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Cyclical Public Policy and Financial Factors

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by

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Abstract

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The Great Recession of 2009 motivated a growing body of research on the quantitative modeling of financial factors and appropriate policy responses. This dissertation is a part of that line of research and looks at the quantitative macroeconomic effects of financial factors on business cycles. The dissertation uses quantitative macroeconomic general equilibrium models (popular dynamic stochastic general equilibrium (DSGE)) that allow flexibility in micro-founded modeling of macroeconomic environments. The dissertation captures financial factors through explicit modeling of financial intermediation, featuring costly state verification and collateral constraints as financial frictions.

The first chapter offers a new quantitative model of credit cycles with endogenous leverage for financial intermediaries. Credit cycle dynamics emerge in a model with endogenous financial intermediary leverage and costly state verification. A trade-off between costly bank capital and a benefit of capital as a buffer against adverse shocks drives intermediary leverage. Bank capital functions as a buffer by reducing value-at-risk. Bank capital is costly as households require a premium to hold risky capital whereas deposits are insured. Changes in intermediary balance sheet size drive credit supply. The model displays three active credit channels: the business conditions channel, the bank net worth channel, and the funding cost channel. The model delivers

empirically observed procyclical credit conditions.

The second chapter investigates how bank monitoring dynamics evolve over the business cycle. The model features lognormal idiosyncratic productivity shocks for firms and endogenous default thresholds with costly state verification. The model presented in this chapter features financial intermediaries who engage in risk-shifting over the business cycle by reducing monitoring activity during business cycle upturns when the chances of loan losses are lower. Bank monitoring is costly, but it can indirectly reduce loan default probabilities by preventing firm moral hazard. As aggregate default probabilities fall over the business cycle, the marginal benefit of loan monitoring drops. In addition, intermediary monitoring is inefficiently low because firms holdup part of the benefit of monitoring.

The third chapter abstracts from financial intermediation and looks at how tax policy should vary across the business cycle in the presence of financial frictions. Financial factors in the model give rise to heterogeneity among households. Optimal income tax rates are more volatile for lower income households. The paper looks at the quantitative properties of Ramsey optimal income tax rates as well as optimal public goods provision.

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Acknowledgments

Introduction

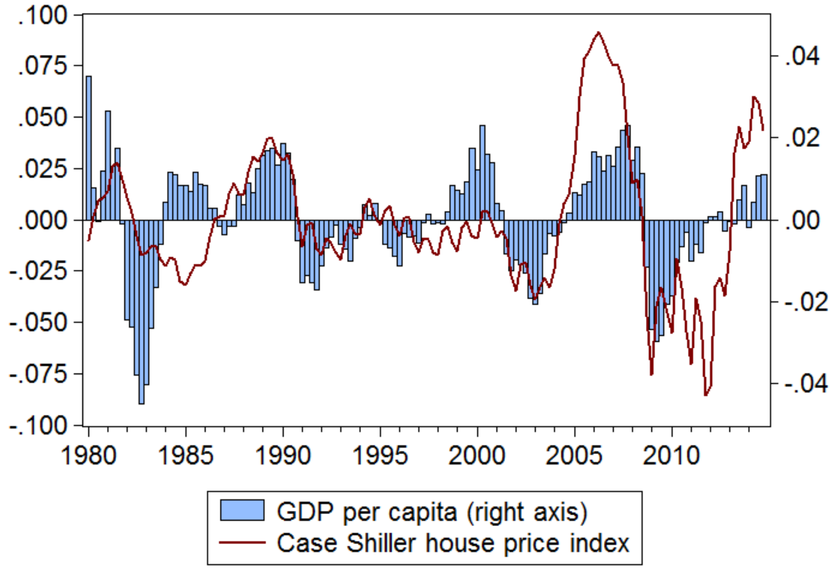
On October 3 2008, the US Department of the Treasury announced the beginning of Troubled Asset Recovery Program (TARP) - an unprecedented fiscal program that eventually spent US $431 billion to rescue the financial system. Two systemically important financial institutions, Bear Sterns and Lehman Brothers had collapsed. In the week preceding October 3, interbank lending had stopped functioning, leaving many banks unable to access interbank funding at all. Subsequently banks faced criminal convictions for under-reporting their true interbank borrowing costs. The breakdown in financial system funding led to an acute credit crunch that saw corporate lending spreads touch 9% against a historical average of 3.4%. Global GDP shrunk by 5% between 2008 and 2009. In the US, the unemployment rate touched 10%. It would take another 5 years before the US unemployment rate decreased to 6%. The financial crisis of 2008 that originated in mortgage lending brought into renewed focus the importance of financial intermediation in the economy. House prices fell, wiping out the equity of house owners, and leaving mortgage loans in default. Investors stopped purchasing mortgages in the secondary market so that banks did not have funds for credit creation. This led to a severe credit crunch, and resulted in diverse and extensive damage to other parts of the economy. Any damage in the seemingly distant world of financial intermediation led to job losses across the board - in all parts of society. This dissertation aims to study this importance of financial factors and public policy in the business cycle.

Since the financial crisis there has been a lot of interest in quantitative modelling of financial factors. Recent work has taken several different approaches to studying these. Brunnermeier and Sannikov (2014) model financial instability created through financial frictions. They show that low risk environments might result in greater systemic risk. In addition their model features benign behavior in 'normal' times and large amplification of shocks during crisis times. Gertler and Kiyotaki (2010) look at how loan losses in the presence of collateral constraints on intermediaries can cause large disruptions in economic activity. Gertler and Karadi (2011) examine the influence of monetary policy under these conditions. Mendoza (2010) looks at occasionally binding collateral constraints and their effect in causing large economic disruptions. Bianchi (2012) explores over-borrowing resulting from systemic externalities in lending markets. Christiano, Motto, and Rostagno (2014) model costly state verification at intermediaries and show that increases in aggregate risk through increase in volatility of idiosyncratic shocks can cause large and influential business cycle fluctuations. They call these fluctuations in volatility 'risk shocks'. Jermann and Quadrini (2010) have a collateral constraint that directly influences firms? labour decisions to explain partly the large drop in employment that happened in the wake of the housing market collapse.

Several books and articles also explore the financial crisis of 2008 in more qualitative depth. These accounts also look in closer detail at key events such as the collapse of systemically important financial institutions that exacerbated the credit crunch. Rajan (2010) looks at how easy credit played a key role in creating financial instability. Before the housing boom, Borio and Lowe (2002) argued that financial instability was present in seemingly calm financial and macroeconomic environments. Paulson (2010) defends his actions as then Secretary of the Treasury as events unfolded into a credit crises. Paulson, Bernanke and their teams at the United States Department of the Treasury and the Federal Reserve did prevent the credit crunch from becoming even worse. They managed that by limiting damage to the financial sector- extending unsecured credit, buying illiquid assets, and injecting equity in financial institutions. Sorkin (2009) looks at how events unfolded during the critical period in 2008 during which the financial sector sustained heavy damage. Geithner (2014) gives the perspective of managing the financial crises while he was Secretary of the Treasury from 2009 to 2013.

Figure 1 shows the interplay of financial conditions and the business cycle. The figure shows that the US housing market and output co-move strongly. The figure also shows that tighter financial conditions, represented by wider corporate spreads, are negatively related to housing prices.

Further work remains to be done in quantitative modelling of financial intermediation. The first two chapters work along that line. The first chapter offers a new quantitative model of credit cycles with endogenous leverage for financial intermediaries. Changes in intermediary leverage influence the economy's credit supply giving rise to empirically observed credit cycle features. The model features three active credit channels, including a bank net worth channel, a funding cost channel, and a business conditions channel. Many recent quantitative financial friction models emphasize the net worth channel of transmission. In its simplest form, a leveraged bank that experiences a reduction in net worth must reduce assets causing fire sales and further net worth reductions. While this channel is indeed highly influential, it is not the only channel of credit cycle transmission. Standard collateral constraints do not allow banks or firms to raise new equity while evidence presented in the chapter shows that financial firms do raise external equity. This suggests that models that only consider the net worth channel miss out on other influential credit channels. Since banks in the model are able to decide their own capital structure, the model de-emphasizes the bank net worth channel that is central in standard credit or borrowing constraint models.



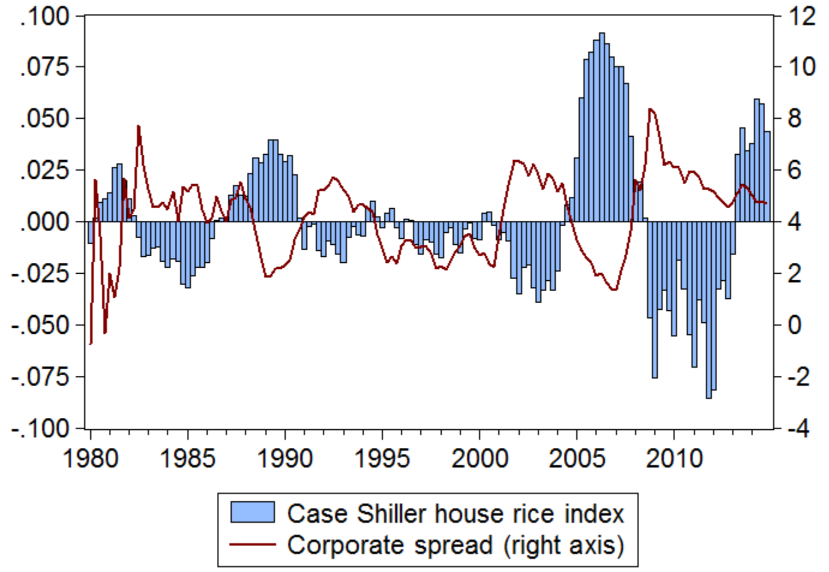


Figure 1: The top panel shows the relation between de-trended house prices and de-trended GDP per capita. There is strong co-movement between the two. The lower panel shows the negative relation between credit spreads and de-trended house prices.

The second chapter investigates how bank monitoring dynamics evolve over the business cycle. The model features lognormal idiosyncratic productivity shocks for firms and endogenous default thresholds with costly state verification. The model is in the line of established work on bank monitoring including the seminal contribution of Diamond (1984). The marginal benefit of bank monitoring drops during business cycle upturns and banks reduce their monitoring activity. This can increase volatility of consumption. In addition, bank monitoring is inefficiently low as firms holdup part of the benefit from loan monitoring. The two key contributions of this chapter are: i) modelling the dynamic properties of bank monitoring incentives, and ii) endogenous default thresholds that allow the model to endogenously track aggregate default rates over the business cycle.

A significant cause of the 2007 United States housing bubble was the drive to make housing affordable for lower income segments of society. While the third chapter does not deal with housing, it does look at how fiscal policy should be geared across different segments of society. The third chapter abstracts from financial intermediation and looks at how tax policy should vary across the business cycle in the presence of financial frictions. A key flashpoint in the 2012 US election in the aftermath of the 2008 financial crisis was whether richer households should contribute more in taxes for to support fiscal outlays such as TARP. The paper describes properties of Ramsey-optimal marginal income tax rates in response to productivity and fiscal spending shocks under a set of conditions. Financial frictions in the model give rise to heterogeneity among households. The chapter shows that behavior of optimal tax rates for lower income households is quite different from optimal taxes for the wealthy. Income tax rates are more volatile for lower income households. One way to implement this would be through automatically stabilizing rebates that vary over the business cycle.

Financial factors remain central in the contemporary economic environment. Central banks around the world are competing to relax monetary policy and undertake quantitative easing in the face of supply-driven disinflationary pressures. Quoting from Borio and Lowe (2002),

"Widespread financial distress typically arises from the unwinding of financial imbalances that build up disguised by benign economic conditions... As a result the financial cycle can amplify, and be amplified by, the business cycle."

The subject of the first chapter is precisely this feedback between the financial cycle and the business cycle, and the remaining dissertation explores financial factors and public policy.

Chapter 1

Credit Cycle Dynamics with Costly Value-at-Risk

Chapter Abstract

Credit cycle dynamics emerge in a model with endogenous financial intermediary leverage and costly state verification. A trade-off between costly bank capital and a benefit of capital as a buffer against adverse shocks drives intermediary leverage. Bank capital functions as a buffer by reducing value-at-risk. Bank capital is costly as households require a premium to hold risky capital whereas deposits are insured. Changes in intermediary balance sheet size drive credit supply. The model displays three active credit channels: the business conditions channel, the bank net worth channel, and the funding cost channel. The model delivers empirically observed procyclical credit conditions. (*JEL* E32, G21, G32)[1]

[1] I would like to thank An Sungbae, Nicolas Jacquet, Hoon Hian Teck, and Phang Sock Yong for valuable suggestions and discussions. I would like to thank conference participants at the joint Econometric Society Australasian Meeting 2014 and Australian Conference of Economists 2014, and at the joint European Meeting of the Econometric Society 2014 and European Economics Association Conference 2014 for valuable questions and discussions. An earlier version of this paper was titled 'The Funding Gap in the Credit Cycle'

1.1 Introduction

Interactions between financial intermediation and the macroeconomic environment may generate business cycle fluctuations. This credit cycle functions via several channels. In their survey on financial intermediation, Gorton and Winton (2003) distinguish between the broad lending channel, where business conditions influence intermediaries, and the bank lending channel, where variations in intermediation activity influence the business cycle. Much of the current literature on credit cycles emphasizes bank net worth channels. In the literature, this channel typically features intermediaries with lending activity constrained by their net worth. The key contribution of this paper is to propose a new model of credit cycles with endogenous intermediary leverage where three credit channels are simultaneously active.

There is some evidence of the interaction between credit conditions and the business cycle. Figure 1 shows cyclical output per capita and the Federal Reserve's Senior Loan Officer Opinion Survey (SLOOS) from 1990Q2 to 2012Q3. Shaded areas indicate NBER recessions. The graph shows the net percentage of survey respondents who indicate they are tightening lending standards for medium and large companies. The SLOOS numbers for small companies are very similar. The figure shows that tightening credit conditions are associated with contractions in cyclical output.

In order to look more quantitatively at the relation between credit and business conditions, I run a vector auto-regression (VAR) of cyclical real output per capita against the cyclical credit spread. The credit spread is the difference between secondary market yields on BAA corporate bonds and US 3-month treasuries. The spread is a measure of credit conditions, where a widening credit spread indicates tighter credit conditions. Both the series are de-trended using the HP filter for quarterly data. The data are from 1980Q1 to 2012Q3. Figure 2 shows the impulse response of the VAR. The figure shows that spreads

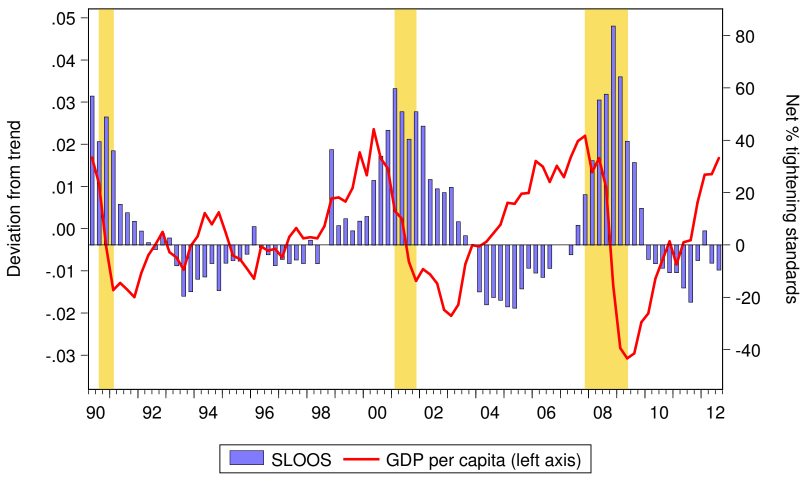


Figure 1.1: Tightening credit conditions associated with contraction in output

respond negatively to an output shock, which is a reflection of the business conditions channel. The impulse responses also show that output responds negatively to tighter credit conditions.

The model proposed here features endogenous intermediary leverage where intermediaries are free to payout and raise capital. Figure 3 shows financial business capital payouts over time using data from the Flow of Funds Accounts. In models without endogenous leverage, the capital payout is always 0. Figure 3 shows that payouts are highly volatile and frequently negative, indicating capital raising by financial businesses. This highlights the importance of endogenous leverage in intermediation models.

I model the credit cycle using a dynamic stochastic general equilibrium model with financial intermediation. The role of intermediaries is to perform a costly state verification following a default. Intermediaries can only recover a portion of the defaulted firm's assets. The non-recoverable portion is a monitoring cost, or a bankruptcy cost. Each bank lends money to one firm by combining capital with risk-free deposits. In the event of a default, the bank faces a maximum loss where its outstanding deposit obligations are larger than the recovered loan amount, and a deposit insurer meets this funding shortfall.

Figure 1.2: VAR of GDP per capita and credit spreads

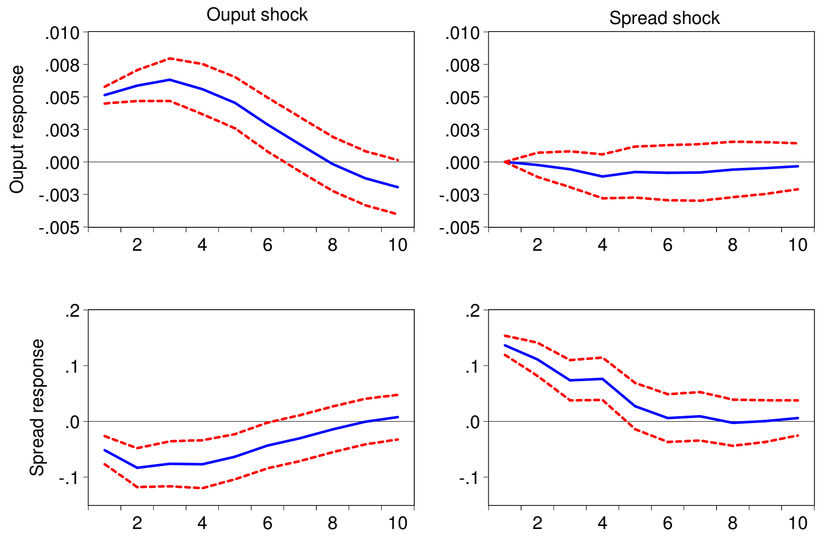
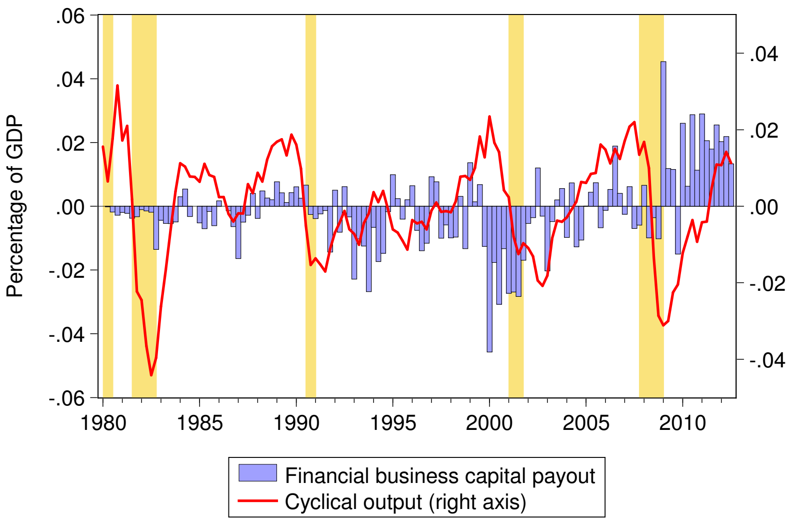


Figure 1.3: Financial business capital payout is volatile



Capital payout calculated as net dividends paid (F7 line 19) + undistributed profits (F7 line 23) - equities (F107 line 27). Shaded areas indicate NBER recessions.

Each bank pays a premium for this insurance, and the premium is convex in the bank's funding needs. This funding shortfall corresponds to the maximum loss, i.e., the bank's value-at-risk. When the capital cushion is greater, the value-at-risk is lower and hence the insurance premium is lower. Thus, bank capital in the model has value as a buffer against adverse times when the bank holds defaulted loans. The bank is free to manage its funding structure dynamically. Risk-averse households require a premium to hold bank capital as it is wiped out in the event of a default. Banks prefer deposits for funding the balance sheet because of deposit insurance and because capital requires this premium return.

Changes in banks' balance sheet sizes generate a credit cycle:

- Broad lending channel

  1. Business conditions channel: An improvement in business conditions improves recovery rates on collateral and reduces bank value-at-risk. This leads to lower insurance premia and allows banks to hold less capital and expand their balance sheets.

- Bank lending channel

  2. Bank net worth channel: Bank net worth has a mixed effect in the model. A greater capital cushion means lower value-at-risk and hence lower insurance premia, so the bank can support a larger balance sheet. On the other hand, capital is a costly way of finance for banks, increasing required returns and hence contracting balance sheets. Equilibrium bank leverage is optimal so that an increase or decrease in capital would reduce welfare.

  3. Funding cost channel: Higher funding costs of deposits mean banks need more funds to support the same balance sheet size. This leads to higher insurance premia and forces banks to contract balance

> sheets. In addition, higher nominal rates mean that households require greater returns on their bank capital holding as well. Higher net worth funding costs mean that the bank prefers to contract the balance sheet leading to reduced credit supply.

The model does particularly well in matching empirical credit spread correlation with output. In the data, credit spreads and output have a correlation of -0.61, and the model-generated correlation is -0.76.

This paper is related to and draws from the extensive work on credit cycles and financial features in business cycles. There are several approaches in the literature for generating credit cycles. Holmstrom and Tirole (1997) use a net worth channel where both banks and firms face moral hazard constraints. In their framework, better-capitalized banks can monitor firms better, and firms with less capital take more risk. Diamond and Rajan (2000) have a framework where banks can threaten to withhold their loan collection skills and extract rent from external equity holders. Higher deposits increase the threat of a bank run in adverse times. When business conditions improve, there is lower chance of distress and bank runs, and the banks can expand balance sheets. The model in this paper is most closely related to Adrian and Shin (2010b) in the Handbook of Monetary Economics. Adrian and Shin (2010b) have a value-at-risk approach, where banks need to keep at least enough capital to cover the maximum loss. The model in this paper features endogenous leverage where the maximum loss may be greater than the capital banks hold. The model in this paper hence moves away from the collateral constraint framework and places less emphasis on the net worth channel of credit cycle transmission.

This paper is also related to recent dynamic financial friction literature. A small sample of this literature includes Bernanke, Gertler, and Gilchrist (1999), Christiano, Motto, and Rostagno (2010), Gertler and Kiyotaki (2011), Mendoza (2010), and Jermann and Quadrini (2012). Much of the literature focuses on net worth channels. This paper proposes a model where capital structure is flexible so that funding channels and business conditions channels are more prominent.

Jermann and Quadrini (2012) look at the effects of financial shocks in the business cycle. They allow for a dynamic capital structure for firms, who choose equity payouts to maximize shareholder value. Endogenous leverage emerges as firms balance tax benefits of debts versus a dynamic borrowing constraint. Jermann and Quadrini (2012) abstract from intermediation and introduce the financial shock as an exogenous disturbance in the borrowing constraint parameter. The shock is a reflection of credit conditions, where a tighter borrowing constraint indicates tougher access to credit. They show that financing conditions are influential in the business cycle.

The remaining article is structured as follows. Section 2 describes the model and the calibration. Section 3 explores the credit channels active in the model and looks briefly at the evidence of credit channels. Section 4 concludes.

1.2 Model

1.2.1 Households

There is a continuum of households mass 1. Each household may save using either bank capital, n_t, or risk-free bank deposits, d_t. Each bank can lend to one firm, and a fraction ω of firms default each period. If the firm defaults, the lender bank's capital is wiped out. Households are diversified across banks, so they receive capital payouts from a fraction $1-\omega$ of banks. The household chooses the bank capital to hold next period n_{t+1}, deposits for next period d_{t+1}, labour hours h_t to supply for the period, and consumption c_t to maximize its preferences. Households objective is to

$$\max_{\{d_{t+1},n_{t+1},h_t,c_t\}} E_0 \sum_{t=0}^{\infty} \beta^t U\left(c_t, h_t\right)$$

subject to the period state-wise budget constraints

$$c_t + \frac{d_{t+1}}{r_t} + n_{t+1} = w_t h_t + \frac{d_t}{\pi_t} + (1-\omega)\, div_t^b n_t + \tau_t \tag{1.1}$$

where w_t is the real wage, r_t is the nominal risk-free interest rate, π_t is inflation, and div_t^b is the real bank capital payout rate. The quantity τ_t captures transfers from the insurer and firms.

The resulting first order condition for deposits is

$$1 = E_t \left\{ \frac{r_t}{\pi_{t+1}} \Lambda_{t,t+1} \right\} \tag{1.2}$$

where $\Lambda_{t,t+1}$ is the household's stochastic discount factor for real payoffs,

$$\Lambda_{t,t+1} = \beta \frac{U'_{c_{t+1}}}{U'_{c_t}}$$

Households can also choose to save in bank capital. If the bank holds a good asset, it commits to payout its entire profits to households, who receive a payment of $div_t^b n_t$. If the bank holds a defaulted asset then the equity payout from the bank is 0. Since each bank lends to one firm, a fraction ω of banks hold defaulted assets. The first order condition for n_t is

$$1 = E_t \left\{ \Lambda_{t,t+1} \left(1-\omega\right) div_{t+1}^b \right\} \tag{1.3}$$

Here div^b represents the household's required payout rate on bank capital.

The household also supplies labour to firms.

$$-U'_h = w_t U'_c \tag{1.4}$$

1.2.2 Banks and Public Deposit Insurance

A bank enters the period with n_t as capital from the owner household, d_t in deposits, and outstanding loans b_t. The bank commits to paying out its entire profits, s_t^b. If the bank holds a non-defaulted asset, it collects interest and principal payment from the firm, pays out depositors, pays an insurance premium, and transfers remaining funds as distribution to the owner household. If on the other hand the bank holds a defaulted asset, it transfers the recovered portion of the loan as well as deposits to the public deposit insurer. The capital payout in that case is 0. Banks do not diversify the default risk across firms.

The bank has capital collateral equal to the principal amount b_t/z_{t-1}, where z_t is the interest rate on loans. If the event of a firm default, the bank recovers a fraction μq_t of the collateral, where q_t is the real price of capital. The bank still owes depositors d_t/π_t, and hence the bank faces a maximum loss (value-at-risk) equal to $(d_t/\pi_t) - \mu q_t\,(b_t/z_{t-1})$. The deposit insurer receives the recovered collateral value and the deposits, and meets payments to depositors. In return for this insurance service the insurer collects a premium from banks. This costly insurance is central in this model. It captures a buffer value of capital for banks. The premium is convex in the expected value-at-risk, and takes the functional form ϕj_t^{γ}, where ϕ and γ are parameters, and j_t is defined as the value-at-risk per unit asset,

$$j_t = \left\{ \frac{(d_t/\pi_t) - \mu q_t\,(b_t/z_{t-1})}{b_t} \right\} \tag{1.5}$$

j_t is a key variable in the model. It is a measure of intermediary risk. This model has multiple credit channels because several different variables affect the value-at-risk. Improved business conditions raise q_t and reduce j_t, higher risk-free interest rates raise d_t and raise j_t, higher n_t reduces j_t, and a greater asset size b_t does not affect j_t unless intermediary leverage changes.

The parameter γ governs the insurance premium elasticity of j_t. When j_t rises by 1%, the insurance premium rises by γ%. Greater elasticity of the premium means that the buffer value of capital is more volatile, and so bank leverage is also more volatile.

Banks prefer financing with deposits rather than capital. Deposit insurance makes deposits attractive to banks, whereas households require greater returns on capital making capital costly. On the other hand, the insurance premium is lower when the bank has more capital cushion. Banks balance between these effects to choose their capital structure. Figure 4 shows the intuition for the bank's capital structure decision. The insurance premium captures the role of bank capital as a buffer against adverse times when the bank holds a defaulted loan. Endogenous leverage emerges in the model as banks balance this buffer value of capital against the capital funding cost.

Spreads arise in this model because of the insurance premium, and because capital financing is more costly than risk-free deposits. Intermediaries pass some cost of the insurance premium to borrowers in the form of higher spreads.

Intermediaries combine capital and deposits from households to lend b_{t+1}/z_t to firms. This is the bank's balance sheet constraint,

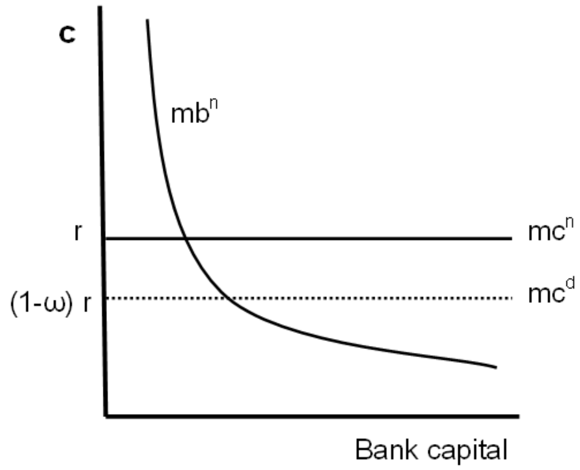
$$\frac{b_{t+1}}{z_t} = n_{t+1} + \frac{d_{t+1}}{r_t} \tag{1.6}$$

The bank's leverage is equal to the assets over the bank capital,

$$lev^b = \frac{b_{t+1}}{z_t n_{t+1}}$$

When it holds a non-defaulted asset, the bank receives a nominal payment

Figure 1.4: Intuition of the bank's capital holding decision



This graph shows the capital decision of the bank holding prices and other allocations constant. The vertical axis is in consumption units. mb^n and mc^n refer to the marginal benefit and marginal cost of bank net worth respectively. The marginal cost of net worth can be viewed as being fixed at r_t taking prices as given. This is because the bank pays out $r_t/(1-\omega)$ but with a probability $(1-\omega)$. mb^n is $z_t + \partial(\phi j_t^\gamma)/\partial n_t$. Each additional unit of capital reduces the payable insurance premium. While j_t is positive and $\gamma > 1$, mb^n is downward sloping. In addition, when $\gamma > 2$, mb^n is convex. The marginal cost of deposits is lower as the insurer pays depositors in the event of default.

b_t from firms, and it pays out d_t to depositors, and pays out the insurance premium. The bank's real profit s_t^b is given by

$$s_t^b = \frac{b_t}{\pi_t} - \frac{d_t}{\pi_t} - \phi j_t^\gamma \tag{1.7}$$

A bank that holds defaulted assets simply transfers liabilities and assets to the insurer and continues business as normal in the following period. The bank maximizes lifetime profits, subject to the balance sheet constraint (6), and the bank profit equation (7).

$$\max_{\{n_{t+1}, d_{t+1}, b_{t+1}\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} (1-\omega) s_t^b$$

Since the bank commits to payout all its profits, we have

$$s_t^b = div_t^b n_t \tag{1.8}$$

The resulting first order condition for credit supply can be expressed in terms of the credit spread, $z_t - r_t$,

$$z_t - r_t = \frac{\gamma \phi j_t^{\gamma-1} \left(r_t b_{t+1} - z_t d_{t+1}\right)}{b_{t+1}^2} \tag{1.9}$$

This condition says that credit supply expands (spreads tighten) when j_t drops. When the premium is elastic and γ is high, the credit supply shifts farther in response to shifts in j_t.

The public insurer receives the premium payment from the $1 - \omega$ banks that are solvent, and it also takes over assets and liabilities from the distressed banks. This means it pays out deposits for the banks with defaulted assets. The insurer can transfer lump-sum amounts to households to meet any excess or shortfall from the transactions. I assume that there is no moral hazard between the insurer and the insolvent bank, so that the bank collects on the defaulted loan. The insurance premium penalizes banks for maintaining a lower capital cushion. In this sense the insurer may be viewed as a regulator who discourages banks from keeping a fragile capital structure.

$$\xi_t = (1-\omega)\,\phi j_t^{\gamma} - \omega\left(\frac{d_t}{\pi_t} - \mu q_t \frac{b_t}{z_{t-1}}\right) \tag{1.10}$$

where ξ_t is a lump-sum transfer to households.

1.2.3 Capital Owner Firms

There is a continuum of capital owner firms with mass 1. They borrow from banks to purchase capital, which they lease out to intermediate good producer firms. A fraction ω of capital owner firms default each period. If a firm defaults, all the capital income for the period is lost and the lender bank takes control of the firm's capital. There is no other default penalty and the firm functions as normal the following period. A capital owner firm solves

$$\max_{\{k_{t+1},b_{t+1}\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \left(1-\omega\right) \left(r_t^k k_t + \left(1-\delta\right) q_t k_t - \frac{b_t}{\pi_t} \right)$$

r_t^k represents the real capital rental rate, δ is the capital depreciation rate, and b_t/π_t is the real loan payment to banks. The firm's balance sheet constraint is

$$q_t k_{t+1} = \frac{b_{t+1}}{z_t} \tag{1.11}$$

where b_{t+1}/z_t is the loan principal.

The firm takes r_t^k and z_t as given, and the associated first order condition for credit demand is

$$r_{t+1}^k + \left(1-\delta\right) q_{t+1} = q_t \frac{z_t}{\pi_{t+1}} \tag{1.12}$$

1.2.4 Goods Producer Firms

Goods production in the model follows a standard setup. The final good in the economy, Y_t is a composite of intermediate goods $y_{i,t}$,

$$Y_t = \left(\int_0^1 y_{i,t}^{1-\frac{1}{\epsilon}} di \right)^{1/\left(1-\frac{1}{\epsilon}\right)} \tag{1.13}$$

The final good producers solve

$$\max_{y_{i,t}} \left\{ P_t Y_t - \int_0^1 p_{i,t} y_{i,t} di \right\}$$

where P_t is the aggregate price index and $p_{i,t}$ is the price of an intermediate good y_i, t. This gives the demand for intermediate goods,

$$y_{i,t} = \left(\frac{p_{i,t}}{P_t}\right)^{-\epsilon} Y_t \tag{1.14}$$

Final goods producers are perfectly competitive, so the aggregate price index is

$$P_t = \left(\int_0^1 p_{i,t}^{1-\epsilon} di\right)^{1/(1-\epsilon)} \tag{1.15}$$

There is a continuum of monopolistically competitive intermediate good producers indexed by $i \in [0, 1]$. Prices are sticky and a fraction $1 - \theta$ of firms can reset their prices in a period. The production technology has a Cobb-Douglas form,

$$y_{i,t} = A_t k_{i,t}^{\alpha} h_{i,t}^{1-\alpha} \tag{1.16}$$

Here A_t represents the aggregate total factor productivity (TFP), which follows an AR(1) process with a shock ν_A,

$$ln\left(A_t\right) = \rho_A ln\left(A_{t-1}\right) + \nu_A \tag{1.17}$$

The intermediate good producer firm tries to maximize the lifetime value of profits, which are distributed to households.

$$\max_{p_{i,t}, k_{i,t}, h_{i,t}} E_t \sum_{t=0}^{\infty} \theta^t \Lambda_{0,t} \left(\frac{p_{i,t} y_{i,t}}{P_t} - r_t^k k_{i,t} - w_t h_{i,t}\right)$$

subject to the demand constraint (14) and the production technology (16).

The associated real marginal cost is

$$mc_t = \frac{r_t^k}{\alpha A_t k_{i,t}^{\alpha-1} h_{i,t}^{1-\alpha}} \tag{1.18}$$

$$mc_t = \frac{w_t}{\left(1-\alpha\right) A_t k_{i,t}^{\alpha} h_{i,t}^{-\alpha}} \tag{1.19}$$

The homogeneous production technology means that marginal cost for all firms is identical at mc_t.

The first order condition for firms is

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \theta^t \left(\frac{p^*_{i,t}}{P_t} \right)^{-1-\epsilon} Y_t \left(mc_t - \frac{\epsilon - 1}{\epsilon} \frac{p^*_{i,t}}{P_t} \right) = 0 \tag{1.20}$$

All firms that re-optimize prices in the period choose the same price, so that $p^*_{i,t} = p^*_t$. Following Schmitt-Grohé and Uribe (2007), I express this first order condition recursively with non-zero inflation in steady state, and track the price dispersion cost ι_t.

$$\iota_t = (1 - \theta) P_t^{*-\epsilon} + \theta \pi^{-\epsilon} \iota_{t-1} \tag{1.21}$$

Equation (15) gives the price evolution equation,

$$1 = \pi_t^{-1+\epsilon} + (1 - \alpha) P_t^{*1-\epsilon} \tag{1.22}$$

where P^*_t is p^*_t / P_t.

1.2.5 Capital Goods Producer Firm

The capital goods producer buys existing capital from the market at price q_t, makes new capital using old capital and goods, and then sells it. Capital goods production is subject to flow investment adjustment costs. The firm solves

$$\max_{K_{t+1}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \left(q_t I_t - I_t \left[1 + F \left(\frac{I_t}{I_{t-1}} \right) \right] \right)$$

The law of motion of capital gives I_t,

$$K_{t+1} = \left((1 - \delta)(1 - \omega) + \omega \mu \right) K_t + I_t \tag{1.23}$$

Capital from the non-defaulted capital owners depreciates at the rate δ, and banks can only recover a fraction μ of capital from defaulted firms.

The first order condition for capital production is given by

$$q_t = 1 + F\left(\frac{I_t}{I_{t-1}}\right) + I_t F'_{I_t}\left(\frac{I_t}{I_{t-1}}\right) + \Lambda_{t,t+1} I_{t+1} F'_{I_t}\left(\frac{I_{t+1}}{I_t}\right) \tag{1.24}$$

1.2.6 Monetary Policy and Equilibrium

The monetary authority follows a smoothed Taylor rule,

$$ln\left(\frac{r_t}{r^*}\right) = \Phi_r ln\left(\frac{r_{t-1}}{r^*}\right) + (1-\Phi_r)\left[\Phi_\pi ln\left(\frac{\pi_t}{\pi^*}\right) + \Phi_y ln\left(\frac{y_t}{y^*}\right)\right] + \varsigma_t \tag{1.25}$$

The starred variables represent steady states, and ς_t is an exogenous stochastic process,

$$\varsigma_t = \rho_\varsigma \varsigma_{t-1} + \nu_\varsigma \tag{1.26}$$

where ν_ς is a monetary policy shock.

Aggregation for the final good gives

$$Y_t = C_t + I_t\left(1 + F\left(\frac{I_t}{I_{t-1}}\right)\right) \tag{1.27}$$

After accounting for price dispersion, the aggregate output is given by

$$Y_t = \left(A_t K_t^\alpha H_t^{1-\alpha}\right)\frac{1}{\iota_t} \tag{1.28}$$

Competitive equilibrium for the economy is the set of processes $\{c_t,\ h_t,\ div_t,\ r_t,\ \pi_t,\ z_t,\ q_t,\ j_t,\ s_t^b,\ \xi_t,\ r_t^k,\ w_t,\ mc_t,\ Y_t,\ P_t^*,\ I_t,\ k_{t+1},\ b_{t+1},\ d_{t+1},\ n_{t+1},\ \iota_t\}_{t=0}^{\infty}$ that satisfy equations (2) - (12), (18)- (25), (27), and (28), given k_0, b_0, d_0, n_0, ι_{-1}, and the exogenous stochastic processes $\{A_t\}_{t=0}^{\infty}$ and $\{\varsigma_t\}_{t=0}^{\infty}$.

1.2.7 Calibration

I calibrate steady state inflation to 0.5% per quarter. I calibrate the time discount factor β to 0.996 to give a nominal risk-free rate of 3.7% annually in steady state. The production parameter α is set to 0.36, and the depreciation parameter δ is 0.025. The values for the intermediate goods firms are in standard ranges - the CES parameter ϵ is 6, and price stickiness parameter θ is 0.75.

The utility functional form is separable in labor and consumption with the following form, where I calibrate η to 1, and χ to 7.69 to get steady state h equal to 0.3 in steady state.

$$U\left(c_t, h_t\right) = log\left(c_t\right) - \chi \frac{h_t^{1+\eta}}{1+\eta}$$

Following Christiano, Eichenbaum, and Evans (2005), the investment adjustment cost function has a flow specification

$$F\left(\frac{I_t}{I_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2$$

where κ is set to 2.48.

TFP shock persistence ρ_A is 0.95 and the shock standard deviation σ_A is 0.007. Monetary shock persistence ρ_ς is 0.5 and standard deviation σ_ς is 0.0025. I calibrate the monetary policy rule parameters Φ_r, Φ_π, and Φ_y to 0.75, 2.4, and 0 respectively. These values for shocks and policy rule parameters are in line with estimates in Smets and Wouters (2007).

The default parameter ω is calibrated to 0.011 and the recovery parameter μ to 0.65. The value for μ is comparable to the long run average recovery rate on loans given default, according to data from the 2010 Moody's default study[2].

[2]Moody's Investor Service. (2011) Corporate Default and Recovery Rates, 1920:2010. *Moody's*

The parameter ω is higher than comparable values in the literature. The long run annual default rate for speculative grade companies is a bit higher than 4% based on default studies from the credit rating agencies, so the average economy-wide marginal default rate may be a bit lower. Coupled with the recovery rate μ the parametrization is moderate.

The financial parameters ϕ and γ are specific to this model. γ governs the elasticity of the insurance premium to the value-at-risk, j_t, and ϕ is the insurance cost scale parameter. γ and ϕ are calibrated simultaneously to match target steady state spread and intermediary leverage. The target quarterly steady state spread is 0.84%, which is the long run average spread between secondary market yields of BAA corporate bonds and US 3 month treasuries. The target steady state bank leverage is 12. This is the average leverage for commercial banks since 1980 based on data from the Federal Reserve's H8 release. Commercial bank leverage has trended downwards significantly over time, especially since the 1990s. However, leverage for shadow banks and capital market intermediaries is much higher than commercial banks as discussed in Adrian and Shin (2010a). γ and ϕ are set to 3.636 and 7.14 respectively. Table 1 summarizes the calibration.

Table 2 shows selected moments from the model. The model does well in matching correlation between spreads and output. The empirical correlation of spreads and output is -0.6, compared to -0.76 in the model. While the model has volatile spreads, empirically spreads are even more volatile.

1.3 Credit Channels

Endogenous Leverage

We can derive the bank's capital structure decision in the model. Re-writing the bank's profit equation (7) after using the balance sheet condition (6) and

Table 1.1: Calibration

Parameter	Description	Value
π^*	inflation	1.005
β	intertemporal discount	0.996
α	intermediate good production	0.36
δ	depreciation	0.025
ϵ	final goods CES production	6
θ	price stickiness	0.75
η	inverse labour supply elasticity	1
χ	labour utility	7.69
κ	investment adjustment cost	2.48
ρ_A	TFP shock persistence	0.95
ρ_ς	Monetary shock persistence	0.5
σ_A	TFP standard deviation	0.007
σ_ς	Monetary shock standard deviation	0.0025
Φ_r	Taylor rule smoothing	0.75
Φ_π	Taylor rule inflation	2.4
Φ_y	Taylor rule output	0
ω	default rate	0.011
μ	recovery rate	0.65
γ	insurance premium elasticity	3.636
ϕ	insurance premium scale	7.14

the payout equation (8) gives

$$n_t \left(div_t^b - \frac{r_{t-1}}{\pi_t} \right) = \frac{b_t}{\pi_t} \left(\frac{z_t - r_t}{z_t} \right) - \phi j_t^\gamma$$

We further manipulate the equation using the household Euler equations and the credit supply equation (9). The resulting expression is shifted one period forward to give the capital asset ratio,

$$\frac{n_{t+1}}{b_{t+1}} = E_t \left\{ \frac{-\pi_{t+1} (1-\omega) \phi j_{t+1}^\gamma}{r_t b_{t+1} \omega - (1-\omega) r_t \phi \gamma j_{t+1}^{\gamma-1}} \right\} \tag{1.29}$$

This expression gives

$$\frac{\partial (n_{t+1}/b_{t+1})}{\partial r_t} = -\frac{(n_{t+1}/b_{t+1})}{r_t}$$

A rise in interest rates increases the opportunity cost of bank capital, and

Table 1.2: Moments

		spread	z_t	Total credit	Bank capital	Invest-ment
Correlation with output	Data	-0.608	-0.224	0.209	0.483	0.813
	Model	-0.764	-0.739	0.822	0.621	0.869
Volatility relative to output	Data	24.5	0.12	1.86	3.76	4.75
	Model	8.28	0.15	0.87	2.62	2.23

Note: Output, total credit, bank capital, and investment are in real per capita terms, logged and de-trended using the HP-filter. z_t is the de-trended BAA yield. Total credit is the credit outstanding to non-financial business. Bank capital is net assets for commercial banks. Data from the Federal Reserve and BEA.

banks respond by increasing leverage. Figure 5 shows the VAR of interest rates and the capital-asset ratio of commercial banks. Following an interest rate shock, capital asset ratios seem to rise initially and then fall. This might be a reflection of adjustment costs in capital structure for intermediaries.

$$\frac{\partial\left(n_{t+1}/b_{t+1}\right)}{\partial j_{t+1}} = \gamma\phi\left(1-\omega\right)\pi_{t+1}j_{t+1}^{\gamma-1}r_t\left(-b_{t+1}\omega+\phi j_{t+1}^{\gamma-1}\left(1-\omega\right)\right)$$

$\partial\left(n_{t+1}/b_{t+1}\right)/\partial j_{t+1} > 0$ in the baseline calibration. However, it can be negative if default rates ω are high so that fewer banks pay the insurance premium. $\partial\left(n_{t+1}/b_{t+1}\right)/\partial j_{t+1}$ increases with ϕ, r_t, and j_{t+1}.

The costly value-at-risk approach in this model looks at changes in credit supply and the effects on the business cycle. Figure 6 shows some evidence of the role of credit supply. The figure shows the impulse response from a VAR of lending rates and total credit outstanding. Lending rates are de-trended secondary market BAA yields, and total credit is de-trended total credit outstanding to non-financial business. The figure shows that higher lending rates are associated with reduction in credit outstanding. This implies that credit supply conditions are particularly influential during contractions in credit.

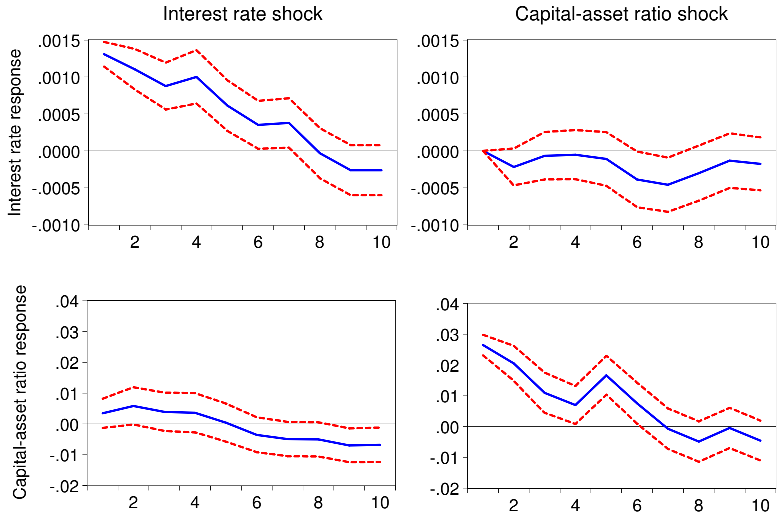


Figure 1.5: VAR of detrended interest rates and de-trended capital-asset ratio for commercial banks. Data for the capital asset ratio derived from the Federal Reserve's H8 release for commercial banks. Interest rates are secondary market yields on US 3-month treasuries. Capital asset ratios rise and then fall following an interest rate shock.

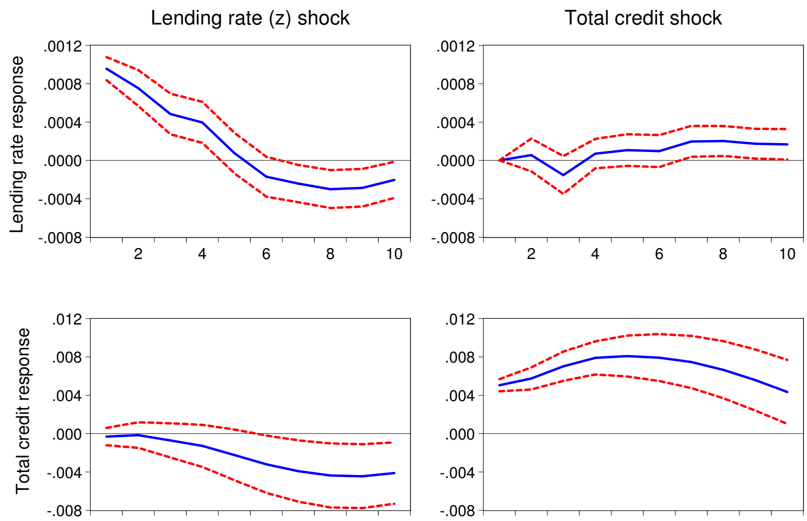


Figure 1.6: VAR of lending rates and total credit outstanding. Credit supply conditions influential in credit contraction as total credit drops following a lending rate shock.

One of the key drivers of the credit channels in the model is equation (9), which governs the credit supply. Equation (9) is shown here for convenience:

$$z_t - r_t = \frac{\gamma \phi j_t^{\gamma-1} \left(r_t b_{t+1} - z_t d_{t+1} \right)}{b_{t+1}^2}$$

From equation (9), we have

$$\frac{\partial \left(z_t - r_t \right)}{\partial j_t} = \left(z_t - r_t \right) \left(\gamma - 1 \right) \frac{1}{j_t} > 0$$

When the value-at-risk per unit asset, j_t, rises, the credit spread rises and banks supply less credit. This is because intermediaries' marginal costs for insurance premium rise. Intermediaries also have to hold more capital to offset the rise in premium, so their marginal funding costs rise. Due to the convexity of insurance premia, the effect is larger if the spreads are large to begin with.

1.3.1 Broad Lending Channel

Business Conditions Channel

An improvement in business conditions increases the willingness of intermediaries to lend. In this model the business conditions channel works principally through asset prices q_t. The credit supply condition (9) shows that $\partial \left(z_t - r_t \right) / \partial q_t$ is negative and so the credit supply increases in q_t.

Consider a TFP shock to look at the business conditions channel. A shock that improves TFP increases the demand for credit as measured by a rise in r^k and a boom in investment. Asset prices rise, driving down the maximum loss, reflecting an improvement in collateral conditions. The insurance premium drops, and banks can afford to expand the balance sheet using deposits, the cheaper funding source. This drives down spreads.

The monetary authority responds to the TFP shock by reducing the nominal rate r_t, triggering the funding cost channel. A drop in div^b means that

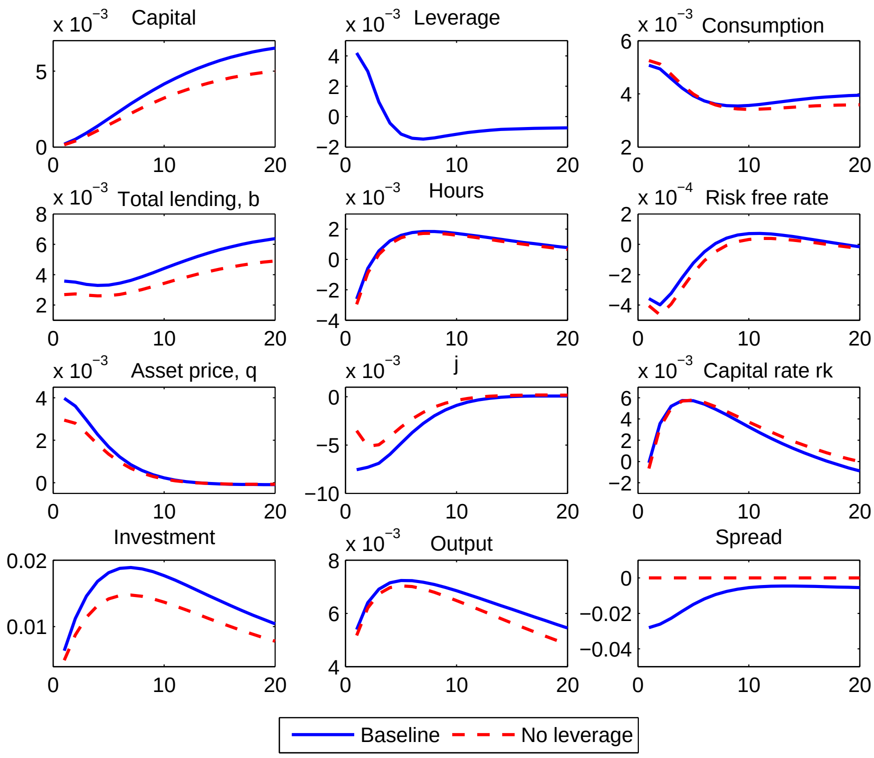


Figure 1.7: Response to 0.7% (1 standard deviation) TFP shock

capital is cheaper and hence banks can afford to keep more capital and drive the insurance premium further down. The net effect is that the bank expands the credit supply. Firms can afford to borrow more resulting in an amplified boom in investment. Figure 7 shows the summary impulse response for a TFP shock. For comparison, I show the same model with ϕ set to 0. When insurance is costless in this way, the optimal bank capital is 0, the credit spread is 0 too, and the credit channels are closed.

I look at the aggregate level empirical evidence for a link between asset prices and credit supply conditions. I run a VAR of the de-trended S&P 500 index and de-trended credit spreads. The VAR shows that credit spreads tighten when asset prices rise. Figure 8 shows the impulse response of the VAR.

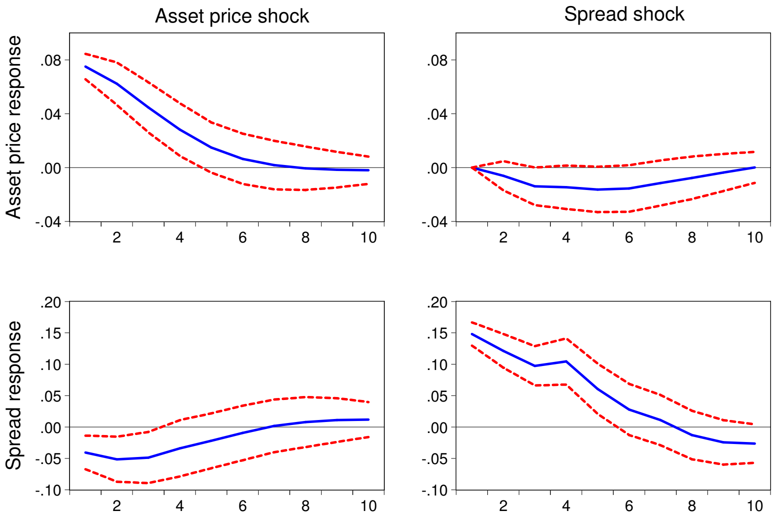


Figure 1.8: VAR of detrended asset prices and de-trended credit spreads. A rise in asset prices leads to tighter spreads, showing the asset price channel is active.

1.3.2 Bank Lending Channel

Bank Net Worth Channel

Bank net worth has an ambiguous effect in the model. Capital is a costly way of financing bank assets, but it also reduces the insurance premium and hence marginal lending costs. Equilibrium capital is optimal in the model so that there is no welfare gain from increasing or decreasing capital levels. One situation where more capital would improve welfare is if banks overestimate their loan recovery rate $\mu q_t b_{t-1}/z_{t-1}$.

At the aggregate level, cyclical bank capital changes do not seem to affect spreads. Figure 9 shows the VAR of bank capital per capita and credit spreads. Bank capital data is obtained from the Federal Reserve H8 Release using data for all commercial banks. Several studies look at the effect of bank capital on lending activity. Gambacorta and Mistrulli (2004) find that better capitalized banks can absorb temporary GDP shocks better, consistent with the model in the paper. Lown and Morgan (2006) also find that bank capital does not appear to affect standards, which is consistent with the results here. They argue that book value of capital may not be the ideal measure for bank capital.

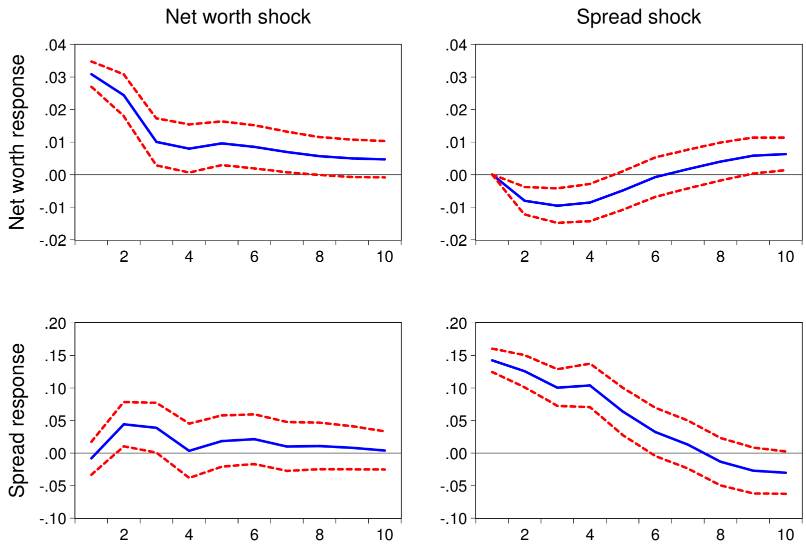


Figure 1.9: VAR of detrended bank capital and de-trended credit spreads

Funding Cost Channel

The household Euler equations imply that div_t^b is related to r_t,

$$E_t\left\{(1-\omega)\, div_{t+1}^b U'_{c_{t+1}}\right\} = E_t \frac{r_t U'_{c_{t+1}}}{\pi_{t+1}}$$

This means that when the real interest rate rises, the required return on capital, div_t^b, also rises. Banks pass on this increase in funding costs to firms. Intermediaries' profitability is eroded and they respond by charging higher spreads to borrowers,. In addition, there is a secondary effect as the real value-at-risk rises and j_t rises. This increases the funding costs and forces banks to rein in credit supply. The result is higher spreads and lower investment. The rise in required returns also increases the average cost of capital. If n_t remains the same, banks need to make more profit to distribute the required return according to the profit equation (7) and profit distribution (8). This causes banks to hold less capital following the increase in r_t.

Figure 10 shows the effect of a monetary policy shock ν_ς with size 0.0025. The size of the shock is one standard deviation, estimated in Smets and

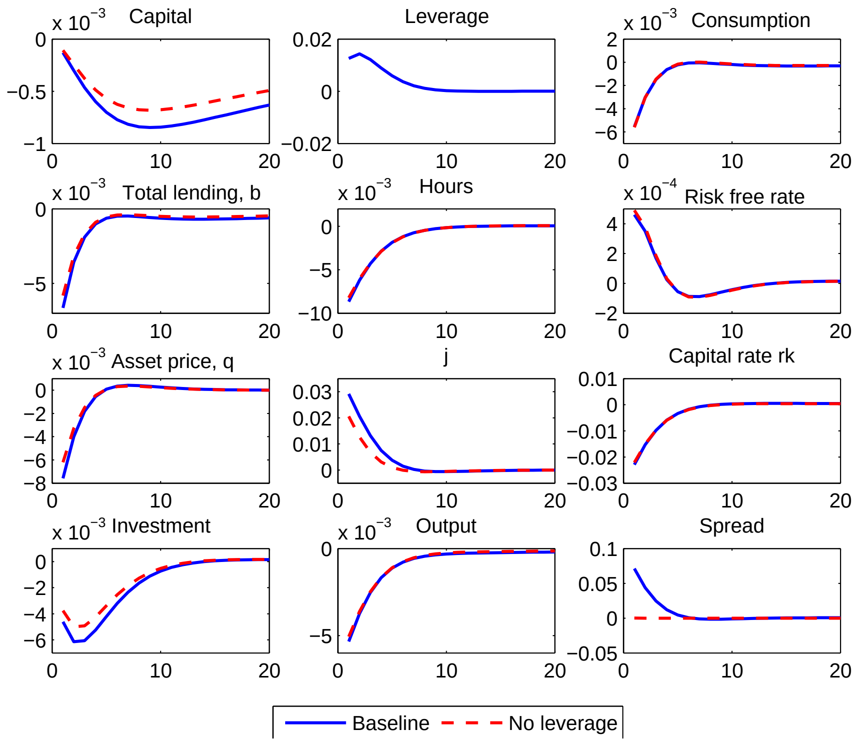


Figure 1.10: Response to one standard deviation monetary policy shock

Wouters (2007) and other related studies. It implies that if inflation is constant, the nominal rate would rise by 0.25%. The relatively small shock size induces small movements in most variables except the spread, which rises by more than 5%. The steady state spread is 84 basis points, so a 5% rise translates to a less than 5 basis point move in the credit spread. Such a move is modest in comparison to empirical spread volatility.

Some empirical work investigates funding channels for banks. Kishan and Opiela (2000), for instance, find that monetary policy effects are largest for small banks with lower capital buffers. Marginal funding costs for banks are not apparent as banks may use a variety of funding methods with different durations.

1.4 Conclusion

This paper proposes a model of credit cycles where three credit channels are simultaneously active. More capital reduces intermediaries' maximum loss resulting in lower costs for insurance premia. This feature captures bank capital's role as a buffer against adverse shocks. Capital is costly because household desire compensation for the extra risk of holding capital versus risk free deposits, and intermediaries prefer funding using deposits because of deposit insurance. Changes in the value-at-risk and cost of capital through the different channels shift the amount banks are willing to lend.

I show that capital payouts for financial businesses are volatile indicating the need to consider endogenous leverage in financial intermediation models. I also present some evidence of the credit channels. I show using a vector auto-regression that credit conditions improve over the business cycle (i.e. they are procyclical). In addition, total credit outstanding drops when lending rates rise, indicating that credit supply is particularly influential in credit crunches. At the aggregate level, bank net worth does not seem to influence credit spreads. Evidence from VARs shows that a rise in asset prices improves credit conditions, indicating the business conditions channel is active.

Chapter 2

Bank Monitoring Dynamics and Inefficiency Over the Business Cycle

Chapter Abstract

How does bank monitoring evolve over the business cycle? The model presented in this paper features financial intermediaries who engage in risk-shifting over the business cycle by reducing monitoring activity during business cycle upturns when the chances of loan losses are lower. The model environment features firm-specific productivity shocks with endogenous default thresholds. Bank monitoring is costly, but it can indirectly reduce loan default probabilities by preventing firm moral hazard. As aggregate default probabilities fall over the business cycle, the marginal benefit of loan monitoring drops. In addition, intermediary monitoring is inefficiently low because firms holdup part of the benefit of monitoring.

JEL codes: E32, G21, D61

2.1 Introduction

A key function of financial intermediaries is to act as delegated monitors for lending on behalf of diversified depositors. The cost of loan monitoring may be too high for individual savers to engage in direct finance of firms' borrowing, and so they rely on banks to pool savings from many agents, finance borrowing, and monitor loans. The bank has private incentives to monitor loans since depositors do not observe bank monitoring activity. This paper looks at how the business cycle influences banks' incentives for monitoring. Banks' incentive for monitoring in the model arises because default is costly and monitoring loans can indirectly reduce the probability of default. Banks risk-shift over the business cycle by choosing to spend less on monitoring during good times when aggregate default probabilities are lower.

The model combines costly state verification following default (introduced by Townsend (1979)) with costly loan monitoring as in Diamond (1984). Firms are ex-ante identical but receive a log-normally distributed idiosyncratic shock within the period. Firms that receive shocks below an endogenous threshold go into default as they cannot meet their debt obligations, and the lending bank incurs a state verification default cost. Firms also have a moral hazard where they receive an opportunity within the period to divert a fraction of production. A banker can prevent the firm from taking this opportunity if she monitors the firm by incurring a monitoring cost. A firm that has diverted some of its production is more likely to default, so that the banker can save on loan default costs by choosing to monitor the firm. Following an aggregate improvement, firms are in general less likely to default, so that the marginal benefit of bank monitoring is lower, and banks monitor less.

The model also features a holdup problem. Banks only receive some fraction of output as loan payment as firms holdup the remaining output. Consider a standard Cobb-Douglas production function, $f(K_t, H_t) = A_t K_t^{\alpha} H_t^{1-\alpha}$ where

K is capital, H is labour hours, and $f(K_t, H_t)$ is output. If competitive homogenous firms borrow to finance 100% of their capital purchase, then the loan repayment would be the capital share of output, $f_k'(K_t, H_t) K_t = \alpha f(K_t, H_t)$. The firm holds up the remaining share of output, and so when the bank chooses the monitoring activity it takes into consideration the benefit from saving $\alpha f(K_t, H_t)$ rather than $f(K_t, H_t)$. This results in inefficiently low monitoring activity.

This paper is related to the large literature on bank monitoring as surveyed in Gorton and Winton (2003). The paper shares the established intuition on bank monitoring with several papers including Berglöf and von Thadden (1994), Gorton and Kahn (2000), Longhofer and Santos (2000), Park (2000), and Rajan and Winton (1995). These studies look at different aspects of bank monitoring. The model in this paper shares the intuition that arises in these papers - the returns to loan-monitoring are greatest in bad states. This paper is closely related to Winton (1999). He argues that banks can risk-shift by monitoring less because depositors cannot observe bank monitoring activity in a timely fashion. He argues that while banks may commit to diversifying their loan portfolio, it is more difficult for them to commit to monitoring. The feature that banks cannot commit to monitoring loans is also an important part of the current model. The two key contributions in this paper are

(i) The model tracks the business cycle dynamics of banks' incentives to monitor loans.

(ii) Endogenous default thresholds within the model allow us to track the dynamics of aggregate default rates.

This paper is also related to the dynamic financial intermediation literature. Bernanke, Gertler, and Gilchrist (1999) incorporated costly state verification into a DSGE environment to generate a credit cycle. Christiano et al (2014) features a model with costly state verification, idiosyncratic firm productivity shocks, and firm leverage to study the effect of ‘risk shocks’ on the business cycle. I abstract from both firms’ and banks’ capital structure. In particular, neither banks nor firms have access to internal funds. This paper focuses on costly bank monitoring dynamics where costly state verification gives the incentive for banks to monitor. There has been a lot of interest in bank risk-shifting arising due to expansive monetary policy (Jiménez, Ongena, Peydró, and Saurina (2014) and the references therein), but less interest in background intermediary risk-shifting over the business cycle.

Default rates tend to be counter-cyclical. Aggregate improvements in business conditions mean that firms do well and are less likely to go into default. Figure 1 shows speculative grade corporate bond annual default rates from 1952 - 2010 (bond default data from Moody’s). The model also generates counter-cyclical default rates for all firms with endogenous default thresholds.

Bank monitoring is largely unobservable. Central banks around the world now conduct credit standards surveys, such as the Federal Reserve’s Senior Loan Officer Opinion Survey (SLOOS), and the ECB’s Bank Lending Survey. Surveys include information on net percentage of banks tightening terms on lending to firms. Terms may give a very rough idea about potential monitoring activity. Figure 2 shows net percentage of banks tightening loan covenants terms to firms. The contemporaneous correlation with cyclical output is -0.17. The net percentage of banks tightening terms is strongly positively correlated with net percentage of banks tightening lending standards.

The rest of the paper is laid out as follows. Section 2 outlines the baseline model and the model. Section 3 gives the model calibration and the baseline results on bank monitoring over the business cycle. Section 4 looks at the influence of dynamic monitoring on the business cycle. Section 5 examines the holdup problem to show that bank monitoring in the model is inefficiently low, and finally section 6 concludes.

2.2 Model

2.2.1 Households

There is a continuum of households of unit mass who maximize lifetime discounted consumption utility. I abstract from the labour supply decision. Households can save in risk-free bank deposits, d_{t+1}, earning an interest rate r_t. Each household owns a firm and receive profits from the firm, Π_t^f, each period. In addition, one member from each household is a banker who returns her profits, Π_t^b, to the household. The representative household's problem is

$$\max_{c_t, d_{t+1}} E_0 \sum_{t=0}^{\infty} \beta^t U\left(c_t\right)$$

subject to the period budget constraint

$$c_t + \frac{d_{t+1}}{r_t} \leq \Pi_t^f + \Pi_t^b + d_t$$

where c_t is consumption and β is the household's intertemporal discount parameter. The standard intertemporal first order condition for households is

$$1 = \beta \frac{E_t U'\left(c_{t+1}\right)}{U'\left(c_t\right)} r_t \tag{2.1}$$

2.2.2 Firms and Banks

At the end of the period, firms borrow funds from banks at an interest rate z_t to purchase capital for next period. The loan amount is b_{t+1} and capital purchased is k_{t+1}. Firms are ex-ante identical as they buy homogenous capital goods from competitive capital goods-producers, and at the end of each period they sell the undepreciated capital goods back to capital goods-producers. In the absence of adjustment costs of capital or similar frictions, the price of capital goods is equal to the consumption good price. The loan market clearing condition is

$$k_{t+1} = \frac{b_{t+1}}{z_t} \tag{2.2}$$

Within the period firms receive an idiosyncratic shock ω_t, which follows a log-normal distribution with parameters $\bar{\omega}$ and σ_ω,

$$ln\left(\omega_t\right) \sim N\left(\bar{\omega}, \sigma_\omega\right)$$

Head, Mayer, and Thoenig (2014) argue that the log-normal distribution fits the actual firm sales distribution. The loan market is incomplete in the sense that the repayment amount b_t does not depend on the realization of the firm's idiosyncratic shock ω_t. This means that firms that receive too low an idiosyncratic shock will default. In the event of a default, banks take over the firm's production and capital for the period, but the firm faces no other penalty for defaulting. If the firm does not default, it repays the loan, b_t, to the bank and pays out profits Π_t^f to the household.

In addition to the idiosyncratic shock, firms also receive an opportunity to divert a proportion $(1-\xi)$ of production during the period, $0 < \xi < 1$. Banks can prevent this moral hazard by choosing to monitor the firms. Bank monitoring is costly, so that the bank incurs a monitoring cost μ for each firm monitored. At the time of making the loan, b_{t+1}, the bank decides the aggregate proportion of firms to monitor, p_{t+1}. However, the bank does not decide the specific firms it will monitor during the period. This is due to a commitment problem. The bank cannot commit at the time of lending that it will not monitor a loan. If the firm believes before-hand that it will not be monitored, then firm owners expect a proportion $(1-\xi)$ of output will be diverted. The firm will hence choose to hold less capital to get higher marginal return on capital. During the period, however, before the opportunity to divert production arises, the bank can monitor the firm and prevent the moral hazard.

The bank would benefit through a lower default rate. Due to this commitment problem banks and firms at time of lending only know the aggregate fraction of firms that the bank will monitor. During the period the bank randomly picks firms to monitor such that the aggregate proportion of monitored firms is consistent. The bank's incentive to monitor some loans comes from the reduced costs arising from loan default due to a lower aggregate default rate.

If on the other hand the bank was able to commit to not monitoring firms, it would lend b^m_{t+1} to monitored firms and b^n_{t+1} to non-monitored firms and then choose to *monitor no firms*. The banker would simply charge an interest rate that compensates her for the increased default risk and then *diversify across all firms*. This way the bank saves on all monitoring costs. Due to the commitment problem the bank is forced to lend b_{t+1} at identical terms to all firms, so that all firms hold the same capital ex-ante, k_{t+1}. In period t a monitored firm therefore produces

$$\omega_t A_t k_t^\alpha$$

where A_t is an aggregate factor productivity shock. A non-monitored firm produces

$$\omega_t \xi A_t k_t^\alpha$$

A monitored firm defaults if it cannot meet debt obligations - specifically, a monitored firm defaults if it receives a shock $\omega < \tilde{\omega}^m$ where $\tilde{\omega}^m$ is such that

$$\tilde{\omega}_t^m A_t k_t^\alpha + (1-\delta)\, k_t = b_t$$

The probability of default for a monitored firm is then $F(\tilde{\omega}^m)$ where $F(\cdot)$ is the cdf of ω. The default threshold for non-monitored firms is such that

$$\tilde{\omega}_t^n \xi A_t k_t^\alpha + (1-\delta)\, k_t = b_t$$

Using the loan market clearing condition, the default thresholds are

$$\tilde{\omega}_t^m = k_t^{1-\alpha} \left(z_{t-1} - (1-\delta) \right) \frac{1}{A_t} \tag{2.3}$$

$$\tilde{\omega}_t^n = k_t^{1-\alpha} \left(z_{t-1} - (1-\delta) \right) \frac{1}{A_t \xi} \tag{2.4}$$

so that the relative default threshold between monitored and non-monitored threshold is constant, $\tilde{\omega}_t^m = \xi \tilde{\omega}_t^n$.

The 'excess default rate', $F(\tilde{\omega}_t^n) - F(\tilde{\omega}_t^m)$, is a proxy for the benefit to the bank for monitoring a loan. If the banker monitors the loan, she can reduce the default rate from $F(\tilde{\omega}_t^n)$ to $F(\tilde{\omega}_t^m)$, and incur reduced loan default costs. Following a positive aggregate shock, both default thresholds shift left, as shown in figure 3. Since the default thresholds proportional, the probability of default for a non-monitored firm, $F(\tilde{\omega}_t^n)$, falls *more* than the probability of default for a monitored firm, $F(\tilde{\omega}_t^m)$. The model predicts that the excess default is counter-cyclical, and this model feature drives the result that bank monitoring activity is counter-cyclical. The marginal benefit of bank monitoring drops during business cycle upturns, while the marginal cost is constant.

Default rates are countercyclical in the model, so default thresholds rise in recessions. The countercyclical excess default in the model hence requires that excess default rises when the default threshold rises,

$$\frac{\partial \left(F(\tilde{\omega}_t^n) - F(\xi \tilde{\omega}_t^n) \right)}{\tilde{\omega}_t^n} > 0 \Rightarrow f(\tilde{\omega}_t^n) - \xi f(\xi \tilde{\omega}_t^n) > 0$$

The pdf of the idiosyncratic shock has to satisfy the above condition to have countercyclical excess default. As the degree of moral hazard increases, ξ becomes smaller, and the restriction on the shock distribution is reduced.

There is some empirical support for a counter-cyclical excess default rate. One way to proxy the excess default rate is to take the difference in delinquency rates between credit card loans (risky) and consumer loans (less risky). Credit card loans serve as a rough proxy for high default rate non-monitored loans, and consumer loans serve as proxy for lower default rated monitored loans. Banks would have an idea of the purpose and client background for consumer loans but not for credit card loans. The cyclical excess default rate has a correlation with cyclical output of -0.493 [1].

An alternate way to proxy the excess default rate is to use the difference in marginal default rates of speculative grade bonds and investment grade bonds. When the excess default is measured this way, the correlation between cyclical output and cyclical excess default is -0.254. The corporate bond default rates are available at annual frequency using Moody's default data from 1952 to 2010.

The firm solves

$$\max_{k_{t+1},b_{t+1}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \Pi_t^f$$

where $\Lambda_{0,t}$ is the stochastic discount factor for time t, and Π_t^f is the firm's profit,

$$\begin{aligned} \Pi_t^f = \;& p_t \int_{\tilde{\omega}_t^m}^{\infty} \left(\omega_t A_t k_t^\alpha + (1-\delta) k_t - b_t\right) \partial F(\omega) \\ & + (1-p_t) \int_{\tilde{\omega}_t^n}^{\infty} \left(\omega_t \xi A_t k_t^\alpha + (1-\delta) k_t - b_t\right) \partial F(\omega) \end{aligned}$$

The firms is monitored with probability p_t and in that case the default threshold is $\tilde{\omega}_t^m$, otherwise $(1-\xi)$ of the output is diverted and the default threshold is $\tilde{\omega}_t^n$. Letting $\Omega_{u,t}^m$ and $\Omega_{u,t}^n$ be the partial expectations of the idiosyncratic shock, $\Omega_{u,t}^m = \int_{\tilde{\omega}_t^m}^{\infty} \omega \partial F(\omega)$ and $\Omega_{u,t}^n = \int_{\tilde{\omega}_t^n}^{\infty} \omega \partial F(\omega)$, we re-write

[1] The unfiltered excess default rate is also negatively correlated with output (correlation -0.304). However, credit card delinquency rates peaked after the recession in 2009Q2 and have dropped significantly since then. As a result, the excess default rate was fairly stationary up to 2009Q2 but has since trended markedly lower.

firm's profit as

$$\begin{aligned}\Pi_t^f = \;& p_t \left\{\Omega_{u,t}^m A_t k_t^\alpha + \left(1 - F\left(\tilde{\omega}_t^m\right)\right)\left[(1-\delta) k_t - b_t\right]\right\} \\ & + (1-p_t)\left\{\Omega_{u,t}^n \xi A_t k_t^\alpha + \left(1 - F\left(\tilde{\omega}_t^m\right)\right)\left[(1-\delta) k_t - b_t\right]\right\}\end{aligned}$$

The firm's first order condition is

$$\begin{aligned} & p_{t+1} E_t \left\{ \begin{array}{c} \alpha \Omega_{u,t+1}^m A_{t+1} k_{t+1}^{\alpha-1} + \left(1 - F\left(\tilde{\omega}_{t+1}^m\right)\right)\left[(1-\delta) - z_t\right] \\ + \left(\Omega_{u,t+1}^m\right)' A_{t+1} k_{t+1}^\alpha \frac{\partial \tilde{\omega}_{t+1}^m}{\partial k_{t+1}} \\ - f\left(\tilde{\omega}_{t+1}^m\right) \frac{\partial \tilde{\omega}_{t+1}^m}{\partial k_{t+1}} \left((1-\delta) k_{t+1} - z_t k_{t+1}\right) \end{array} \right\} \\ & + (1-p_{t+1}) E_t \left\{ \begin{array}{c} \alpha \Omega_{u,t+1}^n \xi A_{t+1} k_{t+1}^{\alpha-1} + \left(1 - F\left(\tilde{\omega}_{t+1}^n\right)\right)\left[(1-\delta) - z_t\right] \\ + \left(\Omega_{u,t+1}^n\right)' \xi A_{t+1} k_{t+1}^\alpha \frac{\partial \tilde{\omega}_{t+1}^n}{\partial k_{t+1}} \\ - f\left(\tilde{\omega}_{t+1}^n\right) \frac{\partial \tilde{\omega}_{t+1}^n}{\partial k_{t+1}} \left((1-\delta) k_{t+1} - z_t k_{t+1}\right) \end{array} \right\} = 0 \end{aligned} \tag{2.5}$$

where

$$\left(\Omega_{u,t+1}^m\right)' \equiv \frac{\partial \Omega_{u,t+1}^m}{\partial \tilde{\omega}_{t+1}^m} \qquad \left(\Omega_{u,t+1}^n\right)' \equiv \partial \Omega_{u,t+1}^n / \partial \tilde{\omega}_{t+1}^n$$

This first-order condition says that the firm considers two dimensions when deciding the amount of capital to hold next period, k_{t+1}. The first dimension is the direct effect of additional capital. Additional capital leads to greater output while the firm receives an idiosyncratic shock above the default threshold. This is the modified marginal product of capital. Provided the firm does not default, it also sells undepreciated capital and pays back the bank loan. Firms also consider the second dimension of additional capital that more capital, and hence more borrowing, increases the firm's expected default rate. These are the terms that have $\partial \tilde{\omega}_{t+1}^m / \partial k_{t+1}$ or $\partial \tilde{\omega}_{t+1}^n / \partial k_{t+1}$. An increase in the default rate means the firm keeps its production less of the time. In addition, the firm pays back loans less often.

Banks pool deposits from households and lend to firms. Each banker is fully diversified across both households and firms. The savings market clearing condition is

$$\frac{b_{t+1}}{z_t} = \frac{d_{t+1}}{r_t} \tag{2.6}$$

Banks solve

$$\max_{p_{t+1},d_{t+1},b_{t+1}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}\Pi_t^b$$

where Π_t^b is the bank's profit. For all firms that do not default, the bank receives the loan repayment amount b_t. For firms that default, the bank takes over all the firm's production and capital and incurs a default cost (or a state verification cost) equal to a proportion $1-\theta$ of the collateral received. Each period, bankers return depositor funds with interest. Bankers also incur a fixed cost μ for each firm that they monitor.

$$\begin{aligned}
\Pi_t^b = \quad & p_t \left\{ \int_{\tilde{\omega}_t^m}^{\infty} b_t \partial F(\omega) + \int_{-\infty}^{\tilde{\omega}_t^m} \theta \left(\omega_t A_t k_t^{\alpha} + (1-\delta) k\right) \partial F(\omega) \right\} \\
& + (1-p_t) \left\{ \int_{\tilde{\omega}_t^n}^{\infty} b_t \partial F(\omega) + \int_{-\infty}^{\tilde{\omega}_t^n} \theta \left(\omega_t \xi A_t k_t^{\alpha} + (1-\delta) k\right) \partial F(\omega) \right\} \\
& - d_t - \mu p_t
\end{aligned}$$

Letting $\Omega_{l,t}^m = \int_{-\infty}^{\tilde{\omega}_t^m} \omega_t \partial F(\omega)$ and $\Omega_{l,t}^n = \int_{-\infty}^{\tilde{\omega}_t^n} \omega_t \partial F(\omega)$,

$$\begin{aligned}
\Pi_t^b = \quad & p_t \left\{ \left(1 - F(\tilde{\omega}_t^m) b_t\right) + \theta \left(\Omega_{l,t}^m A_t k_t^{\alpha} + F(\tilde{\omega}_t^m)(1-\delta) k_t \right) \right\} \\
& + (1-p_t) \left\{ \left(1 - F(\tilde{\omega}_t^n) b_t\right) + \theta \left(\Omega_{l,t}^n \xi A_t k_t^{\alpha} + F(\tilde{\omega}_t^n)(1-\delta) k_t \right) \right\} \\
& - d_t - \mu p_t
\end{aligned}$$

The bank's first order condition for lending is

$$p_{t+1}E_t\left\{\begin{array}{c}\left(1-F\left(\tilde{\omega}^m_{t+1}\right)\right)+\frac{\theta}{z_t}\left(\alpha\Omega^m_{l,t+1}A_{t+1}k^{\alpha-1}_{t+1}+F\left(\tilde{\omega}^m_{t+1}\right)(1-\delta)\right)\\ \\ -f\left(\tilde{\omega}^m_{t+1}\right)b_{t+1}\frac{\partial\tilde{\omega}^m_{t+1}}{\partial k_{t+1}}\frac{1}{z_t}\\ \\ +\frac{\theta}{z_t}\frac{\partial\tilde{\omega}^m_{t+1}}{\partial k_{t+1}}\left\{\left(\Omega^m_{l,t+1}\right)'A_{t+1}k^{\alpha}_{t+1}+f\left(\tilde{\omega}^m_{t+1}\right)(1-\delta)k_{t+1}\right\}\end{array}\right\}=\frac{r_t}{z_t}$$

$$(1-p_{t+1})E_t\left\{\begin{array}{c}\left(1-F\left(\tilde{\omega}^n_{t+1}\right)\right)\\ \\ +\frac{\theta}{z_t}\left(\alpha\Omega^n_{l,t+1}\xi A_{t+1}k^{\alpha-1}_{t+1}+F\left(\tilde{\omega}^n_{t+1}\right)(1-\delta)\right)\\ \\ -f\left(\tilde{\omega}^n_{t+1}\right)b_{t+1}\frac{\partial\tilde{\omega}^n_{t+1}}{\partial k_{t+1}}\frac{1}{z_t}\\ \\ +\frac{\theta}{z_t}\frac{\partial\tilde{\omega}^n_{t+1}}{\partial k_{t+1}}\left\{\left(\Omega^n_{l,t+1}\right)'\xi A_{t+1}k^{\alpha}_{t+1}+f\left(\tilde{\omega}^n_{t+1}\right)(1-\delta)k_{t+1}\right\}\end{array}\right\} \tag{2.7}$$

The direct effect of increasing lending b_{t+1} for banks is that banks receive repayment on non-defaulted loans. This corresponds to the $\left(1-F\left(\tilde{\omega}^m_{t+1}\right)\right)$ term. Through the savings market, they need to pay r_t for the additional funds. The lending spread $z_t - r_t$ covers default costs. Banks realize that lending more to firms increases the loan's default chance, and so banks also take into account the secondary effect of lending, $\left(\partial\tilde{\omega}^m_{t+1}/\partial k_{t+1}\right)\cdot(\partial k_{t+1}/\partial b_{t+1})$. A higher default chance means higher default costs, so this adds to the marginal cost of lending. This effect is slightly moderated because higher lending also means higher collateral and slightly greater recovery given default.

The bank's first order condition for monitoring is

$$\begin{aligned}\mu &= b_{t+1}E_t\left[F\left(\tilde{\omega}^n_{t+1}\right)-F\left(\tilde{\omega}^m_{t+1}\right)\right]\\ &\quad -\theta E_t\left\{\begin{array}{c}\left[F\left(\tilde{\omega}^n_{t+1}\right)-F\left(\tilde{\omega}^m_{t+1}\right)\right](1-\delta)k_{t+1}\\ \\ +\Omega^n_{l,t+1}\xi A_{t+1}k^{\alpha}_{t+1}-\Omega^m_{l,t+1}A_{t+1}k^{\alpha}_{t+1}\end{array}\right\}\end{aligned} \tag{2.8}$$

The condition's interpretation is clear when $\theta = 0$, so that all production and capital is wiped out following default. In that case monitoring a loan can reduce the probability of default from $F\left(\tilde{\omega}^{n}_{t+1}\right)$ to $F\left(\tilde{\omega}^{m}_{t+1}\right)$. With $\theta > 0$, the effect is slightly moderated as the recovery given default is potentially higher when the default probability is higher (provided ξ is not too low). From the bank's perspective, the reduction in default rate applies to the loan repayment, b_{t+1}. As discussed further in section 5, this marginal benefit is too low from the planner's perspective.

2.2.3 Equilibrium

The goods market clearing condition is

$$Y_t = C_t + I_t \tag{2.9}$$

where I_t is aggregate investment. Y_t is aggregate output,

$$Y_t = A_t K_t^{\alpha} \left(p_t \left[\Omega^{m}_{u,t} + \theta \Omega^{m}_{l,t} \right] + (1 - p_t) \left[\Omega^{n}_{u,t} + \theta \Omega^{n}_{l,t} \right] \xi \right) - \mu p_t \tag{2.10}$$

The economy loses a fraction $(1 - \theta)$ of output produced by each firm that defaults. The model also assumes that diverted output is lost from the economy; model features are largely unaffected even if diverted output is not lost from the economy. Since firms start the period with the same amount of capital, capital aggregation is standard. Capital evolution is

$$\begin{aligned} K_{t+1} &= p_t (1 - \delta) \left[1 - F\left(\tilde{\omega}^{m}_{t}\right) + \theta F\left(\tilde{\omega}^{m}_{t}\right) \right] \\ &\quad + (1 - p_t)(1 - \delta) \left[1 - F\left(\tilde{\omega}^{n}_{t}\right) + \theta F\left(\tilde{\omega}^{n}_{t}\right) \right] + I_t \end{aligned} \tag{2.11}$$

Log total factor productivity follows an AR(1) process,

$$ln\left(A_t\right) = \rho ln\left(A_{t-1}\right) + \epsilon_{A,t} \tag{2.12}$$

where $\epsilon_{A,t}$ is a stationary TFP shock and ρ is the TFP shock persistence.

Equilibrium for the aggregate economy is a list $\{C_t, K_t, Y_t,\ p_t, I_t, B_t,\ D_t, \tilde{\omega}_t^m, \tilde{\omega}_t^n\ \ z_t, r_t, A_t\}_{t=0}^{\infty}$ such that equations (1) - (12) are satisfied, given A_0, K_0, B_0, D_0, p_0, and the set of exogenous stochastic disturbances $\{\epsilon_t\}_{t=0}^{\infty}$.

2.3 Countercyclical Bank Monitoring

2.3.1 Calibration

The functional form for utility is $ln\left(c_t\right)$. The model has four standard parameters, the intertemporal discount factor β, the production parameter α, the capital depreciation rate δ, and the TFP shock persistence ρ. I calibrate these within standard ranges; $\beta = 0.991$, $\alpha = 0.3$, $\delta = 0.025$, and $\rho = 0.95$. There are five other parameters in the model to calibrate - the idiosyncratic shock distribution parameters $\bar{\omega}$ and σ_ω, the costly state verification parameter θ, the monitoring cost per firm μ, and the firm moral hazard parameter ξ. $E\left(\omega\right)$ is set to 1, so that

$$e^{\bar{\omega}+\frac{1}{2}\sigma_\omega^2} = 1$$

The remaining four parameters are calibrated simultaneously to meet the following steady-state targets:

1. Since the model features single period loans, the default rate is equal to the delinquency rate. The target annualized default rate on monitored loans is the average delinquency rate on consumer loans since 1987, 3.4%.

2. The target annualized default rate on non-monitored loans is the average delinquency rate on credit card loans since 1991, 4.3%.

3. The credit spread target is 0.84%, the long-run average spread between BAA rated bonds and 3-month treasuries.

4. Steady state $p = 0.64$ to match the average fraction of corporate bonds issued annually that are investment grade. Table 1 summarizes the calibration.

2.3.2 Baseline results

Figure 4 shows the impulse response to a 1% aggregate productivity shock. The correlation of bank monitoring with output in the model is -0.55. This compares with a correlation of -0.17 for SLOOS lending terms and output. The correlation of excess default with default in the model is also -0.55 compared to -0.49 for the excess default data proxy. Table 2 shows four model and data correlations- the monitoring rate, monitored and non-monitored default rates, and the excess default rate. The model setup means that all four variables co-move with output. The default thresholds $\tilde{\omega}^m$ and $\tilde{\omega}^n$ are linearly dependent, giving rise to the co-movement between excess default rates and default rates. The excess default rate drives the bank's monitoring decision, p, giving rise to co movement between excess default and monitoring. The model moments are close to data proxy moments. Table 3 reports the moments using annual corporate bond default rates as default rate proxies.

2.4 Effect of Monitoring on the Business Cycle

In this section I compare business cycle features of the baseline model with a version of the model where bank monitoring activity is fixed. In the comparison model, I set bank monitoring to be constant at it's steady state, $p_t = 0.64 \ \forall t$. This comparison shows how dynamic monitoring incentives influence the business cycle. Table 4 shows the results of this comparison. The table reports the coefficient of variation for several variables as well as the volatility of these variables with respect to output in the model. The column with the header 'amplification percentage' reports the percentage increase in volatility due to dynamic monitoring. Negative percentages in this column indicate that dynamic monitoring damps the variable. By construction both models have the same steady state. Figure 5 shows the impulse responses from the two models.

Dynamic monitoring amplifies consumption volatility. The magnitude of this amplification is large - the coefficient of variation for consumption is about 16% higher when banks choose their desired level of monitoring. An interesting implication of this result is that acyclical monitoring is better for welfare. With dynamic monitoring, banks monitor less during booms resulting in greater diversion of output. Firm owners now require higher return on capital to compensate for higher diversion and invest less. This damps investment during booms. Diverted output can still be consumed, however, and this boosts consumption volatility in the model. Acyclical bank monitoring prevents excess consumption volatility, and is hence better for welfare.

2.5 Monitoring Inefficiency

The holdup problem in the model is clear in a variation of the baseline model with fixed exogenous default rates. In this variation, bank monitoring directly reduces the default rate from γ^n for a non-monitored firm to γ^m for a monitored firm, with $\gamma^n > \gamma^m$. Similar to the baseline model, the bank and firm only know the aggregate proportion of monitoring activity at the start of the period. During the period, banks randomly pick firms to monitor - the number of firms monitored is consistent with the aggregate proportion choice. In the event of a default, firms hand over their output and capital to the bank. Now the firm solves

$$\max_{k_{t+1},b_{t+1}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \Pi_t^f$$

where

$$\Pi_t^f = [A_t k_t^\alpha + (1-\delta) k_t - b_t] \{p_t (1-\gamma^m) + (1-p_t)(1-\gamma^n)\}$$

$$k_{t+1} = \frac{b_{t+1}}{z_t}$$

The bank receives loan repayment when the firm does not default. A monitored firm defaults with probability γ^m and a non-monitored firm defaults with probability γ^n. The bank repays depositors and incurs a monitoring cost per firm. The bank solves

$$\max_{b_{t+1},d_{t+1},p_{t+1}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \Pi_t^b$$

where

$$\begin{aligned} \Pi_t^b &= p_t \{(1-\gamma^m) b_t + \gamma^m \theta (A_t k_t^\alpha + (1-\delta) k_t)\} - d_t \\ & (1-p_t) \{(1-\gamma^n) b_t + \gamma^n \theta (A_t k_t^\alpha + (1-\delta) k_t)\} - \mu p_t \end{aligned}$$

$$\frac{b_{t+1}}{z_t} = \frac{d_{t+1}}{r_t}$$

The households' problem remains unchanged,

$$\max_{c_t,d_{t+1}} E_0 \sum_{t=0}^{\infty} \beta^t U(c_t)$$

subject to

$$c_t + \frac{d_{t+1}}{r_t} \leq d_t + \Pi_t^f + \Pi_t^b$$

We can compare the decentralized economy with the planner's problem.

The planner solves

$$\max_{C_t, K_{t+1}, I_t, Y_t, p_{t+1}} E_0 \sum_{t=0}^{\infty} \beta^t U(C_t)$$

subject to the aggregate constraints

$$Y_t = A_t K_t^{\alpha} \left\{ p_t \left(1 - \gamma^m + \theta\gamma^m\right) + (1 - p_t)\left(1 - \gamma^n + \theta\gamma^n\right) \right\} - \mu p_t$$

$$Y_t = C_t + I_t$$

$$K_{t+1} = K_t (1 - \delta) \left\{ p_t \left(1 - \gamma^m + \theta\gamma^m\right) + (1 - p_t)\left(1 - \gamma^n + \theta\gamma^n\right) \right\} + I_t$$

It can be shown that the first order conditions for the decentralized problem and the planner's problem are equivalent except the first order condition for monitoring activity, p_t. The planner's first order condition for monitoring is

$$\mu = E_t \left\{ \begin{array}{c} \left(A_{t+1} K_{t+1}^{\alpha} + (1-\delta) K_{t+1}\right)(\gamma^n - \gamma^m) \\ +\theta \left(A_{t+1} K_{t+1}^{\alpha} + (1-\delta) K_{t+1}\right)(\gamma^m - \gamma^n) \end{array} \right\} \tag{2.13}$$

whereas the bank's first order condition for monitoring is

$$\mu = E_t \left\{ \begin{array}{c} \left(\alpha A_{t+1} K_{t+1}^{\alpha} + (1-\delta) K_{t+1}\right)(\gamma^n - \gamma^m) \\ +\theta \left(A_{t+1} K_{t+1}^{\alpha} + (1-\delta) K_{t+1}\right)(\gamma^m - \gamma^n) \end{array} \right\} \tag{2.14}$$

The marginal cost of monitoring for both the planner and the bank is μ. However, the marginal benefit of preventing default for the planner is the entire output $A_{t+1}K_{t+1}^{\alpha}$ whereas for the bank it is only $\alpha A_{t+1}K_{t+1}^{\alpha}$. The planner therefore chooses a higher level of monitoring than the bank. One implication of this finding is that banks would make less monitoring effort for firms that rely more on internal finance. These firms would be able to hold up more of the return from lending.

Figure 6 shows that for any given level of steady state monitoring, p, the planner is willing to incur a higher monitoring cost compared to a bank making a decentralized decision. Figure 6 is drawn after calibrating the model as in section 3.1 with γ^n and γ^m calibrated to give the target annualized default rates.

2.6 Conclusion

Banks engage in risk-shifting over the business cycle by saving on monitoring costs during business cycle improvements. Idiosyncratic shocks in the model are normally distributed, so that the chance of receiving sufficiently adverse shocks drops faster for risky firms that earlier needed only 'moderately' adverse shocks to default. An interpretation of this is that prudent firms are less affected by business cycle fluctuations since they are unlikely to default even in cyclical downturns. The marginal benefit of monitoring loans hence reduces following an aggregate improvement.

In addition, banks choose inefficiently low level of monitoring as firms hold up part of the returns from lending activity. One implication of this is that banks are less likely to monitor firms that rely less heavily on external finance.

Tables and Figures

Table 2.1: Model calibration

Parameter	Description	Value
β	intertemporal discount	0.991
α	production	0.300
δ	depreciation	0.025
ρ	TFP persistence	0.950
$\bar{\omega}$	mean of $ln\left(\omega\right)$	-0.11
σ_ω	standard deviation of $ln\left(\omega\right)$	0.469
θ	costly state verification	0.674
μ	monitoring cost	0.012
ξ	firm moral hazard	0.960

Table 2.2: Model and data correlations

Variable	Correlation		Data proxy
	model	data	
p monitoring rate	-0.55	-0.17	SLOOS, net percent banks tightening terms: loan covenants
$F\left(\tilde{\omega}^m\right)$ monitored default rate	-0.55	-0.53	Delinquency rate on consumer loans
$F\left(\tilde{\omega}^n\right)$ non-monitored default rate	-0.55	-0.61	Delinquency rate on credit card loans
$F\left(\tilde{\omega}^n\right)-F\left(\tilde{\omega}^m\right)$ excess default rate	-0.55	-0.49	Credit card - consumer loan delinquency rates

Table 2.3: Model and Data Correlation Using Annual Corporate Bonds Data

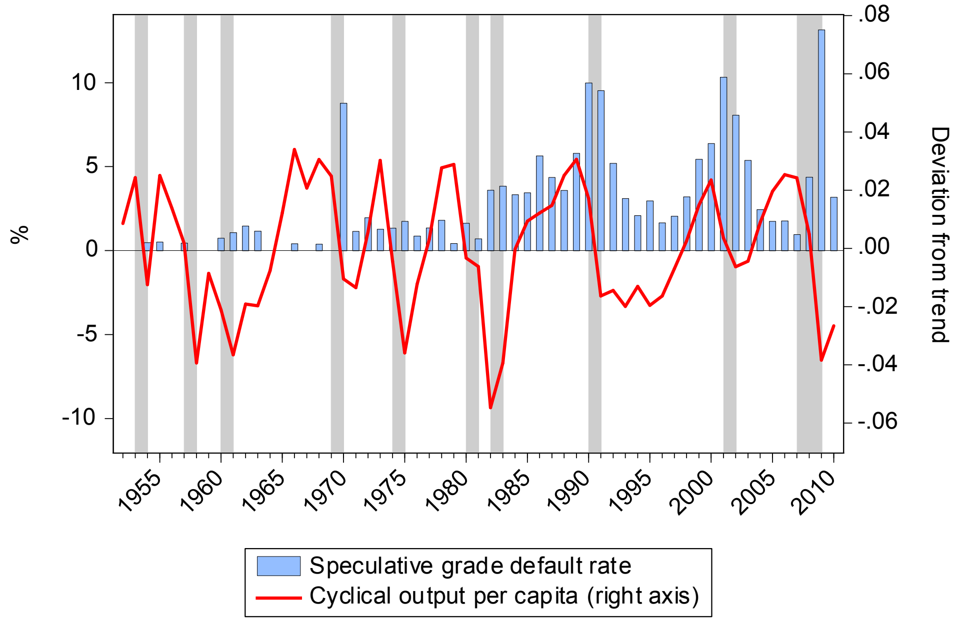
Variable	Correlation		Data proxy
	model	data	
$F(\tilde{\omega}^m)$ monitored default rate	-0.55	-0.16	Investment grade (a) bond default rate
$F(\tilde{\omega}^n)$ non-monitored default rate	-0.55	-0.22	Speculative grade (b) bond default rate
$F(\tilde{\omega}^n) - F(\tilde{\omega}^m)$ excess default rate	-0.55	-0.25	$b - a$

Table 2.4: Effect of dynamic monitoring on the business cycle

	coefficient of variation			volatility relative to Y		
	D	E	F	D	E	F
C	0.0066	0.0058	15.8%	0.50	0.43	16.3%
p	0.0314	0.0000	N/A	2.36	0.00	N/A
Y	0.0133	0.0132	1.0%	1.00	1.00	0.0%
I	0.0433	0.0436	-7.7%	3.26	3.55	-8.2%
B	0.0043	0.0046	-6.5%	0.32	0.36	-11.1%

Table 2.5: D: dynamic monitoring; E: static monitoring; F: amplification percentage

Figure 2.1: Time series of speculative grade marginal default rates



Shaded areas indicate NBER recessions

Figure 2.2: Federal Reserve SLOOS - net percent of banks tightening loan covenant terms to firms

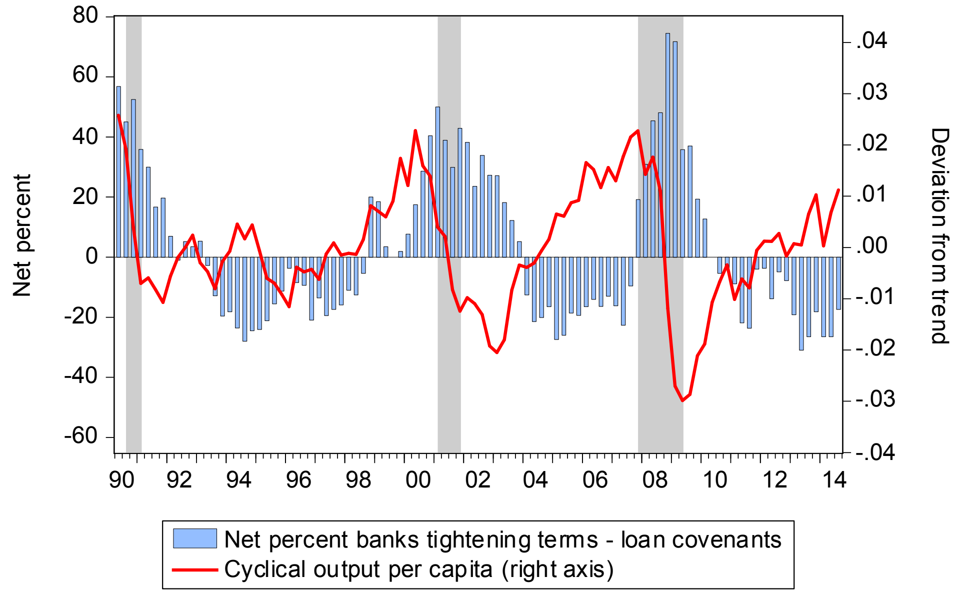
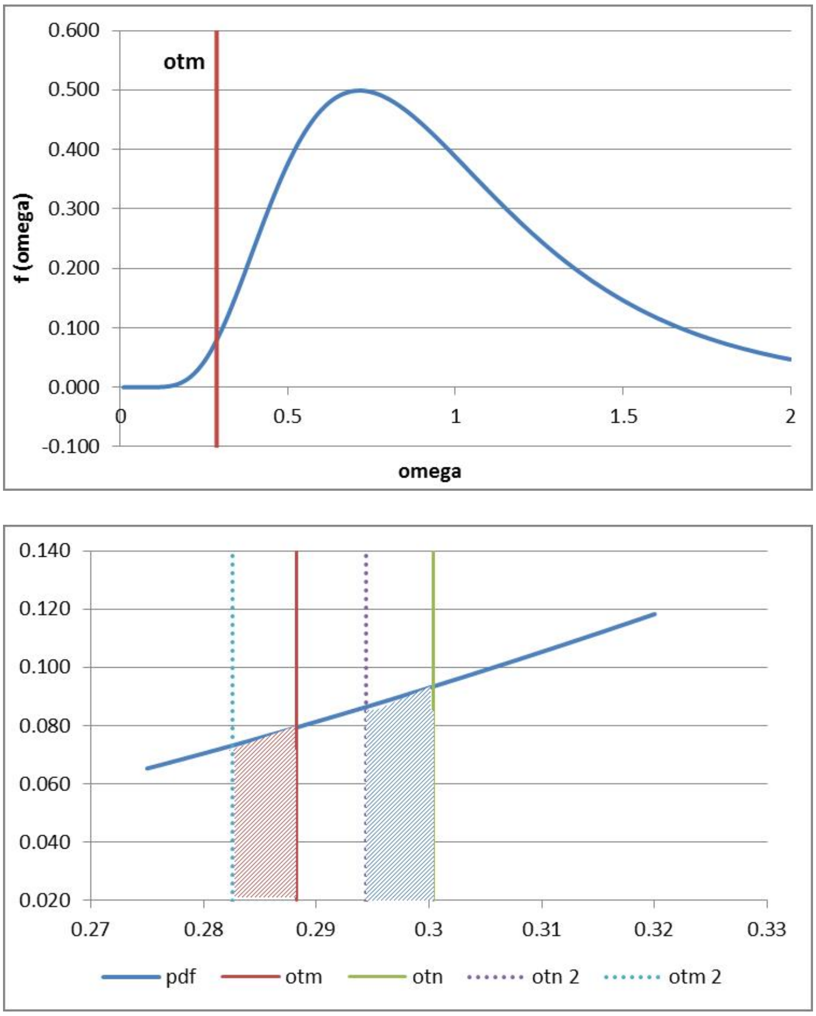
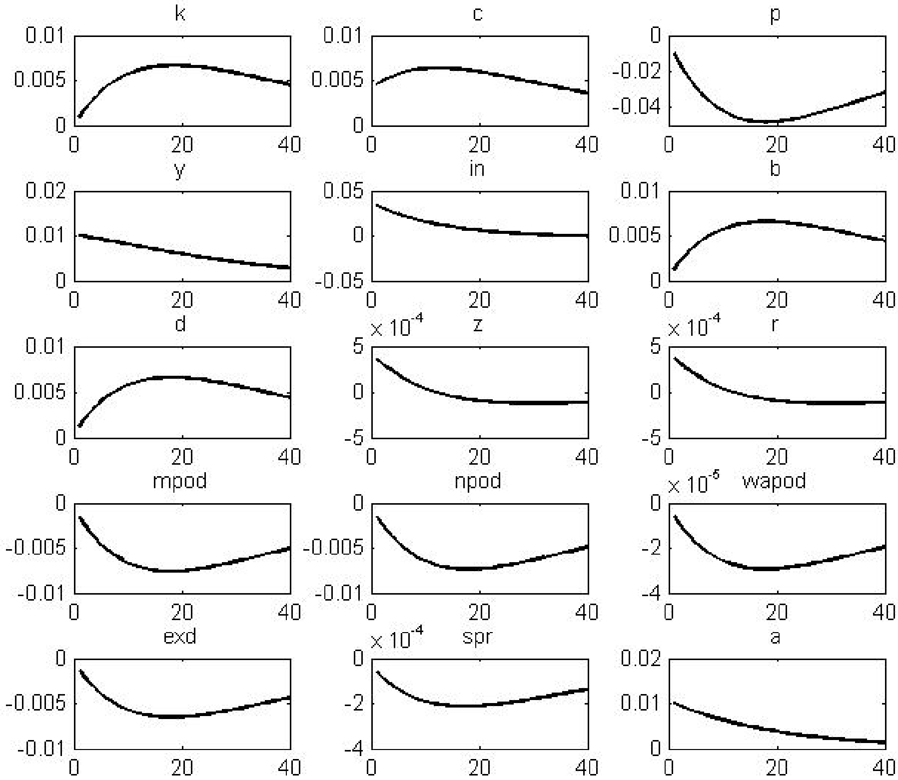


Figure 2.3: A Drop in the Excess Default Rate



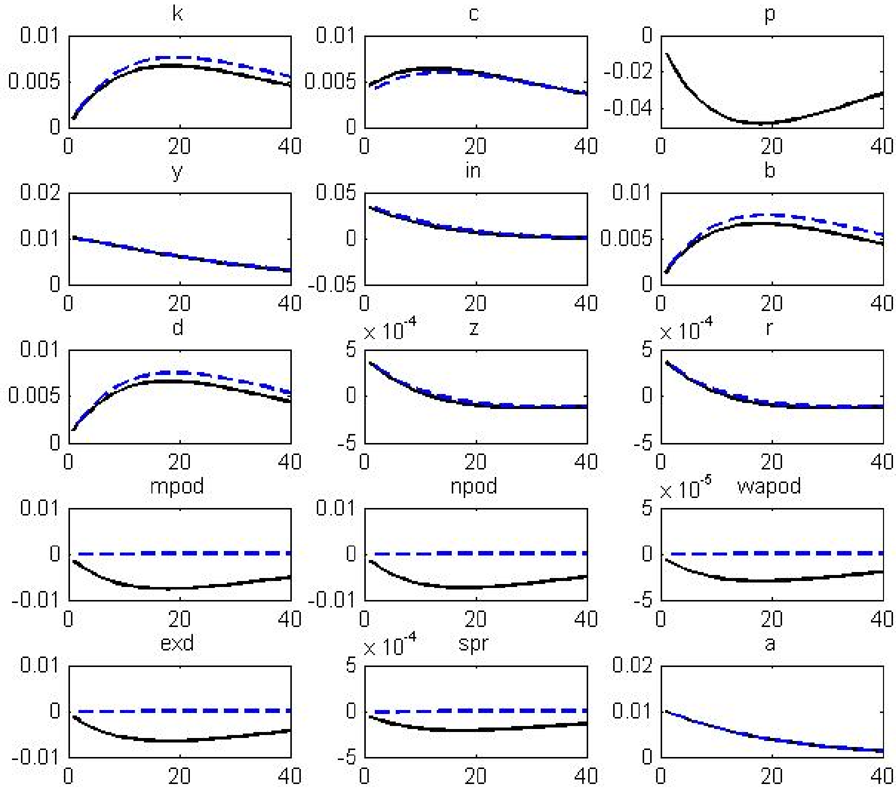
The top panel shows the pdf of omega with the default thresholds. The bottom panel shows a zoom of the pdf around the default thresholds and shows the effect of a left shift in the thresholds. A leftward shift of both thresholds results in a drop in the excess default rate. The excess default rate drops by the difference in area between the taller and shorter trapezia. otm: $\tilde{\omega}^m$ otn: $\tilde{\omega}^n$. Delinquency rate data from Federal Reserve Economic Data.

Figure 2.4: Baseline model response to 1% TFP shock



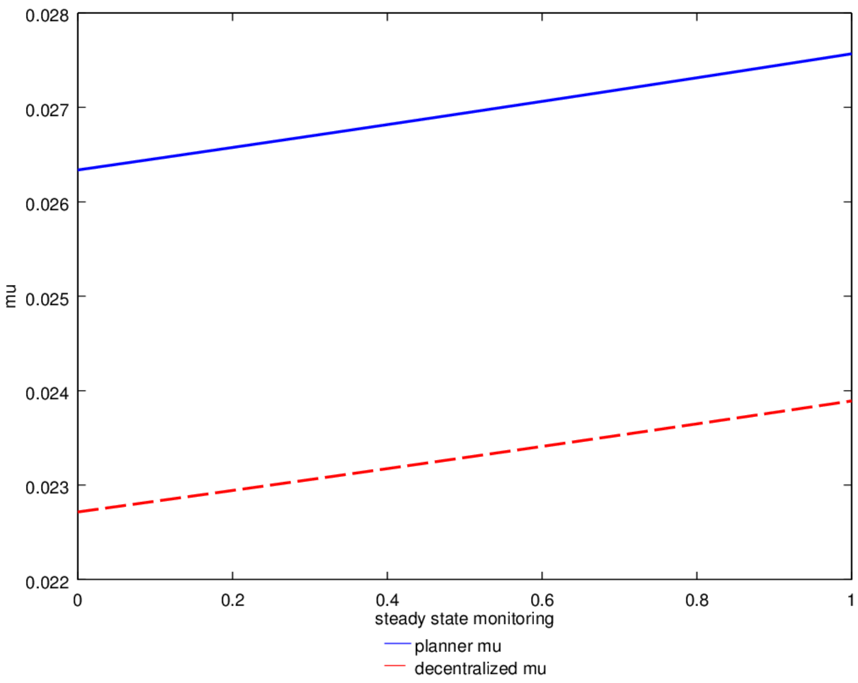
mpod: $F(\tilde{\omega}^m)$; npod: $F(\tilde{\omega}^n)$; wapod: $p_t F(\tilde{\omega}^m) + (1 - p_t) F(\tilde{\omega}^n)$; exd: $F(\tilde{\omega}^n) - F(\tilde{\omega}^m)$; spr: $z_t - r_t$

Figure 2.5: Dynamic and static monitoring impulse responses



mpod: $F(\tilde{\omega}^m)$; npod: $F(\tilde{\omega}^n)$; wapod: $p_t F(\tilde{\omega}^m) + (1 - p_t) F(\tilde{\omega}^n)$; exd: $F(\tilde{\omega}^n) - F(\tilde{\omega}^m)$; spr: $z_t - r_t$

Figure 2.6: Monitoring Cost



Chapter 3

Optimal Fiscal Policy and Public Goods

with Huynh Bao Tan

Chapter Abstract

This paper proposes a DSGE framework with heterogeneous households and government's provision of public goods to analyze the properties of optimal fiscal policy over the business cycles. Our focus is on the quantitative properties of income tax rates optimized by the Ramsey planner for optimal public goods provision. We found that the presence of public goods provision modifies the properties of the optimal taxes compared to earlier results in the literature. The results also show significant heterogeneity in the dynamics of tax rates among households of different income levels. The implication is that the Ramsey planner is highly active in managing tax changes in response to business cycles variations, and that the optimal taxes for the low-income household can differ markedly from that for mid-income and high-income households.

3.1 Introduction

Over the course of the US 2012 Presidential election, a key flashpoint between the candidates was whether affluent households should bear a higher tax burden to finance government spending. The question of optimal taxation and public goods provision has long been given much attention in the literature on public economics. We have had microeconomic foundations established in these areas by the works of Diamond and Mirrlees (1971a, 1971b, 1971c), Atkinson and Stern (1974), and Atkinson and Stiglitz (1976). There have also been works that sought to answer these two questions together, such as Boadway and Keen (1993). Of macroeconomic analysis, Barro (1990) and Judd (1999) provided qualitative insights on the effects of taxes and government spending in growth, while further towards the quantitative side of the literature, recent works on optimal taxation include Jones, Manuelli and Rossi (1993) and Chari, Christiano and Kehoe (1994), as well as Benigno and Woodford (2004). Providing a more quantitative analysis than either Barro (1991) or Judd (1999), Jones, Manuelli and Rossi (1993) also studied the implications of optimal taxation on economic growth. Benigno and Woodford (2004) addressed rather the methodological aspect of solving a Ramsey optimal taxation model using a linear-quadratic approach. Chari, Christiano and Kehoe (1994) investigated the cyclical properties of Ramsey optimal taxes over the business cycles in an RBC framework with aggregate shocks. Their results presented a near constancy of labor income tax and zero ex-ante capital tax to be Ramsey optimal, and also showed that it is welfare-improving when the U.S. switched from its actual tax scheme to the optimal taxation scheme.

Overall, while the question of public good provision has been addressed, it has been mostly confined to qualitative analysis. In an RBC or DSGE framework, to study the quantitative implications of optimal taxes over the business cycles Ã la Chari, Christiano and Kehoe (1994), the added concern of public goods consumption/provision has not been incorporated. Furthermore, while the microeconomic and qualitative literature has provided substantial results on optimal taxes with heterogeneous agents, there is almost no corresponding quantitative analysis done to complement those results.

In this paper we aim to fill this gap in the quantitative literature by investigating the dynamics of Ramsey optimal taxation in the context of public goods consumption/provision in an RBC framework. We adopted the same methodological approach as in Chari, Christiano and Kehoe (1994), that is, we studied the business cycles properties of the Ramsey optimal taxes in a model economy subjected to aggregate shocks. Two main features set our model and scope of analysis apart from previous quantitative efforts. The introduction of a government that takes charge of public goods provision allows us to determine, from the point of view of the Ramsey planner, if and how the optimal taxation dynamics deviate from previous results. With multiple households endowed with different income-earning abilities and paying correspondingly different income tax rates, we hope to shed light on whether there is a distinction in the dynamic properties of labor taxes paid by households with different levels of income stream, particularly in response to aggregate shocks over the business cycles. This feature of agent heterogeneity has found a prominent place in the microeconomic and qualitative analysis, pointing to its relevance in the public finance literature. The need therefore is incorporate this feature into a quantitative framework to unearth (if any) differential tax dynamics among the households with different earning abilities.

Our framework comprises three separate representative households optimizing over their private consumption and leisure choices. In addition they all derive utility from a given level of public goods, for the consumption of which they pay taxes to the fiscal authority. The households are distinguished by their different income levels, for which they pay different income tax rates.

The authority - the Ramsey planner in this case, set tax rates and issue debt, to optimally finance the provision of public goods. Two kinds of production happen in the model. One is the usual private sector production that is used for private consumption and investment and government spending, and the other is a public sector production to produce and maintain the stock of public goods. The fiscal authority in our framework therefore is formalized by the following features: distortionary taxes on income, government debt and public goods production. It is also characterized by a passive fiscal rule to stabilize its debt.

We solved for the Ramsey optimal equilibrium, namely an equilibrium where the Ramsey planner chooses the policy instruments (the income tax rates in our model) to maximize the social welfare, subjected to the competitive equilibrium conditions produced by the model. We ran the model under two main aggregate shocks: a productivity/technological (TFP) shock and a government spending shock (that only affects the exogenous consumption component of total government spending).

Our results indicate that the Ramsey optimal tax policy is highly active in response to business cycles fluctuations. To optimize social welfare and the provision of public goods the Ramsey planner adopts a tax-smoothing regime in response to the two shocks, varying the households' tax rates to cope with changes to the government budget constraint. Among the three households, however, there exists considerable heterogeneity in the dynamics of their tax rates.

Concretely, the optimal income taxes display higher volatilities than the results of CCK (1994) suggested. The volatilities also differ markedly across the households, with lower-income households' taxes displaying progressively higher volatility. The heterogeneity of optimal taxes among the households also shows up in terms of their correlation with output and with the underlying shocks. Overall the results suggest a more active intervention by the Ramsey planner in response to business cycles fluctuations using the income taxes as optimization instruments. Also, by and large, she follows a tax-smoothing regime, that is, tax rates are changed in response to impacts on the government budget constraint. In the case of technological shock, however, the low-income household is subjected to a more Keynesian-style tax regime, the implication of which is that the lowest-income household is shielded to a certain extent from the impact of the shock, while most of the tax-smoothing fiscal policy is born by the middle- and high-income households. The case of government spending shock differs from productivity shock in that there is no different tax treatment for the low-income household in terms of the tax rate's cyclicality with output or the underlying shock. Nonetheless under government spending shock the low-income household still has the smallest responses in terms of consumption and welfare, demonstrating that the Ramsey planner's objective of optimizing social welfare aligns with minimizing the effects of shocks on the household. In addition, the low-income household's labor dynamics stands out from those of the two upper-income households under both shocks. The low-income household's labor displays a higher positive correlation with its private consumption, indicating a larger contribution of labor (dis)utility in dampening the household's welfare responses. Under this Ramsey optimal taxation regime for the baseline calibration, the goal is to keep a stable stock of public goods, hence under both shocks government investment spending is highly volatile but essentially acyclical.

We also ran a number of sensitivity analyses to check the robustness of the optimal tax results. In one, we affirmed the crucial role of public good consumption and provision in the optimal tax results found in the baseline calibration. As the weight of public goods consumption in the households' utility function goes near zero, the volatilities of tax rates decrease appreciably, moving their dynamics nearer to those found in CCK (1994). The cyclicality of the tax rates also changes dramatically. When the Ramsey planner's objective becomes optimizing social welfare based only on private consumptions on labors, there is less need for her to vary the households' tax rates significantly with shocks. As a result the stock of public goods also becomes highly variable and virtually in perfect positive correlation with output, as it no longer features in the social welfare function. Another exercise investigating the sensitivity of the tax results on the households' labor productivities found that the low-income labor productivity has a negative relationship with its tax rate's volatility, while for the two upper-income households the relationship is positive. This again illustrates the Ramsey planner's optimal strategy of using tax policy to limit the impact of shocks on the low-income household and dampen the responses of its consumption and welfare. Lastly, we reran the optimal tax analysis under different specifications of the utility function. We found that different specifications of the utility function also have a role in varying to a certain extent the quantitative dynamics of the optimal taxation results. A separable consumption-leisure specification causes productivity shock to have a more pronounced impact on social welfare, necessitating more shielding to the low-income household but at the same time less burden on the mid- and high-income households. The contribution of labor (dis)utility to a household's welfare becomes less important, causing the Ramsey planner to focus less on using labor dynamics for welfare optimization purpose and thus to arrive at a slightly different set of optimal tax results. A non-separable private-public consumption results in a tax policy that is less responsive to the business cycles, as the level of public goods helps reduce the marginal utilities of consumption. This also leads to pro-cyclical government investment spending and a more volatile stock of public goods. Qualitatively, however, the central optimal tax results remain, that is, the Ramsey planner actively manages income taxes to best respond to aggregate shocks, and there are significant heterogeneity among the households in terms of the properties of their income taxes.

3.2 Model

3.2.1 Households

Our model assumes the existence of three types of household, with each type j representing the average (representative) household from an income group j. Each household is represented by a labor productivity ϵ^j, the rate of income tax tau^j it is subject to, and its mass ξ^j such that $\sum_{\xi^j} = 1$. In our model, for purpose of better matching with tax data we do not propose separate taxes on labor income and on returns on capital. Each household's wage and return on capital are grouped together as taxable income and are subject to the same tax rate τ^j.

Each household maximizes its expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t^j, H_t^j, L_t\right)$$

subject to its budget constraint

$$\begin{aligned}(1+\tau_c) C_t^j + B_{t+1}^j + q_t\left(K_{t+1}^j - (1-\delta) K_t^j\right) &= \left(w_t \epsilon^j H_t^j + r_t^k K_t^j\right)\left(1-\tau_t^j\right) \\ +\phi_k \left(K_t^j + \bar{K^j}\right)^{-2} + \phi_b \left(B_t^j + \bar{B^j}\right)^{-2} & \qquad + \left(1 + r_t^b\right) B_t^j \end{aligned} \tag{3.1}$$

where $C^j, B^j, K^j,$ and H^j are each household's consumption, bond holdings, capital stock and labor supply respectively. L_t is the stock of public goods. We consider the stock of public capital giving utility to the households. Each period the household's spending includes consumption and investments in capital and bonds, while its earnings come from wage, returns on capital and bonds. It pays an income tax of τ^j on its earnings from capital rental and labor, as well as a consumption tax τ_c. Earnings from bonds are tax-exempt. r^k and r^b are returns on capital and bonds, and q_t the price of capital, respectively.

A dynamic model with several types of household poses an indeterminacy problem[1], in that each household's levels of capital and bonds cannot be determined. To overcome this technical issue, borrowing constraints have to be introduced for each household. The borrowing constraints for capital and bonds that each household faces are assumed to take the following form

$$K_t^j > \bar{K}^j \qquad B_t^j > \bar{B}^j$$

We model the borrowing constraints for capital and bonds that each household faces as penalty functions $\phi_k \left(K_t^j + \bar{K}^j\right)^{-2}$ and $\phi_b \left(B_t^j + \bar{B}^j\right)^{-2}$ following Monacelli (2009). This provides the mechanism that punishes the households in terms of costs if their capital and bond holdings come too close to the borrowing limits. These constraints are introduced mainly for technical reasons. The limits are calibrated so that the households' capital and bond holdings produce income streams matching those in the data. Given the size of the aggregate shocks, the households' steady holdings of stock and bond are too far away from the limits for these constraints to be binding.

The resulting first order conditions are thus

$$1 = E_t \Lambda_{t,t+1}^j \left(1 + r_{t+1}^b + \phi_b \left(B_{t+1}^j + \bar{B}^j\right)^{-3}\right) \tag{3.2}$$

$$q_t = E_t \Lambda_{t,t+1}^j \left(\left(1-\delta\right) q_{t+1} + r_{t+1}^k \left(1 - \tau_{t+1}^j\right) + \phi_k \left(K_{t+1}^j + \bar{K}^j\right)^{-3}\right) \tag{3.3}$$

[1] Monacelli (2009) discusses this issue

where Λ^j is the stochastic discount factor,

$$\Lambda^j_{t,t+1} = \beta \frac{U'_{C^j_{t+1}}}{U'_{C^j_t}}$$

The intra-temporal labour supply condition is

$$-U'_{H^j_t} = w_t \epsilon^i H^j_t U'_{C^j_t} \frac{1 - \tau^j}{1 + \tau_c} \tag{3.4}$$

Each household's capital stock evolves according to the following equation

$$K^j_{t+1} = (1 - \delta) K^j_t + I^j_t \tag{3.5}$$

3.2.2 Private Production

Firms maximize profits,

$$\max E_0 \left\{ Y_t - r^k_t K^p_t - w_t H^p_t \right\}$$

given the following Cobb-Douglas production function

$$Y_t = A_t \left(K^p_t\right)^{\alpha} \left(H^p_t\right)^{1-\alpha} \tag{3.6}$$

A is the level of technology with the stochastic shock ν_a. The firms' first order conditions are

$$r^k_t = \alpha A_t \left(K^p_t\right)^{\alpha-1} \left(H^p_t\right)^{1-\alpha} \tag{3.7}$$

$$w_t = (1 - \alpha) A_t \left(K^p_t\right)^{\alpha} \left(H^p_t\right)^{-\alpha} \tag{3.8}$$

3.2.3 Government

We formalize the role of government in this model by having it provide public goods to the households. The expenditure of this nature is called government investment spending, I^g. It goes towards the maintenance of public goods, whose stock L_t evolves according to the following equation

$$L_{t+1} = (1 - \delta^g) L_t + I_t^g \tag{3.9}$$

where public good production I^g takes the following form

$$I_t^g = A_t \left(K_t^g\right)^{\alpha} \left(H_t^g\right)^{(1-\alpha)} \tag{3.10}$$

We can interpret this to mean that the government possesses a production technology identical to that of the private sector and acquires the factors of production directly from the competitive market, or that it contracts out this public good production to the private sector.

Every period the government has to satisfy its own budget constraint,

$$T_t + B_{t+1} = w_t H_t^g + r_t^k K_t^g + g_t Y_t + \left(1 + r_t^b\right) B_t \tag{3.11}$$

tax receipts and proceeds from sale of its bonds to the households must equal its spending and bond interest payments. $g_t Y_t$ is government consumption where g_t is the proportion of output that the government consumes. g_t is assumed to be exogenous and follows an AR(1) process. The aggregate revenue is given by

$$T_t = \sum_i \xi^i \left\{ \tau_{ct} C_t^i + \tau_t^i \left(r_t^k K_t^i + w_t \epsilon^i H_t^i \right) \right\} \tag{3.12}$$

while B_t is the aggregate government debt and is given by

$$B_t = \sum_i \xi^i B_t^i \tag{3.13}$$

In order to maintain a stable evolution path for its debt, the government also makes use of the following simple fiscal rule,

$$ln\left(B_t\right) = \zeta^T ln\left(T_t\right) + \zeta^g \left(w_t H_t^g + r_t^k K_t^g + g_t Y_t\right) \tag{3.14}$$

We assume that the government minimizes the cost of public good production. Assuming competitive markets for factors of production, i.e. the government pays the same wage and return on capital as does the private sector, this leads to the following first order condition

$$\frac{K_t^g}{H_t^g} = \frac{K_t^p}{H_t^p} \tag{3.15}$$

3.2.4 Capital Goods Producers

The model assumes adjustment costs in capital investments. The capital goods producer therefore solves the following maximization problem

$$\max_{I_t} E_0 \sum_{t=0}^{\infty} \left\{ q_t \left(K_{t+1} - \left(1-\delta\right) K_t\right) - I_t F\left(\frac{I_t}{I_{t-1}}\right) \right\}$$

where F is the adjustment cost function,

$$F\left(\frac{I_t}{I_{t-1}}\right) = 1 + \frac{\varphi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2$$

The first order condition is

$$q_t = 1 + \frac{\varphi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 + \frac{I_t}{I_{t-1}}\left(\frac{I_t}{I_{t-1}} - 1\right) - \Lambda_{t,t+1}\varphi_I\left(\frac{I_{t+1}}{I_t}\right)^2\left(\frac{I_{t+1}}{I_t} - 1\right) \tag{3.16}$$

3.2.5 Equilibrium and Aggregation

In equilibrium, aggregate capital, labor, consumption, and investments are given by

$$\sum_j \xi^j K_t^j = K^g + K^p \tag{3.17}$$

$$\sum_j \xi^j H_t^j = H^g + H^p \tag{3.18}$$

$$I_t = \sum_j \xi^j I_t^j \tag{3.19}$$

$$C_t = \sum_j \xi^j C_t^j \tag{3.20}$$

Market clearing requires that

$$Y_t = C_t + I_t F \frac{I_t}{I_{t-1}} + g_t Y_t + I_t^g \tag{3.21}$$

3.2.6 Exogenous Shocks

The model is run subject to two shocks: a TFP shock and a government spending shock. Both take the form of an AR(1) functions

$$ln\left(A_t\right) = \rho_a \left(A_{t-1}\right) + \nu_a \tag{3.22}$$

$$g_t - \bar{g} = \rho_g \left(g_{t-1} - \bar{g}\right) + \nu_g \tag{3.23}$$

where $\bar{g}$ is the parameter representing steady state government consumption share of output.

Equations (1) - (20), and the shock processes (22) and (23) together form the equilibrium conditions of the model.

3.3 Data, Calibration, and Solution Method

3.3.1 Data

For the purpose of calibrating our model to the U.S. economy, we obtained the U.S. macro data from NIPA, and tax return data from the IRS. The data relevant for the calibration of the model are the tax returns, GDP, personal consumption and government spending and investment data. We use the 'Returns With Modified Taxable Income' IRS publication for tax return data.

3.3.2 Calibration

Household utility

The baseline utility function takes the following form

$$\frac{\left(C_j\left(1-H_j\right)^{\gamma}\right)^{1-\sigma}-1}{1-\sigma}(C_h*(1-H_h)^{g}amma)^(1-sigma)-1)+\psi log\left(L_t\right) \quad (3.24)$$

This utility function is identical across household types. The quarterly discount factor is set at 0.99. The risk aversion parameter, σ, is set at 1, meaning that the utility takes the widely used form of a log function, while the labor elasticity, γ, is set at 2.

Household abilities, household masses and steady-state income taxes

The tax return data from NIPA form the basis for our calibration. We used data on taxable income, since they aggregate all sources of income that are liable to tax payments by the households and align well with our model setup. The data gave us access to the amount of tax paid at different levels of income. From this we divided the data into three income groups to match our model: low-income, middle-income and high-income, according to the following income cut-offs: the first 40% of households form the low-income segment, the next

30% form the middle-income segment, and the remaining 30% are the high-income households.

Given the difficulty of getting data on households' capital and bond holdings according to the three income classes that we have defined, we calibrated the model using the mean income calculated for each group. The ratios between the different income classes' mean incomes allowed us to calibrate the capital, bonds and labor productivity, ϵ^j, of each household so that in our model they produce income streams in similar ratios.

Private and public goods production

With Cobb-Douglas production function assumed for both private and public productions, the capital-share parameter is also set identically at 0.36 for both sectors. They also share the same TFP process, so that both sectors are subject at the same time to productivity shocks.

Government investment and consumption spending

We use the government spending data obtained from NIPA for the calibration of government consumption and investment spending in our model. We calibrate steady state g, $\bar{g}$, to be 16% of output, which is the average government consumption share of output from NIPA.

Fiscal rule

The simple fiscal rule is calibrated to ensure stability of the dynamic system in terms of the evolution of government debt. In addition, the parameters of the fiscal rule are chosen so as to produce a 4% risk-free return rate on government bonds and positive values for the household's bond holdings.

Standard errors of exogenous shocks

For shocks to the productivity process, we employ the standard value of 0.007 for the standard error mostly in use in the literature for the U.S. economy. For shocks to government consumption spending, the standard error is calibrated to be 5% of the steady state value of government consumption spending, which works out to be 0.9% of total output.

Appendix Table 1 has the full list of calibrated parameters.

3.3.3 Solution Method

We use Dynare 4.2 to approximate the equilibrium conditions of the model around the model steady state. The computational method used by Dynare is based on the perturbation method. The solution and simulation of the Ramsey optimal equilibrium are also done in Dynare.

3.4 Properties of Ramsey - Optimal Income Taxes

We present in this section the results of the baseline calibration. Table 1 reports the dynamics of the optimal income tax rates and government investment spending in three cases: under productivity shock only, under government spending shock only and under both shocks. The model is simulated for 4000 periods, and this simulation is repeated 200 times, each time producing one set of simulated data. We then averaged over these 200 sets of data to obtain the needed statistics. Table 1 shows the properties of this simulation.

The first observation is that the Ramsey optimal tax policy is highly responsive to the business cycle. The effective income tax varies to a good extent with productivity shocks, and quite significantly so with changes in government spending. It also displays positive correlation with both shocks, and highly so

Table 3.1: Properties of cyclical Ramsey-optimal income taxes

	Prod shock only	g shock only	Both shocks
High income tax			
%StdDev	2.96	16.60	16.87
Corr with output	-0.2123	-0.5575	-0.2414
Corr with shock(s)	-0.0505	0.9772	-0.0074; 0.962
Auto-correlation	0.0992	0.9644	0.9377
Mid income tax			
%StdDev	5.01	27.62	28.13
Corr with output	-0.5220	-0.5800	-0.3017
Corr with shock(s)	-0.3500	0.9812	-0.0614; 0.9652
Autocorrelation	0.4215	0.9706	0.9531
Low income tax			
%StdDev	11.27	33.08	35.01
Corr with output	0.5015	-0.4627	-0.0151
Corr with shock(s)	0.5223	0.9368	0.1718; 0.8865
Autocorrelation	0.1616	0.9226	0.8431
Effective income tax			
%StdDev	5.11	24.52	25.09
Corr with output	0.0886	-0.5338	-0.1803
Corr with shock(s)	0.1935	0.9693	0.0415; 0.9489
Autocorrelation	-0.0320	0.9573	0.9161
Gov inv spending			
%StdDev	11.55	15.65	19.44
Corr with output	0.0349	-0.0012	0.0185
Corr with shock(s)	0.0553	-0.0192	0.0331; -0.0153
Autocorrelation	-0.3085	-0.3121	-0.3111

in the case of shock to government spending

Moreover, the three households are not prescribed the same optimal policy. There is appreciable heterogeneity in terms of volatility: the volatility of the optimal tax rate for each household varies according to its income- the lower the income, the higher the volatility. Also, in response to productivity shock alone, the Ramsey optimal taxes have another considerable source of heterogeneity across the households. The correlation between the tax rates and output varies widely. The two higher-income households have their tax rates negatively correlated with output (with the tax rate of the middle-income household highly more so), while the optimal tax for the lowest income household has a positive correlation with output. The result on the overall effective tax rate is that it is essentially acyclical (with very small positive correlation with output and a small positive correlation with underlying shock). The impact of government spending shock on the other hand is more uniform: all three tax rates are negatively correlated to output with similar magnitudes, and are almost perfectly positively correlated with the underlying shock.

The implication of the optimal Ramsey tax results for the case of productivity shock is that they are a variation of the tax-smoothing regime of Barro (1979). The autocorrelations of the three tax rates show no correlation with the persistence of the underlying productivity shock. Essentially, the Ramsey planner manages tax changes so as to counter the effects of unanticipated shocks to the government's budget constraint. For instance, when productivity declines, bringing down tax receipts, the Ramsey planner raises tax rates in order to make up for the shortfall. However, the striking observation about the Ramsey optimal tax regime in this case is that the low-income household is not subjected to it. In fact, the Ramsey planner applies a more Keynesian-style taxation to the low-income household to buffer it against variations in productivity. The positive correlation between the low-income tax rate and output / productivity means that the tax rate is often raised or lowered together with rises and falls in output/productivity. The fact that the low-income household's tax rate is highly variable means the Ramsey planner is highly responsive to smoothing the impact of shocks on the household. Another important implication from these results is that the middle-income household (or the collective mid-income group) appears to bear the largest part of the impact from tax changes in response to productivity shocks. Its tax rate is significantly more negatively correlated to output, and its volatility higher, than the high-income household's tax rate.

From the Ramsey planner's point of view, these tax dynamics are optimal for social welfare because, for example in the event of an adverse productivity shock, they make sure that even though the responding tax hikes might exacerbate the drops in consumptions from the high-income and mid-income households, this allows the low-income household to suffer a less drastic drop in the low-income household's consumption (hence its own welfare). With the low-income household's marginal utility of consumption much higher than the other two households due to its much lower consumption point on the utility curve, a reduction in its consumption would translate to a higher reduction in its welfare than would the same reduction do to the welfares of the two higher-income households. By sacrificing the appropriate amounts of consumption from the two higher-income households, to ensure that the low-income household's tax burden is reduced and to lessen the contraction in the household's consumption, the Ramsey planner ensures that the overall reduction in social welfare is optimal in response to the shock. The consideration by the Ramsey planner of public goods provision also plays an important role. As public goods provision is crucial in maintaining social welfare, and productivity shocks naturally affect the government's ability to maintain the stock of public goods, the optimal consideration involves a trade-off between less active fiscal intervention that would better maintain private consumption and the maintenance of public goods. In this aspect, the Ramsey planner decides that it is optimal for the two upper income households to shoulder the bulk of public goods servicing, otherwise the welfare cost on the low-income household in terms of private consumption loss would be too great.

The Ramsey optimal taxation scheme also achieves its intended purpose through its effects on labor. The low-income household's hours worked display distinct dynamics from those of the two upper-income households in that they are also more volatile, just like its tax counterpart, and more highly positively correlated with output (in the case of productivity shock). Thus, as productivity goes up (down), the low-income household's hours worked also tend to go up (down) more, and in larger percentage, than the other two households. Since the low-income tax rate is also pro-cyclical, as output expands (contracts), the higher (lower) tax rate causes the low-income household to work more (less), meaning that the income effect dominates. Consequently, this labor dynamics, facilitated by the optimal taxation scheme, helps dampen the response of the household's welfare: when for instance productivity shrinks causing utility from consumption to shrink, utility from leisure increases (or, disutility from labor decreases), countering the negative effect of the shock. For this end, the optimal taxes are engineered so as to induce a pre-dominant substitution effect on the low-income household.

That a large part of the tax burden falls on the middle-income household may have come as a surprise. However, a look at the model's dynamics shows this is due to the fact that the contribution of the middle-income household to overall tax receipts is the largest, and extracting a higher percentage of its income (more than the high-income household) to subsidize the low-income group ensures the lowest fall in social welfare.

Government spending shock brings out different dynamics of optimal taxes, even though overall the Ramsey planner still appears to follow a tax-smoothing regime. The near perfect positive correlation between the tax rates and the underlying spending shock means that the Ramsey planner raises or lowers taxes when the government budget is negatively or positively affected. The tax rates are also highly serially correlated, with their autocorrelations apparently matching the persistence of the underlying shock. Given the spending shock's serially correlated nature and direct impact on the government budget constraint, and the Ramsey planner's basing the tax changes on the expected changes in government budget, it is expected thus that the optimal tax rates follow more manifestly the characteristics of the underlying shock than the case of productivity shock, whose impact on the government budget constraint is less immediate. This is evidenced by the fact that as the persistence of the underlying government spending shock is reduced, the autocorrelations of the three tax rates decrease accordingly, as well as the tax rates' volatilities. Conversely, for the case of productivity shock, a less persistent shock brought no corresponding reduction in the tax rates' volatilities and no comparably obvious changes in the tax rates' autocorrelations tracking the change in the shock's persistence.

The case of government spending shock also differs from productivity shock in that the low-income household does not receive a different tax treatment from the rest of households. When a positive spending shock hits the government, for example, and the government needs to raise taxes to finance its increased spending, it does so for all three tax rates. It might seem that the Ramsey planner only provides fiscal buffer to the low-income household in the case of productivity shock and not in the case of government spending shock. Nonetheless, analysis of the impulse response functions of consumptions and welfares of the three households shows that under both shocks the low-income household's private consumption and welfare are subjected to smaller changes in percentage terms than the other two households. Thus, the optimal taxation response by the Ramsey planner under government spending shock still involves subjecting the low-income household to less variability in consumption and welfare (so during contracting business cycles the low-income household experiences less dramatic declines in consumption and welfare). This is also born out by the dynamics of labor. The low-income household's hours worked display essentially the same positive relation with welfare (or private consumption) as in the case of productivity shock: a positive (negative) shock to government spending would shrink the household's consumption, putting negative pressure on the household's welfare, but it also tends to lower the household's hours worked, thus providing a positive push to welfare. Hence, it is due to the different nature of government spending shock from productivity shock that the dynamics of the low-income household's tax differ between the two shocks, but the overall effect of the Ramsey optimal taxation on the low-income household is still to bring out a large substitution effect on the household's labor, and use it to moderate the shock's impact on the household's welfare.

The case of running the model economy under two shocks shows that the overall optimal tax results would depend on the relative strengths of the two shocks. In our analysis, a 0.9% GDP standard error for the government consumption spending stochastic process brings about a much larger response from the Ramsey optimal taxation regime. So under this baseline calibration, the tax results for both shocks together very much take on the characteristics of an optimal tax regime under government spending shock.

Our framework also brings to light the required dynamics of government investment spending (and hence of the stock of public goods) under the Ramsey optimal tax regime. To optimally provide public goods to the households, the Ramsey planner requires government investment to be highly variable over the business cycles and virtually uncorrelated with output and underlying shocks.

This has the effect of maintaining a stable stock of public goods and minimizing the shocks' impact on the households' welfares coming from changes in the public goods level. The result is that under either shock the percentage standard deviation of the stock of public goods is only around 0.3%. For a separable specification of private and public consumptions, this appears to be the optimal strategy for the Ramsey planner in terms of public goods provision. In section 5.4 we will consider the outcome of optimal public goods provision when private and public consumptions are non-separable.

Another relevant dynamic unearthed by the model is the relationship between public goods provision and government debt under the Ramsey optimal taxation regime. Under productivity shock alone, government debt has a negative correlation with both output and government investment spending, while under government spending shock alone, it is positively correlated with output but negatively correlated with government investment spending. Again the debt dynamics among the three households are far from homogeneous. Most consistent is the high positive correlation between the high-income household's debt with output and the high negative correlation between the low-income household's debt with output. This means that during business cycles expansion the high-income household tends to hold more government debt while the low-income household tends to decrease its bond holdings.

We also run the model under two alternative calibrations, ones that have higher values of risk aversion parameters for the households. Table 2 reports the Ramsey optimal policy results for these two calibrations, where sigma is calibrated at 2 and 3.5 (the steady state is virtually unaffected, except those related to marginal utilities of consumption and labor, and to welfares). What immediately stands out is that the effective income tax is now negatively correlated with output and productivity, more highly so with higher risk aversion. This is mostly contributed by the higher negative correlations between the mid-income tax rate and productivity/output, and the lower positive correlations between the low-income tax rate and productivity/output. The tax rates' volatilities however do not vary monotonically with the risk aversion parameter, such that at sigma=3.5 they are all less variable over the business cycles than at sigma=2. It should also be remarked that at both sigma=2 and 3.5, the volatility of the high-income tax decreases compared to sigma=1, while volatilities of the two lower-income taxes are higher than when sigma=1.

These changes in the optimal taxation dynamics reflect the different costs to welfare that would result from changes in consumption and labor due to the different curvatures of the utility function at higher values of the risk aversion parameter. The interpretation is that the tax burden on the high-income household is lessened, evidenced by its tax rate's lower volatility and the movement of its correlation with output towards positive territory. The burden on the mid-income household on the other hand increases. An important factor to consider is that at high values of risk aversion, with non-separable consumption-labor utility, the contribution of labor to welfare fluctuations becomes much larger, as only slightly different levels of hours worked mean vastly different marginal (dis)utility of labor. Though not reported here, our simulation results show that as the risk aversion parameter gets larger, the hours worked of all three households become more and more highly positively correlated with their own consumptions and welfares. Again, the volatility of the low-income household's hours worked is the highest; together with their procyclicality, this contributes to the dampening of the low-income household's welfare as desired by the Ramsey planner. At the same time this dampening effect on welfare coming from labor becomes more important for the two upper-income households as well, despite the different tax dynamics especially for the mid-income household. In addition, as the risk aversion gets larger,

Table 3.2: Ramsey optimal taxes with different risk aversion

	Sigma=2	Sigma=3.5
High income tax		
%StdDev	2.52	1.56
Corr with output	-0.2249	0.1475
Corr with shock(s)	-0.0473	0.3512
Auto-correlation	0.4488	0.9009
Mid income tax		
%StdDev	5.88	5.74
Corr with output	-0.8384	-0.8562
Corr with shock(s)	-0.7701	-0.8737
Autocorrelation	0.9198	0.9585
Low income tax		
%StdDev	13.98	12.08
Corr with output	0.2061	0.1626
Corr with shock(s)	0.2290	0.1421
Autocorrelation	0.1729	0.2641
Effective income tax		
%StdDev	5.62	4.04
Corr with output	-0.1811	-0.2358
Corr with shock(s)	-0.1119	-0.2284
Autocorrelation	0.2860	0.5604
Gov inv spending		
%StdDev	14.55	19.62
Corr with output	0.1152	0.4890
Corr with shock(s)	0.1661	0.5674
Autocorrelation	-0.1123	0.3931

hours worked for the three households become more volatile. Together with their increasingly more positive correlation with output/productivity, it is clear that the welfare costs of changing labor patterns become a lot more important at high risk aversion values, and the Ramsey planner has to engineer a tax regime so that the labor responses of the households move together with their consumptions to help dampen the shocks' impact on in their welfares. With this tax policy, therefore, the households' responses in terms of labor are determined overwhelmingly by the substitution effect.

The dynamics of government investment spending also change. It becomes more volatile and more positively correlated with output and productivity, the higher the risk aversion, so that at $\sigma = 3.5$ these correlations become highly positive. Consequentially, higher risk aversion also has the effect of making the stock of public goods more volatile. It is apparent that the higher curvature of the utility function causes the trade-off in the Ramsey planner's optimization of social welfare to be skewed more towards maintaining the portion of households' welfare that comes from private consumption and labor, so much so that the planner lets the component of social welfare coming from public goods consumption fluctuate more than she would do so at $\sigma = 1$.

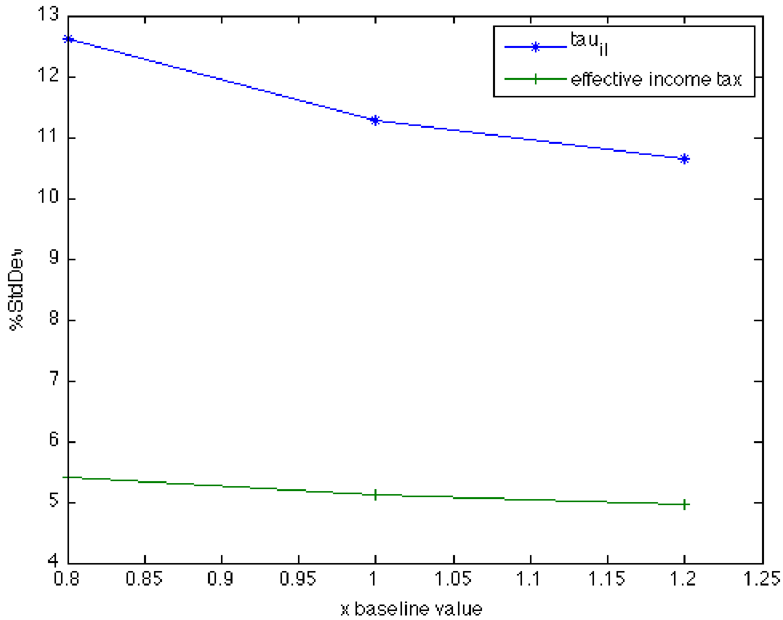
As has been shown, the curvature of the utility function plays an important role in determining the properties of the Ramsey optimal taxation regime. However, essential heterogeneity in the tax dynamics among the three households remains.

3.5 Sensitivity Analyses of Optimal Taxes

3.5.1 Household's Abilities

It is expected that the households' abilities (represented by their labor productivities in the model) play an important role in determining the optimal

Figure 3.1: Sensitivity to Lower Income Ability



tax results. In this section we assess how sensitive our results are to changes in these abilities. We simulated the model with each of the three abilities adjusted to 0.8 and 1.2 times their baseline values. Figures 1 to 3 plot the results of this exercise.

The striking result is that only for the low-income tax rate does a decrease in the household's ability lead to an increase in the tax rate's volatility. The opposite happens for the mid-income and high-income tax rates. In terms of sensitivity, the low-income tax rate displays highest sensitivity to changes in the household's ability. Again, this is tied mostly to the fact that the low-income household's consumption point is situated at a higher marginal utility than the two-upper income households. Any changes in the household's income-earning ability have a direct impact on the household's consumption and would cause large fluctuation in its welfare. This necessitates higher fiscal adjustment on the part of the Ramsey planner.

These results point strongly to the different treatment that the Ramsey planner has for the low-income household in terms of the optimal taxes

Figure 3.2: Sensitivity to Middle Income Ability

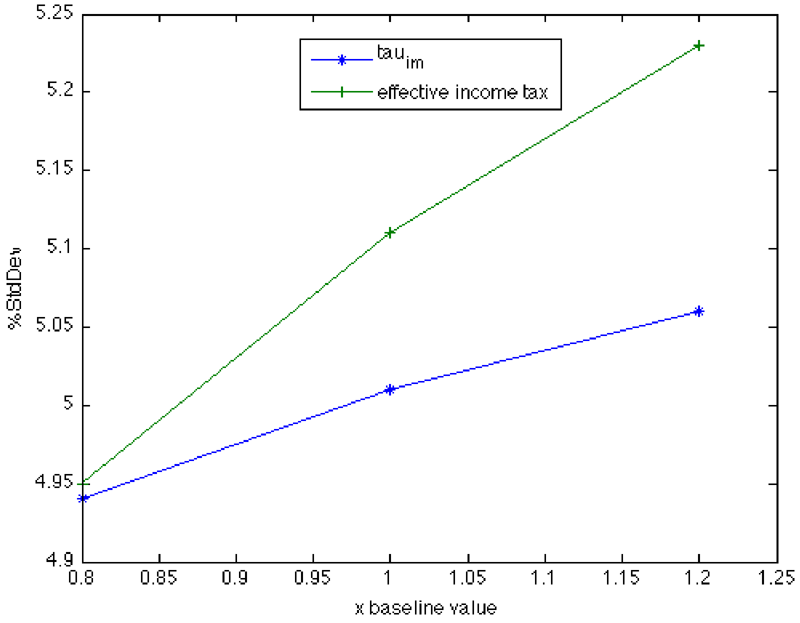
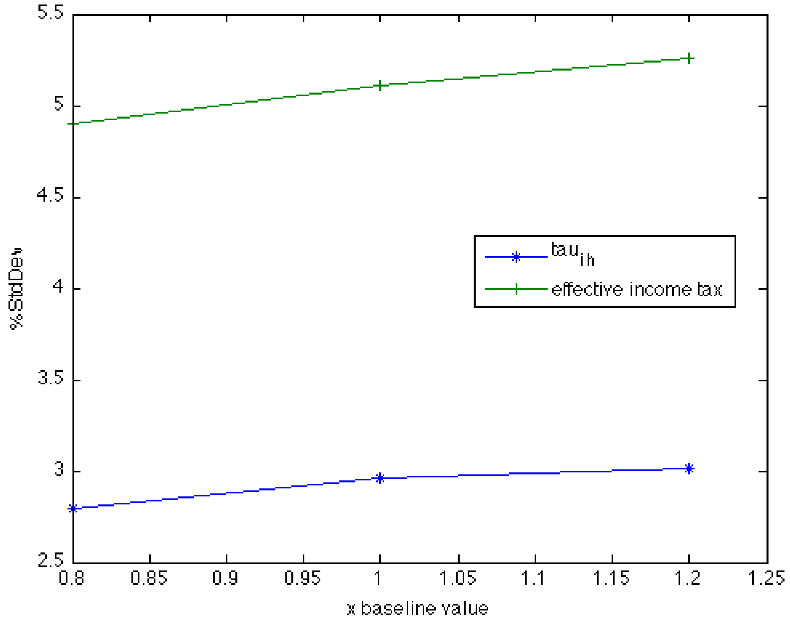


Figure 3.3: Sensitivity to Higher Income Ability



to levy. As the correlations between the tax rates and output/productivity do not change drastically (not reported here), the interpretation is that, as the low-income household's income-earning ability gets lower, the household needs more active fiscal intervention from the Ramsey planner to smooth the shock's impact. More active intervention in this case would simply mean larger changes to the low-income tax rate whenever a change in productivity occurs, to dampen fluctuations in the household's consumption and welfare. On the other hand, since the correlations of mid-income and high-income tax rates with output are of the reverse sign to that of low-income tax rate and output, lower income-earning abilities for these households cause the opposite reaction from the Ramsey planner. Lower incomes translate to lower consumptions for these two households, thus, e.g. when productivity shrinks, the Ramsey planner cannot afford to engineer as large reductions in their consumptions (thus welfares) to buffer the low-income household as at higher abilities, as the costs to overall welfare would be too great. The result is smaller variations in their tax rates in response to changing productivity.

Throughout all these changes to households' labor productivity, the Ramsey planner keeps the dynamics of government investment spending and stock of public goods essentially the same. Government investment spending is kept virtually acyclical, and the stock of public goods shows very small variability.

3.5.2 Weight of Public Goods in Households' Utility Functions

In this section, we assess the importance of public goods provision to the dynamics of optimal tax policy seen in section 4. To do that, we varied the weight of public goods consumption in the households' utility function. In doing so we made the Ramsey planner place varied degrees of importance on the optimal provision of public goods. Table 3 reports the findings (productivity shock only).

It is apparent that a large part of the optimal policy's variability is attributed to the consideration of public goods provision. When psi is very small, the results approach those of CCK (94), that is, the tax rates vary little with productivity changes. Furthermore, the correlations between the tax rates and output/productivity can change in sign and magnitude quite dramatically. At such small value of psi, the Ramsey planner's overriding objective is to optimize social welfare based on just the households' private consumption and labor. Without public goods provision in the planner's objective, the mid-income household becomes the main provider in tax revenues to bring balance to the government budget constraint, while both the low-income and high-income households both benefit from pro-cyclical tax rates. The lower volatilities of the tax rates reflect the fact that there is no longer as much pressing need to keep up tax revenues for the maintenance of the stock of public goods. Indeed, at $\psi = 0.05$, government investment spending becomes highly pro-cyclical. As a result, the percentage standard deviation of the stock of public goods jumps to 15% (compared to just 0.03% for the baseline calibration), and the stock of public goods becomes almost perfectly positively correlated with output. This public goods has become more or less another component of government spending similar to consumption spending, and the Ramsey planner has no interest in keeping it stable for social welfare maximization; she simply invests more or less in it according to the fluctuations in the business cycles. The smaller need for tax revenues also explains the results in that it is sufficient for the Ramsey planner to target the mid-income household for its tax-smoothing purpose, while the cost to welfare of including the high-income household in the tax-smoothing scheme outweighs the benefit.

When psi gets higher, the curvature of the log-utility coming from public goods consumption becomes higher as well; any fluctuations in the level of

Table 3.3: Sensitivity Analysis to Public Good Substitution Importance

	$\psi = 0.05$	$\psi = 0.4$	$\psi = 2.0$
High income tax			
%StdDev	1.54	2.93	3.02
Corr with output	0.5938	-0.4539	-0.1235
Corr with shock(s)	0.6257	-0.1917	0.0684
Mid income tax			
%StdDev	1.68	5.32	4.89
Corr with output	-0.5305	-0.7307	-0.4040
Corr with shock(s)	-0.4964	-0.4998	-0.1945
Low income tax			
%StdDev	5.82	10.75	11.94
Corr with output	0.5920	0.2849	0.5418
Corr with shock(s)	0.5133	0.4201	0.6033
Effective income tax			
%StdDev	2.28	4.98	5.35
Corr with output	0.4520	-0.1907	0.1845
Corr with shock(s)	0.4136	0.0307	0.3273
Gov inv spending			
%StdDev	40.60	13.00	9.93
Corr with output	0.8285	-0.0958	0.0206
Corr with shock(s)	0.8241	0.1038	0.0379

public goods cause greater changes to social welfare. The Ramsey planner's focus thus shifts more towards maintaining a stable stock of public goods. The result is that government investment spending quickly becomes less volatile and moves towards acyclicality, and the volatility of the stock of public goods decreases, so that at $\psi = 2$, compared to the baseline calibration there is about 30% reduction in percentage standard deviation (the steady-state level of public goods stays largely the same). At the same time, the stronger impact of public goods on social welfare also forces the Ramsey planner to effect smaller changes to the part of household's utility that comes from private consumption and labor. This brings about the necessary changes in the optimal tax dynamics observed in the fourth column. The burden on the upper-income households is reduced slightly, while there is an increased buffer for the low-income household. Nonetheless, the essential characteristics of the Ramsey optimal tax regime in the context of public goods provision do not change.

3.5.3 Separable Utility for Consumption and Leisure

In this section we investigate the properties of Ramsey-optimal taxation in the case where the households? consumption and leisure are separable in their utility function. Concretely, we use the following specification of utility function

$$\zeta log\left(C_t^j\right) + (1-\zeta)\, log\left(1 - H_t^j\right) + \psi log\left(L_t\right) \tag{3.25}$$

where ζ is calibrated at 0.3. The results are displayed in table 4, after a slight re-calibration to keep the income streams close to the baseline calibration. Even though the key ratios and moments are kept in line with their U.S. empirical counterparts as in the baseline calibration, the steady-state values of certain variables necessarily change, such as those of consumptions, stock of public goods, and labors. The values of welfares and marginal utilities of consumption and labor also move because of this different form of utility function.

In the case of technological shock, the negative correlation between output and the two higher-income tax rates becomes lower in magnitude, while the low-income tax rate becomes more positively correlated with output. As a result the effective tax now has a more significantly positive correlation with output and with the underlying shock. The tax-smoothing burden on the mid-income household has been significantly reduced (the high-income household to a lesser extent), while the Keynesian characteristics of the low-income household's tax rate becomes more pronounced.

Together with the changes in their volatilities, it is clear that the optimal tax regime is less active with regards to the two upper-income households, but more so with respect to the low-income household. As we can recall from section 4, the optimal change in social welfare in response to productivity shock is achieved by ensuring a minimal drop in the low-income household's utility by engendering the appropriate drops in the two higher-income households' welfare.

The changed tax dynamics therefore tell us that with this particular specification of private consumption and labor utility, the impact of the shock on the households' welfare is more pronounced, and correspondingly the Ramsey planner has to reduce the fiscal burden on the upper-income households while increasing the buffer for the low-income household. This can be explained in terms of the contribution of labor's utility to the welfares of the three households. A separable private consumption-labor utility results in marginal (dis)utilities of labor for the three households that are closer together than they are under the baseline calibration. Without the influence of private consumption level on the curvature of labor utility, the contribution of changes in labor to fluctuations in welfare diminishes. Correspondingly the

Table 3.4: Results with fully separable utility

	Prod shock only	gov spending shock only
High income tax		
%StdDev	2.90	15.86
Corr with output	-0.1013	-0.5060
Corr with shock(s)	0.1441	0.9807
Mid income tax		
%StdDev	4.52	25.49
Corr with output	-0.2840	-0.5235
Corr with shock(s)	-0.0155	0.9831
Low income tax		
%StdDev	12.69	29.76
Corr with output	0.5935	-0.4439
Corr with shock(s)	0.6811	0.9312
Effective income tax		
%StdDev	5.42	22.60
Corr with output	0.2830	-0.4937
Corr with shock(s)	0.4637	0.9711
Gov inv spending		
%StdDev	6.97	9.52
Corr with output	0.0118	-0.0160
Corr with shock(s)	0.0268	-0.0152

Ramsey planner places less importance on using labor to moderate the impact of shocks on welfares. For the low-income household, this is shown by a strongly less positive correlation between the low-income household's labor and private consumption (or welfare) compared to the baseline case, which speaks of a smaller dampening effect on the household's welfare contributed by changes in labor decision. The Ramsey planner has to apply a more active pro-cyclical tax to the low-income household to provide a stronger buffet through private consumption. For the two upper-income households, as the Ramsey planner is no longer able to moderate the effects of counter-cyclical taxes on their consumptions effectively with changes in their labor decisions, she has to reduce the counter-cyclicality as well as the responsiveness of their taxes.

In the case of government spending shock, there is a small reduction in the volatilities of all three tax rates, and they get slightly less negatively related to output. This means a less active optimal tax regime in response to government spending shock that applies to all three households. This is also explained through the contribution of labor to welfare as above. The difference from productivity shock is that, for this shock the low-income tax has the same cyclicality as the other two taxes. So, given the diminished influence of changes in labor on welfare, the tax regime for the low-income has to be less active as well. This is born out by the same statistics that the low-income household's hours worked become less positively correlated with its private consumption (or welfare).

The dynamics of government investment spending also changes in that it becomes less volatile under both shocks compared to the baseline calibration. But this is attributed mostly to the fact that the steady-state stock of public goods has become lower in the new calibration. The important point is that it remains essentially acyclical, so that the stock of public goods varies by less than 0.2% from its steady-state value under either shock. Thus, under this alternative specification of the utility function, the objective of optimal public goods provision still has the same outcome as under the baseline calibration.

Overall, the main characteristics of the optimal tax dynamics are not altered. There remains heterogeneity among the three households in terms of the taxes they pay, with the low-income household standing out strongly from the other two households in the case of productivity shock. And under either shock, responses of the low-income household's consumption and welfare are more muted. In order to maximize social welfare and optimally provide public goods service, the Ramsey planner still follows essentially a tax-smoothing regime coupled with dampening the effects of the business cycles variations on the low-income household.

3.5.4 Non - Separable Utility

In this section we investigate the properties of Ramsey-optimal taxation in the case where the households' private consumption and public goods consumption are non-separable in the utility function. Concretely, we use the following specification of utility function

$$U\left(C_t^j, H_t^j, L_t^j\right) = \frac{\left(C_t^j + \psi log\left(L_t^j\right)\left(1 - H_t^j\right)^{1-\sigma}\right)}{1-\sigma} \tag{3.26}$$

where σ is kept at 0.99 and ψ is calibrated at 0.1. This is a value chosen to keep the consumption patterns of the three households close to the baseline calibration while keeping the share of public goods in the utility function significant. Higher values of ψ would depress their consumption levels to the point of turning negative in the steady state. The results are displayed in table 5, after a slight re-calibration to keep the income streams close to the baseline calibration. The key ratios and moments are also kept as in line with their

U.S. empirical counterparts as in the baseline calibration.

It is clear that the responsiveness of the Ramsey optimal policy decreases quite noticeably for both shocks. The tax rates' volatilities are all lower compared to the baseline calibration, especially for the low-income household. Also, in the case of productivity shock, the counter-cyclicality of the two upper-income tax rates increases, while the pro-cyclicality of the low-income tax rate decreases. The outcome of Ramsey optimal tax policy with regards to optimal provision of public goods also changes. Government investment becomes more positively correlated with output/underlying shocks for both shocks. As a result, the stock of public goods fluctuates a lot more than it does under the baseline calibration (at a percentage standard deviation of 4 ? 5%, compared to around 0.3% for the baseline calibration).

With non-separable private-public consumptions, the level of public goods plays a direct role in determining the households' marginal utilities of consumption. With public consumption now added to private consumption, the marginal utilities of consumption across the households are all lower compared to the baseline case. This has the general effect of moderating the impact of shocks on consumptions and on welfares, thus the generally less active tax regime indicated by lower volatilities of the tax rates. In the case of productivity shock, what this means for the Ramsey planner is that the low-income household does not need as strong a buffer against the shock's impact, which results in a less variable and less pro-cyclical tax policy for the household. The mid- and high-income also benefit from smaller changes to their tax rates in response to changing productivity. And under government spending shocks, all three households are subjected to a less variable tax regime.

Concerning public goods consumption, a barely moving level of public goods may no longer be optimal to welfare. As discussed before, the trade-off for the Ramsey planner is to balance between a stable provision of public

Table 3.5: Results with non-separable utility

	Prod shock only	Gov spending shock only
High income tax		
%StdDev	2.06	16.08
Corr with output	-0.3480	-0.6421
Corr with shock(s)	-0.3239	0.9853
Mid income tax		
%StdDev	4.85	23.28
Corr with output	-0.7049	-0.6272
Corr with shock(s)	-0.6584	0.9866
Low income tax		
%StdDev	6.68	28.87
Corr with output	0.2246	-0.5744
Corr with shock(s)	0.1059	0.9595
Effective income tax		
%StdDev	3.53	21.82
Corr with output	-0.2774	-0.6147
Corr with shock(s)	-0.3127	0.9798
Gov inv spending		
%StdDev	19.04	15.07
Corr with output	0.5227	0.2430
Corr with shock(s)	0.5675	0.6117

goods and minimizing the impact of the needed tax policy on households' consumptions. Given the lower marginal utilities of consumption in this case, maintaining a stock of public goods as stable as before would require a tax policy that is more aggressive than necessary. To the Ramsey planner, a more volatile stock of public goods could be entertained as long as it can be balanced with smaller impacts on private consumption and labor given the right tax policy. The less active tax regime and the more volatile stock of public goods seen here are thus the result of this consideration, indicating the shift in the planner's priority towards less fiscal intervention. With less emphasis on maintaining a stable stock of public goods across the business cycles, government investment spending becomes pro-cyclical, as the Ramsey planner lets public goods maintenance be dictated more by the fluctuations in output.

Another way to understand the impact of non-separable private-public consumption is to look at the relationship between consumptions and the stock of public goods. Since what goes into the households' utility functions is the current stock of public goods (i.e. it is predetermined at the start of a period), it is rather misleading to read into the correlation between the stock of public goods and the consumption variables as reported in Dynare. Rather, it is more instructive to look at the policy functions of the households' consumption variables, more specifically the coefficients of the current stock of public goods in these policy functions. Compared to the baseline calibration, there is a clear reversal in sign of these coefficients. When the utility of public goods consumption is separable, these coefficients are positive. Conversely they are negative under the non-separable specification. The compensating effect of public goods consumption is very clear: it dampens the responses of private consumptions.

The overall implication for the Ramsey planner is that when public and private consumptions are non-separable in the utility, she needs not pursue an aggressive optimal tax regime to maintain a stable stock of public goods, and government investment spending can be let to follow the business cycles (to a certain degree).

3.6 Conclusion

In this paper we provided a quantitative treatment of the issue of optimal tax policy in the context of heterogeneous households and public good provision. We furthered the literature in two main ways, first by bringing optimal public goods provision into a stochastic, quantitative framework with aggregate shocks, and second by providing a detailed look at the heterogeneity of the optimal tax policy across households of different income groups.

We calibrated the model economy to broadly match the macro characteristics of the US economy and solved for the Ramsey optimal equilibrium with the households' tax rates as optimizing instruments. We obtained the dynamic properties of optimal taxes across the business cycles, and found several illuminating implications.

The Ramsey planner is highly active in managing changes to the income tax rates in response to technological shock and government spending shock, and seems to follow a tax-smoothing fiscal regime. Furthermore, she does not prescribe the same optimal tax plan to all three households in the model. There is considerable heterogeneity across the households in terms of their tax rates' variability and correlation with the underlying shocks and with output. The optimal tax implication in the case of productivity shock is that the middle-income and high-income households shoulder most of the tax-smoothing regime desired by the Ramsey planner, while the low-income household gets rather the Keynesian tax treatment. The government spending shock on the other hand requires the three households' tax rates have the same cyclicality with output/underlying shock. Nonetheless there remains a similarity between the two cases of shocks, in that there is buffer for the low-income household to minimize the impact of shocks on its welfare, and the household's labor dynamics contribute to this buffering. Optimal provision of public goods requires that the Ramsey planner provide government investment spending that is essentially uncorrelated with output/underlying shocks, so that fluctuations in the stock of public goods are kept to a minimum across the business cycles.

Our sensitivity analyses highlighted the importance of public goods consumption in the households' utility function in the optimal tax results obtained in the baseline calibration. Without public goods consumption/provision, in the case of productivity shock, the Ramsey optimal tax regime becomes much less responsive to shock, and the stock of public goods is left to fluctuate significantly and in almost perfect positive correlation with output. Alternative specifications of the utility function also have the effects of modifying slightly the tax dynamics of the three households. A separable private consumption-leisure utility lessens the contribution of labor (dis)utility to welfare. Consequently the Ramsey optimal tax policy is modified to relieve the tax-smoothing burden on the upper-income households while at the same time giving the low-income more assistance. A non-separable private-public consumption has the effect of shifting the Ramsey planner's trade-off more towards reducing the tax regime's responsiveness and letting the stock of public goods fluctuate more. With households' marginal utilities of consumption reduced by the presence of public goods, there is no longer as much a need to have an aggressive fiscal intervention to keep the stock of public goods stable as suggested by the results of the baseline calibration. Lastly, in the case of productivity shock, the low-income tax rate's volatility increases with decreases in the household's labor productivity, while the reverse happens for the two upper-income households. This again highlights the central result of the Ramsey optimal taxation regime, in that the Ramsey planner subjects the low-income household to a different tax treatment so as to buffer it against the impact of shocks.

Conclusion

This dissertation studied

(i) The financial cycle and the inter-linkages of the financial system and the real economy. The model proposed in the dissertation matches empirical cyclical properties of financial conditions as measured by credit spreads.

(ii) Bank monitoring over the business cycle. The model proposed in chapter 2 showed that banks choose to spend less on monitoring during benign business conditions potentially causing build up of poor lending.

(iii) Optimal taxes under financial frictions. The model in chapter 3 shows that income for financially constrained households are procyclical for lower income households and more acyclical for higher income households.

Further work in understanding financial factors will have to address some recent features of financing in the economy:

(i) **The rise of direct finance:** Benign financing conditions since 2002 has led to an increasing prevalence of corporations tapping savers directly. This is a huge shift for financial intermediation whose role in direct financing is limited to underwriting and initial sale of bonds. This means that banks no longer perform traditional functions of intermediation including monitoring and screening. Figure 3.4 shows corporate bonds outstanding as a fraction of bonds and bank debt outstanding over time.

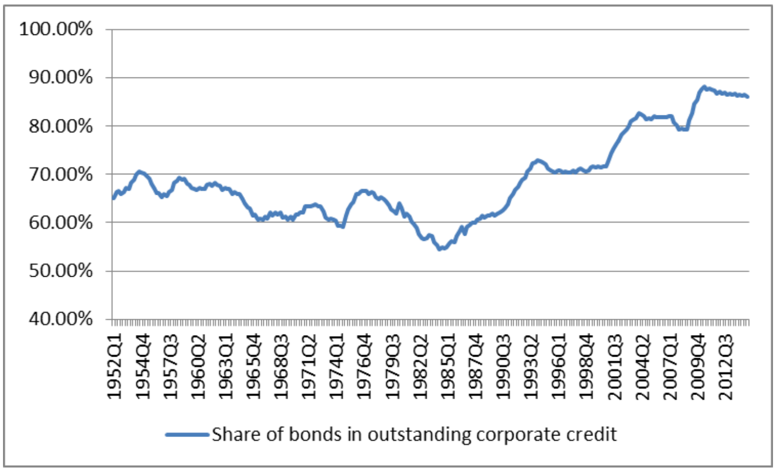


Figure 3.4: Chart showing share of corporate bonds outstanding divided by the sum of outstanding bank commercial and industrial loans and corporate bonds outstanding. Data from Federal Reserve Flow of Funds release.

(ii) **Securitization:** Increasing securitization, where banks sell their loan portfolios to investors, also undermines traditional functions of banking.

(iii) **The rise of offshore direct finance:** Shin (2013), in a speech at the Federal Reserve Bank of San Francisco, highlighted the risks arising from the surge in offshore direct financing. Emerging market corporations and banks are increasingly turning to offshore markets to tap into easy monetary conditions abroad. Offshore bond issuance is a source of easy money. This exposes emerging markets to financial risks from exchange rate movements and changes in monetary policy abroad.

(iv) **Sustained current account imbalances:** Global waves of liquidity arising from large and persistent current account imbalances have contributed to financial instability and disinflationary pressures. Countries with large current account deficits and surpluses remain vulnerable to external shocks.

(v) **Credit conditions and jobless recoveries:** There are some theories about why modern global recession recoveries see slow job creation. For instance, Koenders and Rogerson (2005) argue that firms wait for recessions to layoff excess staff hired during long cyclical boom phases of the business cycle. On the other hand, financing conditions may also affect job creation. Jermann and Quadrini (2012) look at liquidity constraints resulting in firms laying off workers. Further work could examine the influence of credit conditions in job creation.

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