, we can derive the total lending volume Nq_t in the credit market as well as the expected profits π^e_t of the bank.

The stationary state of this system can be deduced by calculating the fixed point of equation (5.3.3). According to Border (1989), a fixed point can be defined as follows: let f be a function mapping a set K into itself, and a fixed point of f is a point $z \in K$ satisfying $f(z) = z$. From the Brouwer fixed point theorem, we have that if K is a compact[1] and convex subset[2] of Euclidean space, then every continuous function mapping K into itself has a fixed point. In our case here, the function f is mapping a given time period expected lending rate $r^e_{l,t-1}$ to the next period expected lending rate. We know that the lending rate has to belong to $[0, 1]$, which is a compact and convex subset of Euclidean space. Hence, equation (5.3.3) has a fixed point.

Note that we discuss the stability of this dynamical system from a mathematical point of view in this chapter. This approach is different from the literature discussed in section 3.5. Most of these studies focus on certain factors in the credit market that cause instability. For example, the series of papers published

[1] A subset K of a topological space X is compact if for every open cover of K there exists a finite sub-cover of X. See Munkres (1966).

[2] A convex subset is referred to those subsets that for every pair of points within the subset, every point on the straight line segment that joins them is also within the subset.

by Diamond and Rajan explain the instability of the banking system from liquidity prospective; the studies of Allen and Gale mainly focus on the interaction between asset values, borrowers and bank. Our approach to the stability of the financial system is purely from the mathematical definition of a stable dynamical system. In mathematics, a stable dynamical system refers to the case that when there are small perturbations of initial conditions, the trajectories of dynamical systems and solution of the system will not change significantly. Therefore, when we argue the banking system is stable from the prospective of our model in this chapter, we refer to the trajectories of the interest rate on bank loans and bank profits are relatively stable. In other words, these trajectories do not change much under small perturbations in the credit market.

Although our approach to financial stability is different from the existing literature, it has some characteristics that are similar to a stable financial system we mentioned in section 3.5. These are: first, the financial system should be able to efficiently and smoothly transfer resources from savers to investors. Second, financial risks should be assessed and priced reasonably accurately and should also be relatively well managed. Third, the financial system should be in such a condition that it can comfortably absorb financial and real economic surprises and shocks. A mathematical definition of a stable system in our model is equivalent to the third characteristic. If the dynamical system we specify for the credit market is stable, then any 'shock' will not cause significant change in the lending rate and bank profits. This implies that the banking system can absorb the external shock. Moreover, since the trajectory for lending rate is stable in a competitive credit market, we can deduce that the financial risk is priced reasonably accurately and well managed, which is the second characteristic. As a result, our definition of and approach to financial stability in this chapter can capture certain aspects of the credit market.

Next, we derive the stationary conditions of the fixed point.

Since it is a fixed point, the expected lending rate in this period has to equal to next period's expected lending rate, that is $r^e_{l,t} = f(r^e_{l,t-1}) = r^e_{l,t-1}$. This together with equation (5.2.4), we can deduce that the true lending rate $r_{l,t}$ has to be the same as the expected lending rate $r^e_{l,t}$. Therefore, the stationary lending rate, say $\bar{r}$, needs to equal to the expected lending rate $r^e_{l,t}$. Similarly, equations (5.2.7) and

(5.3.2) can be written as the stationary lending rate and lending volume. Hence, we have 3 different conditions for the system to be stationary: (i) $\bar{r} = r^e_{l,t}$, (ii) $\bar{q_t} = q_f + \bar{q}_{v,t} = q_f + \beta(\frac{\bar{r}-\delta^e_t}{\alpha})^{\frac{1}{\alpha-1}}$, (iii) $N\bar{q_t}\bar{r} = R$.

The stationary lending rate also needs to satisfy:

$$
\begin{aligned}
& \bar{q_t} - q_t - \beta(\frac{\bar{r}-\delta^e_t}{\alpha})^{\frac{1}{\alpha-1}} = 0 \\
\Rightarrow\ & q_f(\frac{\bar{q_t}}{q_f} - 1) - \beta(\frac{\bar{r}-\delta^e_t}{\alpha})^{\frac{1}{\alpha-1}} = 0 \\
\Rightarrow\ & q_f(\frac{\bar{q_t}\bar{r}}{q_f} - \bar{r}) - \bar{r}\beta(\frac{\bar{r}-\delta^e_t}{\alpha})^{\frac{1}{\alpha-1}} = 0 \\
\Rightarrow\ & q_f(R/Nq_f - \bar{r}) - \bar{r}\beta(\frac{\bar{r}-\delta^e_t}{\alpha})^{\frac{1}{\alpha-1}} = 0 \\
\Rightarrow\ & q_f(r_{max} - \bar{r}) - \bar{r}\beta(\frac{\bar{r}-\delta^e_t}{\alpha})^{\frac{1}{\alpha-1}} = 0
\end{aligned}
\tag{5.3.4}
$$

r_{max} is the lending rate that corresponds to the case when all the banks simply use equity to finance their loans (i.e. the credit supply quantity is q_f).

The first derivative of equation (5.3.3) evaluated at the fixed point is (note that $R = N\bar{q_t}\bar{r}$):

$$
\begin{aligned}
f'(\bar{r}) &= 1 - \gamma_1 + \frac{\gamma_1 R}{N\bar{q_t}^2(\bar{r}-\delta_t)}\frac{\beta}{\alpha-1}(\frac{\bar{r}-\delta_t}{\alpha})^{\frac{1}{\alpha-1}} \\
&= 1 - \gamma_1 + \frac{\gamma_1\bar{q}_{v,t}\bar{r}}{\bar{q_t}(\alpha-1)(\bar{r}-\delta_t)}
\end{aligned}
\tag{5.3.5}
$$

The fixed point $\bar{r}$ is stable if the absolute value of the first derivative of equation (5.3.3) at $\bar{r}$ is strictly less than 1, and unstable if it is strictly greater than 1. Hence, we have:

$$
\begin{aligned}
& -1 < 1 - \gamma_1 + \frac{\gamma_1\bar{q}_{v,t}\bar{r}}{\bar{q_t}(\alpha-1)(\bar{r}-\delta_t)} < 1 \\
\Leftrightarrow\ & \tfrac{(\gamma_1-2)(\alpha-1)}{\gamma_1}\frac{\bar{r}-\delta_t}{\bar{r}} < \frac{\bar{q}_{v,t}}{\bar{q_t}} < \frac{(\alpha-1)(\bar{r}-\delta_t)}{\bar{r}}
\end{aligned}
\tag{5.3.6}
$$

By definition, α is greater than 1. Lending interest rate $\bar{r}$ is greater than default rate δ in general, so $0 < \frac{\bar{r}-\delta_t}{\bar{r}} < 1$. As a result, whether the two boundaries of the above inequality are greater than zero mainly depends on the value of γ_1.

5.3.1 Estimation of the parameters

In this section, we estimate the values of the key parameters in our credit market cobweb model using a set of data on loan provision and total loan advanced from banks balance sheets over Q1 2000 to Q3 2012.

The actual default rate is estimated from the financial statements of 4 major British banks, namely Barclays, HSBC, Lloyds Banking Group and Royal Bank of Scotland[1]. We use the loan loss provision data divided by the total loan stated on their balance sheets to estimate the actual default rate. We estimate the default rate for each quarter from Q1 2000 to Q3 2012, so there are 51 estimated default rates. These estimated default rates are used as the proxies of actual default rate and we show them in Table 5.1 below. Using this default rate, we estimate the values for parameters γ_1, α and β as follow.

γ_1 is the adjustment speed parameter of actual to expected lending rate. In practice, we expect this number is positive, so we change γ_1 from 0 to 1 and calculate the expected lending rate and the expected profits for banks in 51 time periods. The results are shown in Figure 4 on page 158 and Figure 5 on page 159, respectively.

We can see that the expected lending rate is relatively stable when γ_1 is small (< 0.4). The expected lending rate fluctuates around 5% in this range of γ_1. However, the magnitude of expected lending rates change significantly when $\gamma_1 > 0.4$ and there are some unexpected values of $\gamma_1 > 0.7$, which appeared to be unreasonable. A similar pattern can be observed from the expected profits of banks. Therefore, we set $\gamma_1 = 0.2$ in the numerical analysis in next section. By assumption, $\alpha > 1$, so we change α from 1.1 to 5 to calculate the expected lending rate and the expected profits of banks over the 51 periods. When α is too large (about 3 in this case), left hand side of equation (5.3.1) becomes very close to zero and cannot produce a realistic result. Hence, we only plot the graphs for $\alpha \in [1.1, 2.5]$.

Figure 6 on page 159 shows how the expected lending rate change over 50 periods when α change. We can see that the expected lending rate is relatively stable when $\alpha > 1.5$. The expected profits of banks are shown in Figure 7 on

[1]Source: Bloomberg

T	δ^e	T	δ^e
Q1 2000	1.93	Q3 2006	1.20
Q2 2000	1.94	Q4 2006	1.23
Q3 2000	1.89	Q1 2007	1.17
Q4 2000	1.84	Q2 2007	1.11
Q1 2001	1.84	Q3 2007	1.15
Q2 2001	1.84	Q4 2007	1.19
Q3 2001	1.79	Q1 2008	1.22
Q4 2001	1.74	Q2 2008	1.25
Q1 2002	1.78	Q3 2008	1.48
Q2 2002	1.82	Q4 2008	1.72
Q3 2002	1.84	Q1 2009	1.85
Q4 2002	1.86	Q2 2009	1.98
Q1 2003	1.81	Q3 2009	2.25
Q2 2003	1.77	Q4 2009	2.52
Q3 2003	1.78	Q1 2010	2.57
Q4 2003	1.26	Q2 2010	2.62
Q1 2004	1.71	Q3 2010	2.73
Q2 2004	1.64	Q4 2010	2.85
Q3 2004	1.49	Q1 2011	2.84
Q4 2004	1.34	Q2 2011	2.83
Q1 2005	1.30	Q3 2011	2.87
Q2 2005	1.26	Q4 2011	2.90
Q3 2005	1.24	Q1 2012	2.85
Q4 2005	1.22	Q2 2012	2.80
Q1 2006	1.20	Q3 2012	2.95
Q2 2006	1.17		

Table 5.1: Estimated default rate

page 160. In this case, it is more difficult to estimate the most suitable α based on the expected profits. But, α should not be too close to 2.5 since the expected profits would become unreasonably high. Hence, we set $\alpha = 2$ in the numerical analysis in the next section.

According to our definition of β (equation (5.2.2)), we expect it to be a much larger number compared to the other parameters. Here, we examine the effect of changing β from 100 to 1000.

Figure 8 on page 160 shows how the expected lending rate change over 50 periods as β change. We observe that the expected lending rate is more stable when $\beta \in [400, 700]$. By looking at the expected profits of banks in Figure 9, we expect β to be less than 800. Hence, we set $\beta = 500$ in the numerical analysis section below.

5.3.2 Numerical examples

In this section, we illustrate the credit market cobweb model with some numerical examples.

Example 1

With the estimated real default rates in Table 5.1, we can start with some initial value of the default rate, say δ_0, and use equation (5.2.5) to derive the expected default rate. Once we know the expected default rate, we can use equation (5.3.3) to calculate the expected lending rate over the same time period.

In this numerical example, we normalise the bank's equity to 1 and assume banks will distribute all the profits as dividend, so the bank's equity is a constant. Other constants values specified in this example is shown in Table 5.2 below.

Time period	50		α	2
Number of banks	10		β	500
Macro-economics factor M_2	3		σ_2	1
γ_1	0.2		γ_2	0.2

Table 5.2: Constant parameters in the model

We use the past 12 years of historical average default rate and lending rate[1]

[1]Source: Bloomberg and Datastream

as our initial values. So $\delta_0^e = 1.85\%$ and $r_{l,0}^e = 5\%$. A summary of the simulated result is presented in Table 5.3 on page 93.

We plot the expected lending rate and the difference between two period lending rates in Figure 10 on page 161 and Figure 11 on page 162, respectively. We can see that the expected lending rate mainly fluctuates in the range of $[3.6\%, 5.4\%]$. The changes in lending rate (absolute value) is mainly less than 7×10^{-3} (70 base points) over the whole sample period. If we only look at the first 30 observations, we observe that most of the changes in the lending rates are less than 40 basis points. However, the absolute value changes in the last 10 cycles are significantly different from earlier periods. We believe this is due to the global financial crisis that began in early 2007. Our estimated default rate in Table 5.1 on page 90 shows that the default rate begun to increase in the second half of 2008. These changes in default rate caused the lending rate to change in greater magnitude compared to the first 30 observations. We believe the pattern of the change in the default rate change is the main driver of the change in lending rate. Thus, we can deduce that the stability of the banking system depends on the default rate. This is exactly in line with equation (5.3.6) suggested. Since the default rate is a stochastic variable, which is affected by a number of economic factors, and the banks' forecast of default rate does not have 100% accuracy, it is not a surprise that we do not obtain an equilibrium in this numerical example. Given that banks cannot forecast with 100% accuracy, the banking system is most likely to be unstable in reality.

Figure 12 on page 162 shows the expected profits of banks. Again the major fluctuations occur in the final 10 periods of our sample. This is most likely accounted by the financial crisis as explained above.

We plot the optimal leverage ratio indicated by our model in Figure 13. This ratio is calculated as

$$\text{Leverage ratio} = (\text{Total Liability and Equity} - \text{Equity})/\text{Equity}$$

The leverage ratios are mostly below 8, and since the variable credit supply is funded by deposits, this indicates the optimal capital structure of banks in our sample have moderate leverage. The average optimal leverage ratio across

Time	$\delta\%$	$q_{v,t}$	$r_{L,t}\%$	q_t	Profit
1	1.87	6.54	4.48	7.54	0.33
2	1.88	6.30	4.40	7.30	0.31
3	1.88	5.32	4.01	6.32	0.25
4	1.87	4.83	3.81	5.83	0.22
5	1.87	5.51	4.07	6.51	0.26
6	1.86	6.97	4.65	7.97	0.36
7	1.85	6.08	4.28	7.08	0.30
8	1.83	6.38	4.38	7.38	0.32
9	1.82	6.09	4.25	7.09	0.29
10	1.82	6.87	4.56	7.87	0.35
11	1.82	5.79	4.14	6.79	0.27
12	1.83	5.93	4.20	6.93	0.29
13	1.83	6.40	4.39	7.40	0.32
14	1.81	7.01	4.62	8.01	0.36
15	1.81	7.55	4.83	8.55	0.40
⋮	⋮	⋮	⋮	⋮	⋮
36	1.36	6.97	4.15	7.97	0.32
37	1.46	7.06	4.28	8.06	0.33
38	1.56	6.36	4.11	7.36	0.29
39	1.70	6.15	4.16	7.15	0.29
40	1.86	4.94	3.84	5.94	0.22
41	2.01	4.23	3.70	5.23	0.19
42	2.13	5.04	4.15	6.04	0.24
43	2.22	5.75	4.55	6.75	0.30
44	2.37	7.31	5.29	8.31	0.43
45	2.46	5.83	4.80	6.83	0.32
46	2.54	5.58	4.77	6.58	0.31
47	2.60	5.25	4.70	6.25	0.29
48	2.66	3.60	4.10	4.60	0.18
49	2.70	4.24	4.40	5.24	0.22
50	2.72	3.14	3.98	4.14	0.16

Table 5.3: example 1

50 periods is around 6. We calculate the average leverage ratios for four major British banks, namely Barclays, HSBC, Lloyds Banking Group and Royal Bank of Scotland[1], based on their balance sheets numbers from 2000 to 2012. The result is summarised in Table 5.4.

Barclays	HSBC	Lloyds	RBS
29	14	25	27

Table 5.4: Average leverage ratio

We appreciate these banks have business models that differ from the traditional commercial banking model. This may cause their leverage ratios to be higher than the one suggested by our model. However, compared to the 6 times of leverage suggested by our model, such a significant difference may necessitate regulator to take appropriate actions.

Example 2

In this example, we keep the default expectation constant and assume it to be 1.85%, the estimated average default rate estimated in in Table 5.1 on page 90. In this case, we do not need to rely on the real default rate for our iteration. We can simulate more than 50 periods as we did earlier.

Next we illustrate some cases with stable fixed points. To determine whether a fixed point exists or not, we calculate the difference in the expected lending rate, say $err(t)$, between two consecutive periods. Our Matlab programme terminates at the point when $err(t) < threshold$. We set the threshold to 10^{-5} initially. The results are shown in Figure 14 on page 163 and Figure 15 on page 164. We can see that the change in expected lending rate converges to zero after 113 periods given the threshold is 10^{-5}. If we increase the threshold to 10^{-8}, this convergence requires 35364 periods. (See Figure 16 on page 164 and Figure 17 on page 165)

[1]Source: Bloomberg

5.4 Credit market cobweb model with regulatory capital requirement

Generally, banks are subject to capital constraints, so they may not be able to increase their deposits to the optimal level suggested by our model. In this section, we introduce capital requirement into our model.

The capital ratio (say φ) for a typical bank can be calculated as $\frac{q_f}{q_t}$, where q_f is the amount of lending funded from the bank's equity and q_t is the total lending of this bank. For simplicity, we assume the risk weighting for all these loans is one, so the risk weighted asset of the bank is equal to its total lending. Under the Basel regulatory framework, banks are required to have risk-based capital ratios at least at a certain threshold, say d. Hence, the capital requirement in our model is equivalent to

$$\varphi = \frac{q_f}{q_t} = \frac{q_f}{q_f + q_{v,t}} \geq d \tag{5.4.1}$$

Alternatively, we can rewrite the above inequality as

$$\frac{q_{v,t}}{q_f} \leq \frac{1-d}{d} \tag{5.4.2}$$

Hence, the stable condition (5.3.6) is equivalent to

$$\begin{aligned} &\frac{(\gamma_1 - 2)(\alpha - 1)}{\gamma_1}\frac{\bar{r} - \delta_t}{\bar{r}} < 1 - d < \frac{(\alpha - 1)(\bar{r} - \delta_t)}{\bar{r}} \\ \Leftrightarrow \quad & 1 - \frac{(\alpha - 1)(\bar{r} - \delta_t)}{\bar{r}} < d < 1 - \frac{(\gamma_1 - 2)(\alpha - 1)}{\gamma_1}\frac{\bar{r} - \delta_t}{\bar{r}} \end{aligned} \tag{5.4.3}$$

This implies that the capital ratio for banks needs to be within certain boundaries in order to have a stable credit market. This supports the policy of capital requirement. The regulator should set the minimum capital ratio above the lower bound according to the estimated lending rate and the default rate. We also observe that these boundaries are subject to the change in default rate. As a result, we expect these stability conditions to change over time. When the economy is in a recession and actual default rate is high, we can see from equation (5.4.3) that both of the lower bound and upper bound for d become smaller, which implies the credit market can be stable even if banks lower their capital ratios. However, if regulator raises the capital requirement in this scenario, there is a risk that d exceeds the upper bound and can make the credit market unstable. On the other hand, if there is strong economic growth and the default rate is low, the boundaries become bigger. This suggests that the regulator should increase the capital requirement to prevent excessive supply of credit in the market. In summary, it is necessary for the regulator to have a flexible capital policy to incorporate this feature of the credit market cobweb model.

This result is in line with the existing literature on the procyclical nature of the banking sector as we discussed in section 2.2. Credit supply expands at the growth phase of the economy due to low default rate, which causes the riskiness of the bank to increase. Thanks to the valuation of assets and low default rate (low risk) in this period, the risk-weighted capital ratios of banks tend to be high. This allows bank to expand its asset side of the balance sheet to generate more profits. The expansion of credit supply tends to form certain type of bubbles. The bubbles inevitably go bust. Borrowers start to default causes banks suffer losses and bank begin to tighten credit supply, which further constrains the business activities. From the regulatory capital prospective, high default in this period will cause certain assets in the balance sheet of the bank to be downgraded, which will increase the risk weighted assets. This together with low bank equity value can significantly lower the risk weighted ratio for the bank and causes capital constraint. This may cause the fire sales problem and further exacerbate the down market as we mentioned in section 2.2. As a result, we believe a countercyclical capital policy that raises capital requirement in the growth phase of the economy and reduce the capital requirement in the bad times, can tackle the procyclicality of credit supply and bank capital level better.

5.4.1 Optimal capital ratio of banks

In this section, we use the parameters estimated earlier to simulate the optimal capital ratio of banks under the capital requirement.

Example 3

In this example, the parameters are exactly the same as those used in Table 5.2 on page 91. The only difference here is that we include a minimum capital ratio in the calculation. For each time period, we calculate the quantity of unconditional optimal credit supply of a typical bank, and then the capital ratio for this bank by calculating $\varphi = \frac{q_f}{q_t}$. We can compare this φ with the pre-set minimum regulatory capital requirement d to determine the conditional optimal credit supply q_t. If $\varphi > d$, then nothing changes and we use the q_t calculated earlier to carry out the iteration. On the other hand, if $\varphi < d$, then we set $f/q_t = d$ and work out a new q_t to continue the iterations.

Figure 18 on page 166 and Figure 19 on page 167 shows how the expected lending rate and capital ratio evolve when the minimum capital ratio is 10%. We can see that this minimum capital requirement does not affect the bank's optimal capital ratio at all. For the minimum capital requirement at 13%, the results are shown in Figure 20 on page 167 and Figure 21 on page 168. We can see that when the optimal capital ratio is set at 13% for a number of time periods, and most of them are between time period number 20 and 40. This indicates that bank's activities are restricted in a few number of cases. For the capital ratio at 15%, the results are shown in Figure 22 on page 168 and Figure 23 on page 169. We can see that the bank's optimal capital ratio equal to 15% in most of the cases. This suggests that the minimum capital requirement is too high, which restricts bank's normal business activities.

Next, we examine the stability boundaries derived earlier by using $c = 13\%$. Figure 24 on page 169 shows the case when $\gamma_1 = 0.2$. We can see that these two boundaries do not have any effect on the optimal capital ratio. If we increase γ_1 to 0.7 (i.e. the largest γ_1 that we derived earlier), the result changes to Figure 25 on page 170. We observe that the lower bound exceeds the optimal capital ratio in a few cases, which suggests the banking system was unstable during this period. We believe this is due to the unexpected shock in the credit market. In our program, this shock is generated by a normal random number generator. This suggests the need for a countercyclical capital policy. With a countercyclical policy in place, the minimum capital requirement will adjust according to the lending rate and the expected default rate, which helps to stablise the credit market.

5.5 Concluding remarks

In this chapter, our main contribution is the formulation of a credit market cobweb model to study the dynamics of the credit supply and demand. We derive the dynamic equations for the expected lending rate, banks' profit as well as the stability conditions for the market under two different scenarios: unconstrained lending and capital constrained credit supply. We also carry out numerical analysis to study the dynamic properties of the model, which highlights the stability conditions of the banking system, by allowing the default rate and regulatory capital requirement to vary. This credit market cobweb model can be a useful tool in identifying the long run credit supply in certain markets such as the housing market, where there are lags of adjustment for the lender to realise borrowers default and losses. Our model provides a theoretical framework for the future empirical research in the mortgage supply to the housing market. While we can use the model in this chapter to study the long run impact of raising capital requirement on the housing market specifically, our objective of this thesis is focus on the credit market more generally.

Our results in this chapter also lend support to the risk-based capital requirement policy: banks need to hold a specified amount of regulatory capital to ensure the stability of the banking industry. More specifically, our results suggest the necessitate of countercyclical regulatory capital requirement. This is essentially due to the nature of credit market where the default rate on loan is a stochastic process, which is difficult to predict with high accuracy. The credit market stability conditions vary depending on the difference between the expected and the actual default rate. A countercyclical capital policy can accommodate the forecasting errors over economic cycles. The countercyclical capital policy also affects the banks portfolio allocation decision between risky assets and safe asset. To this end, in chapter 6 we turn to the analysis of banks portfolio adjustment in response to higher regulatory capital requirement.

Chapter 6

Supply Side: Optimal Bank Portfolio Allocation and Basel III

The credit market cobweb model in chapter 5 is based on a crucial assumption that the credit market is competitive, we relax this assumption in this chapter and develop a structural model of an optimal portfolio allocation decision between the safe asset and the risky assets for a representative bank. Our model builds on the dynamic portfolio allocation model of Furfine (2001). We incorporate the expected probability of default and specify a number of different cost functions to make the model more applicable to reflect the asset side positions of bank balance sheet. We establish the optimality conditions for a representative bank to select its asset portfolio. To illustrate these optimality conditions explicitly we also carry out a regression analysis to investigate the dependence of the probability of default and the risky loan size by using a set of panel data on four major British banks over the time period from 1991 to 2010. The implications of the model are illustrated with some numerical analysis. The optimal portfolio of bank is calculated under different regulatory requirements. The results show that the optimal portfolio allocation decision of a representative bank varies depending on the changes in risk weighted capital requirement and leverage, which provide some useful insights into the deleveraging decision and adjustments of portfolio weights from risky to safe assets for the bank.

The rest of this chapter is organised as follows. Section 6.1 sets out a general introduction of optimal bank portfolio allocation. Section 6.2 develops a multi-period model that explicitly captures the effect of the probability of default on the optimal portfolio allocation decision of bank. Section 6.3 derive the optimal conditions of the model. In Section 6.4, the implications of the model are illustrated with some numerical analysis. Section 6.5 concludes.

6.1 Introduction

The Bank of England Quarterly Bulletin (January 2012) reported that:

The annual rate of growth in the stock of lending to UK businesses was negative in the three months to November (2011). The stock of lending to small and medium-sized enterprises continued to contract. The annual rate of growth in the stock of secured lending to households was little changed. Mortgage approvals by UK-resident mortgage lenders for house purchase were broadly unchanged in the three months to November. Total net consumer credit flows were positive over this period, though remained subdued.

This suggests that the bank financing available to the UK borrowers continue to shrink despite the long standing quantitative easing (QE) and historical low interest rate policy of 0.5%. The QE is an unpresidented monetary policy that has been targeted to stablise the banking system through liquidity support. In the United Kingdom, the principal strategy of QE involves asset purchases from banks. Joyce, Tong and Woods (2011) in their Bank of England publication outline QE in the UK as follows:

The Bank of England's asset purchases were overwhelmingly focused on purchasing a large amount of UK government bonds. Between March 2009 and January 2010, the Bank purchased 200 billion pounds of assets, mostly medium and long-dated gilts. These asset purchases represented nearly 30% *of the amount of outstanding gilts held by the private sector at the time and around* 14% *of annual nominal GDP. Combined with earlier liquidity support measures to the banking sector, these purchases increased the size of the bank's balance sheet relative to GDP threefold compared to its pre-crisis level. The Government also authorised the Bank to pursue a number of activities targeted to improve the functioning of specific financial markets. This included purchases of high-quality commercial* *paper and corporate bonds. The scale of these operations was much less than for the gilt purchases, consistent with the Bank acting as a backstop purchaser/seller with the intention of improving market functioning.*

The volume of bank lending is an important reflection of the QE liquidity support in the UK. Without this liquidity support, the aggregate lending volume would have obviously collapsed. The QE appears to have been successful in preventing systematic collapse in lending volume, however, according to the Bank of England January 2012 report the aggregate volume of lending in the UK remains well below the desired level.

One of the reasons for the low aggregate lending volume in the UK is the implementation of Basel III higher capital requirement. Basel III sets out a set of measures of capital requirement, leverage and liquidity ratios that are aimed to strengthen the stability of the global banking system. The capital requirement standard and the new capital buffer in the Basel III requires banks to hold the target level of capital as well as higher quality of capital compared to Basel II. The new leverage ratio introduces a non-risk based measure to supplement the risk-based minimum capital requirement. The new liquidity ratio ensures that an adequate funding is maintained in the event of crisis. All of these requirements impose substantial cost to banks in the form of higher cost of equity capital. According to a recent European central bank paper Slovik and Cournede (2011), the cost of Basel III implementation is estimated in the range of -0.05 to -0.15 percentage point per annum of reduction in GDP growth rate. Moreover, to meet the 4.5% for the common equity ratio target, 6% for the Tier 1 capital ratio target, which will become effective in the scheduled date in 2015, the lending spreads charged by banks is estimated to increase around 15 basis points on average. The 7% for the common equity ratio target and 8.5% the Tier 1 capital ratio target, which will become effective in 2019, is expected to increase the lending spreads charged by banks by about 50 basis points. Angelini and et al. (2011) suggest that each percentage point increase in the capital ratio causes a median 0.09% decline in the level of steady state output, relative to the baseline. Bowman et al. (2011), drawing on evidence from Japan, argue that the QE will not have a significant impact on the volume of lending by banks.

In view of the above implication of the QE and Basel III regulatory changes, we intend to assess the impact of these measures on the composition of the assets holding of a representative bank. There are a number of empirical studies [Bernanke et al. (1991), Hall (1993), Hancock and Wilcox (1994), and Hancock et al. (1995)] that have analysed the assets holding of a bank. As we discuss in section 3.1, these studies typically use regression analysis to estimate the growth rate of bank lending with respect to various control variables such as bank capital, capital shock and other macro economics indicators. These empirical studies suffer from a drawback that they lack a structural model of bank optimal asset allocation decisions. This limitation makes it difficult to obtain robust result of the estimate of the impact of the changing capital regulation. This provides a motivation for us to develop a structural model of the optimal asset allocation of a bank. We investigate the following three important aspects: First, what is the optimal composition of assets in the portfolio of a bank? Second, how does this optimal composition of assets change in response to the changes in regulatory requirement? Third, how does this optimal composition of assets change in response to the QE?

In this chapter, we develop a structural model of an optimal portfolio allocation decision of a representative bank between the safe asset and the risky assets. Our model builds on the dynamic portfolio allocation model of Furfine (2001). Furfine (2001) demonstrates that a bank has different forms of cost functions under different scenarios. This is because a given increase in regulatory capital requirement has a smaller effect on a well capitalised bank than that on a poor capitalised bank. He proposes an adjustment cost function for bank that represents the relationship between gross growth rate of bank lending and the demand for loan. This study does not, however, explicitly account for the expected probability of default, which is an important component of the risk weighted capital requirement. It is essential to include the probability of default in the study of the optimal composition of assets in the portfolio of a bank. Moreover, Furfine (2001) assumes a downward sloping and convex cost function, which implies the cost for a bank decreases continuously with capital. If this was the case in practice, we would expect to observe 100% equity finance in bank capital structure that correspond to the minimum of the cost of equity to the bank. Modigliani and Miller (1958) and Modigliani and Miller (1963) suggest that the weighted average cost of capital of a firm is minimised at 100% debt in the presence of tax. The assumption in Furfine (2001) is indirect contradict with the well established result in the corporate capital structure theory. In addition, with the cost of bankruptcy (or the cost when a bank's capital approaches the regulatory requirement), the static tradeoff theory suggests that the weighted average cost of the capital is minimised at some given amount of leverage. In this chapter, we therefore follow the traditional corporate finance literature and specify the cost function of bank rather than that proposed in Furfine (2001). Our specification of the model also explicitly accounts for the expected probability of default of loans. All of the results and mathematical equations in the proof of section 6.3 and section 6.4 are derived by the author of this thesis.

6.2 Bank assets allocation model

The model we develop in this session is a structural model of an optimal portfolio allocation decision between the safe asset and the risky assets for a representative bank. We incorporate the expected probability of default and specify a number of cost functions to make the model to reflect the asset side positions of bank balance sheet.

6.2.1 Balance sheet

For a typical traditional commercial bank, the composition of the asset side of its balance sheet includes treasury securities, mortgage, credit card, line of credit and commercial loan, and the liability side includes deposit, long term debt and equity. The bank has the flexibility to choose its assets and capital structure based on the risk adjusted rate of return. For simplicity, we consider a case where the bank can choose between two assets: the safe (treasury security) and risky asset (loan), which have different credit risks. We use A^R and A^S to denote risky loan and treasury security, respectively. Assuming no default on the risky asset, these two assets generate the rate of returns are r^R and r^S, respectively. On the liability side, we combine the deposit and long term debt into a single debt category, which is denoted by D. The bank pays out a rate r^D on its debt.

We assume that rebalancing of its debt portfolio is costless. The bank can reduce the amount of D it holds by lowering the deposit rate it offers, and conversely it can raise it D by raising the deposit rate. We further assume that the adjustment process is completed within one period. The capital held by the bank is denoted by K. From this setup, we specify the balance sheet constraint of the bank at time t as:

$$A_t^R + A_t^S = D_t + K_{t-1} \tag{6.2.1}$$

Note that the capital has a lag of one period. This is because the bank has to make its portfolio allocation decision at the beginning of period t, and therefore the bank funds its assets by the capital available at time t. We note that the risky loan can default, and the bank can use its retained earning to repurchase its own shares or sell additional shares during the time period t, so the bank's capital K_t can either be greater or smaller than K_{t-1}. This is one of the difference between our model and that proposed in Furfine (2001). In Furfine (2001), however, there is no default in the risky loan that implies both the risky and the safe asset are identical.

6.2.2 Regulatory capital requirement

In line with Basel III, we assume there is a target leverage ratio as well as a risk weighted capital requirement for the bank. The risk weighted capital requirement in Basel III is similar to that in Basel II, but the risk coverage of the capital framework is stronger. The introduction of the leverage ratio puts a floor under the build-up of excessive leverage in the banking system. It also provides an additional safeguard against operational risk and measurement error. The measure of leverage ratio based on gross exposure is simpler than other risk based measures. Basel III also introduces a liquidity measure refers to the Net Stable Funding Ratio, which is calculated by dividing the proportion of long-term assets by the long term and stable funding. Since both customer deposit and long term debt can be classified as the long term and stable funding, the balance sheet constraint in equation 6.2.1 will automatically fit this liquidity measure. Therefore, we do not need to consider the new liquidity constraint here.

The leverage requirement at the beginning of period t is defined as:

$$\frac{K_{t-1}}{A_t^R + A_t^S} \geq c_t \tag{6.2.2}$$

where c_t is the leverage requirement at time t.

The risk weighted capital requirement at the beginning of period t is defined as:

$$\frac{K_{t-1}}{w_R A_t^R + w_S A_t^S} \geq d_t \tag{6.2.3}$$

where d_t is the risk weighted capital requirement at time t, w_R and w_S are the risk weighting for risky loan and treasury security, respectively. The regulator set the weightings w_R and w_S for risky and safe assets, respectively, and banks know the risk weightings. In the former Basel I the assets were classified and grouped in five categories according to credit risk, carrying risk weights of zero (e.g. home country sovereign debt), ten, twenty, fifty, and up to one hundred percent (e.g. corporate debt without collateral). The total risk weighted asset is the sum of all the asset classes. The regulator also set the value c_t and d_t, which are the minimum leverage ratio and risk weighted capital ratio. In Basel III the proposed Tier 1 risk weighted capital ratio is 6%, and a supplemental 3% non-risk based leverage ratio which serves as a backstop to the risk weighted capital measure. The 6% Tier 1 risk weighted capital ratio will be enforce in January 2015, and the leverage measure will be running parallel between 2013-2017, and then migrate to Pillar 1 from 2018.

Here, we investigate how the change in leverage requirement and risk weighted capital requirement affect the asset allocation decision of the bank.

For simplification, we further define that the bank's leverage ratio and risk weighted capital ratio at time t, respectively, as

$$k_t^L = \frac{K_{t-1}}{A_t^R + A_t^S}$$

and

$$k_t^R = \frac{K_{t-1}}{w_R A_t^R + w_S A_t^S}$$

Again, we specify the capital K_{t-1} in the numerator, which indicates that the banks can choose the amount of risky asset and safe asset depending on the amount of capital in time $t-1$.

6.2.3 Three cost functions

Apart from the explicit cost of debt r_D, the bank incurs additional cost that vary with the demand for loan. We define the adjustment costs function as

$$J_t = (w_R A_t^R + w_S A_t^S) j(l_t - \rho_t) \tag{6.2.4}$$

where

$$l_t = \frac{w_R A_t^R + w_S A_t^S}{w_R A_{t-1}^R + w_S A_{t-1}^S}$$

so l_t is the gross growth rate of risk weighted assets at time t. ρ_t is a measure of the demand for loan at time t, and the adjustment cost function j is convex and depends on the difference between growth rate of risk weighted assets and the demand for loan $l_t - \rho_t$.

This is the same cost function as in Furfine (2001), which specifies that the bank will incur cost if it adjusts its loan portfolio in a way that is different from loan demand. If the loan demand increases but the bank tries to shrink its loan portfolio, then it will incur a cost due to the adverse effect on its business relationship. Conversely, if the bank expands its loan portfolio when loan demand is weak it also may face costs because it has to lower its credit standards to accept more applicants.

Moreover, there are implicit costs for the bank when either its leverage ratio k_t^L or risk weighted capital ratio k_t^R approach the minimum requirement. The regulator may impose some restrictions on a poorly capitalised bank. In an extreme scenario recapitalisation can be expensive as was recently the cases for RBS and Lloyds incurred restructuring costs when they needed to be partly nationalised. In addition, there can be restriction imposed on certain activities and damage to business reputation. The extent of these costs is evident in the share price performance of the well capitalised HSBC bank compared to the less well capitalised RBS and Lloyds in the post 2007 crisis. Evidently, failing to meet the capital requirements imposes real costs on the bank shareholders. The closer a bank is to the regulatory minimum, the more likely these costs are to be of significance.

Holding too much capital above the minimum requirement also involves a cost to the bank. This is because the extra capital held may not generate the return to shareholders. Given two banks A and B with identical assets portfolio and have the same amount of risk weighted assets. We expect that both bank A and bank B will generate the same amount of profit over a given period. But if A holds more equity, it will have a lower return on equity (ROE) than B. Hence, holding too high capital is also undesirable for bank shareholders. Furfine (2001) does not take the return on equity into consideration. In this we expicitly consider the impact of capital requirement on the return on equity and use different specification of cost function to capture the likely effect of excessive holding of capital.

Next, we specify two cost functions G_t and H_t for the risk-based capital ratio and leverage ratio as follow:

$$G_t = (w_R A_t^R + w_S A_t^S)\gamma g(k_t^R - d_t) \tag{6.2.5}$$

and

$$H_t = (A_t^R + A_t^S)\gamma h(k_t^L - c_t) \tag{6.2.6}$$

where γ is a multiplicative factor that captures the regulatory enforcement of capital requirements, g and h are two convex functions that measure the per unit costs of approaching the two regulatory requirements. As we discuss earlier, there are two distinct costs associated with holding capital. One is the cost of regulatory restriction on the activities of the bank, and the other is the cost of holding excessive capital. We expect the cost of holding capital to initially decline with increases in capital up to the point where the optimal capital structure is achieved, but beyond that point the cost increases with holding additional capital. See Figure 26 on page 171 for an example of the cost function for $g(k_t^R - d_t)$. In Figure 26, point A represents the regulatory minimum capital requirement and point B is the optimal equity capital ratio for a bank. When the capital ratio for a bank is close to the regulatory minimum, the cost issuing equity is higher. It can be seen in Figure 26 that our cost function g decreases as k_t^R in this part of the curve. Once the capital ratio of the bank is greater than the optimal ratio, the g becomes an increasing function of k_t^R.

Our specification of the cost function is in line with the static trade-off theory of optimal capital structure where too high debt results in high bankruptcy costs. In the case of the bank's leverage ratio and risk weighted capital ratio approach the regulatory limits, the cost of bankruptcy outweigh the benefit of using leverage. Conversely, as bank builds higher cushion of capital relative to the regulatory minimum, its cost function will be minimised at a certain point. If the regulator increases the Tier 1 capital requirement from 4% to 6% as was the case in Basel III, we expect the impact of this increase will be smaller for a bank with a Tier 1 capital ratio of 8% than a bank with a Tier 1 capital ratio 6%.

In line with Furfine (2001), we multiply the per unit risk-based capital cost with total risk weighted assets to account for the fact that only the risk adjusted portion of lending is subject to this cost in equation 6.2.5. The same applies to the per-unit leverage cost.

The justification for using a multiplicative factor here is to allow for the fact that the local regulators have discretion over the enforcement of tighter or looser the regulatory requirement level. The way we model the per unit costs of approaching the two requirements capture the difference in the impact of tightening requirement on well capitalised and low leverage banks and poor capitalised and high leverage banks.

6.2.4 Market setting

We assume the lending interest rate r_t^R is greater than the risk free rate r_t^S at all time although the spread between them may be changed.

6.2.5 The expected probability of default

As we discussed earlier, default is absent from the model proposed in Furfine (2001). There is no point in studying credit market without considering loan default. In this section, we will discuss how an expected probability of default can be fitted in our model. This is one of our key contributions in this chapter.

The bank makes its decisions to lend on the basis of its expected probability of default. Let δ_t be the expected probability of default at time t. For simplification, we will assume this default rate only depend on the size of the loan portfolio A_t^R and the macroeconomic factor M_t:

$$\delta = \delta(A_t^R, M_t) \tag{6.2.7}$$

The macroeconomic factor M_t is specified as a lag dependent process and the size of the loan portfolio A_t^R:

$$M_t = M_t(M_{t-1}, A_t^R) \tag{6.2.8}$$

Although more complex specification of structural and dynamic default process may enrich the analysis but given that the main objective here is to investigate the bank's portfolio allocation decision we just focus on this simple default model.

6.2.6 The evolution of bank capital

We specify the evolution of bank capital as a function of the expected probability of default, and the decision to retain earning and/or repurchase (or sell) shares as follow:

$$K_t = K_{t-1} + r_t^R(1 - \delta_t)A_t^R + r_t^S A_t^S - r_t^D D_t + E_t \tag{6.2.9}$$

where E_t is the amount of net equity issuing. Negative E_t simply represents that the bank repurchase share or pays dividend during time t. Positive E_t represents the bank issue of new shares during this period t.

We further specify that:

$$e_t = \frac{E_t}{w_R A_t^R + w_S A_t^S}$$

so e_t is the net equity issued per unit of risk weighted asset, and there is a cost function $\lambda(e_t)$ that represents the cost of adjusting equity.

6.2.7 The objective function of bank

From the above set up, we can assume that the objective of the bank is to maximise the present value of its future cash flow less all the costs by choosing the optimal level of risky loan A_t^R, treasury security A_t^S and net equity issuing E_t:

$$max \quad \mathbb{E}\sum_{t=1}^{\infty}\beta^t[r_t^R(1-\delta_t)A_t^R + r_t^S A_t^S - r_t^D D_t + E_t\lambda(e_t) - G_t - H_t - J_t] \tag{6.2.10}$$

where $\mathbb{E}$ represents expectation, and the β is a discounted factor.

6.3 Optimum conditions

Lemma 6.3.1. *Equations (6.3.1), (6.3.2) and (6.3.3) characterise the optimal portfolio allocation decision of a bank at a given time t.*

$$\begin{aligned} &X - r_t^D - w_R\gamma(g - k_t^R g') - \gamma(h - k_t^L h') + w_R\lambda'(e_t)e_t^2 - w_R(j + l_t j') \\ &= -\beta\mathbb{E}[(r_{t+1}^D - \gamma g'(k_{t+1}^R) - \gamma h'(k_{t+1}^L))(X - r_t^D) - w_R j' l_{t+1}^2] \end{aligned} \tag{6.3.1}$$

$$\begin{aligned} &(r_t^S - r_t^D) - w_S\gamma(g - k_t^R g') - \gamma(h - k_t^L h') + w_S\lambda'(e_t)e_t^2 - w_S(j + l_t j') \\ &= -\beta\mathbb{E}[(r_t^S - r_t^D)(r_{t+1}^D - \gamma g'(k_{t+1}^R) - \gamma h'(k_{t+1}^L)) - w_S j' l_{t+1}^2] \end{aligned} \tag{6.3.2}$$

$$\lambda(e_t) + e_t\lambda'(e_t) + \beta\mathbb{E}(r_{t+1}^D - \gamma g'(k_{t+1}^R) - \gamma h'(k_{t+1}^L)) = 0 \tag{6.3.3}$$

Proof 6.3.1. *In order to obtain the first order condition, we differentiate (6.2.10) with respect to A_t^R, A_t^S and E_t.*

From the balance sheet constraint, we have

$$D_t = A_t^R + A_t^S - K_{t-1}$$

and differentiating with respect to A_t^R gives

$$\frac{\partial D_t}{\partial A_t^R} = 1 - \frac{\partial K_{t-1}}{\partial A_t^R} = 1$$

Next, differentiating (6.2.10) gives:

$$\frac{\partial (E_t \lambda(e_t))}{\partial A_t^R} = E_t \frac{\partial \lambda(e_t)}{\partial e_t} \frac{\partial e_t}{\partial A_t^R} = E_t \lambda'(e_t) \frac{-w_R E_t}{(w_R A_t^R + w_S A_t^S)^2} = -w_R \lambda'(e_t) e_t^2 \tag{6.3.4a}$$

$$\begin{aligned}
\frac{\partial G_t}{\partial A_t^R} &= w_R \gamma g + (w_R A_t^R + w_S A_t^S)\gamma \frac{\partial g}{\partial k_t^R} \frac{\partial k_t^R}{\partial A_t^R} \\
&= w_R \gamma g + (w_R A_t^R + w_S A_t^S)\gamma g' \frac{-w_R K_{t-1}}{(w_R A_t^R + w_S A_t^S)^2} \\
&= w_R \gamma g - w_R \gamma k_t^R g' \qquad (6.3.4b)
\end{aligned}$$

$$\frac{\partial H_t}{\partial A_t^R} = \gamma h + (A_t^R + A_t^S)\gamma h' \frac{-K_{t-1}}{(A_t^R + A_t^S)^2} = \gamma h - \gamma h' k_t^L \tag{6.3.4c}$$

$$\frac{\partial J_t}{\partial A_t^R} = w_R j + (w_R A_t^R + w_S A_t^S) j' \frac{\partial l_t}{\partial A_t^R} = w_R j + w_R l_t j' \tag{6.3.4d}$$

$$\frac{\partial r_t^R (1-\delta_t) A_t^R}{\partial A_t^R} = r_t^R \left(1 - \frac{\partial \delta_t}{\partial A_t^R} A_t^R - \delta_t\right) \tag{6.3.4e}$$

In order to simplify the expression, we let $X = r_t^R(1 - \frac{\partial \delta_t}{\partial A_t^R} A_t^R - \delta_t)$.

Remember that there is a K_{t-1} in equation (6.3.4), which is not related to A_t^R. But in period $t+1$, there will be a term K_t, which is directly affected by the choice of A_t^R as can be seen from equation (6.2.9). Hence, we need to consider $\frac{\partial K_t}{\partial A_t^R}$ in order to evaluate $\frac{\partial G_{t+1}}{\partial A_t^R}$ and $\frac{\partial H_{t+1}}{\partial A_t^R}$. From equation (6.2.9), we have:

$$\frac{\partial K_t}{\partial A_t^R} = \frac{\partial r_t^R (1-\delta_t) A_t^R}{\partial A_t^R} - r_t^D = X - r_t^D \tag{6.3.5}$$

We know that $\frac{\partial D_{t+1}}{\partial A_t^R} = -\frac{\partial K_t}{\partial A_t^R} = -(X - r_t^D)$

Hence, we have:

$$\frac{\partial G_{t+1}}{\partial A_t^R} = (w_R A_t^R + w_S A_t^S)\gamma \frac{\partial g(k_{t+1}^R)}{\partial k_{t+1}^R}\frac{\partial k_{t+1}^R}{\partial A_t^R} = \gamma \frac{\partial g(k_{t+1}^R)}{\partial k_{t+1}^R}\frac{\partial K_t^R}{\partial A_t^R} = \gamma \frac{\partial g(k_{t+1}^R)}{\partial k_{t+1}^R}(X - r_t^D) \tag{6.3.6}$$

Similarly, we can get the expression for H_{t+1}:

$$\frac{\partial H_{t+1}}{\partial A_t^R} = \gamma \frac{\partial h(k_{t+1}^L)}{\partial k_{t+1}^L}(X - r_t^D) \tag{6.3.7}$$

We also need to consider the term J_{t+1}:

$$\frac{\partial J_{t+1}}{\partial A_t^R} = j' \frac{\partial l_{t+1}}{\partial A_t^R} = j' l_{t+1}^2 (-w_R) \tag{6.3.8}$$

Finanlly, we consider the term

$$\frac{\partial r_{t+1}^R (1 - \delta_{t+1}) A_{t+1}^R}{\partial A_t^R} = r_{t+1}^R A_{t+1}^R \frac{\partial \delta_{t+1}}{\partial A_t^R} = r_{t+1}^R A_{t+1}^R \frac{\partial \delta_{t+1}}{\partial M_t}\frac{\partial M_t}{\partial A_t^R} = 0$$

Putting all above together and solving first order condition for A_t^R, we have equation 6.3.1.

Similarly, we can have the first order condition for A_t^S, which is specified by equation 6.3.2.

The calculation of E_t is slightly different.

$$\frac{\partial (E_t \lambda(e_t))}{\partial E_t} = \lambda(e_t) + E_t \frac{\partial \lambda(e_t)}{\partial e_t}\frac{\partial e_t}{\partial E_t} = \lambda(e_t) + \frac{E_t \frac{\partial \lambda(e_t)}{\partial e_t}}{(w_R A_t^R + w_S A_t^S)} = \lambda(e_t) + e_t \lambda'(e_t) \tag{6.3.9a}$$

$$\frac{\partial D_{t+1}}{\partial E_t} = -\frac{\partial K_t}{\partial E_t} = -1 \tag{6.3.9b}$$

$$\frac{\partial G_{t+1}}{\partial E_t} = (w_R A_t^R + w_S A_t^S)\gamma \frac{\partial g}{\partial k_{t+1}^R}\frac{\partial k_{t+1}^R}{\partial E_t} = \gamma \frac{\partial g(k_{t+1^R})}{\partial k_{t+1}^R}\frac{\partial K_t^R}{\partial E_t} = \gamma \frac{\partial g(k_{t+1}^R)}{\partial k_{t+1}^R} \tag{6.3.9c}$$

$$\frac{\partial H_{t+1}}{\partial E_t} = \gamma \frac{\partial h(k_{t+1}^L)}{\partial k_{t+1}^L} \tag{6.3.9d}$$

Substituting and rearranging gives equation 6.3.3. ■

Once the bank specify its own cost functions $(j(l_t - \rho_t), g(k_t^R - d_t), h(k_t^L - c_t), \lambda(e_t))$, there will be only 3 unknown variables (k_t^R, k_t^L, e_t), which are specified by equations (6.3.1), (6.3.2) and (6.3.3). Hence, we can solve the 3 equations simultaneously to find out the optimal portfolio allocation decision.[1]

6.4 Numerical analysis

Given our objective in this chapter is to demonstrate the optimal portfolio allocation decision of the bank reacts to the regulatory requirement change, now we specify some functional form for the cost functions, and estimate the relationship between loan default and loan supply. Due to the complexity of the model, however, the cost functions may different from bank to bank. Instead of providing a close form solution, we present some numerical analysis to illustrate the above analysis in this section.

For simplicity, we make an additional assumption that the risk weighting for safe asset is zero (i.e. $w_S = 0$) in this section. Hence, equation (6.3.2) can be simplified to

$$(r_t^S - r_t^D) - \gamma(h - k_t^L h') + \beta \mathbb{E}[(r_t^S - r_t^D)(r_{t+1}^D - \gamma g'(k_{t+1}^R) - \gamma h'(k_{t+1}^L))] = 0 \quad (6.4.1)$$

This numerical analysis involves four main stages. Stage 1 is the empirical estimation of the expected probability of default, which we carry out using historical data from banks balance sheet. Stage 2 specifies the functional forms of three cost functions. Stage 3 derives the optimum conditions based on input from stage 1 and 2. Finally, stage 4 simulates the optimal bank asset allocation with respect to the regulatory leverage requirement, capital requirement, and leverage and capital requirements jointly.

[1] Note that we did not include the leverage and risk weighted capital constraints ((6.2.2) and (6.2.3)) into our calculation above. So there is a chance that optimal allocation suggested by the model may violate (6.2.2) and (6.2.3), which indicate these banks should operate in a way that one of the leverage and risk weighted capital constraints is binding.

6.4.1 Stage 1: empirical analysis for default

Here, we specify in equation (6.2.7) an empirical relationship between the estimated default rate as the dependent variable and the risky loan size and the macro-economic conditions as the two independent variables. We do acknowledge that the estimated default rate depends on other parameters in reality. Our simple specification may have problem of omitted variables. The reason for this simplification is as follows. No matter how robust is the predictive power of a given model from which the expected default rate is estimated, it is still an estimated parameter. Inevitably, for its portfolio allocation decision, the bank has to rely on the estimated next period's default rate. This estimated default rate can be different from the actual one. But, our model is only concerned about estimated default rate since bank has to make its portfolio allocation decision based on the estimated default rate although there are potential forecast errors. Hence, we keep the empirical analysis here as simple as possible given that the main objective of this chapter is to analyse the impact of change in regulatory capital on the bank's portfolio allocation decisions. The key contribution of this chapter is the optimal conditions we derived in section 6.3. Here, we numerically demonstrate these optimality conditions by specifying a linear relationship between loan size and estimated default rate as follows:

$$\delta_t = b_0 + b_1 log(A_t^R) + b_2 M_t \tag{6.4.2}$$

where coefficient b_0 is a constant, b_1 capture the effect of loan portfolio size on the estimated default rate and b_2 capture the effect of macro-economic conditions on the estimated default rate.

Next, we use panel regression to estimate the coefficients in equation 6.4.2. The relevant data on the estimated default rate and the risky loan size are obtained annually from the balance sheets data of HSBC, Barclays, RBS and Lloyds banking group from Bloomberg. The sample period is from 1991 to 2010 except for Lloyds banking group that only available from 1995 to 2010. All of the data are adjusted for mergers and acquisitions. As a proxy for the estimated default rate we use the *Reserve for losses on loan* account divided by total loan amount. The risky loan size is directly obtained from the *Total Loan* entry in the balance sheet of each bank. Note that we are only interested in the expected default rate by the banks instead of the actual default rate. We believe that reserve for losses on loan on the balance sheets of the banks is the best possible data we can obtain to represent this expected default rate.

We use GDP, M4 and the base rate as a proxy for macro-economic condition. This set of data is obtained from the World Bank and Bank of England, and over the same sample period as the bank loan data. The World Bank define GDP as follow: 'GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars. Dollar figures for GDP are converted from domestic currencies using single year official exchange rates. For a few countries where the official exchange rate does not reflect the rate effectively applied to actual foreign exchange transactions, an alternative conversion factor is used.' M4 money supply is defined as the private sector's holding of sterling notes and coin; sterling deposits, including certificates of deposit; commercial paper, bonds, FRNs and other instruments of up to and including five years' original maturity issued by UK MFIs; claims on UK MFIs arising from repos (from December 1995); estimated holdings of sterling bank bills and 35% of the sterling inter-MFI difference. The base rate is the rate set by Bank of England for Barclays, Lloyds TSB, HSBC and National Westminster banks. We believe GDP, M4 money supply and base rate can indicate the general health of the economy, which will have a direct impact on the expected default rate. Other macroeconomic indicators such as GDP/Capital, GNI and GNI/Capital have been tested in the model but the results are not significant different. It is possible there are other relevant indicators are omitted from our model. But, as we mentioned before, we are only interested in obtaining an expected default rate, which allow banks to make asset allocation decisions. The accuracy of this expected default rate has attracted lots of interest in finance, but it is beyond the scope of this thesis. We therefore keep this part of the analysis as simple as possible and only include GDP, M4 money supply and base rate as our macroeconomic data.

Table 6.1 below presents a subset of the data sample.

Table 6.1: Regression Data

Bank	Year	Loan	Reserve	GDP(bn)	M4(thousand)	Base rate %
1	2010	440,326	12,384	1,460	2,150	0.50
1	2009	430,959	10,735	1,390	2,040	0.50
1	2008	468,338	6,523	1,450	1,930	4.50
⋮	⋮	⋮	⋮	⋮	⋮	⋮
4	1997	90,395	2,433	830	720	6.50
4	1996	88,707	2,488	782	681	6.00
4	1995	82,490	2,999	733	622	6.50

We apply the log transformation of the loan, GDP and M4. We use STATA to perform the panel regression analysis. The expected default rate denoted by *drate* is the dependent variable in the regression equation 6.4.3. We first perform the Hausman test to check for the random effect in this panel data. The null hypothesis is that both fixed and random effects are consistent and the alternative hypothesis is that random effect is not consistent. To perform a Hausman test, we first estimate the fixed and random effects models. Then we use STATA command 'hausman' with 'sigmamore' option to obtain test statistics. The relevant output is as follow:

```
Test:  Ho:  difference in coefficients not systematic

                 chi2(2) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                         =        6.61
               Prob>chi2 =        0.04
               (V_b-V_B is not positive definite)
```

We reject the null hypothesis since the p-value is 0.04, which is less than the 5% significance level. Hence, we can conclude that we should use random effect in the panel regression.

Next, we run random effect panel regression on the following empirical specification:

$$drate = b_0 + b_1 log(Loan) + b_2 log(GDP) + b_3(Base\ \ rate) + b_4 log(M4) \quad (6.4.3)$$

The relevant regression output is in Table 6.2 below:

Table 6.2: Panel regression result

Random-effects GLS regression	Number of obs = 76
Group variable: bank	Number of groups = 4
R^2: within = 0.76	Obs per group: min = 16
R^2 between = 0.58	avg = 19.0
R^2 overall = 0.73	max = 20
Random effects u_i Gaussian	Wald chi2(2) = 990.30
corr(u_i, X) = 0 (assumed)	Prob > chi2 = 0.0000

drate	Coef.	Robust Std. Err.	z	$P > \|z\|$
lnloan	0.005	0.0005	9.84	0
lngdp	-0.09	0.01	-8.28	0
lr	-0.001	0.0005	-2.16	0.03
lnm4	0.04	0.006	6.19	0
_cons	2.07	0.24	8.63	0

The overall R^2 is 0.73, which indicates that the independent variables explain more than 70% of the variability of the dependent variable. The Chi square test for the whole model indicates that at least one of the independent variables significantly contributes to the dependent variable. The log risky loan size, the log GDP, the log M4 money supply and base rate together explain a significant amount of the variation in the default rate. The p-values indicate all of these four factors are significant at the 5% level.

From the estimated coefficients, the log risky loan size and the log M4 have the correct positive signs as we expect and the log GDP and base rate also have the negative signs as we expect. Obviously, we would expect higher default rate to be associated with higher proportion of risky loans in banks' portfolio. Generally, in order to increase the risky loan size banks resolve to relax their lending standards. Stiglitz-Weiss also suggests that bank charges higher interest rate on risky loans, which obviously associated with the higher expected default rate. Among the four parameters, the estimated default rate is the most sensitive to per unit change in the log of GDP, which also reasonable since the economic cycle has a great impact on the default rate.

Based on the above output of the panel regression, we know that for any unit change in the total loan size (A_t^R) will cause the default rate change by $0.005log(\Delta A_t^R)$. We use this parameter of the total loan size in our input in our numerical analysis in section 6.4.4 to identify the optimal portfolio decisions for banks.

6.4.2 Stage 2: cost functions

Here, we assume some specific functional forms for the cost functions.

We use the same cost functions as Furfine (2001) for the adjustment cost (l_t) and net equity issuing cost ($\lambda(e_t)$):

$$j(l_t - \rho_t) = \frac{1}{2}\alpha(l_t - \rho_t)^2 \tag{6.4.4}$$

$$\lambda(e_t) = \theta + \frac{1}{2}\theta e_t^2 \tag{6.4.5}$$

Following Furfine (2001) we use the same functional forms of the cost functions and the estimated parameters as specified by the author, which are reproduced in Table 6.3 below:

Table 6.3: Parameter values

Parameter	Description	Estimated Value
α	Parameter influences curvature of the adjustment cost function	0.000059
θ	Parameter influences the level of equity issuing costs	0.161668
ρ	Average level of loan demand	1.02
γ	Regulatory monitoring cost parameter	0.68

As discussed earlier in section 6.2.3, we justify the use of a different functional form of the capital holding cost compared to that used in Furfine (2001). Our cost functions $g(k_t^R)$ and $h(k_t^L)$ are as follow:

$$g(k_t^R) = \eta(k_t^R - (d + \hat{d}))^2 \tag{6.4.6}$$

$$h(k_t^L) = v(k_t^L - (c + \hat{c}))^2 \tag{6.4.7}$$

where d is the risk weighted capital requirement, $\hat{d}$ is the capital cushion to minimise the risk weighted capital holding cost, c is the leverage ratio requirement, and $\hat{c}$ is the capital cushion to minimise the capital holding cost. [1]

[1]Note that the power 2 in (6.4.6) and (6.4.7) is chosen so as to continue the calculation in

By specifying this form of capital holding function, we assume that the cost of holding capital for the bank is minimised at a certain point, which is greater than the regulatory requirement. Once the capital holding of the bank deviate from this point, its capital holding cost increases. This suggests that the bank incurs costs either way by holding too much capital or holding not sufficient capital. The level of capital cushion, however, differs from bank to bank since it depends on the value of the benefit of lower regulatory restriction. As discussed earlier, this is equivalent to the static trade-off theory in corporate finance, where the benefits of using debt and the costs of financial distress suggests that there is an optimal capital structure that minimises the cost of capital. It is difficult, however, to quantify the costs of financial distress, which include legal fees, cost of damage the reputation, cost of losing market share, etc. The fact that these costs may be different from bank to bank makes the task of estimating the costs of financial distress even more complex. Consequently, it is difficult to estimate the value of $g(k_t^R)$ and $h(k_t^L)$ directly and also the parameters η, v, $\hat{d}$ and $\hat{c}$ in equations (6.4.6) and (6.4.7). Therefore, we derive a relationship between η and v from the optimisation conditions (6.3.1) and (6.3.2). By rewriting either (6.3.1) or (6.3.2), we have

$$k_{t+1}^R = \frac{v}{\eta} k_{t+1}^L + constant \tag{6.4.8}$$

By regressing the risk weighted capital ratio k_{t+1}^R on the leverage ratio k_{t+1}^L using the same data sample as in section 6.4.1, we obtain the estimated coefficient of $\frac{v}{\eta}$ is 0.73. Hence, once we specify value of η then we know the value of v.

6.4.3 Stage 3: optimisation conditions with the assumed functional forms of cost functions

Here, we can substitute the cost functions with the specified functional forms in the previous section into the optimisation conditions set out in equation (6.3.1),

this numerical example. The result does not change significantly if power 4, 6, etc is chosen.

(6.3.2) and (6.3.3) to obtain:

$$\theta + \frac{3}{2}\theta e_t^2 + r_t^D - 2\gamma\eta(k_t^R - (d + \hat{d})) - 2\upsilon\gamma(k_t^L - (c + \hat{c})) = 0 \tag{6.4.9}$$

$$(r_t^S - r_t^D)[1 + r_t^D - 2\gamma\eta(k_t^R - (d + \hat{d})) - 2\upsilon\gamma(k_t^L - (c + \hat{c}))] - \upsilon\gamma[(c + \hat{c})^2 - (k_t^L)^2] = 0 \tag{6.4.10}$$

$$\begin{aligned}&[r_t^R(1 - \delta_t - A_t^R \tfrac{\partial \delta_t}{\partial A_t^R})][1 + r_t^D - 2\gamma\eta(k_t^R - (d + \hat{d})) - 2\upsilon\gamma(k_t^L - (c + \hat{c}))] \\ &-w_R\gamma\eta[(d + \hat{d})^2 - (k_t^R)^2] - \upsilon\gamma[(c + \hat{c})^2 - (k_t^L)^2] - w_R\tfrac{\alpha}{2}(1 - \rho_t)^2 = 0\end{aligned} \tag{6.4.11}$$

For simplicity, we specify a naive expectation mechanism to forecast the values of the parameters in next period adjusted for the discount factor. That is we use the parameters values at time t to approximate the expected values in $t + 1$.

In order to numerically determine the optimal portfolio allocation, we take the current values of the relevant variables prevailing at March 2012 as inputs. These values of variables are set out in Table 6.4 below.

Table 6.4: Assumed Parameter values

Parameter	Description	Assumed Value
r^R	Interest rate on loans	0.06
r^S	Rate of return from safe asset	0.005
r^D	Interest rate on deposits	0.01
K	Initial capital level	1
η	Parameter influences the risk-basked capital requirements	100
δ	Estimated default rate	0.02

For simplicity we normalise the initial capital level K to 1. We tried several different values of η (a.k.a. the parameter influences the risk-basked capital requirements) but it makes not significant difference to the result so long as η is greater than 100. See Figure 27 on page 172 for a plot of η against the optimal proportion of the bank's risky asset. If η is too large, then υ is also large[1] and the

[1]Note that we deduce $\frac{\upsilon}{\eta} = 0.73$ in section 6.4.2.

costs $g(k_t^R)$ and $h(k_t^L)$ dominate the other costs. The default rate is estimated using the average default rate for the banks in our sample.

6.4.4 Stage 4: numerical Results

We solve equations (6.4.9), (6.4.10) and (6.4.11) numerically for the optimal levels of safe and risky asset in a bank's asset portfolio using the inputs from the earlier sections. We use Matlab for solving this optimisation problem. In this section, we present the following three cases: Case I represents the increase in regulatory leverage requirement and constant risk weighted capital requirement. Case II represents the increase in risk weighted capital requirement and constant regulatory leverage requirement. Case III represents increase in both regulatory leverage requirement and risk weighted capital requirement. Not surprisingly, all of our results indicate that the bank will shrink its total assets in response to the regulation changes. Since the magnitude of this shrinkage will depend on bank specific data, we solely focus on the proportions (in percentage term) of risky assets and safe asset in the portfolio of the bank in the remaining of the analysis.

Case I: $d + \hat{d} = constant$ **and** $c + \hat{c}$ **changes**

First, we keep $d + \hat{d}$ (risk weighted capital requirement + capital cushion) constant and vary $c+\hat{c}$ (leverage requirement + leverage cushion) to examine how the bank would response to these regulatory changes. Setting the risk weighting for risky asset (w_R) to 1, we look at two different values of $d + \hat{d}$. The results are shown in Figure 28 on page 173. The first plot shows the case that $d+\hat{d} = 0.12$ and the second plot shows the case that $d+\hat{d} = 0.10$. From these plots, it can be seen that the percentage of risky asset in bank's balance sheet increases linearly as the leverage requirement increases for both values of $d+\hat{d}$. This positive linear relationship does not change when we change the values of $d+\hat{d}$. The only thing that changes is the gradient, which becomes smaller as the value of $d+\hat{d}$ increases from 0.10 to 0.12. This indicates that when the risk weighted capital requirement is relatively high, the optimal portfolio allocation is less sensitive to the regulatory leverage requirement. This is likely due to the fact the bank's capital constraint is nearly binding in this case.

When we change the risk weighting (w_R) for risky asset from 1 to 0.8, the positive linear relationship between the percentage of risky asset and leverage requirement does not change. We can see this in Figure 29 on page 174.

The relationship between leverage requirement and bank's optimal portfolio allocation decision can be intuitively interpreted as follow. First, we know from equations (6.2.2) and (6.2.3) that when the risk weighting for safe asset is zero, the regulatory leverage requirement and risk weighted capital requirement are:

$$\frac{K_{t-1}}{A_t^R + A_t^S} \geq c_t \tag{6.4.12}$$

$$\frac{K_{t-1}}{w_R A_t^R} \geq d_t \tag{6.4.13}$$

We can see from the above expression that $d \geq c$, and the equality sign only holds if $w_R = 1$ and $A^S = 0$. In other words, we know the risk weighted capital ratio will be greater than or equal to its leverage ratio. If the there is no change in the risk weighted regulatory capital requirement (i.e. $d = constant$), then $d + \hat{d}$ is a constant. Meanwhile, if the regulatory leverage requirement increase (i.e. increase c), holding of safe asset will incur more costs to banks since it is part of the denominator in equation (6.4.12). Though holding risky assets can also incur further cost to the banks, it offers a higher rate of return. Hence, the banks have an incentive to increase the percentage of risky asset in their portfolios. This is true no matter whether the bank is forced to raise capital or not. If a bank is well capitalised, which means both their risk weighted capital and leverage ratios are greater than the regulatory requirements, it will not be necessary for the bank to raise new capital when the regulatory leverage requirement changes. Due to the higher return on the risky assets, the bank will hold more risky assets. If a bank is poorly capitalised, it will be forced to raise capital. The investors may require a higher rate of return under this scenario, which will force the bank to hold more risky asset as well. We can see the relationship in Figure 28 and 29.

We also observe that when the risk weighted capital requirement and leverage requirement become very close to each other, our model suggests the optimal decision of the bank should be to hold risky assets in exceed of 100% of its total asset, which means the bank should short sell the safe asset. But this violates the condition that $A^S \geq 0$, so it implies that the bank should not hold any safe asset in this case (i.e. $A^S = 0$). In reality, banks do have the option to short sell the safe asset, but they need to find a counterparty to facilitate the trade, which increases the counterparty risk/default risk. This reduces the risk weighted capital ratio under the Basel III. We do not, however, consider the counterparty risk in our model, and the model implies the optimal decision for bank is to only hold risky asset in this case. Hence, this has an implication for regulator that the risk weighted capital requirement should not be set too close to the regulatory leverage requirement.

Case II: $c + \hat{c} = constant$ and $d + \hat{d}$ changes

Next, we will keep $c + \hat{c}$ constant and only change $d + \hat{d}$. Repeating what we have done so far, we can plot the relationship between optimal percentage of the risk assets in the portfolio of a bank and the risk weighted capital requirement as shown in Figure 30 on page 175 and Figure 31 on page 176. We can see that the model implies that the bank should reduce the proportion of its risky asset under this scenario. The explanation for this action is as follow. When the risk-weighted capital requirement is raised, we can see from equation (6.4.13) that the bank can reduce its holding of risky assets to satisfy the new requirement. So the proportion of risky assets in the bank's balance sheet will be reduced. We also assume that the safe asset does not carry any risk weighting in the risk-weighted asset calculation. Hence, if the bank increases its holding of safe asset, its risk-weighted asset will not increase. It is not surprise that our result indicates the bank will allocate a greater proportion of its assets to the safe asset in this case.

Case III: Both $c + \hat{c}$ and $d + \hat{d}$ changes

Finally, we look at the case that c and d increase together. Table 6.5 shows how the optimal portfolio allocation changes given both $d + \hat{d}$ and $c + \hat{c}$ change by 100 basis points when the risk weighting for risky asset is 1. Table 6.6 on page 124 shows the same parameters but with $w_R = 0.8$. This is also presented in Figure 32 on page 177. We only present the result for 100 basis points change in regulatory requirements here. The results do not change significantly if we use 200 basis points change rather than 100 basis points.

The results of this numerical analysis imply that bank should allocate more to risky assets if both d and c change. Again, the explanation given in Case

Table 6.5: Optimal Portfolio Allocation when both d and c change $w_R = 1$

$A^R\%$	$A^S\%$	$d+\hat{d}$	$c+\hat{c}$	w_R
0.55	0.45	0.08	0.05	1
0.60	0.40	0.09	0.06	1
0.65	0.35	0.1	0.07	1
0.68	0.32	0.11	0.08	1
0.71	0.29	0.12	0.09	1
0.73	0.27	0.13	0.1	1
0.75	0.25	0.14	0.11	1
0.77	0.23	0.15	0.12	1
0.78	0.22	0.16	0.13	1
0.79	0.21	0.17	0.14	1
0.81	0.19	0.18	0.15	1

Table 6.6: Optimal Portfolio Allocation when both d and c change $w_R = 0.8$

$A^R\%$	$A^S\%$	$d+\hat{d}$	$c+\hat{c}$	w_R
0.67	0.33	0.08	0.05	0.8
0.74	0.26	0.09	0.06	0.8
0.80	0.20	0.10	0.07	0.8
0.84	0.16	0.11	0.08	0.8
0.88	0.12	0.12	0.09	0.8
0.91	0.09	0.13	0.1	0.8
0.93	0.07	0.14	0.11	0.8
0.95	0.05	0.15	0.12	0.8
0.97	0.03	0.16	0.13	0.8
0.99	0.01	0.17	0.14	0.8

I applied here. No matter the bank hold safe asset A^S or risky loan A^R will incur cost when the risk weighted capital requirement and leverage requirement increase together. But the risky asset can offer a higher rate of return than safe asset, so the banks should increase the percentage of risky assets. Note that we only consider the proportion of the risky assets in the balance sheet of the bank. The optimal total value of the risk assets and safe asset the bank should hold is not considered here. This is because this optimal total value will different from one bank to another.

The results can be summarised as Table 6.7 below:

Risk weighted capital requirement	Leverage requirement	risky asset %	safe asset %
Unchanged	Increase	Increase	Decrease
Increase	Unchanged	Decrease	Increase
Increase	Increase	Increase	Decrease

Table 6.7: Results

6.4.5 Cursory discussion of the policy of quantitative easing (QE)

As we discussed in chapter 2 most central banks embarked upon a series of QE policy measure, which had significant effect on bank's asset portfolio. In this chapter, we have so far considered only the effect of Basel III regulatory capital requirement and leverage requirement. The numerical result we have presented above indicates that banks should increase the proportion of risky assets in their portfolios in response to these regulatory changes. According to the Bank of England report (January 2012), however, lending by banks to SME in the UK has declined dramatically since 2007. This fact does not necessarily contradict our numerical results. First, banks can shrink their asset portfolios while increase the proportion of risky assets in their portfolio.

Second, the presence of QE policy has a significant impact in the credit market. In the UK as well as US and other countries, the policy of asset purchases by central bank is a form of QE policy. In a Bank of England paper Joyce, Tong and Woods (2011), the authors outline how this QE policy has been implemented. £200bn of medium to long term government bonds, which represented 14% of annual nominal GDP of the UK, were purchased by Bank of England in 2009. Other interventions include the liquidity support to the banking sector (banks can swap assets to Treasury Bills), recapitalisation of Lloyds Banking Group (Lloyds) and Royal Bank of Scotland (RBS), deposits guarantee, and the asset protection scheme. These interventions together with the QE policy helped the British banks to strengthen their balance sheets. Joyce, Tong and Woods (2011) show that the banks' asset value as a percentage of GDP was increased to three times the pre-crisis figure. If a central bank purchase such a large amount of government bonds, we would expect to observe a significant reduction in the government bond yields. In Joyce, Lasaosa, Stevens and Tong (2011), the authors quantify the impact of the Bank of England's asset purchase program. They show that the medium to long term UK government bond yields fell by 100 basis points due to the QE policy. This effectively boosted up the total return from holding safe asset, which provided an incentive to banks to increase their holdings of the safe asset in anticipation of another round of QE policy. The series of QE measures explain why the asset allocation decisions of banks are different from what our results. In the absence of QE intervention, Basel III may cause the banks to shrink their balance sheets, but increase the proportion of their asset allocation to risky assets. In fact, the combined effect of Basel III and the Bank of England's asset purchase program have been directly responsible for the reduction in availability of funding to the private sector.

6.5 Concluding remarks

In this chapter, our aim has been to investigate the effect of Basel III regulatory capital requirement and leverage requirement on the optimal portfolio allocation between safe and risky assets for a representative bank. The key features of our model include a multi-period decision horizon of a bank, a dynamic default function with an expectation mechanism, a loan portfolio adjustment cost function, and cost of capital function. Our model extends the optimal portfolio allocation model by Furfine (2001), which did not explicitly consider the significance of the expected default rate in the risky assets. Our main contribution is twofold. First, by incorporating the expected default rate into the return on risky assets, we charaterise the optimal conditions by a set of equations that depends on the specific functional forms of the cost functions. Second, we present numerical analysis of the model based on a set of parameter values that we estimate empirically using a sample of balance sheet data and macro-economic data. The results of this numerical analysis imply that bank should increase the proportion of risky assets if both regulatory leverage requirement and capital requirement are raised. This result, however, do not concur with the observed portfolio adjustment by banks since the 2007 global financial crisis. The quantitative easing policy pursued by central banks since 2007 together with the implementation of Basel III have induced banks to reduce their risky lending in favour of holding safer government securities. As a result, it is important for the central banks and regulators to estimate the combined effects of these policy tools.

We can use this general bank portfolio selection model to study the specific components of real estate assets on bank's balance sheet. The credit supply to the real estate sector can be viewed as a type of risky asset with specific risk weighting in our model. For instance, if a bank only lends to the real estate sector and holds safe government securities, we can use the optimal conditions we derived in this chapter to determine the optimal level of mortgage supply of a bank. Further decomposition of into land, office buildings, houses and industrial buildings can be studied. The key risk factor for investing in vacant land is the cost of carry since it does not generate ongoing income. The principal risks for investing in office are finding credit tenants and shifts in the location of business activity. Bank therefore needs to apply different risk weightings to these assets depending on their risk attributes. If we are interested in the interaction between the credit supply to two of these assets, say land and houses, we can replace the safe asset in our model with land, which carry certain non zero risk weighting, and use the risk weighting for houses to replace the risky asset risk weighting in our general model. Then our optimal conditions derived in this chapter can be applied and we can identify the optimal levels of credit supply to these two assets. If we are interested to see the portfolio selection decisions on a number of assets include safe asset, land, houses, commercial properties and industrial properties, we can add more risk parameters into the model. This will increase complexity of the model, but the derivation of the stability conditions remains the same.

Having considered the supply side of the credit market through bank's optimal portfolio allocation decision in this chapter, our focus in the next chapter is to investigate the magnitude of credit rationing by considering both the supply side as well as the demand side of the credit market.

Chapter 7

Demand and supply: Credit Rationing Under Risk-based Capital Requirement

In the previous two chapters, we specified the supply side of the credit market by using a cobweb approach and the optimal asset allocation decisions of banks under the regulatory capital requirement. This chapter is concerned with both the credit supply by banks and the demand for credit. We study the impact of higher regulatory Tier I capital ratio requirement on the magnitude of credit rationing and profitability of bank. Based on Stiglitz-Weiss, we analyse a model in which a bank may adjust the asset or liability side of its balance sheet. The model uses the rate of return required by shareholders of the bank to capture possible reactions under binding or non-binding capital constraint. It has been well documented that the introduction of Basel III capital requirement has prompted most banks to adjust the asset side of their balance sheets because of high cost of raising new equity. We show that both a poorly capitalised bank and a bank holding capital buffer react in the same manner to change in regulatory requirement by raising the lending rate on risky loans and by shrinking risky loan portfolio. Based on this result, we suggest that a countercyclical capital policy is more suitable than raising capital requirement when the economy is in a distressed environment. We present a number of possible scenarios to explain how the higher lending rate can affect the magnitude of credit rationing depending on the demand and supply conditions in credit market. We show that both the higher lending rate and the change in magnitude of credit rationing have an adverse effect on the profitability of bank.

The rest of the chapter is organised as follows. Section 7.1 sets out a general introduction of credit rationing and capital requirement. Section 7.2 presents the model of the relationship between capital requirement and credit supply. Section 7.3 analyses the impact of minimum capital requirement on the lending rate. Section 7.4 investigates some wider implications of capital requirement on the magnitude of credit rationing. Section 7.5 discusses the effect of capital requirement on the profitability of bank. Section 7.6 concludes.

7.1 Introduction

Bernanke (2006) in his speech remarked 'Much more so than in the past, banks today are able to manage and control obliger and portfolio concentrations, maturities, and loan sizes, and to address and even eliminate problem assets before they create losses Basel II will make it easier for supervisors to identify banks whose capital is not commensurate with their risk levels and to evaluate emerging risks in the banking system as a whole'. Yet, a few months later the sub-prime crisis revealed a different story: banks did not manage to eliminate problem assets before they created losses. The first signs of distress emerged in 2006 when HSBC, the world's third-largest bank, disclosed its bad-debt provisions soar to \$10.8 billion as a result of defaults in its sub-prime portfolio. Banks that had adopted aggressive trading and investment activities became vulnerable to illiquidity in the wholesale money markets, earnings volatility from marked to-market assets, and illiquidity in structured finance markets. The CRS Report for Congress (November 2008) noted 'By September, not a single 'bulge bracket' investment bank remained standing: they had either failed (Lehman Brothers), merged (Merrill Lynch and Bear Stearns), or converted themselves into commercial bank holding companies (Goldman Sachs and Morgan Stanley)' . Banks' inability to eliminate vast quantities of problem assets forced the Federal Reserve along with other major central banks to take unprecedented measures including liquidity support, extended deposit insurance, asset purchase programmes, and recapitalisation of banks to rescue the global financial system from a contagion of bank failures.

Two simultaneous sources of pressure squeezed banks' balance sheets: funding pressure and capital-related pressure. Falling asset values and deleveraging eroded profitability that inevitably result in a sharp decline in the market values of equity. Between 2006 and 2009, the top-30 banks suffered a 52 percent overall loss in their market capitalisation, which included a significant stock market recovery during 2009 (Laeven and Valencia (2010)). Banks shed assets both through sales and by cutting back lending. Even a small capital shortfall can result in large deleveraging through the multiplier effect. The multiplier effect of deleveraging, which takes place through capital shortfall but not through funding shortfall, caused a severe contraction of credit to the private sector. Because mark-to-market accounting require leveraged institutions to reduce their position by $\$x$ times their leverage ratio when they suffer losses of $\$x$, the ultimate impact on new lending to businesses and households can be enormous. According to the European Central Bank Financial Stability Report (June 2012)[1] '...a capital shortfall of EUR 100 billion could, depending on the extent to which it is covered through changes in liabilities or via asset reductions, require as much as a EUR 1,250 billion reduction of risk-weighted assets and even more in terms of total assets.'

There is ample empirical evidence that provides insights into the extent of decline in lending to private sector through the deleveraging process. Ivashina and Scharfstein (2010) found that during August and December of 2008 there was a 36 percent reduction in monthly loan origination by a bank with the median deposit-to-asset ratio relative to the previous year. In comparison, the bank that had the deposit-to-asset ratio with one standard deviation below the mean the reduction was as high as 51 percent. Greenlaw et al. (2008) also find that there was '\$2.3 trillion contraction in intermediary balance sheets, of which roughly \$1 trillion represent a decline in lending to households, businesses, and other non-levered entities.' Indeed, as Bernanke and Lown (1991) argue, a capital-related pressure results in '...a significant leftward shift in the supply curve for

[1] http://www.ecb.europa.eu/pub/fsr/html/index.en.html

bank loans, holding constant both the safe real interest rate and the quality of potential borrowers.'

Our purpose in this chapter is to offer a simplified theoretical analysis of the impact of regulatory capital shortfall on bank lending by adopting Stiglitz-Weiss notion of credit rationing. It will be argued that the relationship between risk weighted capital requirement and credit rationing is more complex than might appear at first glance and that, in particular, it can be shown that higher risk weighted capital requirement may either increase or decrease the magnitude of credit rationing. The problem of capital shortfall can be separated into two problems for analysis of a poorly capitalised bank and a bank holding capital buffer. The first is the process by which the composition of assets (i.e. shift from risky loan to government securities) and the lending rate can be adjusted sufficiently to generate the required rate of return on capital necessary to maintain the supply of credit. In Agur (2011) the adjustment takes place on the liability side of bank's balance sheet (lowering leverage), which implies that banks supply less credit due to their downsized balance sheets. The change in composition of assets from risky to safe assets, however, tends to ease the pressure on the lending rate and reduce the profitability; both effects result in credit contraction.

The second part of the problem of capital shortfall is whether the adjustment will affect the magnitude of credit rationing. This problem has two facets: whether the magnitude of credit rationing increases or decreases as a consequence of a change lending rate and whether the lending rate has a greater impact on demand for credit than on supply of credit. This chapter is concerned with the first of these facets and the argument will assume that the adjustment mechanism will suffice. We will demonstrate that higher regulatory capital requirement affects the lending rate only within a certain region and, thus, striking the right balance between recapitalisation and credit rationing is inherently difficult. The answer to the second facet will be provided by a discussion of the prevailing credit market conditions.

Our model in this chapter is different from Suarez and Sussman (1997) in a number of ways. First, we modify Stiglitz-Weiss credit rationing model to incorporate the Basel III capital requirement. Suarez and Sussman (1997) do not consider the regulation of bank's capital. Our approach allows us to capture the recent developments in the credit market. Second, the main focus in this chapter is on the short run effect of higher capital requirement on the magnitude of credit rationing. In the short tun, it is difficult for banks to raise capital and this inevitably causes them to adjust their asset portfolios. Our approach is different from the overlapping generations model in Suarez and Sussman (1997) that studies the credit rationing over two-periods, where portfolio adjustment of banks is not considered. Third, our focus is on the effect of adverse selection and not on the moral hazard problem, which allows Suarez and Sussman (1997) to demonstrate the impact of change in the amount of effort borrowers put into the projects. Whilst Suarez and Sussman (1997) offer how moral hazard affects the payoff to both borrowers and banks, it does not explain the magnitude of credit rationing.

In this chapter, we modify Stiglitz-Weiss credit rationing model to incorporate the Basel III capital requirement and propose a rate of return approach to capture the short run effects on credit supply and the magnitude of credit rationing. All of the results and the mathematical equations in the proofs of this chapter are derived by the author of this thesis.

7.2 The credit market model under capital requirement

In this section, we consider three participants in the credit market, namely, regulator, borrowers and banks. As described earlier, the model extends and modifies the work by Stiglitz-Weiss and Agur (2011). We begin with a set of assumptions and then present the optimisation problem of a representative bank under regulatory constraints. We derive a set of results and provide some economic intuitions.

Assumptions

This model is concerned with the impact of higher regulatory Tier I capital ratio on the credit market. This is a static model focusing on the short term effects when the regulator increases the capital requirement at a specific point. The key differences between our model and the one in Stiglitz-Weiss is the capital requirement. Since the capital regulation framework is absence in Stiglitz-Weiss, they do not have a regulator in their model and do not distinguish risky assets and safe asset. Our assumptions about borrowers are the same as those in Stiglitz-Weiss.

Regulator:

The regulator sets the minimum capital requirement. Here, we just consider the Tier 1 capital. This is the original amount of capital stock of the bank, net retained profit and other qualified Tier 1 capital. In the standard single period setting we consider only the amount of equity at the beginning of period as Tier 1 capital. Let φ be the minimum capital requirement (capital ratio)[1] set by the regulator. For a traditional commercial bank that holds a portfolio of risky loans and safe government securities, we can define the risk-weighted capital ratio as

$$\varphi = \frac{E}{w_L L + w_S G}$$

where E is the amount of bank's equity, L is the amount of risky loans the bank has issued, G is the amount of government securities held by the bank, w_L and w_S are the risk weightings for risky loans and government securities, respectively.

To simplify, we further assume that the risk weighting for the government securities is zero and the risk weighting for portfolio of risky loans is 1. This implies that there is only one type of risky asset for bank to invest, which is the same as Stiglitz-Weiss. We have

$$\varphi L = E$$

Borrowers:

There are N borrowers, each has one and only one investment project. Without loss of generality, we can number these borrowers/projects in numerical order, which represents their riskiness. i.e. $\theta \in 1, 2, 3, \ldots, N$, and the bigger the θ, the greater the volatility of project returns, which implies greater risk of the project. These projects are assumed to be observationally identical in the sense of mean

[1] We will use these two terms interchangeably in the remaining analysis.

preserving spreads.[1]

We assume that borrowers have identical initial wealth and need to borrow amount B from bank to start their projects. The rate of interest borrowers have to pay is r_L, which is determined by the bank. Based on this set up, Stiglitz-Weiss showed that for a given level of interest rate on the loan, there is a critical value θ^* such that a borrower borrows from the bank if and only if $\theta > \theta^*$. This critical value will increase if the level of interest rate increases. (i.e. $\frac{\partial \theta^*}{\partial r_L} > 0$)

Banks:

There are M identical banks in the credit market, so we can analyse the action of a representative bank. To simplify, we assume there are only two types of assets the bank holds in its portfolios: risky assets (loans) and safe asset (government securities), which provides risk free return r_S. We further assume that the risky assets are observationally identical initially by the way we model the borrowers, which ensures that all the risky assets on the balance sheet of the bank have the same risk weighting.

Let L be the amount of loans on the balance sheet, G be the amount of safe asset, and E be the original amount of bank capital. We assume that when the regulator raises the capital requirement, the bank cannot adjust the amount of capital without cost. This implies that the market for bank capital is not frictionless. Moreover, since we only focus on the short term impact, the inside equity (retain earning, dividend, share repurchase) does not change. Hence, the amount of total equity is constant in the short term. Thus, when the regulator sets a higher capital requirement, the bank will first sell its risky assets to meet the capital shortfall rather than incur the cost associated with raising additional equity.

The bank funds the portfolio of its assets by issuing deposits, which has an interest rate r_D. We assume the amount of deposits is influenced only by the monetary policy set by the central bank and, therefore, is out of the control of individual bank. Hence, the liability side of the balance sheet is fixed, which implies:

$$L + G = constant$$

[1] The definition of mean preserving spreads is given in section 3.2.

Furthermore, we can normalise the rate of interest on deposits r_D to zero, and then r_L and r_S just represent the spreads between the two.

Let δ to be the expected loss given default per unit of L. This is different from the default rate on the loan in the sense that δ excludes the amount of money the bank can recover from the collateral in the event of default. In this sense, we can say that $(r_L - \delta)L$ is the one period return on the risky loan. In this model, we assume δ is an increasing function of r_L (e.g. Figure 35 on page 180). This is because higher lending rate will increase the default rate in the loan portfolio, which will cause greater losses.

Next, we specify the objective function of the bank. The return on equity is the key variable that shareholders are concerned with. The bank is assumed to maximise the rate of return on equity, which is constant as explained above. The objective function can be expressed as:

$$\begin{aligned} \max \quad v(r_L) &= \tfrac{(r_L-\delta)L+r_SG}{E} \\ &= \tfrac{r_L-\delta}{\varphi} + \tfrac{r_SG}{E} \end{aligned} \tag{7.2.1}$$

The main distinguishing feature of our model in relation to the existing literature is that we focus on maximising the return on equity (ROE) rather than the absolute value of bank. Generally, banks use ROE as one of their key measure of performance. For example, Barclays in its annual report set a 13% ROE target and mentions: "We continue to believe that a return on equity of 13% is the right goal... We remain fully committed to delivering 13% returns over time, by driving improved business performance, reducing expenses, and maintaining a disciplined approach to capital and funding costs." Similarly, RBS in its 2011 annual report uses the ROE to compare the performanc of different lines of its business activities. UBS recently shut down its fixed income business based on its shortfall of the target ROE performance. Hence, we can justify the use of ROE in our model given that it is widely used as a performance target by banks.

Note that L is not equal to the amount of loan the bank is willing to supply, instead it is the amount the bank actually can lend out under different economic conditions. So L is equal to the smaller of two, the demand or supply of credit.

We assume that the safe asset is risk free, and therefore has a zero weighting. Given the recent European sovereign debt crisis, we should bear in mind not all government debt has zero risk weighting. For simplicity, here we do not consider risk weighting on government debt here, but this is a possible area of research in the future.

7.3 The lending interest rate and capital requirement

We consider the effect of a change in capital requirement on the bank lending rate under two scenarios. First, the case when the bank's capital constraint is binding. This represents a poorly capitalised bank that has issued the maximum possible amount of loans. As a comparison, we also study the well capitalised bank whose capital constraint is not binding.

7.3.1 Capital constraint is binding

Initially, we assume the capital constraint is binding for the bank. Under the Modigliani and Miller (1958) (MM) the optimal capital structure the valued of the firm is maximised at 100% of debt and the required rate of return on equity is an increasing function of the leverage ratio. Follow the MM proposition, we can assume a bank chooses the optimal leverage given its regulatory capital requirement. Hence, the capital constraint for this bank is always binding.

Under this framework, we can show the following Lemma.

Lemma 7.3.1. *If the capital constraint is binding, the lending interest rate r_L will be an increasing function of φ.*

Here, we provide two possible proofs of this lemma. The first one is straight forward while the second is more robust.

Proof 7.3.1. By definition, the risk weighted capital ratio can be expressed as

$$\varphi = \frac{E}{L}$$

Differentiating this with respect to the interest rate r_L, we can have

$$\frac{\partial \varphi}{\partial r_L} = \frac{\partial \varphi}{\partial L}\frac{\partial L}{\partial r_L} = -\frac{E}{L^2}\frac{\partial L}{\partial r_L} \tag{7.3.1}$$

We know that both E and L^2 are positive. Hence, we just need to determine the sign of $\partial L/\partial r_L$ in order to examine the relationship between φ and r_L.

We deduce that the total amount of lending is a decreasing function of r_L (i.e. $\partial L/\partial r_L \leq 0$) as follow. We know that L is the amount of loans, and it is equal to the smaller of the demand or supply. Also, assuming the normal demand curve for credit is downward sloping, the demand for credit varies inversely with r_L. A decrease in r_L does not necessarily imply L would increase because L is the smaller of the two demand or supply. Also, given that the capital constrain is binding in the short run and the equity is assumed to be fixed, the bank cannot increase the supply of credit. Moreover, given the objective function in equation 7.2.1, the bank does not reduce the supply of credit when the lending rate goes down. If, however, it reduces the supply of credit, it needs to reallocate the reduced amount of capital to the safe asset, which has a lower rate of return. In this case, the bank would simply supply either the quantity of credit demanded or the maximum amount it can lend under the capital constraint depending on which quantity is smaller. As a result, the total amount of lending L will remain the same. So we have $\frac{\partial L}{\partial r_L} \leq 0$.

We can illustrate the above argument in a standard demand and supply diagram (Figure 36 on page 181)[1]. We have the normal downward sloping demand curve and the supply curve is perfectly inelastic since the capital constraint is binding. The quantity of supply is zero when the lending rate is less than or equal to $\delta + r_S$ [2], and the bank cannot change the quantity supplied for any

[1]The credit supply and demand curves are chosen for illustration purpose. We appreciate that Arnold and Riley (2009) propose a credit supply function that has a global maximum at the maximum interest rate bank can charge. They deduce that the hump shape supply function proposed in Stiglitz-Weiss is not true. However, they do not consider capital requirement as well as the rate of return. So the credit supply curve in our model could be significantly different from that in Arnold and Riley (2009). The figure here is just for demonstration purpose.

[2]Note that $r_L < \delta + r_S$ could happen either at a very low interest rate or at a very high interest rate since the loss given default δ will change as interest rate changes. We refer to the two critical levels of interest rates that equal to $\delta + r_S$ as r_L^u and r_L^d in Figure 36 on page 181.

lending rate above $\delta + r_S$. Suppose that demand is equal to supply initially at point A and $L = L_A$. If the interest rate falls to r_L^1, the demand will increase to point C, so $L = min(Q_D, Q_S) = L_A$, where Q_D, Q_S are the quantity of demand and supply, respectively. If the lending rate rises to r_L^2, the demand will fall to point B, so $L = min(Q_D, Q_S) = L_B$. Hence, if the bank charges a lending rate $r_L > \delta + r_S$, then $\frac{\partial L}{\partial r_L} \leq 0$. If $r_L < \delta + r_S$, then the bank will hold only the government security. But we know that the lending rate r_L is set by the bank, which implies that r_L will never be set at such a level.

Hence, Equation 7.3.1 implies that $\frac{\partial \varphi}{\partial r_L} \geq 0$ for any $\varphi > 0$. ■

An alternative way of obtaining the same result is given below.

Proof 7.3.2. By differentiating Equation 7.2.1 with respect to r_L, and applying the first order condition and rearranging, we have

$$\frac{\partial \varphi}{\partial r_L} = \frac{\varphi}{r_L - \delta}\left(1 - \frac{\partial \delta}{\partial r_L} - \frac{r_S}{E}\frac{\partial L}{\partial r_L}\varphi\right) \tag{7.3.2}$$

Given that $r_L - \delta$ has to be greater than 0. If this is not the case, the bank will only hold the government security. We then have

$$r_L > \delta$$

Hence

$$1 > \frac{\partial \delta}{\partial r_L} \tag{7.3.3}$$

This implies that the loss given default rate is changing at a smaller rate than the lending rate.

Also, $\varphi > 0$ by definition. Following the same logic in the first proof, we have $\frac{\partial L}{\partial r_L} \leq 0$. We consider the case $\frac{\partial L}{\partial r_L} = 0$ and $\frac{\partial L}{\partial r_L} < 0$ separately.

Case I: $\frac{\partial L}{\partial r_L} = 0$

$$\frac{\partial \varphi}{\partial r_L} = \frac{\varphi}{r_L - \delta}\left(1 - \frac{\partial \delta}{\partial r_L}\right) > 0$$

Since $\frac{\partial \varphi}{\partial r_L}$ always has the same sign as $\frac{\partial r_L}{\partial \varphi}$, we know $\frac{\partial r_L}{\partial \varphi} > 0$ for any $\varphi > 0$. Hence, the conclusion is that any increase in capital requirement will increase the lending rate on the loan.

Case II: $\frac{\partial L}{\partial r_L} < 0$

By re-arranging Equation 7.3.1, we have

$$\frac{\partial \varphi}{\partial r_L} \begin{cases} > 0 \quad \text{if} \quad \varphi > \dfrac{1 - \dfrac{\partial \delta}{\partial r_L}}{\dfrac{\partial L}{\partial r_L}} \frac{E}{r_S} = \varphi^* \\ \\ < 0 \quad \text{if} \quad \varphi < \dfrac{1 - \dfrac{\partial \delta}{\partial r_L}}{\dfrac{\partial L}{\partial r_L}} \dfrac{E}{r_S} = \varphi^* \end{cases} \tag{7.3.4}$$

Since $\frac{\partial L}{\partial r_L} \leq 0$, and we know that E and r_S are both positive number. Also, from Equation 7.3.3, we know $\frac{\partial \delta}{\partial r_L} < 1$, then $\dfrac{1 - \dfrac{\partial \delta}{\partial r_L}}{\dfrac{\partial L}{\partial r_L}} \dfrac{E}{r_S} < 0$. We know that the capital requirement φ has to be greater than zero, and therefore we have

$$\varphi > 0 > \frac{1 - \frac{\partial \delta}{\partial r_L}}{\frac{\partial L}{\partial r_L}} \frac{E}{r_S}$$

Hence, we can deduce that $\frac{\partial \varphi}{\partial r_L} > 0$ for any $\varphi > 0$, which is the same result as shown above. ■

The second proof is more robust ($\frac{\partial \varphi}{\partial r_L} > 0$ compared to $\frac{\partial \varphi}{\partial r_L} \geq 0$ the first one). The result indicates that an increase in capital requirement will cause lending rate on the bank loan to rise and it shrinks the loan portfolio of the bank. A decrease in capital requirement, however, can have the opposite effect - the bank will reduce lending rate and increase the size of its loan portfolio.

Lemma 7.3.1 implies that when the regulator increases capital requirement, poorly capitalised banks [1] will raise the lending rate they charge on the loans and shrink the risky loan portfolio to meet the capital requirement. A consequence of this is that the total lending volume in the market falls, which can cause the investment activity and even the whole economy to slow down. This suggests

[1]By poorly capitalised banks, we mean the banks whose capital constraint is binding.

that if most of the banks are poorly capitalised and the economy is in a recession, the regulator should not increase the capital requirement in such a distressed environment. It should only raise capital requirement when the economy is in a growth phase. In summary, a countercyclical capital requirement policy is preferable in the case of a poorly capitalised banking system.

7.3.2 Capital constraint is not binding

In this part, we assume the capital constraint is not binding for the bank. This is a more realistic case since the majority of banks (and building societies) do hold capital buffers in practice. This type of practice does contradict the Modigliani-Miller's proposition (with taxes) for capital structure. It is, however, in line with the static trade-off theory, which seeks to balance the costs of financial distress with the tax shield benefits from using debt. Under the static trade-off theory, banks will choose the capital structure that minimise their weighted average cost of capital, which can differ from across banks since the costs of distress are different. In this sense, the banks will not choose the maximum level of leverage and, therefore, capital buffer exists. We refer to this as a well capitalised banking system.

If a bank does hold capital buffer, however, the return on equity will decrease since the capital buffer does not generate any additional profit. We can see this from equation 7.2.1:

$$v(r_L) == \frac{(r_L - \delta)L + r_S G}{E}$$

Capital buffer implies E will become greater but L does not change. G will increase but offers lower rate of return than the risky assets. Hence, a lower overall rate of return on assets. These banks are choosing a suboptimal rate of return since they have a different form of the objective function that minimises the weighted average cost of capital. Nonetheless, our analysis for poorly capitalised banks is still valid in this case if we assume these banks keep the proportion of the capital buffer fixed. The constraint for these well capitalised banks becomes the capital requirement plus their target capital buffer ratio, and this new constraint is binding initially, therefore, Lemma 7.3.1 is still valid here.

We can obtain the same conclusion here as we had for the case of a poorly capitalised bank. An increase in capital requirement causes a well capitalised bank to decrease the volume of lending and, consequently, have an adverse effect on the overall economic activity. As a result, the regulator should not try to increase the capital requirement when the economy is in a recession. Again, a countercyclical capital requirement policy is preferable.

7.3.3 A summary of the effect of binding and non-binding capital constraint

We should bear in mind that the effect of change in capital requirement on the lending rate is limited if $r_L = \delta + r_S$. The above analysis assumed that the bank will only set the lending rate r_L such that $r_L > \delta + r_S$. The case $r_L < \delta + r_S$ could happen when either r_L is too low or r_L is too high. It is easy to understand that when r_L is too low the bank will not want to lend. But, why the bank does not want to lend when the lending rate is too high? The answer to this question is simply that the loss given default δ will rise as r_L increases, which can cause the risk adjusted return to be lower than the return on the safe asset. This is in line with Stiglitz-Weiss result that if the bank raises the lending rate, safe borrowers withdraw from the credit market before the risky borrowers. As a result, the bank will set the lending rate in a reasonable range to make sure that the risk adjusted return $r_L - \delta > r_S$. Let us say for any $r_L > r^u$ and $r_L < r^d$, the risk adjusted return on loans is lower than the return from the safe asset (i.e. $r_L < \delta + r_S$). Lemma 7.3.1 suggests r_L is positively correlated with φ, so an increase in capital requirement φ will cause the bank to raise lending rate r_L. Consequently, there will be a corresponding value of φ, say φ^u, that makes $r_L = r^u$. The bank will not adjust its lending rate if the capital requirement is raised above this upper bound.

In summary, for any

$$\varphi > \varphi^u$$
$$\frac{\partial r_L}{\partial \varphi} = 0$$

Hence, we know that an increase in capital requirement will not have any effect on the lending rate r_L.

Similar conclusion can be reached for the lower bound of r_L. There is a lower bound φ^d for changes in capital requirement that can effectively change the lending rate. For any

$$\varphi < \varphi^d$$
$$\frac{\partial r_L}{\partial \varphi} = 0$$

Putting this together, we have:

$$\frac{\partial r_L}{\partial \varphi} \begin{cases} > 0 & \text{if} \quad \varphi \in [\varphi^d, \varphi^u] \\ = 0 & \text{Otherwise} \end{cases} \tag{7.3.5}$$

Combining the above analysis with our discussion on well capitalised banks, Lemma 7.3.1 should be restated as follow.

Lemma 7.3.2. *If the capital requirement is within certain range $[\varphi^d, \varphi^u]$, the lending rate r_L is positively correlated with φ. If the capital requirement is outside this range, changes in capital requirement does not have any effect on the lending rate r_L. This result holds for both poorly capitalised bank and well capitalised bank.*

7.4 The magnitude of credit rationing

Recall that there are N borrowers, and each has one and only one investment project. The numerical order of these N projects represent their riskiness. i.e. $\theta \in 1, 2, 3, \ldots, N$, and the bigger the θ, the greater the volatility of the project return implies greater risk of the project. These borrowers have identical initial wealth and need to borrow B from the banks to start their projects. Stiglitz-Weiss show that for a given level of lending rate on the loans, there is a critical value θ^* such that a borrower borrows from the bank if and only if $\theta > \theta^*$. This critical value will increase if the level of lending rate increases. (i.e. $\frac{\partial \theta^*}{\partial r_L} > 0$). As a result, $N - \theta^*$ is the number of borrowers who apply for loans given an lending rate r_L, and $B(N - \theta^*)$ is the aggregate demand for loan in the credit market.

Also, note that there are M identical banks in the credit market. As a result, we just need to analyse the action of a representative bank. Let S be the amount of loan a typical bank would like to supply given the lending rate r_L. Note that this S is different from the L in the previous section. S represents the quantity of credit the bank is willing to supply and L is the smaller of the quantity of supply or demand. Hence, we denote MS as the aggregate supply of loan in the credit market.

Now, let us define the magnitude of credit rationing as the difference between demand and supply:

$$\Omega = B(N - \theta^*) - MS \tag{7.4.1}$$

Recall that the definition of credit rationing Stiglitz-Weiss:

Among a group of observationally identical borrowers some will receive loan and others not. For those borrowers who have been denied loans would not be able to borrow even if they indicate a willingness to pay more than the market lending rate or to put up more collateral than that demanded by the bank.

Our definition of the magnitude of credit rationing is in line with Stiglitz-Weiss's definition. Once $\Omega > 0$ the bank needs to randomly reject borrowers from an observationally identical group of borrowers.

We investigate how the magnitude of credit rationing changes with the capital requirement. We only consider the bank that faces a binding capital constraint in this part of the analysis. This is because we assume that a well capitalised bank has capital buffer target and therefore is not subject to a tighter binding constraint. Hence, these two types of banks will take the same action as they did before the capital requirement changed.

Based on our definition of the magnitude of credit rationing and Lemma 7.3.2, we prove the following Lemma:

Lemma 7.4.1. *Depending on the level of capital requirement, a rise in the minimum capital requirement can either increase or decrease the magnitude of credit rationing.*

Proof 7.4.1. Differentiate Equation 7.3.3 with respect to φ, we can get

$$\begin{aligned} \frac{\partial\Omega}{\partial\varphi} &= \frac{\partial(B(N-\theta^*))}{\partial\theta^*}\frac{\partial\theta^*}{\partial r_L}\frac{\partial r_L}{\partial\varphi} - M\frac{\partial S}{\partial\varphi} \\ &= -B\frac{\partial\theta^*}{\partial r_L}\frac{\partial r_L}{\partial\varphi} - M\frac{\partial S}{\partial\varphi} \end{aligned} \tag{7.4.2}$$

Stiglitz-Weiss's result shows that the critical value of the riskiness of loan applicant θ^* is an increasing function of r_L. So we have $\frac{\partial \theta^*}{\partial r_L} > 0$.

From the proof in Lemma 7.3.1, we know that the credit supply curve is perfectly inelastic, and an increase in capital requirement will shift the whole supply curve to the left. Hence, we have $\frac{\partial S}{\partial \varphi} < 0$. This also can be deduced from the fact that the equity of bank is fixed in the short run and the only way it can increase the risk weighted capital ratio is to reduce the risk weighted assets, which is the loan portfolio. Hence, an increase in capital requirement will reduce the supply of credit.

From Lemma 7.3.2, we know $\frac{\partial r_L}{\partial \varphi} > 0$ for any $\varphi \in [\varphi^d, \varphi^u]$, and $\frac{\partial r_L}{\partial \varphi} = 0$ otherwise. We consider these two cases separately.

Case I: $\frac{\partial r_L}{\partial \varphi} = 0$

If $\varphi \notin [\varphi^d, \varphi^u]$, then $\frac{\partial r_L}{\partial \varphi} = 0$. Equation 7.4.2 becomes:

$$\frac{\partial \Omega}{\partial \varphi} = -M \frac{\partial S}{\partial \varphi}$$

Since $\frac{\partial S}{\partial \varphi} < 0$, we have $\frac{\partial \Omega}{\partial \varphi} > 0$ in this case.

Case II: $\frac{\partial r_L}{\partial \varphi} > 0$

In this case, rearranging the terms in Equation 7.4.2 to give:

$$\frac{\partial \Omega}{\partial \varphi} \begin{cases} > 0 & \text{if} \quad \frac{\partial r_L}{\partial \varphi} < (-M\frac{\partial S}{\partial \varphi})/(B\frac{\partial \theta^*}{\partial r_L}) \\ = 0 & \text{if} \quad \frac{\partial r_L}{\partial \varphi} = (-M\frac{\partial S}{\partial \varphi})/(B\frac{\partial \theta^*}{\partial r_L}) \\ < 0 & \text{if} \quad \frac{\partial r_L}{\partial \varphi} > (-M\frac{\partial S}{\partial \varphi})/(B\frac{\partial \theta^*}{\partial r_L}) \end{cases} \tag{7.4.3}$$

Since $\frac{\partial S}{\partial \varphi} < 0$, the right hand side of $\frac{\partial r_L}{\partial \varphi} < (-M\frac{\partial S}{\partial \varphi})/(B\frac{\partial \theta^*}{\partial r_L})$ is positive.

From equation 7.3.2, we know that $\frac{\partial \varphi}{\partial r_L} = \frac{\varphi}{r_L - \delta}(1 - \frac{\partial \delta}{\partial r_L} - \frac{r_S}{E}\frac{\partial L}{\partial r_L}\varphi)$. Hence, we can find the critical value of the minimum capital requirement ratio in order to determine the sign of $\frac{\partial\Omega}{\partial\varphi}$ by solving φ from

$$\frac{r_L-\delta}{\varphi(1-\dfrac{\partial\delta}{\partial r_L}-\dfrac{r_S}{E}\dfrac{\partial L}{\partial r_L}\varphi)} < \frac{-M\dfrac{\partial S}{\partial\varphi}}{B\dfrac{\partial\theta^*}{\partial r_L}} \tag{7.4.4}$$

Since $\frac{\partial r_L}{\partial\varphi}>0$, we know $1-\frac{\partial\delta}{\partial r_L}-\frac{r_S}{E}\frac{\partial L}{\partial r_L}\varphi>0$, the above inequality become

$$f(\varphi)=M\frac{\partial S}{\partial\varphi}\frac{r_S}{E}\frac{\partial S}{\partial r_L}\varphi^2-M\frac{\partial L}{\partial\varphi}(1-\frac{\partial\delta}{\partial r_L})\varphi-(r_L-\delta)B\frac{\partial\theta^*}{\partial r_L}>0 \tag{7.4.5}$$

This is a quadratic function. Since $M\frac{\partial S}{\partial\varphi}\frac{r_S}{E}\frac{\partial L}{\partial r_L}>0$, and $f(0)=(r_L-\delta)(-B)\frac{\partial\theta^*}{\partial r_L}$, which is less than 0 by assumption, we can conclude that the positive root of $f(\varphi)=0$ is the critical value for φ in this case. Let us call this value $\hat{\varphi}_+$, but due to the complexity, we do not give an explicit expression here. Hence, we have

$$\frac{\partial\Omega}{\partial\varphi}\begin{cases} >0 & \text{if} \quad \varphi>\hat{\varphi}_+ \\ =0 & \text{if} \quad \varphi=\hat{\varphi}_+ \\ <0 & \text{if} \quad 0<\varphi<\hat{\varphi}_+ \end{cases} \tag{7.4.6}$$

We can summarise the two cases together

Scenario I: $\hat{\varphi}_+<\varphi^d$

$$\frac{\partial\Omega}{\partial\varphi}>0 \quad \text{if} \quad \varphi>0 \tag{7.4.7}$$

Scenario II: $\hat{\varphi}_+\in[\varphi^d,\varphi^u]$

$$\frac{\partial\Omega}{\partial\varphi}\begin{cases} >0 & \text{if} \quad 0<\varphi<\varphi^d \\ <0 & \text{if} \quad \varphi^d<\varphi<\hat{\varphi}_+ \\ >0 & \text{if} \quad \hat{\varphi}_+<\varphi \end{cases} \tag{7.4.8}$$

Scenario III: $\hat{\varphi}_+>\varphi^u$

$$\frac{\partial\Omega}{\partial\varphi}\begin{cases} >0 & \text{if} \quad 0<\varphi<\varphi^d \\ <0 & \text{if} \quad \varphi^d<\varphi<\varphi^u \\ >0 & \text{if} \quad \varphi^u<\varphi \end{cases} \tag{7.4.9}$$

We ignore the case that $\frac{\partial \Omega}{\partial \varphi} = 0$ when $\varphi = \hat{\varphi}_+$ in the above summary since this only happens if the change in φ is infinitely small around the point $\hat{\varphi}_+$, but we know that the change in capital requirement cannot be infinitely small, so this case has been ruled out. ■

It is convenient to visualize this result in a graph[1] as set out in Figure 37 on page 181 for Scenario I. Following Stiglitz-Weiss we assume the initial lending rate is below the market clearing level and credit rationing exists. In Figure 37, r_L^0 is the initial lending rate and L_0 is the initial lending volume. The red line represents the initial magnitude of credit rationing. If the regulator raises capital requirement, we know that the supply curve of credit will shift to left and the demand for credit will move along the demand curve as a result of the change in lending rate. Suppose the lending rate increases to r_L^1 and the supply curve shifts to L_S^1. These combine effect imply that the higher capital requirement has a greater impact on the supply of credit than on lending rate. The green line represents the new magnitude of credit rationing. Comparing the initial magnitude of credit rationing against the new magnitude of credit rationing, we can see that the green line is greater than the red line. Hence, the magnitude of credit rationing is greater when there is higher capital requirement. If the capital requirement rises above φ_u, the corresponding lending rate is r_u, we know from our previous discussion that the bank will not raise the lending rate any further. Instead, the bank will charge an lending rate marginally below r_u, and decrease the supply of credit to a level that marginally satisfies the capital requirement. We denote this L_S^2 in Figure 37. Therefore, if the current capital requirement is above φ_u and the regulator imposes even higher capital requirement, the lending rate will not change, but L_S^2 will shift further to the left. Inevitably, the magnitude of credit rationing (Orange line in Figure 37) will rise. [2]

Figure 38 on page 182 presents Scenario II, $\hat{\varphi}_+ \in [\varphi^d, \varphi^u]$. The only difference between this case and the scenario I, $\hat{\varphi}_+ < \varphi^d$, is that when the capital requirement rises above a certain level within the range of $[\varphi^d, \varphi^u]$, there is a possibility

[1] The credit supply and demand curves are chosen for illustration purpose.

[2] Note that we only consider the change in magnitude of credit rationing within the range $\varphi \in [\varphi^d, \varphi^u]$ and $\varphi > \varphi^u$ separately. The case that δ increases from the range $[\varphi^d, \varphi^u]$ to some $\varphi > \varphi^u$ will need to know the exact value of each parameters to evaluate.

that the demand for credit will decrease more than the supply of credit. As can be seen in Figure 38, if the capital requirement is increases for the first time, the lending rate increases to r_L^1 and supply curve shifts to L_S^1, so the magnitude of credit rationing (green line) goes up. But if the capital requirement is raised further, the lending rate can increase to $r_L^{'}$ and the credit supply curve will shift to $L_S^{'}$ in this scenario, thereby lowering the magnitude of credit rationing (black line). When $\varphi > \varphi^u$, the effect will be the same as in Scenario I.

Figure 39 on page 182 presents Scenario III, $\hat{\varphi}_+ > \varphi^u$. In this case, any increase in capital requirement within the range $[\varphi^d, \varphi^u]$ will reduce the magnitude of credit rationing. A possible explanation for this is that the demand for credit is more sensitive to changes in capital requirement than the supply of credit. But, if the capital requirement exceeds the range $[\varphi^d, \varphi^u]$, the magnitude of credit rationing will go up.

In summary, the effect of higher regulatory capital requirement on the magnitude of credit rationing is very sensitive to the shapes of the credit demand and supply curves.

7.5 The profitability of bank and capital requirement

Along with the effect of higher capital requirement on the magnitude of credit rationing, the regulator should also consider the effect on the profitability of bank. Normally higher capital requirement can be expected to reduce the profitability. Moreover, we expect the return on equity to fall, assuming that the bank can costlessly adjust its equity without changing its asset side, because the numerator of the ROE is unaffected but the denominator goes up. However, this will not be the case in our model since we assume the bank cannot change its equity in the short run. Consequently the bank has to shrink its risky asset holding in order to meet the higher capital requirement. In this case, the denominator of ROE does not change, but we need to investigate the effect on the risk weighted asset (numerator).

We can show the following lemma:

Lemma 7.5.1. *Risk weighted capital requirement policy only has effect on the profitability of the bank in the region of* $[\varphi^d, \varphi^u]$*. Inside this region, there is an optimal risk weighted capital ratio that maximises the profitability.*

Proof 7.5.1. We differentiate equation 7.2.1 with respect to φ to investigate how the bank's return would change if the capital requirement change. Rearranging the terms in the first order condition gives:

$$\frac{\partial v}{\partial \varphi} = \frac{\varphi \dfrac{\partial r_L}{\partial \varphi} - (r_L - \delta - r_S)}{\varphi^2} \tag{7.5.1}$$

From Lemma 7.3.2, we know that $\frac{\partial r_L}{\partial \varphi} > 0$ for any $\varphi \in [\varphi^d, \varphi^u]$, and $\frac{\partial r_L}{\partial \varphi} = 0$ otherwise. We consider these two cases separately.

Case I: $\frac{\partial r_L}{\partial \varphi} = 0$

This case represents the scenario that the higher capital requirement does not have any effect on the lending rate. This condition only holds if $\varphi \notin [\varphi^d, \varphi^u]$. Also, the condition $r_L - \delta \leq r_S$ holds. Under such a scenario, the bank has two choices: it can either it holds no risky asset, effectively acts as broker of for the safe asset, or charge the lending rate r_L^d and r_L^u that corresponds to φ^d and φ^u. Next, the former case implies the bank does not function as a financial intermediary and, therefore, its profitability is unaffected by the higher capital requirement. The later case implies $r_L - \delta - r_S = 0$, so $\frac{\partial v}{\partial \varphi} = 0$.

Case II: $\frac{\partial r_L}{\partial \varphi} > 0$

This case represents the scenario that the higher capital requirement does affect the lending rate in contrast to the previous case.

The denominator of Equation 7.5.1 is $\varphi^2 > 0$, and therefore we just need to consider the numerator

$$\varphi \frac{\partial r_L}{\partial \varphi} > r_L - \delta - r_S \tag{7.5.2}$$

From equation 7.3.2, we know that $\frac{\partial \varphi}{\partial r_L} = \frac{\varphi}{r_L - \delta}(1 - \frac{\partial \delta}{\partial r_L} - \frac{r_S}{E} \frac{\partial L}{\partial r_L} \varphi)$. Hence, we have $\frac{\partial v}{\partial \varphi} > 0$, if and only if

$$\frac{r_L - \delta}{1 - \dfrac{\partial \delta}{\partial r_L} - \dfrac{r_S}{E} \dfrac{\partial L}{r_L} \varphi} > r_L - \delta - r_S \tag{7.5.3}$$

Since $\frac{\partial r_L}{\partial \varphi} > 0$, we have $1 - \frac{\partial \delta}{\partial r_L} - \frac{r_S}{E}\frac{\partial L}{r_L}\varphi > 0$. Rearranging the terms in Equation 7.5.3 can give us that $\frac{\partial v}{\partial \varphi} > 0$, if and only if

$$\varphi < \frac{1 - \dfrac{\partial \delta}{\partial r_L} - \dfrac{r_L - \delta}{r_L - \delta - r_S}}{\dfrac{r_S}{E}\dfrac{\partial L}{\partial r_L}} = \bar{\varphi} \tag{7.5.4}$$

Note that $\frac{\partial L}{\partial r_L} \leq 0$, so the denominator is less than zero. So if $1 - \frac{\partial \delta}{\partial r_L} - \frac{r_L - \delta}{r_L - \delta - r_S} > 0$, then $\bar{\varphi} < 0$.

Since the capital requirement has to be greater than zero, we can conclude that $\frac{\partial v}{\partial \varphi} < 0$ for any $\varphi \in [\varphi^d, \varphi^u]$. This implies that an increase in capital requirement will reduce the profitability of bank.

If $1 - \frac{\partial \delta}{\partial r_L} - \frac{r_L - \delta}{r_L - \delta - r_S} < 0$, it is possible that $\bar{\varphi} \in [\varphi^d, \varphi^u]$. Therefore, an increase in capital requirement up to $\bar{\varphi}$ can increase the profitability.

We can summarise the above analysis as follow:

For $\bar{\varphi} \notin [\varphi^d, \varphi^u]$

$$\frac{\partial v}{\partial \varphi} < 0 \quad \text{for} \quad \text{any} \quad \varphi \in [\varphi^d, \varphi^u] \tag{7.5.5}$$

For $\bar{\varphi} \in [\varphi^d, \varphi^u]$

$$\frac{\partial v}{\partial \varphi} \begin{cases} > 0 & \text{if} \quad \varphi^d < \varphi < \bar{\varphi} \\ < 0 & \text{if} \quad \bar{\varphi} < \varphi < \varphi^u \end{cases} \tag{7.5.6}$$

■

7.6 Concluding remarks

The return on equity is one of the most important measures of performance used by banks. This chapter considers the effect of higher regulatory capital requirement on lending rate, the magnitude of credit rationing and profitability. More specifically, we formulate an optimisation problem based on the ROE of bank that better captures the business decisions in reality. Other features of the model include the asset allocation between safe and risky assets, fixed amount of equity in the short run, and both the supply of credit as well as the demand of credit, that enable us to assess the magnitude of credit rationing in the credit market. We derive three key results which depend on the specification of an upper bound and a lower bound of capital requirement. First, within these bounds, the lending rate is shown to be an increasing function of capital requirement. We build on Stiglitz-Weiss to study the effect of capital requirement on credit rationing. Our main contribution here is to quantify the magnitude of credit rationing. Second, following from the first result, the magnitude of credit rationing is shown to depend crucially on the specific forms of the credit supply and demand functions. This result suggests that the regulator needs to consider the magnitude of credit rationing in setting capital requirement. In practice, the regulator has multiple objectives, of which stability of the banking system has been an overriding consideration in the aftermath of 2007 crisis. During the crisis, the banking system experienced forced deleveraging, fire sales of assets and portfolio restructuring, aimed at the sole purpose of recapitalisation, which resulted in contraction of credit supply to corporates and households. Under this set of circumstances the timing of setting higher capital requirement is crucial because the option to raise new equity to recapitalise banks in deteriorating economic conditions was limited. Our results demonstrate that a flexible countercyclical regulatory capital requirement is more desirable for accommodating economic activities. Third, there is an optimal risk weighted capital requirement that maximises the profitability of bank within the bounds specified. Outside of these specified bounds, risk weighted capital requirement is shown to be ineffective.

This credit rationing model is a useful tool for real estate investors. As investors anticipate higher capital requirement for banks in the near future, they can assess the likely implication on the magnitude of credit rationing, which inevitably affect the success of their loan application. For the regulator and policy makers, it is crucial to take into account the short run changes in the magnitude of credit rationing to prevent the formation of housing bubbles[1].

[1]An example is the Chinese housing market in recent years

Chapter 8

Conclusions

This thesis studies a number of effects of Basel III higher capital requirement on the credit market. The Basel III was introduced to address the loophole of banking regulation that resulted from the 2007 global financial crisis. After the crisis, the waxing issue has been under-capitalisation of many global banks. The introduction of Basel III was seen as a major long term measure to strengthen the stability of the global banking system and support economic recovery. The capital requirement measure in Basel III is one of the most important policy tools to support this aim. There is, however, ample empirical evidence that the implementation of this higher regulatory capital requirement has caused a significant reduction in the supply of credit. In this thesis, we assess the impact of higher capital requirement on the supply of credit and the changes in the magnitude of credit rationing. We make a number of contributions to the existing literature on the effects of higher capital requirement and credit rationing.

First, we adapt the maximum likelihood method to empirically analyse the extent of disequilibrium in the UK credit market. Our sample period from 2000 to 2012 covers a period of significant change in the banking sector as discussed in chapter 2. Our results indicate that the UK credit market is generally in disequilibrium over the sample period with the quantity of credit demand exceeding the quantity of credit supply, which is in line with our expectation. Based on these results and the lessons learnt from the 2007 global financial crisis, we formulate three theoretical models to study the impacts of higher regulatory capital requirement on the credit market. Under the assumption of perfect competitive banking system, we develop a credit market cobweb model to study the dynamics of the supply and demand of credit. Under the unconstrained lending scenario and capital constrained credit supply scenario, we analytically derive the evolution of the expected lending rate, the profit for bank and the stability conditions. We also present numerical analysis to demonstrate these results. The results show that the stability conditions for the banking system vary over time, and regulatory capital requirement can ensure the stability of the banking system.

We then relax the assumption of the perfectly competitive banking system in order to investigate the effect of Basel III regulatory capital requirement and leverage requirement on the optimal portfolio allocation between safe and risky assets for a representative bank. By incorporating the expected default rate into the return on risky assets, we characterise the optimal conditions by a set of equations that depend on the specific functional forms of the cost functions. A numerical example is presented to illustrate the effect of higher capital requirement on the bank portfolio selection decision. This provides a useful basis from which to explain the recent shrinkage of bank lending following the 2007 global financial crisis.

Having considered the supply side of the credit market through the cobweb approach and the optimal portfolio allocation approach, next we study the magnitude of credit rationing by considering both the supply side as well as the demand side of the credit market. We develop an optimisation of the rate of return decisions for the bank. First we show that there is a positive relationship between the lending rate and capital requirement. Based on this result, we deduce that raising the capital requirement can have a significant impact on the magnitude of credit rationing, but the effect will depend on the specific forms of the credit supply and demand functions. Three different demand functions are specified to illustrate this result. We further derive that raising the capital requirement may have an adverse effect on the profitability of the bank.

The results in this thesis have a number of policy implications. First, the disequilibrium model in chapter 4 can help central banks to identify the main drivers of credit market disequilibrium. Based on the results of our cobweb credit model in chapter 5, we believe the risk-based capital requirement policy is essential for the stability of the banking sector. More importantly, all of our results suggest the necessity of a countercyclical regulatory capital requirement policy. This is essentially due to the nature of credit market where the default rate on loan is a stochastic process. This makes the credit market vulnerable to default shocks. A countercyclical capital policy can provide a more flexible mechanism for addressing the default shocks by setting appropriate guidelines to banks for the portfolio allocation over the economic cycles. Moreover, our results in chapter 7 imply that the countercyclical capital policy can reduce the magnitude of credit rationing.

During the recent global financial crisis, the central banks attempted to stimulate the economic growth by using the policy of quantitative easing. Our results in chapter 6 show that the QE policy may have increased the return on safe asset. Consequently, the QE policy prevented the banks from lending to risky borrowers because the risk adjusted return on the safe asset far exceeded that on the risky assets. Thus, QE policy did not seen to have achieved the objective of increasing the supply of credit. The central banks have to carefully re-assess the likely combined effect of different policies to ensure banking stability and boost the credit supply to risky borrowers.

Our general models and results in this thesis provide a number of useful bases for the future study in real estate credit market. First, real estate investors can use the disequilibrium model in chapter 4 to identify the main factors that affect the success of their mortgage applications and assess the general conditions of the mortgage supply in the market. Depending on the characteristics of the specific real estate sector, we can either use the cobweb approach we proposed in chapter 5 or bank portfolio selection approach in chapter 6 to study the long run effect of raising capital requirement on the credit supply to the real estate market. Given that the capital requirement for banks will continue to change in the future, we can use the credit rationing model proposed in chapter 7 to quantify the short run changes in the magnitude of credit rationing, which can give regulator and policy makers insight into the effect of Basel III on the real estate market.

We would like to point out some limitations of this thesis as well as a number of potential future research areas. First, we use 'representative bank' approach in this thesis. This simplification can offer the advantage of reducing the complexity of the model and keeping the result tractable. But, the interbank market is absence means that this approach cannot capture the correlation between banks. As a result, extending our models to incorporate heterogeneous banks will be one of our future research areas. Second, we do not distinguish inside and outside equity in our models for simplicity. In reality, the equity portion of the bank can either come from retained earning or from outside capital. By considering both credit rationing in the asset side and equity rationing in the liabilities side of the balance sheet for a representative bank, we may be able to obtain more complete results of the full impact of Basel III higher capital requirement. Third, our credit rationing model is a static two-period model, however, in reality banks operate as an on-going concern over an indefinite time horizon. A multi-period model, therefore, may provide a more general theoretical framework for analysing intertemporal effects of higher capital requirement. Our credit market cobweb model and bank optimal portfolio model can form the basis for extending the credit supply side of this multi-period model. This extension may require a more general model that incorporates the demand side of the credit market, which maintains the 'identical borrowers' in the sense of Stiglitz-Weiss. Fourth, we do not consider the role of deposit insurance in our models. Deposit insurance can reduce the probability of a bank run significantly. Hence, it may have an impact on the magnitude of credit rationing. Again, in order to obtain tractable results, we ignore the role of deposit insurance in this thesis. This could be a potential future research area. Fifth, in addition to the numerical analysis provided in this thesis, it may be more realistic to carry out empirical analysis of our models if the relevant data is available. Finally, in order to ensure the results are tractable, the models developed in this thesis do not consider the irrational behaviour of participants in the credit market. Extending the models to incorporate bounded rationality and prospect theory would make the models more realistic but at the cost of added complexity.

Appendix A

.1 List of figures for Chapter 4

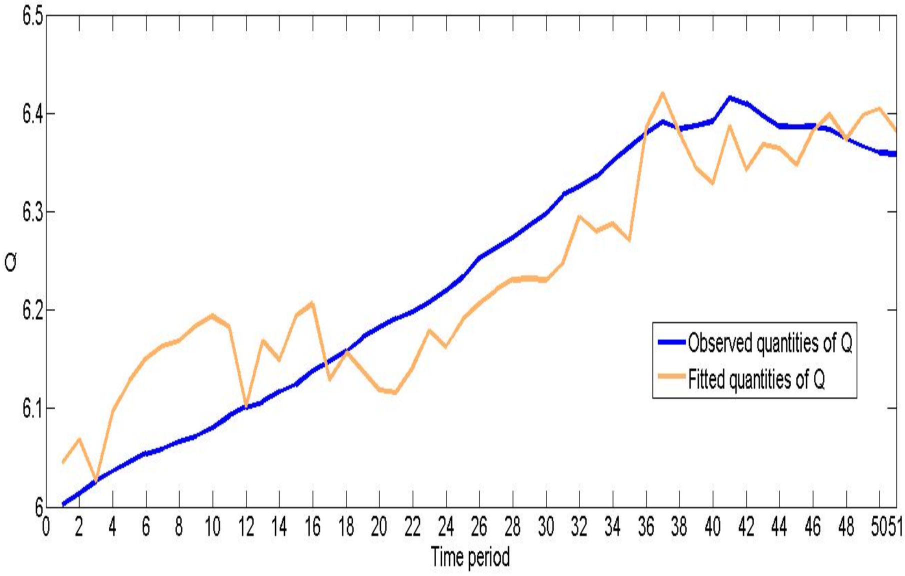


Figure 1: Fitted Q

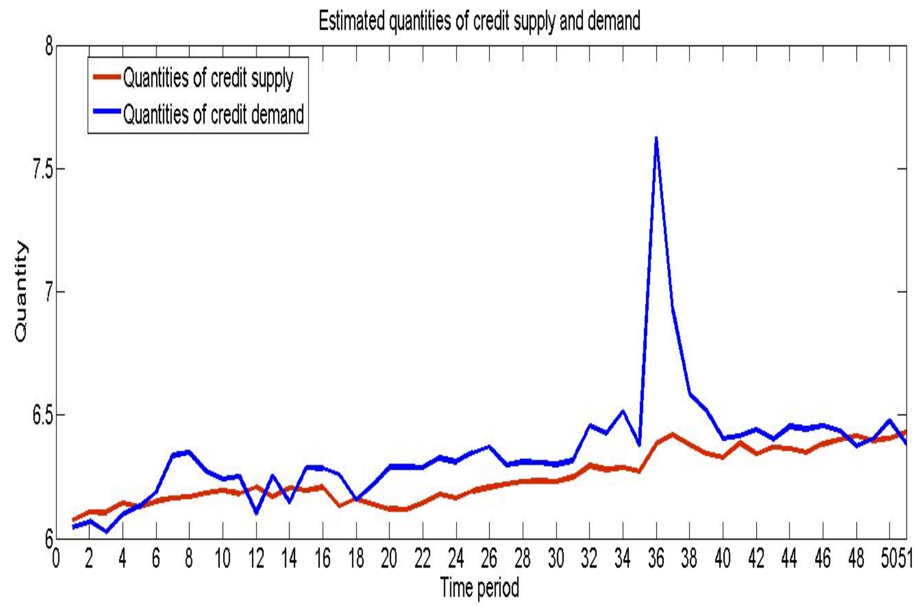


Figure 2: Estimated quantities of credit supply and demand

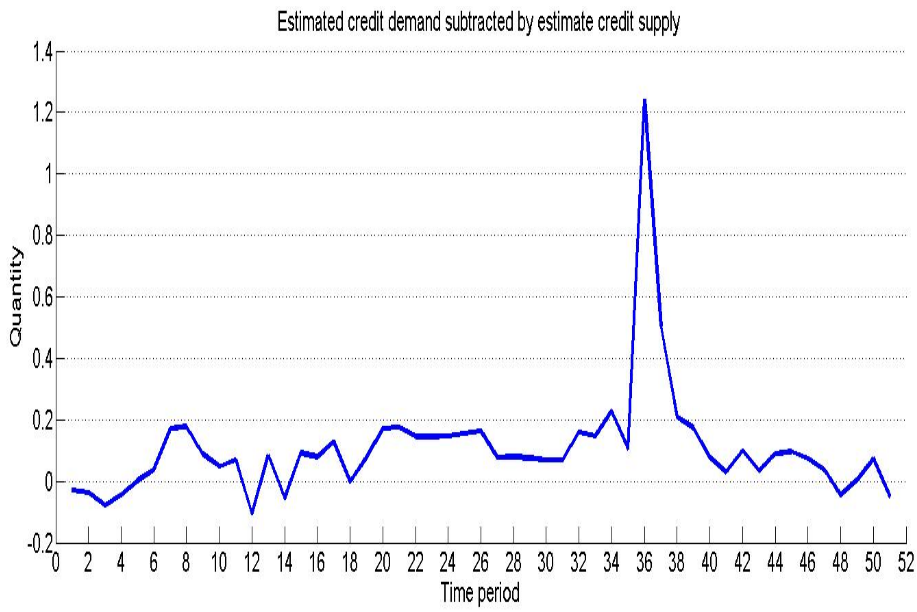


Figure 3: Estimated credit market disequilibrium

.2 List of figures for Section 5.3

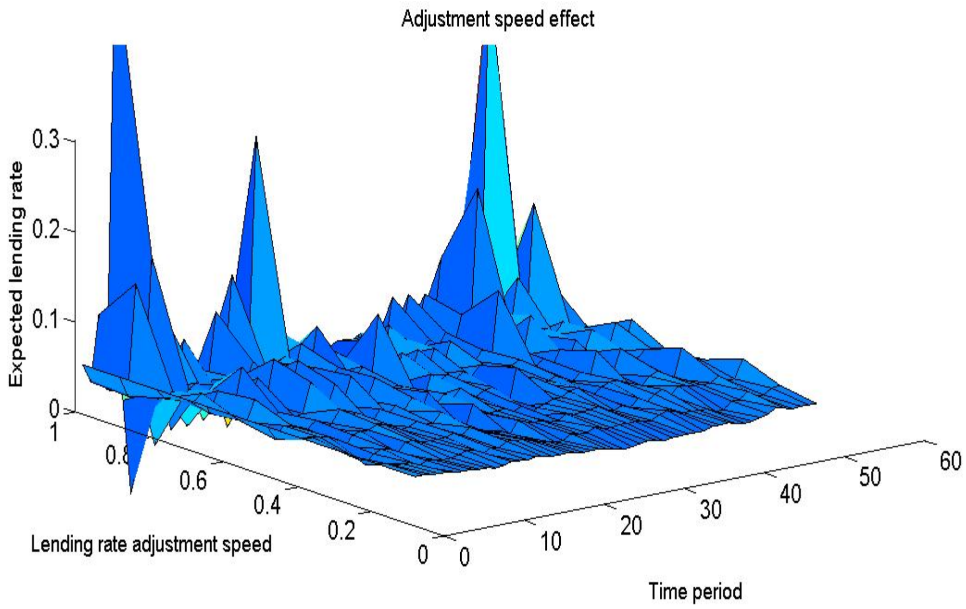


Figure 4: Expected lending rate VS Lending rate adjustment speed

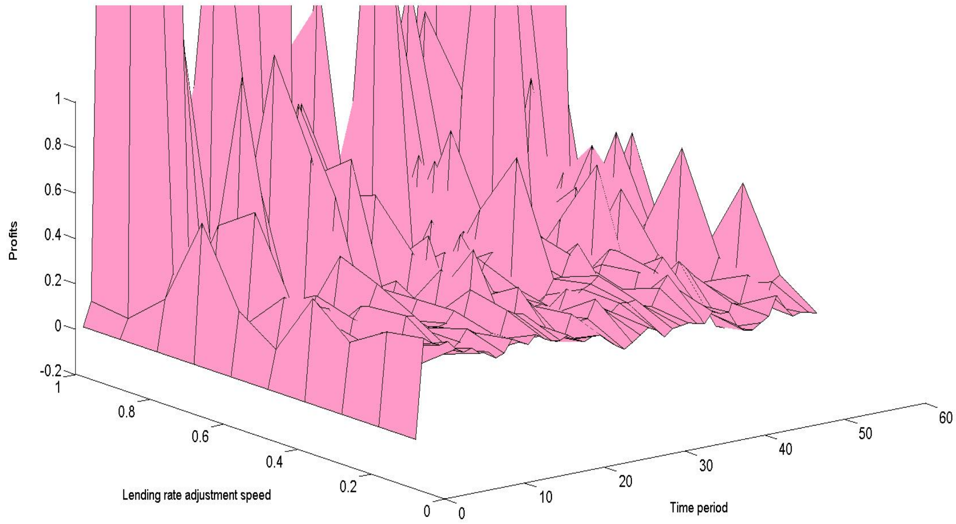


Figure 5: Expected profits VS Lending rate adjustment speed

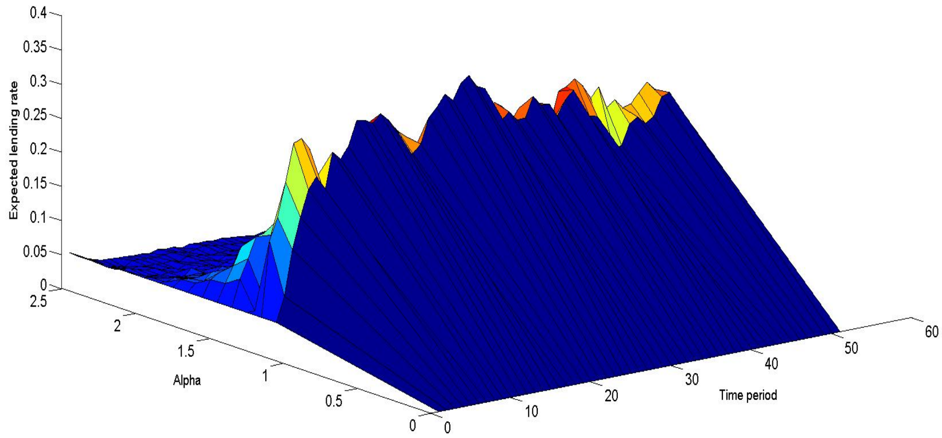


Figure 6: Expected lending rate VS Marginal cost constant alpha

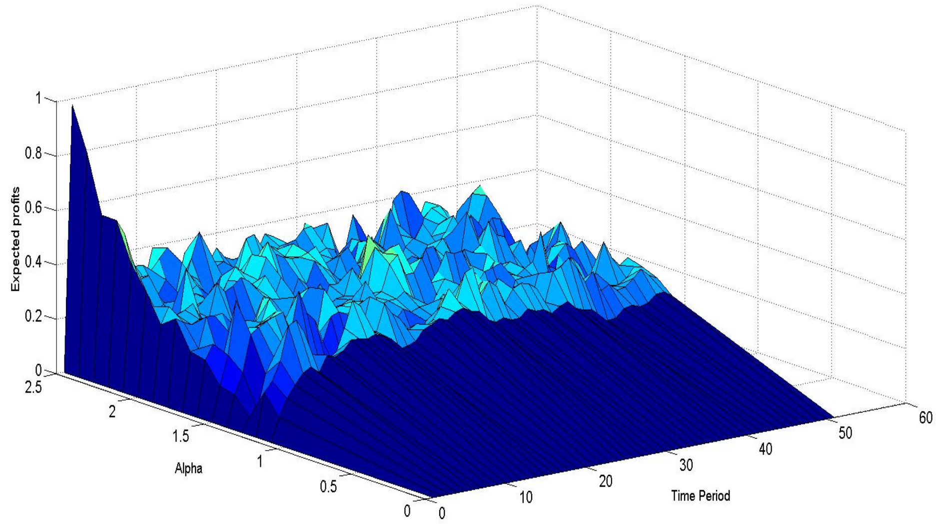


Figure 7: Expected profits VS Marginal cost constant alpha

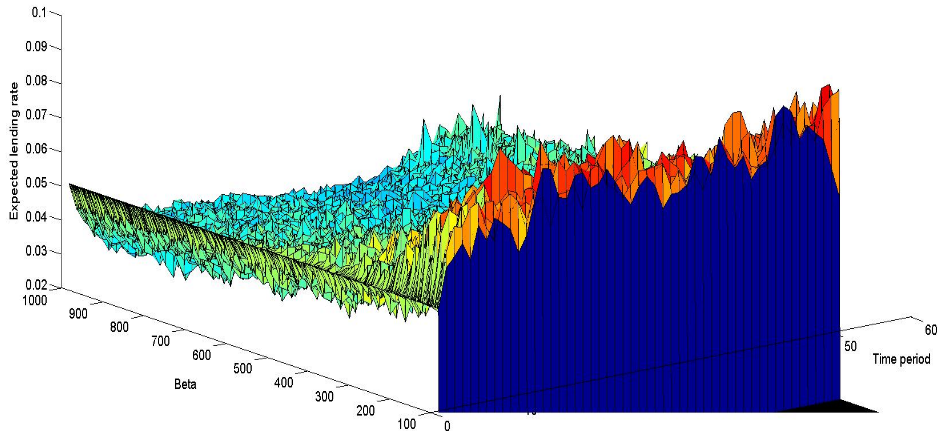


Figure 8: Expected lending rate VSMarginal cost constant beta

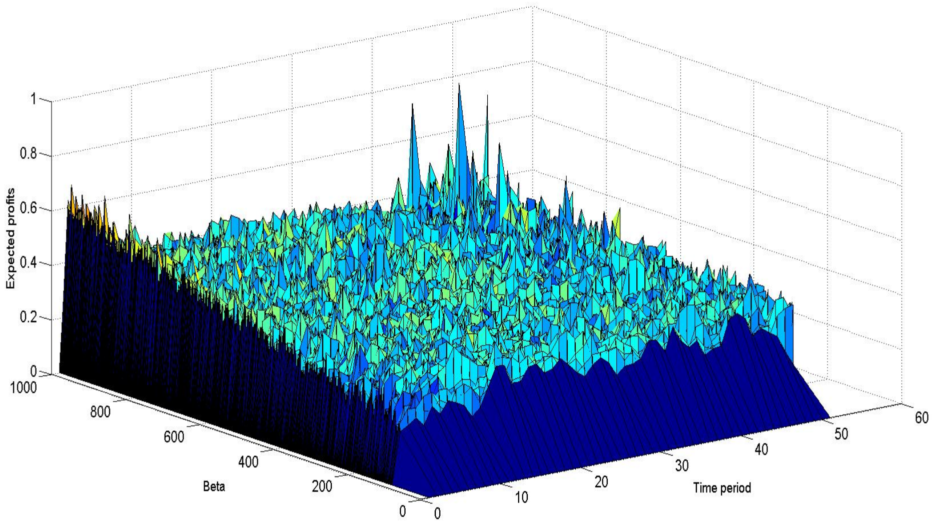


Figure 9: Expected profits VS Marginal cost constant beta

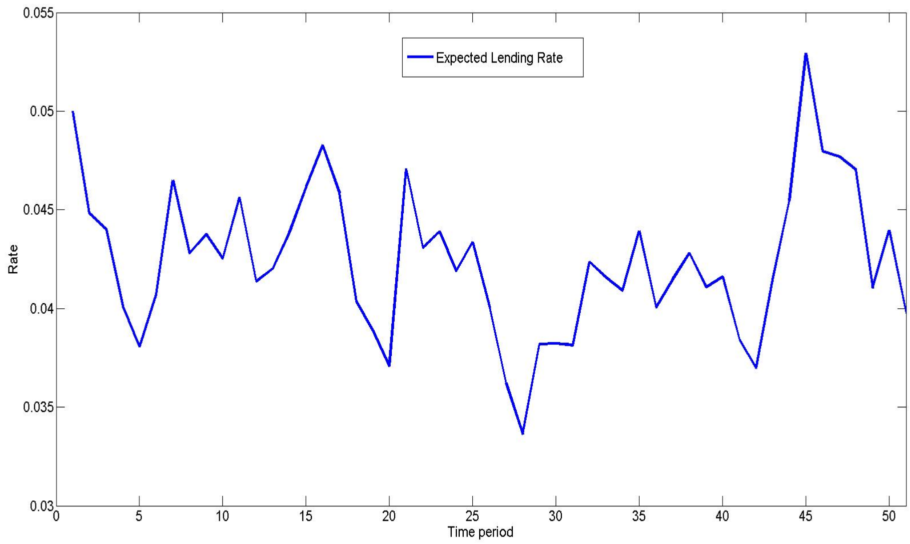


Figure 10: Expected Lending Rate

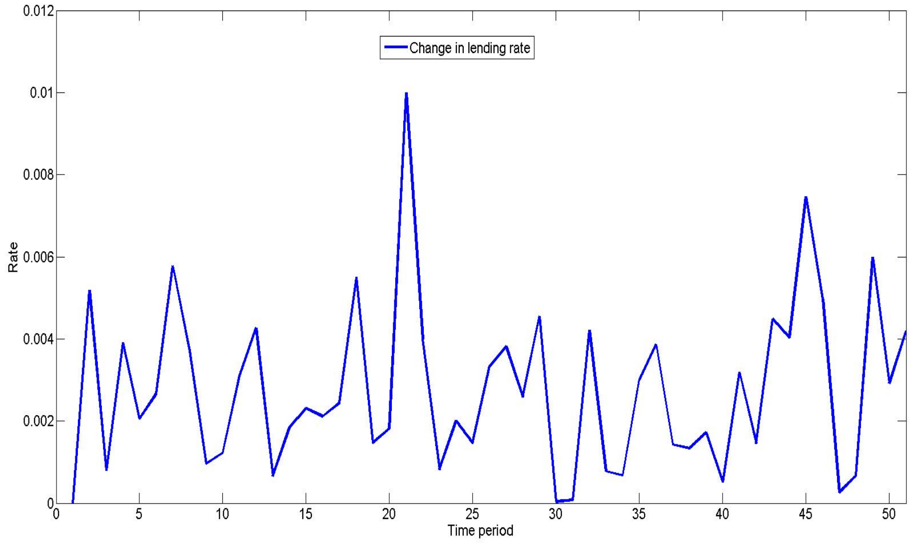


Figure 11: Expected change in lending rate

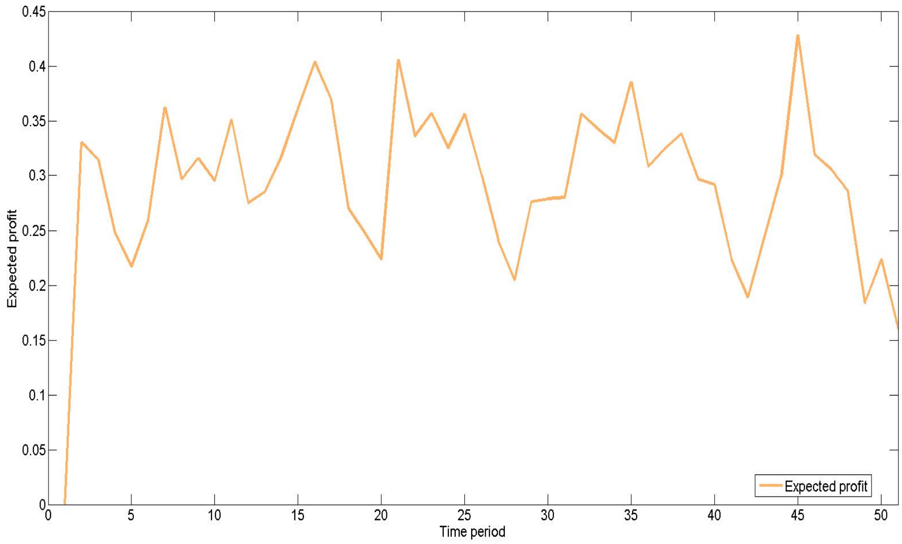


Figure 12: Expected bank's profit

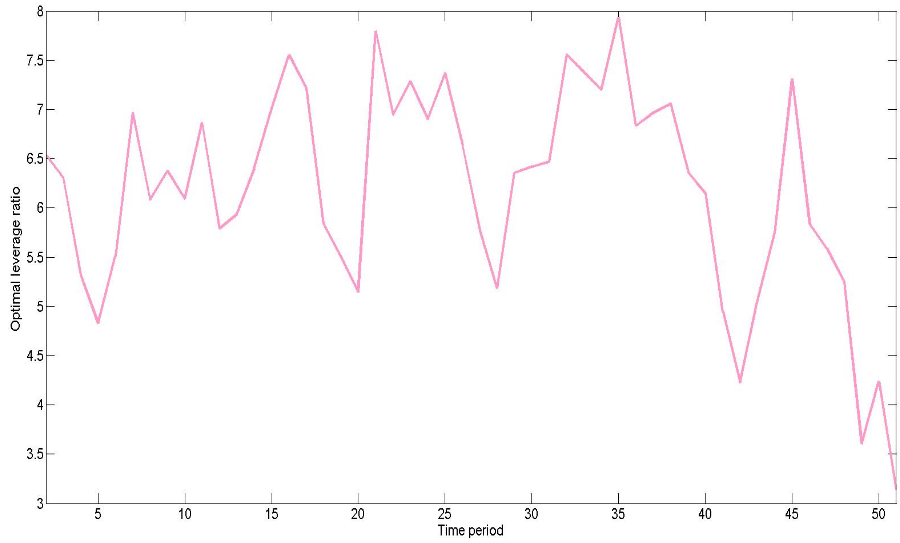


Figure 13: Expected bank's optimal capital structure

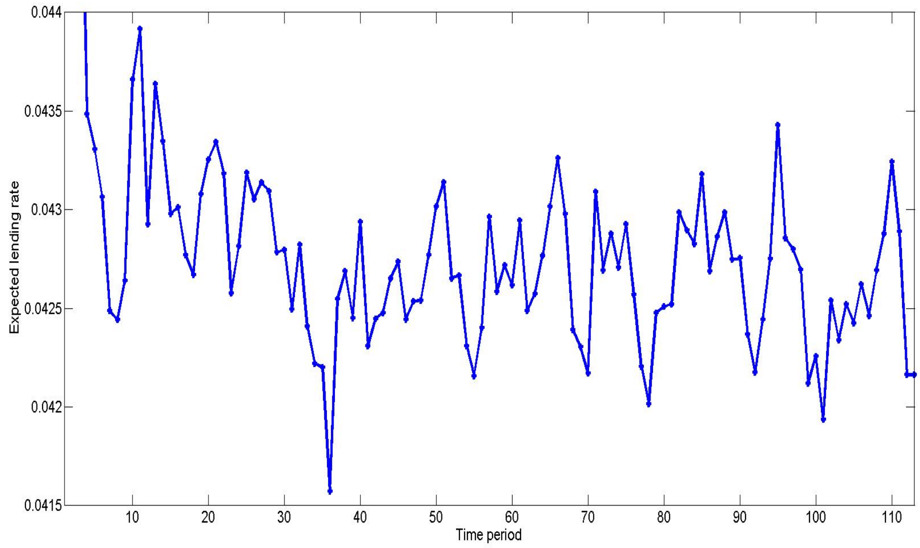


Figure 14: Expected bank lending rate

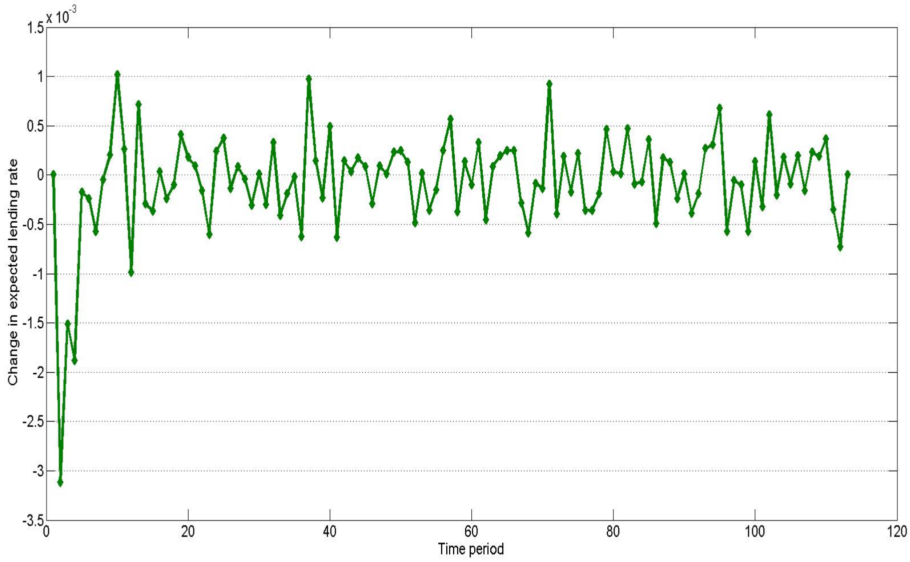


Figure 15: Expected change lending rate

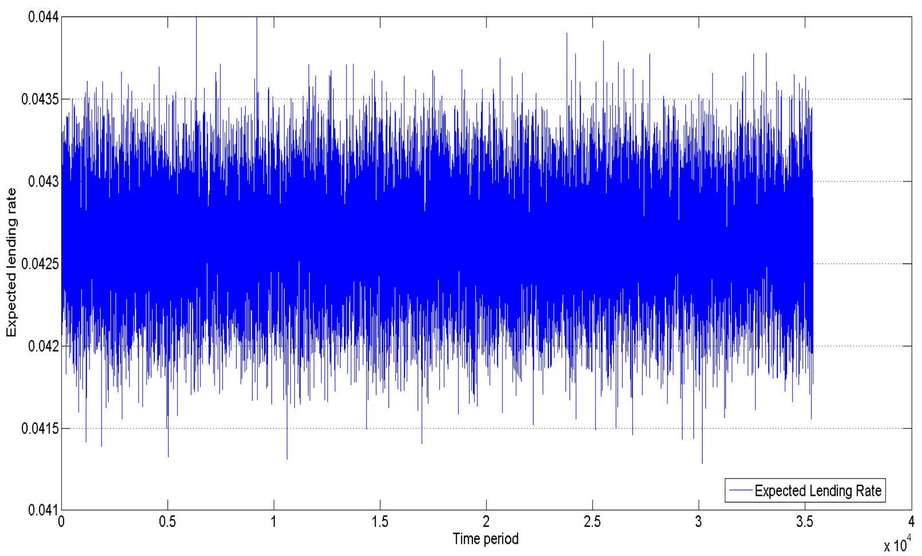


Figure 16: Expected lending rate

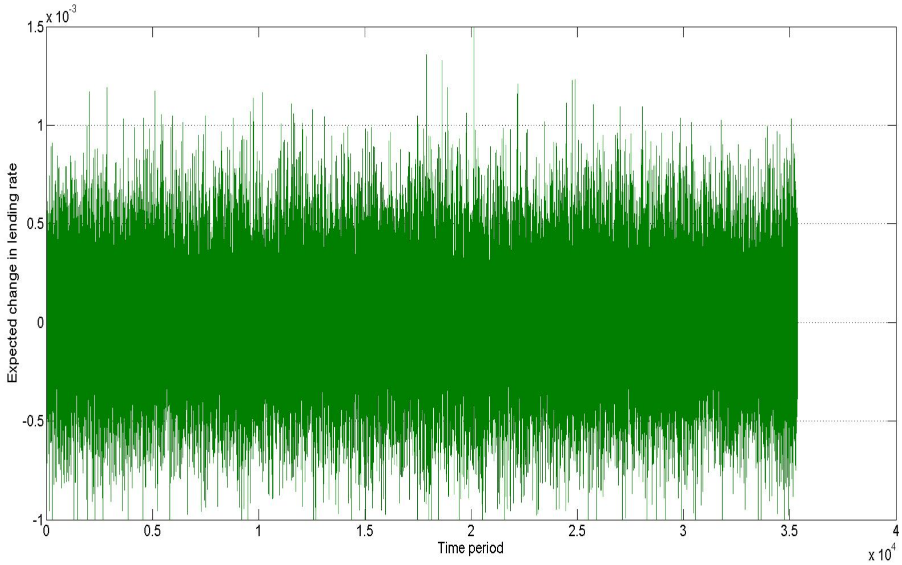


Figure 17: Expected change lending rate

.3 List of figures for Section 5.4

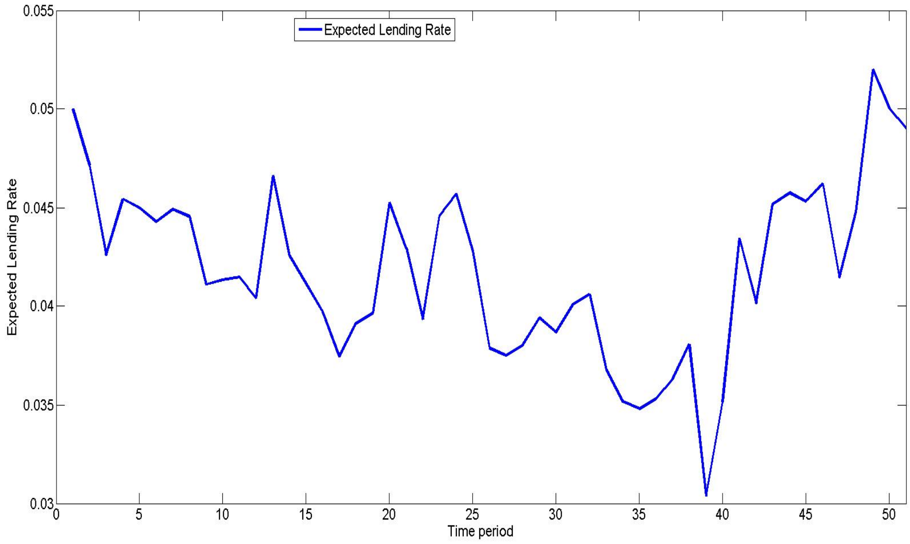


Figure 18: Expected lending rate under risk-based capital requirement: $\gamma_1 = 0.2, d = 0.10$

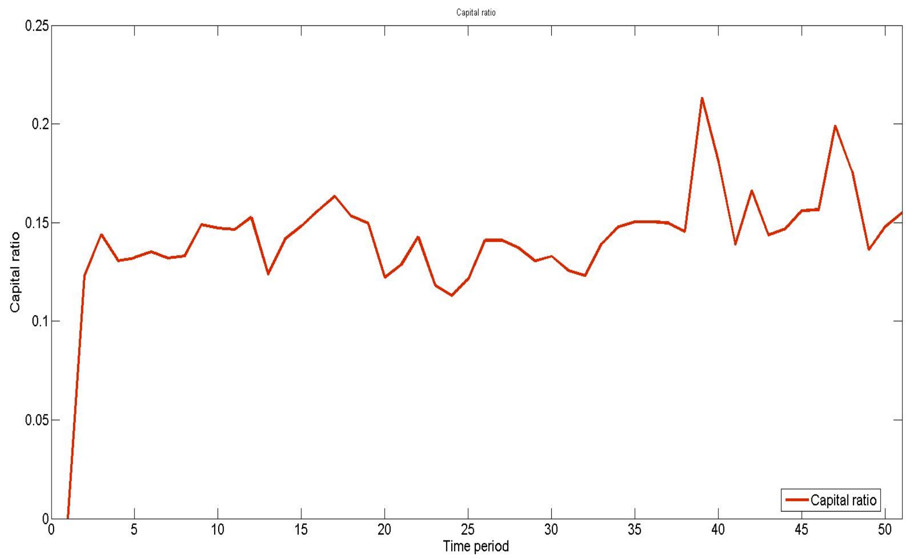


Figure 19: Expected optimal capital ratio under risk-based capital requirement: $\gamma_1 = 0.2, d = 0.10$

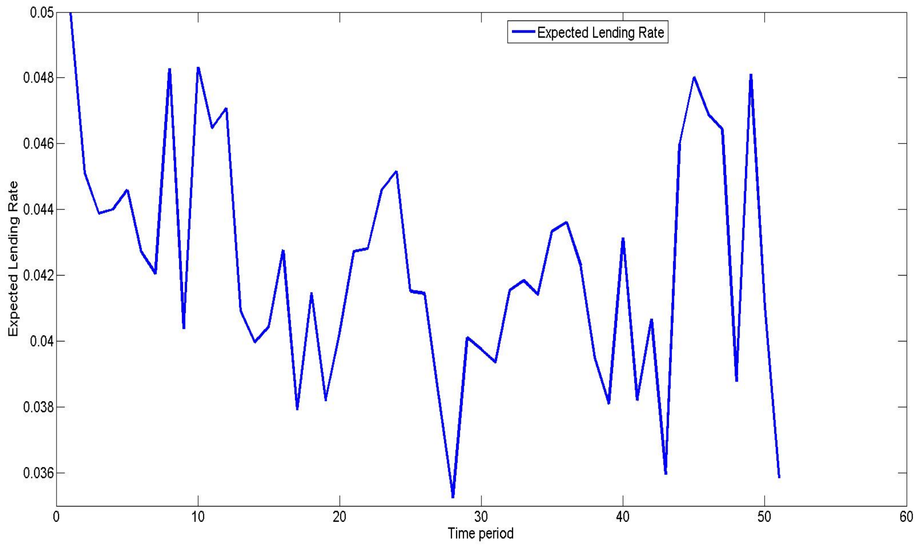


Figure 20: Expected lending rate under risk-based capital requirement: $\gamma_1 = 0.2, d = 0.13$

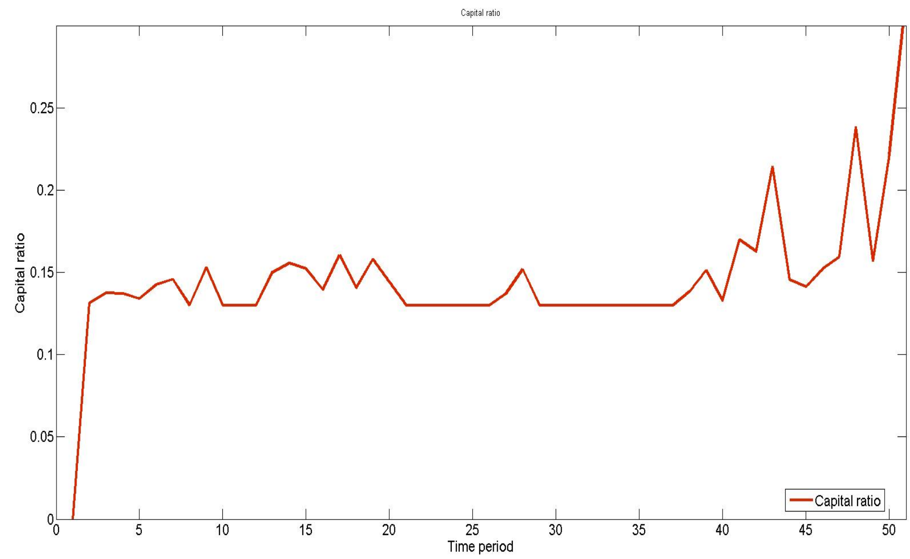


Figure 21: Expected optimal capital ratio under risk-based capital requirement: $\gamma_1 = 0.2, d = 0.13$

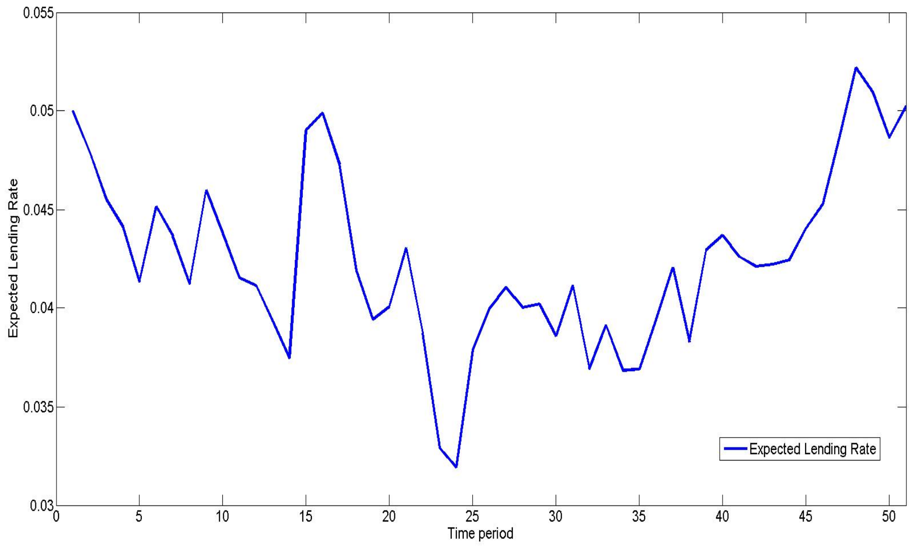


Figure 22: Expected lending rate under risk-based capital requirement: $\gamma_1 = 0.2, d = 0.15$

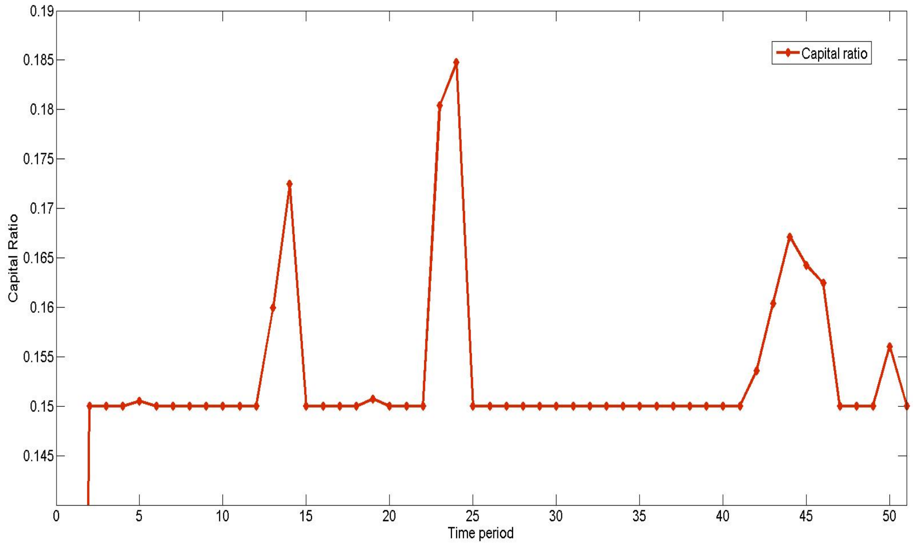


Figure 23: Expected optimal capital ratio under risk-based capital requirement: $\gamma_1 = 0.2, d = 0.15$

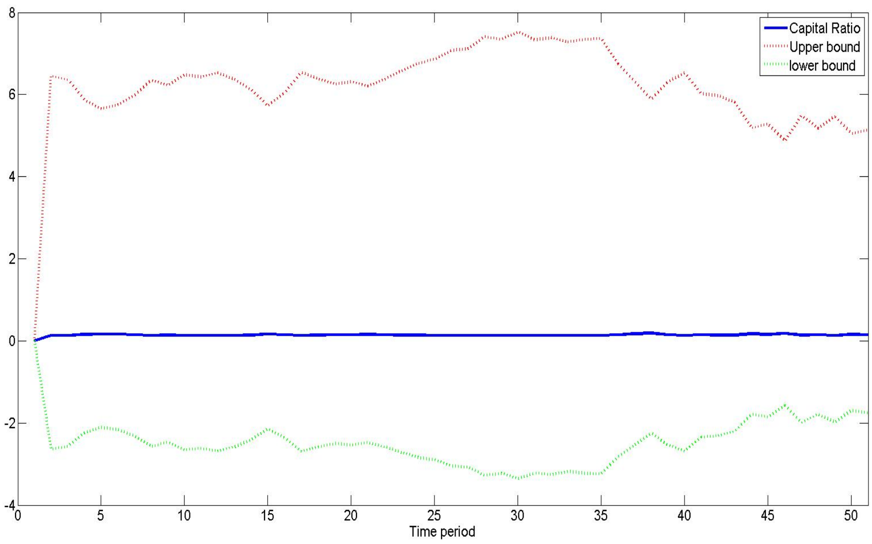


Figure 24: Expected optimal capital ratio boundaries: $\gamma_1 = 0.2, d = 0.10$

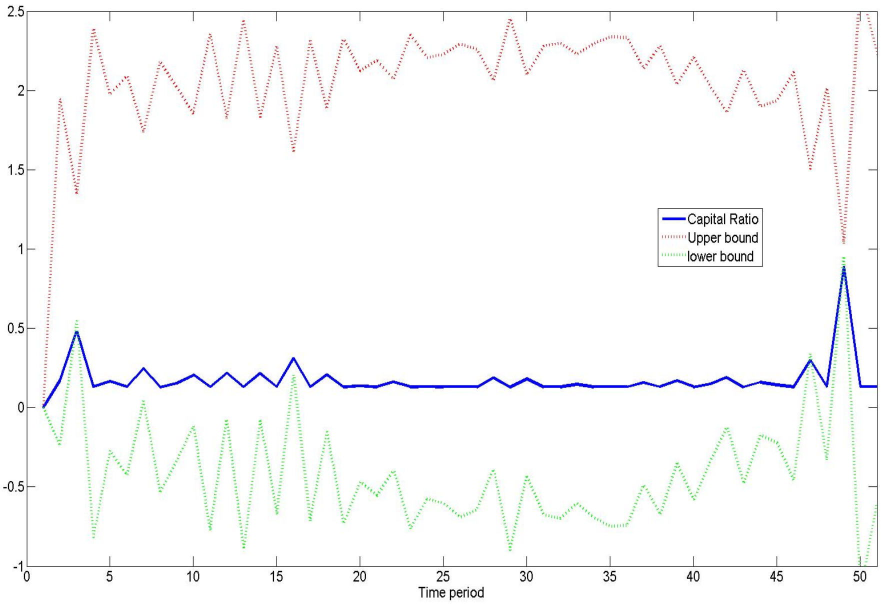


Figure 25: Expected optimal capital ratio boundaries: $\gamma_1 = 0.7, d = 0.10$

.4 List of figures for Chapter 6

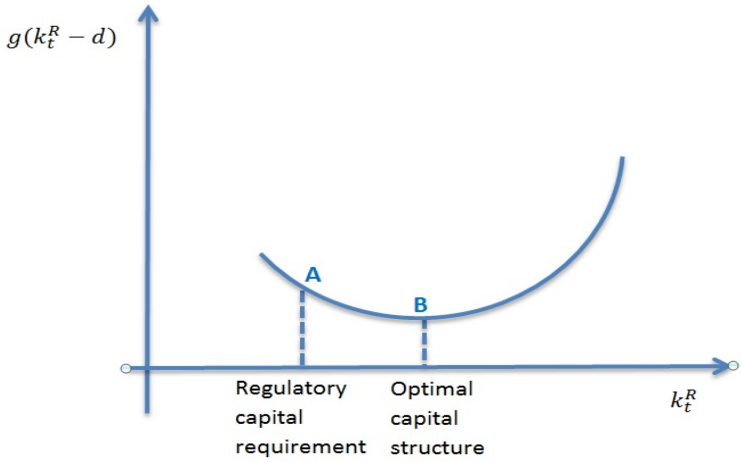


Figure 26: Capital holding cost function

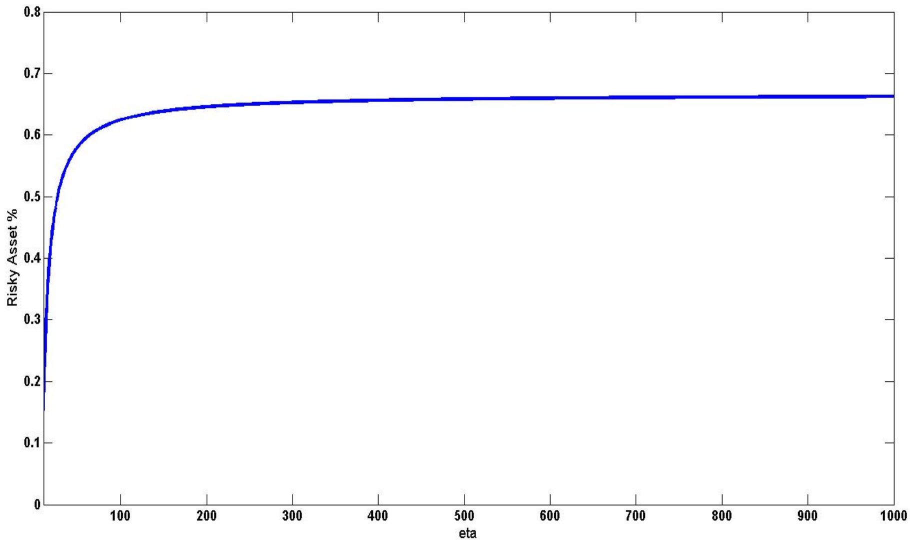


Figure 27: η again the optimal proportion of the bank's risky asset

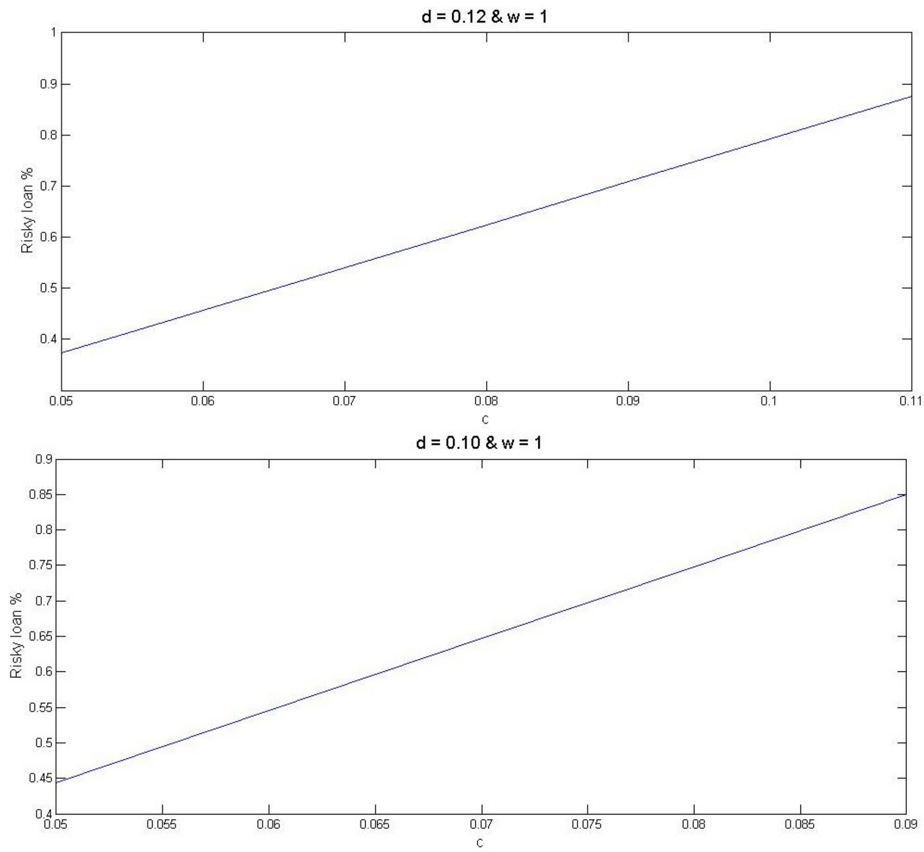


Figure 28: $w_R = 1$

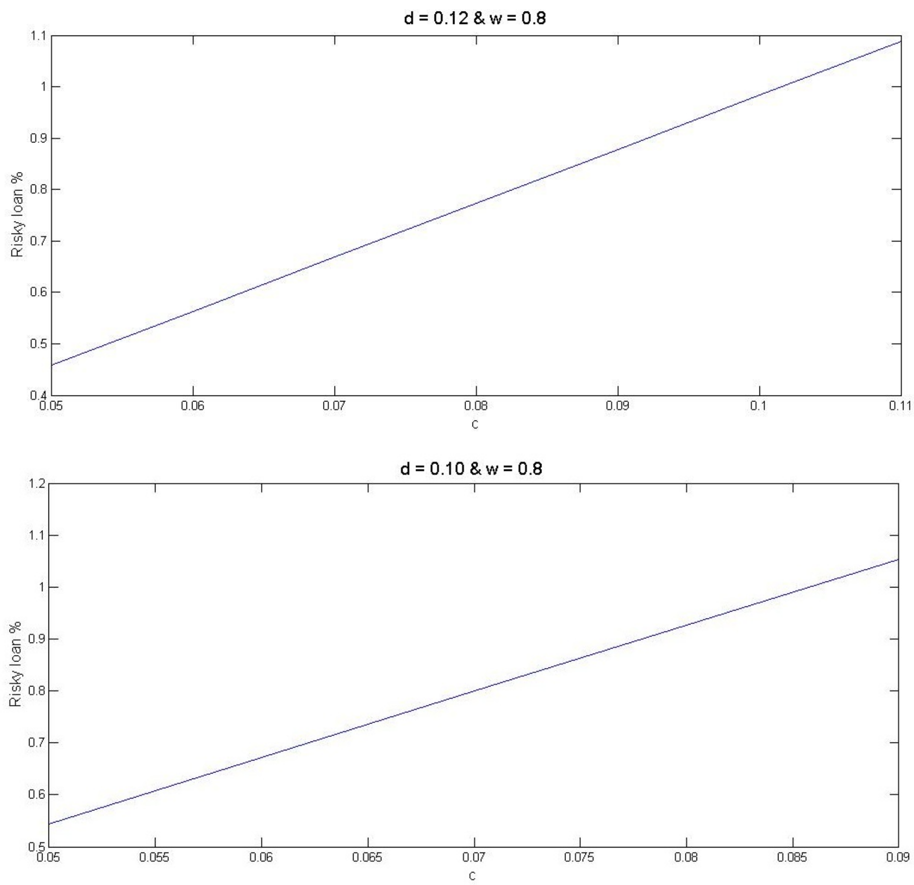


Figure 29: $w_R = 0.8$

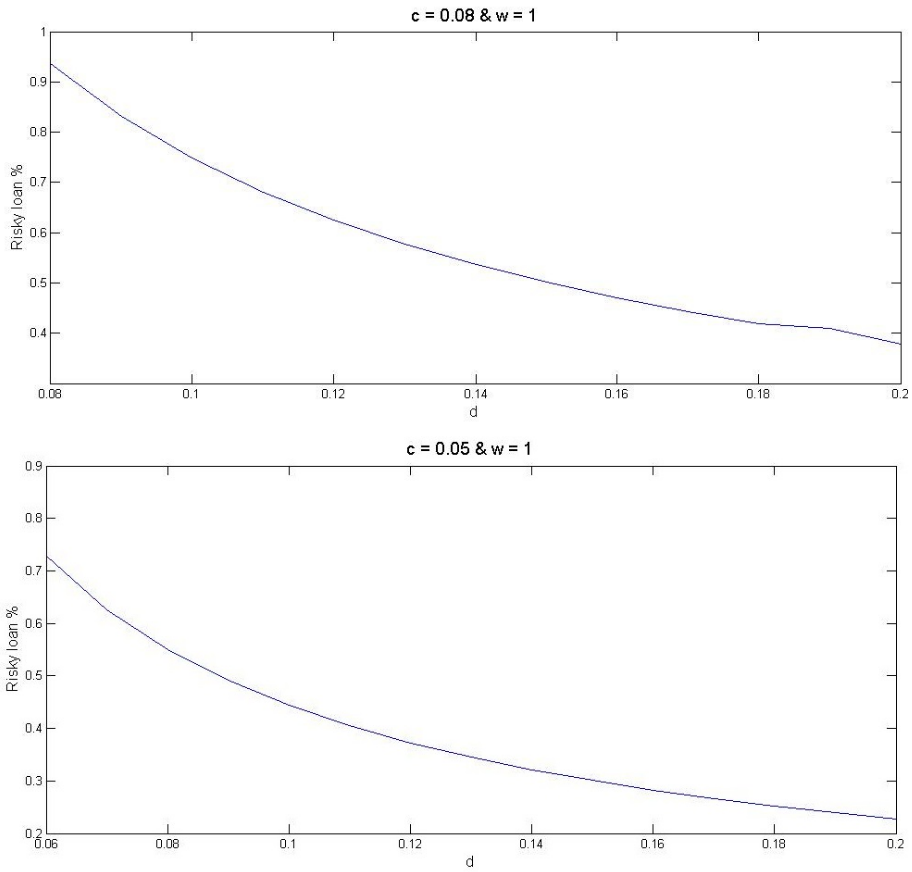


Figure 30: $w_R = 1$

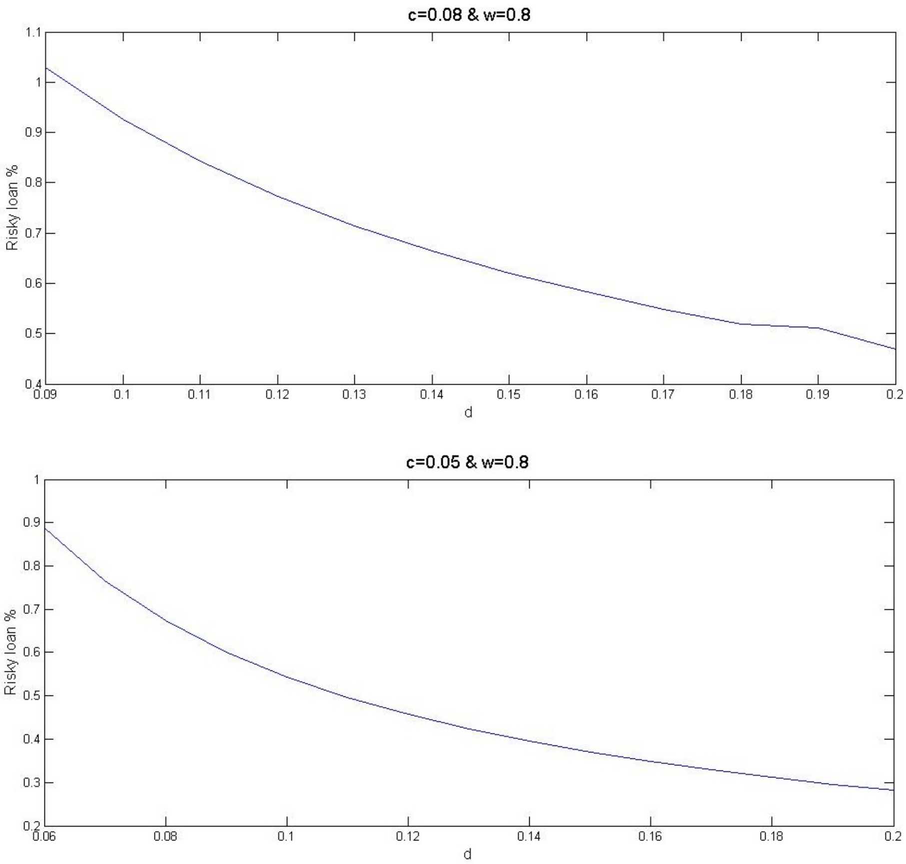


Figure 31: $w_R = 0.8$

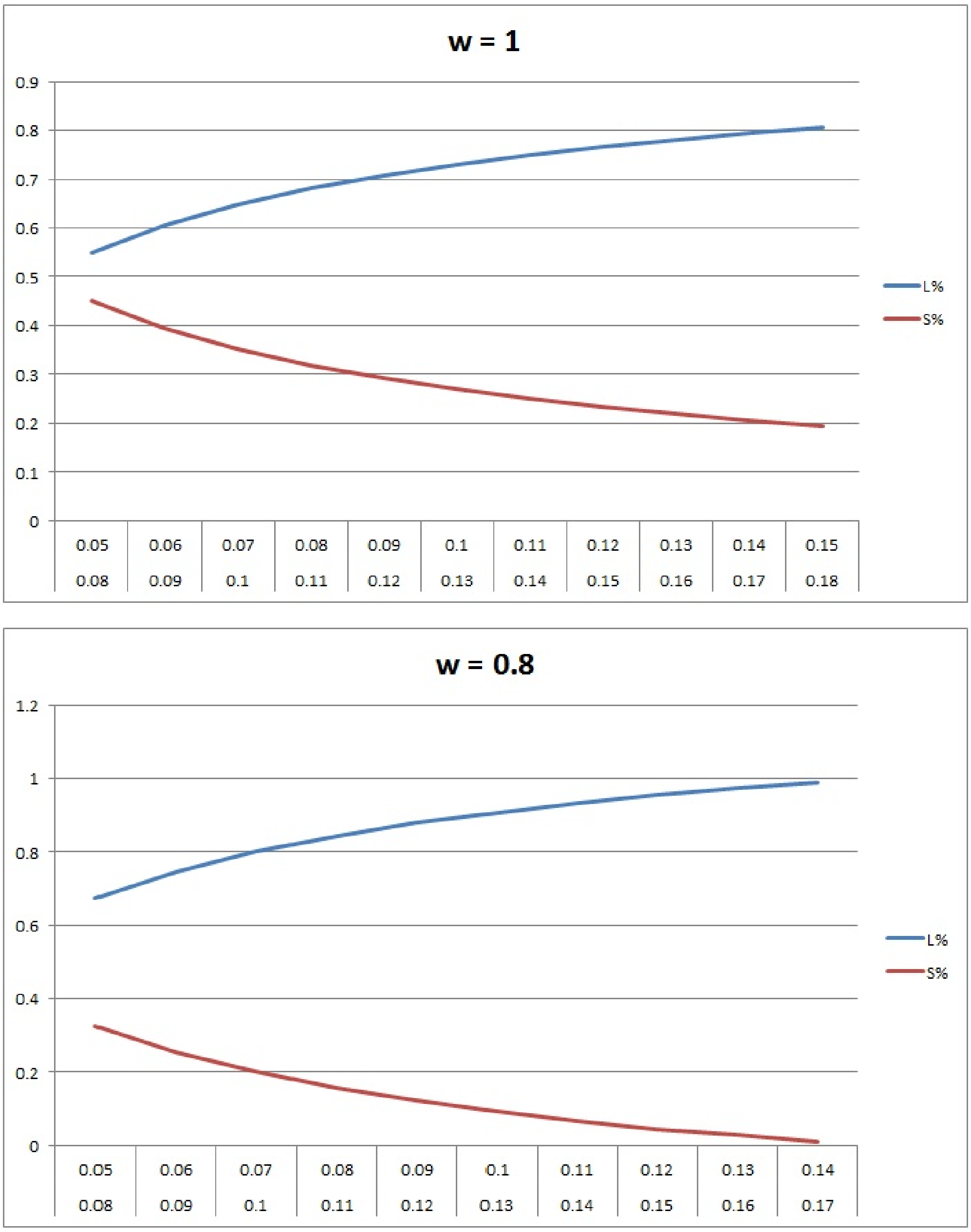


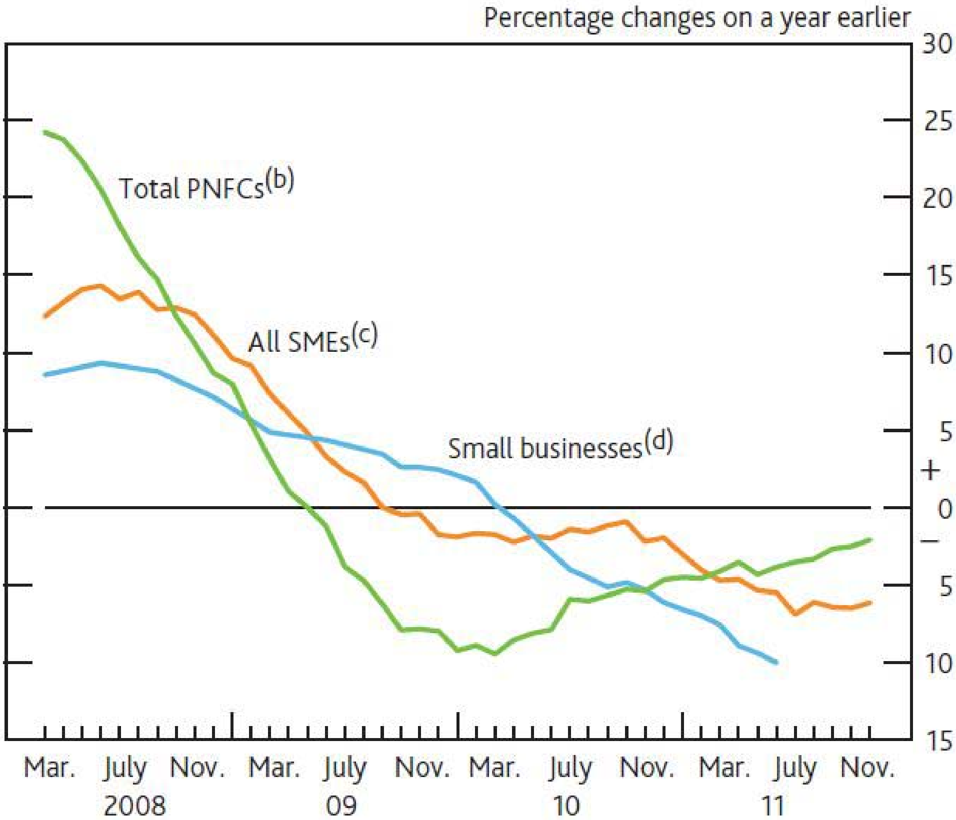
Figure 32: Optimal portfolio allocation when both c and d change

	Averages							2011		
	2007	2008	2009	2010	2011 Q1	2011 Q2	2011 Q3	Sep.	Oct.	Nov.
Net monthly flow (£ billions)	7.4	3.8	-3.9	-2.1	-1.7	-1.2	-0.4	-1.2	-0.2	1.8
Three-month annualised growth rate (per cent)	20.9	10.7	-7.7	-5.1	-3.8	-2.1	-2.8	-1.0	-0.2	0.3
Twelve-month growth rate (per cent)	16.8	17.9	-1.8	-7.1	-4.3	-3.7	-3.2	-2.8	-2.3	-2.1

(a) Lending by UK monetary financial institutions to PNFCs. Data cover lending in both sterling and foreign currency, expressed in sterling terms. Seasonally adjusted.

Figure 33: Lending to UK businesses (source: Bank of England)

Lending to Small and Medium-sized Enterprise[(a)]



Sources: Bank of England, BBA, BIS and Bank calculations.

(a) Rate of growth in the stock of lending. Non seasonally adjusted.
(b) Data cover lending in both sterling and foreign currency, expressed in sterling terms.
(c) Source: monthly BIS survey, Bank calculations. Lending by four UK lenders to enterprises with annual bank account debit turnover less than £25 million. Data cover lending in both sterling and foreign currency, expressed in sterling terms. Data prior to January 2009 have been revised.
(d) Source: BBA. Lending by seven UK lenders to commercial businesses with an annual bank account debit turnover of up to £1 million. Sterling only. This survey terminated at June 2011. Available at www.bba.org.uk/statistics/small-business.

Figure 34: ending to small and medium-sized enterprises

.5 List of figures for Chapter 7

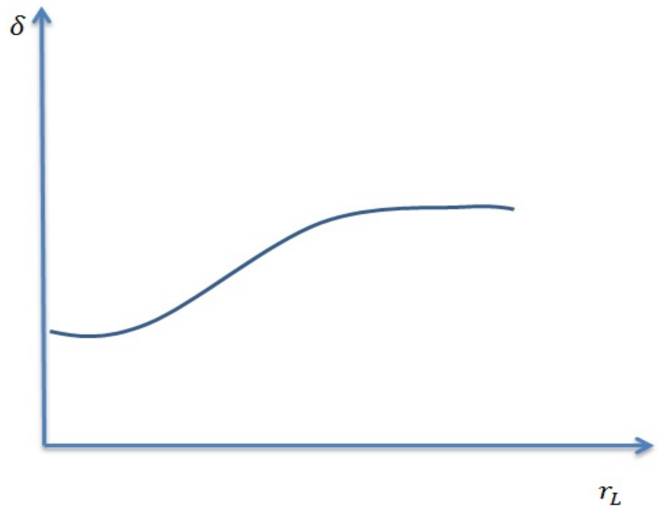


Figure 35: Loss Given Default and Lending Rate

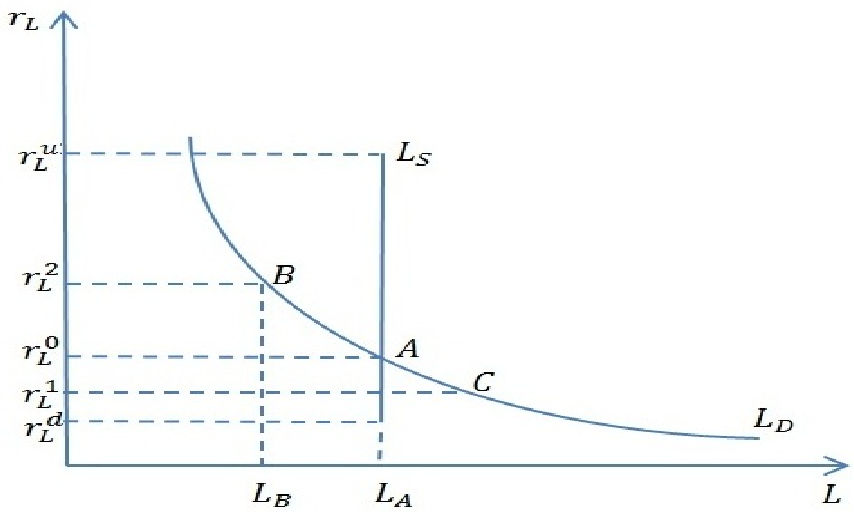


Figure 36: Credit Demand and Supply diagram

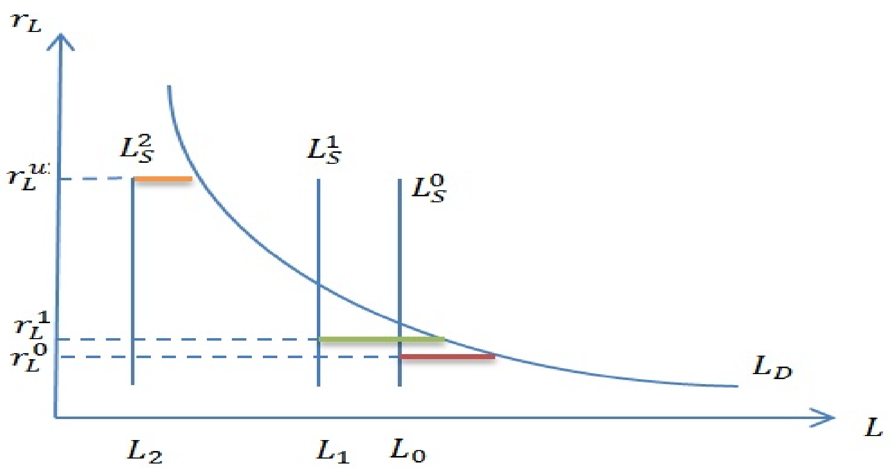


Figure 37: Credit rationing magnitude Scenario I

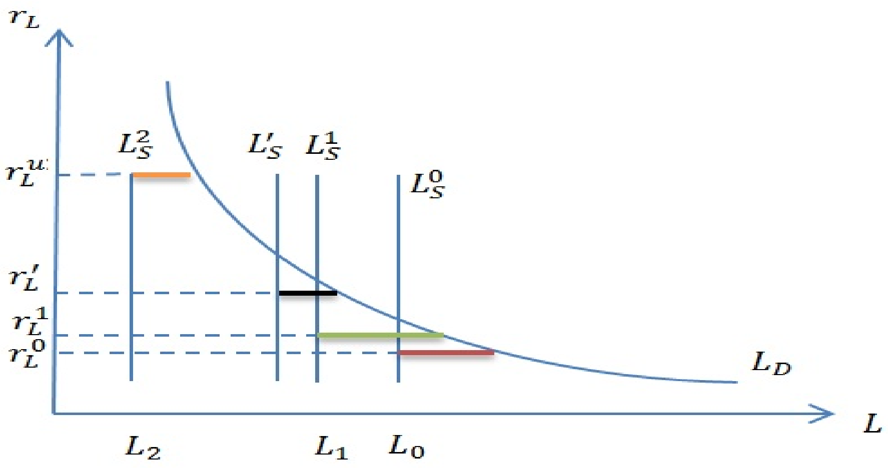


Figure 38: Credit rationing magnitude Scenario II

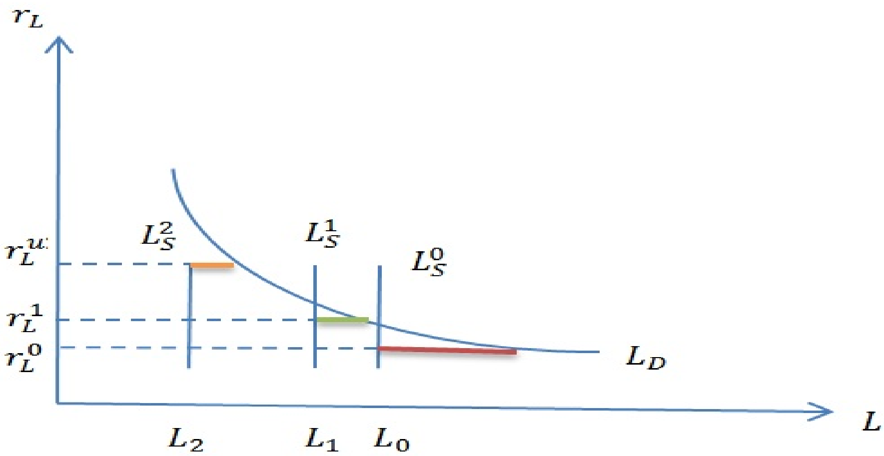


Figure 39: Credit rationing magnitude Scenario III

Appendix B

.6 Matlab code for Chapter 5

Matlab code for section 5.3.1:

```
clear;


T = 50; %number of time period

N = 10; %number of banks


gamma2 = 0.2; %adjustment speed for default rate

alpha = 2; %constant terms for deposit

beta = 500;

sigma = 1; %s.d. for random shock on banks' total revenue

M = 3; %macro-economics variables that determine banks' total revenue

f = 1; %bank's equity

data=xlsread('realdefaultrate.xls');

D=data(:,2);

delta(1) = 0.0185; %starting point for default rate
```

```
for i = 1:10;

    gamma1(i) = i/10;

    r(i,1) = 0.05; %starting point for lending rate

    Z(i) = 0;

for t = 2:T+1;

    delta(t) = delta(t-1) + gamma2*(D(t-1)-delta(t-1));

    r(i,t) = (1-gamma1(i))*r(i,t-1)+ gamma1(i)*(M+normrnd(0,sigma))

    /(N*(f+beta*((r(i,t-1)-delta(t-1))/alpha)^(1/(alpha-1))));

    v(i,t) = beta*((r(i,t)-delta(t))/alpha)^(1/(alpha-1));

    q(i,t) = f + v(i,t); %total lending amount

    Phi(i,t) = v(i,t)/q(i,t);

    z(i,t) = r(i,t)*(1-delta(t))*q(i,t) - (v(i,t)/beta)^alpha;

    Z(i) = Z(i) + z(i,t); %accumulated bank profits

    err(i,t) = abs(r(i,t) - r(i,t-1));

end

end

x = 1:t;

figure1=figure;

surf(x, gamma1,   r)

figure2=figure;

surf( x, gamma1,  z)
```

Matlab code for section 5.3.2:

Example 1:

```
clear;

fid=fopen('simulation.csv', 'w')
```

```
T = 50; %number of time period
N = 10; %number of banks
gamma1 = 0.2; %adjustment speed for lending rate
gamma2 = 0.2; %adjustment speed for default rate
alpha = 2; %constant terms for deposit
beta = 500;
sigma = 1; %s.d. for random shock on banks' total revenue
M = 3; %macro-economics variables that determine banks' total revenue
f = 1; %bank's equity
data=xlsread('realdefaultrate.xls');
D=data(:,2);
r(1) = 0.05; %starting point for lending rate
delta(1) = 0.0185; %starting point for default rate
Z = 0;
c = 0.13; %capital requirement
for t = 2:T+1;
    delta(t) = delta(t-1) + gamma2*(D(t-1)-delta(t-1));
    r(t) = (1-gamma1)*r(t-1)+ gamma1*(M+normrnd(0,sigma))
    /(N*(f+beta*((r(t-1)-delta(t-1))/alpha)^(1/(alpha-1))));
    v(t) = beta*((r(t)-delta(t))/alpha)^(1/(alpha-1));
    q(t) = f + v(t); %total lending amount
    Phi(t) = f/q(t);
    if Phi(t) < c
         Phi(t) = c, v(t) = (1-c)*f/c;
     end
```

```
    z(t) = r(t)*(1-delta(t))*q(t) - v(t)*((v(t)/beta)^alpha);
    Z = Z + z(t); %accumulated bank profits
    err(t) = abs(r(t) - r(t-1));
end
  x = 1:t;
 figure1=figure;
 plot(x,r)
 legend('Expected Lending Rate',0, 0)
 set(gca,'FontSize',16)
 figure2=figure;
 plot(x,Phi)
 title('Capital ratio')
 legend('Capital ratio',0,0)
 set(gca,'FontSize',16)
 figure3=figure;
 plot(x,err);
 title('Change in lending rate')
 legend('Change in lending rate',0,0)
 set(gca,'FontSize',16)
 figure4=figure;
 plot(x,z);
 legend('Expected profit',0,0)
 set(gca,'FontSize',16)
fclose(fid)
```

Example 2

```
clear;

T = 100000; %number of time period
N = 10; %number of banks
gamma1 = 2; %adjustment speed for lending rate
gamma2 = 0.1; %adjustment speed for default rate
alpha = 2; %constant terms for deposit
beta = 500;
sigma = 0.1; %s.d. for random shock on banks' total revenue
M = 3; %macro-economics variables that determine banks' total revenue
f = 1; %bank's equity
r(1) = 0.05; %starting point for lending rate
delta = 0.0185; %starting point for default rate
Z = 0;
c = 0.12; %capital requirement

 for t = 2:T+1 ;
    r(t) = (1-gamma1)*r(t-1)+ gamma1*(M+normrnd(0,sigma))
    /(N*(f+beta*((r(t-1)-delta)/alpha)^(1/(alpha-1))));
    v(t) = beta*((r(t)-delta)/alpha)^(1/(alpha-1));
    q(t) = f + v(t); %total lending amount
    Phi(t) = f/q(t);
    z(t) = r(t)*(1-delta)*q(t) - (v(t)/beta)^alpha;
    Z = Z + z(t); %accumulated bank profits
    err(t) = r(t) - r(t-1);
```

```
    if (abs(err(t)) < 10^(-5))
          break;
    end
 end
 x = 1:t;
 figure1=figure;
 plot(x,r)
 title('Expected Lending Rate')
 legend('Expected Lending Rate',0, 0)
 figure3=figure;
 plot(x,err);
 title('Change in expected lending rate')
 legend('Change in expected lending rate',0,0)
```

Matlab code for section 5.4:

```
clear;
T = 50; %number of time period
N = 10; %number of banks
gamma1 = 0.2; %adjustment speed for lending rate
gamma2 = 0.2; %adjustment speed for default rate
alpha = 2; %constant terms for deposit
beta = 500;
sigma = 1; %s.d. for random shock on banks' total revenue
M = 3; %macro-economics variables that determine banks' total revenue
f = 1; %bank's equity
```

```
data=xlsread('realdefaultrate.xls');
D=data(:,2);
delta(1) = 0.0185; %starting point for default rate


for t = 2:T+1;
    delta(t) = delta(t-1) + gamma2*(D(t-1)-delta(t-1));
    r(i,t) = (1-gamma1)*r(i,t-1)+ gamma1*(M+normrnd(0,sigma))
    /(N*(f+beta*((r(i,t-1)-delta(t-1))/alpha)^(1/(alpha-1))));
    v(i,t) = beta*((r(i,t)-delta(t))/alpha)^(1/(alpha-1));
    q(i,t) = f + v(i,t); %total lending amount
    Phi(i,t) = f/q(i,t);
    if Phi(i,t) < c
         Phi(i,t) = c(i), v(i,t) = (1-c(i))*f/c(i);
    end
    z(i,t) = r(i,t)*(1-delta(t))*q(i,t) - (v(i,t)/beta)^alpha;
    Z(i) = Z(i) + z(i,t); %accumulated bank profits
    err(i,t) = abs(r(i,t) - r(i,t-1));
end
x = 1:t;
 figure1=figure;
 plot(x,r)
 set(gca,'FontSize',16)
 legend('Expected Lending Rate',0, 0)
 figure2=figure;
 plot(x,Phi)
```

```
set(gca,'FontSize',16)
title('Capital ratio')
legend('Capital ratio',0,0)
```

.7 Matlab code for Chapter 6

```
clear;
% define the parameters
theta = 0.161668; % Parameter influences the level of equity issuing costs
alpha = 0.000059; % Parameter influences curvature of the cost function
gamma = 0.68; % Regulatory monitoring cost parameter
a = 0.06; % lending interest rate
b = 0.01; % deposit interest rate
r = 0.005; % government security interest rate
rho = 1.02; % Average level of loan demand
K = 1; % initial capital

% parameters from panel regression
delta = 0.020898876; % default rate

% variables to be changed
w = 1; % risk weighting for loan

t=1;
   for d = 0.08:0.01:0.2
```

```
  for c = 0.05:0.01:d

eta = 100;    % Parameter influences the risk-basked capital requirements
%v = 0.135*eta; % Parameter influences the leverage requirement
v = 0.73*eta;
F = @(x) [(r -b)*(1+b-2*gamma*eta*(x(1)-d)+2*gamma*v*(x(2)-c))
  -gamma*v*(c^2-(x(2))^2);
  (a*(1-0.00386-delta)-b)*(1+b-2*gamma*eta*(x(1)-d)+2*gamma*v*(x(2)-c))
  -w*gamma*eta*(d^2-(x(1))^2)-gamma*v*(c^2-(x(2))^2)-w*(1-rho)^2*alpha/2];

InitialGuess = [0.15; 0.10];
options=optimset('Display','iter','MaxFunEvals' , 1000);
z = fsolve(F, InitialGuess, options);

L = K/(w*z(1));
S = K/z(2) - L;

%write the output
XY(1,t) = z(1);
XY(2,t) = z(2);
XY(4,t) = L;
XY(5,t) = S;
XY(7,t) = L/(L+S);
XY(8,t) = S/(L+S);
XY(9,t) = eta;
```

```
XY(10,t) = v;
XY(11,t) = d;
XY(12,t) = c;
t=t+1;
       end
end

xlswrite('guess2.xlsx',  XY');
plot3(XY(11,:),XY(12,:),XY(7,:));
xlabel('d');
ylabel('c');
zlabel('L%');
grid on;
axis square;
```

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