

Optimal Monetary and Macroprudential Policies: Gains and Pitfalls in a Model of Financial Intermediation*

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Abstract

We estimate a quantitative general equilibrium model with nominal rigidities and financial intermediation to examine the interaction of monetary and macroprudential stabilization policies. The estimation procedure uses credit spreads to help identify the role of financial shocks amenable to stabilization via monetary or macroprudential instruments. The estimated model implies that monetary policy should not respond strongly to the credit cycle and can only partially insulate the economy from the distortionary effects of financial frictions/shocks. A counter-cyclical macroprudential instrument can enhance welfare, but faces important implementation challenges. In particular, a Ramsey planner who adjusts a leverage tax in an optimal way can largely insulate the economy from shocks to intermediation, but a simple-rule approach must be cautious not to limit credit expansions associated with efficient investment opportunities. These results demonstrate the importance of considering both optimal Ramsey policies and simpler, but more practical, approaches in an empirically grounded model.

JEL Classification Code: E58, E61, and G18

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1 Introduction

A growing chorus of voices has suggested that counter-cyclical macroprudential policies may help insulate the economy from inefficient fluctuations caused by disturbances to financial intermediation, while other views have emphasized a need for monetary policy to counteract such developments in the absence of macroprudential tools or evidence regarding their efficacy.¹

We examine the role of monetary and macroprudential policy in limiting inefficient economic fluctuations, including fluctuations in the credit cycle. To study these issues, we build a quantitative model that incorporates key frictions from the New-Keynesian models used for monetary policy and some of the financial frictions important for understanding the role of intermediation in business-cycle fluctuations. In the theoretical framework presented, financial intermediaries facilitate the transformation of household savings into productive investment projects. Financial frictions imply that fluctuations in the balance sheet of intermediaries can distort lending and investment decisions. We estimate the model, using macroeconomic variables and the credit spread of [Gilchrist and Zakrajsek \(2012\)](#) to identify disturbances in credit intermediation. The analysis of policy approaches considers outcomes under a Ramsey implementation of monetary and/or macroprudential policies as well as the (more realistic) case of simple rules. Relative to previous work (discussed below), our analysis considers optimal policy assuming that the economy is subject to many types of shocks developed in the literature (e.g., technology, financial, and nominal shocks) and compares outcomes under a Ramsey approach in which the response is optimized for each shock separately and under a simple-rules approach in which the rule responds to observed variables, rather than fundamental shocks. This multiple-shock and Ramsey/simple-rule comparison illustrates the constraints that arise when using either macroprudential or monetary-policy adjustments to promote welfare – constraints that are not apparent in smaller, calibrated

¹[Svensson \(2012\)](#) describes in detail developments in Sweden between 2008 and 2012, a period over which this debate affected policy deliberations at the Riksbank.

models that emphasize one (or few) shocks or the Ramsey approach.

Monetary policy can limit the adverse consequences of disturbances within the intermediation sector through two distinct channels: First, monetary policy can act directly upon aggregate demand, and thus improve the liquidity condition of the financial intermediaries *indirectly* by affecting overall business cycle condition. Second, monetary policy can directly affect the borrowing costs and risk-taking of the financial intermediaries. However, these possible beneficial effects may be accompanied by influences that distort the efficient savings decisions of households – in particular, changes in the stance of monetary policy influence spending and production through wealth and intertemporal substitution channels that include direct effects beyond those bearing directly on spending financed by intermediaries, implying distortions when monetary policy is used to address developments within the intermediation sector.²

Given the potential distortions associated with using monetary policy for macroprudential purposes, we analyze a tax on intermediary leverage as a macroprudential instrument, in the spirit of recent contributions emphasizing such a tax in models with leverage constraints (e.g., [Bianchi, Boz, and Mendoza \(2012\)](#), [Jeanne and Korinek \(2013\)](#), and [Farhi and Werning \(2016\)](#)). (While we emphasize the connection to these earlier theoretical contributions, the review in [Cerutti, Claessens, and Laeven \(2015\)](#) shows that a significant number of countries have adopted taxes on the balance sheets of intermediaries as a policy tool.) The analysis of the interaction of monetary and macroprudential policies proceeds in several steps. We first consider optimal policy strategies as chosen by a Ramsey social planner maximizing the welfare of the agents in the model. The analysis of such optimal policies includes optimal monetary policy in the absence of a macroprudential instrument and the optimal setting of the macroprudential instrument when monetary policy is governed by a simple rule for the nominal interest rate, conditional on the leverage-tax instrument. (A second set of questions, not addressed herein, is whether other instruments are superior to a leverage tax and the

²[Boivin, Kiley, and Mishkin \(2010\)](#) discuss the wealth and intertemporal substitution channels through which monetary policy influences spending and production.

optimal choice of instrument in this class of models.)

These optimal Ramsey strategies are complex, model-dependent functions of the entire “state vector”. Because of this complexity and model-dependence, we follow the consideration of optimal policies with a description of how simple policy rules perform relative to the optimal policies.

In addition to the comparison of simple rules, the analysis emphasizes the importance of estimation for identification of important parameters and the role of alternative shocks. Within the model, monetary and macroprudential policy have different effects and hence are effective in stabilizing the response to the economy to different types of disturbances. As a result, the quantitative importance of these policy instruments for economic stabilization is an empirical question that cannot be addressed solely through a consideration of model structure—as is typical in calibrated models focusing on a single or very-limited set of shocks to the economy.

Several conclusions emerge. First, monetary policy should not respond strongly to the credit cycle as strong responses to credit inhibit the response of investment and consumption to gains in productive efficiency. In other words, monetary policy under a simple interest-rate rule cannot distinguish “good” and “bad” credit. Moreover, monetary policy can only partially insulate the economy from the distortionary effects of financial frictions/shocks. A counter-cyclical macroprudential instrument can enhance welfare, but also faces implementation challenges. In particular, a Ramsey planner who adjusts a leverage tax in an optimal way can largely insulate the economy from shocks to intermediation, but a simple-rule approach must be cautious not to limit credit expansions associated with efficient investment opportunities – that is, simple rules for a macroprudential instrument face the same challenges as those facing monetary policy in distinguishing “good” and “bad” credit. The results demonstrate the importance of considering both optimal Ramsey policies and simpler, but more practical, approaches in an empirically grounded model.

Related literature: The analysis herein builds on several strands of recent research.

Our starting point is the introduction of a central role for financial intermediation in the transformation of household savings into productive capital (e.g., work following [Gertler and Kiyotaki \(2010\)](#)). Our implementation most closely resembles that of [Kiley and Sim \(2014\)](#): In particular, we emphasize, as in that earlier work, the need for intermediaries to make lending decisions prior to having complete knowledge of their internal funds, which exposes intermediaries to liquidity risk and the possibility of needing to raise costly external funds. Relative to [Kiley and Sim \(2014\)](#), we allow for intermediary default, an extension which creates a market-based leverage constraint on intermediaries (driven by the willingness of households to hold risky intermediary debt). The result is a New-Keynesian dynamic general equilibrium model in which intermediaries affect asset pricing in much the same way as emphasized in work on intermediary-based asset pricing models such as [He and Krishnamurthy \(2012\)](#).

The interaction between financial frictions and optimal monetary policy was the focus in [Bernanke and Gertler \(1999\)](#), [Gilchrist and Leahy \(2002\)](#), and [Iacoviello \(2005\)](#), each of which examined how monetary policy should respond to asset prices. The analysis herein includes both potential macroprudential elements in monetary policy reactions – such as adjustments of the nominal interest rate to movements in credit spreads or the volume of credit – and macroprudential policies, as in the theoretical contribution of [Collard, Dellas, Diba, and Loisel \(2012\)](#). We contribute to the literature in several ways. We estimate a dynamic-stochastic-general equilibrium model with financial intermediation and shocks to both the ([Woodford \(2003\)](#)) natural rate of interest and to idiosyncratic risk of the type emphasized in, for example, [Christiano, Motto, and Rostagno \(2013\)](#). This allows a *quantitative* examination of the interaction of monetary policy with a macroprudential instrument, in contrast to the dominant calibration approach pursued in earlier work. Moreover, we use credit spreads as an observable to discipline the identification of shocks to financial conditions, following research that has emphasized the important role for such indicators in understanding the business cycle (e.g., [Gilchrist and Zakrajsek \(2012\)](#)). Finally, we consider both optimal policies - that

is, the approach of a Ramsey planner - and optimal simple rules.

Each of these features of the analysis differentiate our work from the literature focusing on monetary and macroprudential policy in DSGE models with financial intermediation. For example, [Melina and Villa \(2015\)](#) estimate a model and examine optimal simple rules for monetary policy, but do not consider financial shocks of the type we emphasize, ignore macroprudential policy, eschew analysis of Ramsey policies, and do not connect to the literature on credit spreads. [Kannan, Rabanal, and Scott \(2012\)](#) calibrate their model, consider an ad hoc loss function, and analyze only simple rules. [Christensen, Meh, and Moran \(2011\)](#), [Gelain, Lansing, and Mendicino \(2013\)](#), [Lambertini, Mendicino, and Punzi \(2013\)](#), and [Rubio and Carrasco-Gallego \(2014\)](#) calibrate their models and consider simple rules only. [Bailliu, Meh, and Zhang \(2012\)](#) and [Quint and Rabanal \(2014\)](#) estimate models using Canadian and euro area data, respectively, and consider simple rules only.

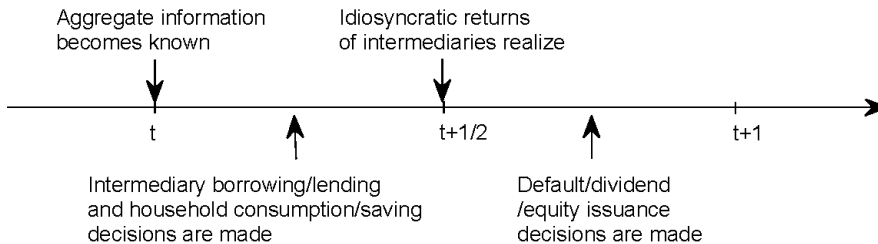
The remainder of this paper is organized as follows. Section 2 develops the dynamic general equilibrium model that works as a laboratory for our policy analysis. Section 3 analyzes the optimal policies that would be pursued by a Ramsey planner. Section 4 studies the potential gains and pitfalls of implementing macroprudential policies via simple policy rules. Section 5 concludes.

2 The Model

The model economy consists of (i) a representative household, (ii) a representative firm producing intermediate goods, (iii) a continuum of monopolistically competitive retailers, (iv) a representative firm producing investment goods, and (v) a continuum of financial intermediaries.

In the model, financial intermediation plays a central role because of two assumptions. First, the representative household lacks the skills necessary to directly manage financial investment projects and saves/borrows through securities issued by financial intermediaries.

Figure 1: Sequence of Events



Second, intermediaries make lending/investment commitments prior to the realization of returns on past investments, and these commitments imply some risk that intermediaries must raise outside funds—through inter-bank lending markets or other capital markets—in a manner that may be costly. To implement this idea in a tractable manner, we assume outside funds take the form of equity and that raising external equity in response to a funding shortfall is costly (in line with a large related literature). The specific timing and financial frictions in our model are developed more fully in the following subsections.

2.1 The Financial Intermediary Sector

In the model, financial intermediaries fund investment projects by issuing debt and equity securities. Debt is tax-advantaged and subject to default, while equity issuance is associated with a sizable issuance cost. This cost involves the sale of new shares at a discount (or dilution cost)—a reduced-form way to capture the lemon premium imposed on issuers due to asymmetric information (Myers and Majluf (1984)) and the empirical regularity that direct costs associated with equity issuance are substantially greater than those associated with debt issuance or deposit-taking (Calomiris and Tsoutsoura (2010)). Despite the tax advantage and default option associated with debt, intermediaries use both debt and equity financing, as the default premium associated with debt financing rises as intermediary leverage increases.

To highlight the notion that lending/investment commitments place intermediary liquidity and capital at risk, we adopt the following timing convention. We split a time period into

two sub-periods and assume that lending and borrowing (e.g., asset and liability) decisions have to be made in the first half of the period t ; idiosyncratic shocks to the returns of the projects made at time $t - 1$ are realized in the second half of the period t , at which point lending and borrowing decisions cannot be reversed (until period $t + 1$). Figure 1 describes this flow of decisions.³ This set of assumptions has two advantages. First, the intra-period irreversibility in lending and borrowing decisions, in conjunction with costs of external equity financing, generates *precaution* in lending decisions, which distorts the efficient allocation of credit. Second, the timing convention helps us derive an analytical expression for the equity issuance and default triggers of intermediaries, allowing a sharp characterization of the equilibrium. (In the absence of this timing assumption, the distribution of intermediaries' balance sheets across periods would be non-degenerate, implying substantial computational complexities).

2.1.1 The Intermediary Debt Contract

We model the borrowing and lending relationship between a financial intermediary and an investor (implicitly an agent working for the representative household without agency friction) using a standard debt contracting framework. As will be shown, the intermediary problem is essentially linear, and henceforth we focus on a project scale with a unit value. Consider a financial intermediary, which mixes debt and equity capital to finance its lending/investment, which turns a random return $1 + r_{t+1}^F$ after tax. The return is composed of aggregate (r_{t+1}^A) and idiosyncratic components (ϵ_{t+1}) such that $1 + r_{t+1}^F = \epsilon_{t+1}(1 + r_{t+1}^A)$. The idiosyncratic component has a time-varying lognormal distribution ($F_{t+1}(\cdot)$), in which the volatility level σ_t follows an AR(1) process while the first moment is time-invariant (and normalized to

³Another related approach would be the following. One can assume that a random fraction of households require early redemption of their debt/deposits at intermediaries in the second half of the period. In this case, the idiosyncratic redemption rate replaces the idiosyncratic shocks to the return on lending. Owing to the illiquidity of the investment project, the intermediary has to raise additional funds on the inter-bank market or elsewhere to meet the “run”. This will create a similar effect on the lending decision of the intermediary under the assumption that raising such funds involves a cost analogous to the cost of outside equity we emphasize.

equal one, $\mathbb{E}_t[\epsilon_{t+1}] = 1$). The time-variation in the second moment of the idiosyncratic return will have aggregate implications under the financial-market frictions considered herein. In particular, an intermediary may need to raise external funds (if its idiosyncratic return implies insufficient balance-sheet capacity to meet lending commitments).

Denote the fraction of the investment project financed with equity capital by m_t . $1 - m_t$ then denotes the fraction of borrowed funds. If the intermediary does not default on debt in the next period, it repays $(1 + r_{t+1}^B)(1 - m_t)$ to the investor, where r_{t+1}^B is the interest rate on debt. In this case, the intermediary's payoff (its realized net-worth denoted by N_t) is given by $N_t = \epsilon_{t+1}(1 + r_{t+1}^A) - [1 + (1 - \tau_c)r_{t+1}^B](1 - m_t)$, where τ_c denotes the corporate income tax rate. In the event of default, the intermediaries net worth drops to zero, and the lender recovers the liquidation value of the project. Liquidation involves a cost, equal to a fraction η of the project value. The post-default return for the investor is then given by $(1 - \eta)\epsilon_{t+1}(1 + r_{t+1}^A)$.

A default-trigger value for the idiosyncratic shock is found by setting $N_t = 0$ and solving for the trigger value ϵ_{t+1}^D – where realizations of the idiosyncratic return below this value imply default:

$$\epsilon_{t+1} \leq \epsilon_{t+1}^D \equiv (1 - m_t) \frac{1 + (1 - \tau_c)r_{t+1}^B}{1 + r_{t+1}^A}. \quad (1)$$

Using the default trigger value, we can express the participation constraint for the investor as

$$1 - m_t \leq \mathbb{E}_t \left\{ M_{t,t+1} \left[(1 - \eta) \int_0^{\epsilon_{t+1}^D} \epsilon_{t+1}(1 + r_{t+1}^A) dF_{t+1} + \int_{\epsilon_{t+1}^D}^{\infty} (1 - m_t)[1 + r_{t+1}^B] dF_{t+1} \right] \right\} \quad (2)$$

where $M_{t,t+1} \equiv \beta(\Lambda_{t+1}/\Lambda_t)/(\Pi_{t+1})$ with β , Λ_t and Π_{t+1} being the time discount factor, the marginal utility of consumption of the representative household, and (the gross rate of) inflation, respectively.

2.1.2 Intermediary Equity Finance

We now turn to the problem of intermediary equity financing. As mentioned earlier, equity issuance involves a dilution cost in which issuers are forced to sell new shares *at a discount* – an assumption adopted widely in corporate-finance literature (see, [Hennessy and Whited \(2007\)](#) and [Bolton and Freixas \(2000\)](#)). We denote the discount (haircut) of new share by $\varphi \in (0, 1)$.

We denote equity-related cash flow by D_t . D_t is dividends paid when positive, and equity issuance when negative. With the assumption of costly equity issuance, actual cash inflow from issuance ($-D_t$) is reduced to $-(1 - \varphi)D_t$. Total equity related cash flow for an intermediary can be expressed as $\varphi(D_t) \equiv D_t - \varphi \min\{0, D_t\}$. Suppose that the intermediary invests in S_t units of investment projects whose market price is given by Q_t . The flow of funds constraint for a financial intermediary is then given by

$$Q_t S_t = \epsilon_t (1 + r_t^A) Q_{t-1} S_{t-1} + (1 - m_t) Q_t S_t - (1 - m_{t-1}) (1 + (1 - \tau_c) r_t^B) Q_{t-1} S_{t-1} - \varphi(D_t). \quad (3)$$

The constraint states that new investment (the left side) should equal the sum of return on assets from investment last period and new borrowing minus the payment on existing debt from last period and equity-related cash-flow.

We define an equity-financing trigger ϵ_t^E as the level of idiosyncratic shock below which a financial intermediary must raise external funds. The trigger can be found by setting $D_t = 0$ and solving the flow of funds constraint for ϵ_t^E :

$$\epsilon_t^E = (1 - m_{t-1}) \frac{1 + (1 - \tau_c) r_t^B}{1 + r_t^A} + \frac{m_t Q_t S_t}{(1 + r_t^A) Q_{t-1} S_{t-1}} = \epsilon_t^D + \frac{m_t Q_t S_t}{(1 + r_t^A) Q_{t-1} S_{t-1}}. \quad (4)$$

This implies that the equity financing trigger is strictly greater than the default trigger – that is, a financial intermediary chooses recapitalization before it is forced to declare bankruptcy.

2.1.3 Value Maximization

A Symmetric Equilibrium Our timing convention and the risk neutrality of intermediaries imply a symmetric equilibrium in which all intermediaries choose the same lending/investment level and capital structure (m_t). The shadow value of the participation constraint (θ_t , the multiplier associated with constraint (2)) is also identical for all intermediaries because borrowing decisions are made before the realization of the idiosyncratic shock.

However, the distribution of dividends and equity financing depend on the realization of idiosyncratic shocks, and thus have non-degenerate distributions. Since the flow of funds constraint depends on the realization of the idiosyncratic shock, the ex-post shadow value of the constraint, denoted by λ_t , also has a non-degenerate distribution.

To simplify the dynamic problem, it is convenient to split the intermediary problem into two stages in a way that is consistent with the timing convention. In the first stage, the intermediary solves for the value maximizing strategies for lending and borrowing prior to the resolution of idiosyncratic uncertainty. In the second stage, the intermediary solves for the value maximizing dividend/issuance strategy based upon all information, including the realization of its net worth.

Formally, we define two value functions, J_t and $V_t(N_t)$. J_t is the *ex-ante* value of the intermediary before the realization of the idiosyncratic shock while $V_t(N_t)$ is the *ex-post* value of the intermediary after the realization of the idiosyncratic shock. In our symmetric equilibrium, the ex-ante value function does not depend on the intermediary specific state variables. The ex-post value function $V_t(\cdot)$, however, depends on the realized internal funds, N_t , which is a function of the realized idiosyncratic shock. (As noted above, N_t cannot fall below zero, as such cases result in default.) Since the first stage problem is based upon the conditional expectation of net-worth, not the realization, it is useful to define an expectation operator $\mathbb{E}_t^\epsilon(\cdot) \equiv \int \cdot dF_t(\epsilon)$, the conditioning set of which includes all information up to time

t , except the realization of the idiosyncratic shock.⁴

Financial intermediaries are owned by the representative household, and hence discount future cash flows by the household's stochastic pricing kernel, $M_{t,t+1}$. In stage 1, the intermediary maximizes shareholder value by solving for the size of its lending, debt, and equity through choices for the aggregate project size $Q_t S_t$, the capital ratio m_t , and the default trigger ϵ_{t+1}^D),

$$J_t = \max_{Q_t S_t, m_t, r_{t+1}^B} \{ \mathbb{E}_t^\epsilon [D_t] + \mathbb{E}_t [M_{t,t+1} \cdot \mathbb{E}_{t+1}^\epsilon [V_{t+1}(N_{t+1})]] \} \quad \text{s.t (2) and (3)}. \quad (5)$$

After the realization of the idiosyncratic shock, the intermediary solves

$$V_t(N_t) = \max_{D_t} \{ D_t + \mathbb{E}_t [M_{t,t+1} \cdot J_{t+1}] \} \quad \text{s.t (3)} \quad (6)$$

Problem (5) determines for the optimal lending/borrowing /default choices based upon $\mathbb{E}_t^\epsilon [N_t]$ and $\mathbb{E}_t^\epsilon [D_t]$. In stage 1, the intermediary does not know whether default, equity issuance, or dividend payouts will occur following the realization of its idiosyncratic return. In state 2, problem (6) solves for the optimal level of distribution/issuance based on the realization of net-worth.

2.1.4 Optimal Intermediary Investment

The shadow value of internal funds of financial intermediaries (the Lagrangian multiplier associated with (3)) plays an essential role in determining the size of intermediaries' balance sheet and the mix of debt and equity used to finance this balance sheet. Since investment and capital structure decisions are to be made prior to the revelation of idiosyncratic shock, the intermediaries' first-stage problem is a function of the expected shadow value of internal

⁴From the perspective of households, there is no new information in the second half of the period because of the law of large numbers: At the beginning of each period, the household exactly knows how much additional equity funding is required for the intermediary sector as a whole (as indicated by the timing of household decisions in figure 1). This ensures that the lending and borrowing decisions of intermediaries are consistent with the savings decisions of households.

funds, $\mathbb{E}_t^\epsilon[\lambda_t]$.

When an intermediary receives a “good” realization of asset returns, it will pay excess earnings as dividends to shareholders. At this point, the shadow value of internal funds is equal to 1 (the value of the funds sent to shareholders). However, if the intermediary cannot fulfill its lending commitments given its idiosyncratic realization and must raise outside (equity) funds, which happens with a probability $F_t(\epsilon_t^E)$, the shadow value of internal funds jumps to $1/(1 - \varphi)$ owing to the dilution cost of φ per unit of equity raised.⁵ Since the shadow value takes 1 with probability $1 - F_t(\epsilon_t^E)$ and $1/(1 - \varphi)$ with probability $F_t(\epsilon_t^E)$, the expected shadow value is given by

$$\mathbb{E}_t^\epsilon[\lambda_t] = 1 - F_t(\epsilon_t^E) + \frac{F_t(\epsilon_t^E)}{1 - \varphi} = 1 + \mu F_t(\epsilon_t^E) > 1, \quad \mu \equiv \frac{\varphi}{1 - \varphi}. \quad (7)$$

In the appendix, we show that the efficiency conditions of problem (5) and (6) imply that the following asset-pricing formula holds in equilibrium:

$$1 = \mathbb{E}_t \left\{ M_{t,t+1} \frac{\mathbb{E}_{t+1}^\epsilon[\lambda_{t+1}]}{\mathbb{E}_t^\epsilon[\lambda_t]} \cdot \frac{1}{m_t} [1 + \tilde{r}_{t+1}^A - (1 - m_t)[1 + (1 - \tau_c)r_{t+1}^B]] \right\} \quad (8)$$

where the modified asset return $1 + \tilde{r}_{t+1}^A$ is defined as

$$1 + \tilde{r}_{t+1}^A \equiv \frac{\mathbb{E}_{t+1}^\epsilon[\lambda_{t+1} \max\{\epsilon_{t+1}, \epsilon_{t+1}^D\}]}{\mathbb{E}_{t+1}^\epsilon[\lambda_{t+1}]} (1 + r_{t+1}^A). \quad (9)$$

As an asset-pricing formula, (8) has several important features. First, it is a levered asset-pricing formula, as can be seen in the fact that the borrowing cost needs to be subtracted from the gross asset return and this *net* asset return is levered up by a factor $1/m_t$. In our model, low uncertainty induces the intermediaries to lever up their balance sheets in order to raise the return on equity by taking greater risk. This implies that the time-varying

⁵To see this, consider the fact that the intermediary in need of outside equity to fulfill its financial obligation is indifferent between having additional internal funds of $1 - \varphi$ dollar and issuing 1 dollar of new shares since the latter option involves φ of dilution cost.

volatility shock in our environment creates *pro-cyclical* leverage.

Second, the dynamic ratio of the shadow value of internal funds $\mathbb{E}_{t+1}^\epsilon[\lambda_{t+1}]/\mathbb{E}_t^\epsilon[\lambda_t]$ creates a wedge between the pricing kernel of the representative household and the asset return, potentially creating inefficiency. If the balance-sheet condition of intermediaries as measured by the expected shadow value of internal funds, is perceived to be worse today than tomorrow, the effective discount rate of the financial intermediaries is elevated—boosting the required return on lending/investment projects and leading to a more conservative lending/investment strategy today. Equation (8) is essentially an application of the liquidity-based asset pricing framework (LAPM, [Holmstrm and Tirole \(2001\)](#)) in a dynamic general equilibrium model.

6.

Finally, as can be seen in (9), limited-liability bounds the effective asset return through a “default option”, making the asset return convex with respect to the idiosyncratic shock. The default option is more valuable when uncertainty regarding the asset return increases as can be seen in the interaction between λ_{t+1} and the truncated return, $\max\{\epsilon_{t+1}, \epsilon_{t+1}^D\}(1 + r_{t+1}^A)$. This, however, does not imply that the financial intermediaries will increase their lending to risky assets at a time of heightened uncertainty. While greater uncertainty boosts the risk appetite of the intermediaries through the default option, the same increase in uncertainty boosts the expected shadow values of cash flow, thereby elevating the required return on lending for the intermediaries, which then reduces lending to risky assets. Furthermore, households require greater protection from default, increasing the borrowing costs for the intermediaries.⁷

⁶See [He and Krishnamurthy \(2008\)](#), who derive an intermediary specific pricing kernel by assuming risk aversion for the intermediary. Also see [Jermann and Quadrini \(2012\)](#), who derives a similar pricing kernel by assuming a quadratic dividend smoothing function.

⁷Note that the max operator enters the effective return term inside the expectation operator. This means that the realized return is kinked, but its expected value is a smooth function of other state variables. An analogy can be made with the value of European call option, where the realized value of the option is kinked, but the expected value is a smooth function of the current price of the underlying asset. As a result, the max operator does not create any problem for us to use perturbation methods. See the appendix for the analytical expression for the effective return.

2.2 The Rest of the Economy

To close the model, we now turn to the production, capital accumulation, and the consumption/labor supply decisions of non-financial firms and households. Regarding the structure of production and capital accumulation, we assume that the production of consumption and investment goods are devoid of financial frictions. This assumption, while strong, helps us focus on the friction facing the financial intermediaries in their funding markets rather than the friction in their lending (investment) market. ⁸

2.2.1 Production and Investment

There is a competitive industry that produces intermediate goods using a constant returns to scale technology; without loss of generality, we assume the existence of a representative firm. The firm combines capital (K) and labor (H) to produce the intermediate goods using a Cobb-Douglas production function, $Y_t^M = a_t H_t^\alpha K_t^{1-\alpha}$, where the technology shock follows a Markov process, $\log a_t = \rho_a \log a_{t-1} + \sigma_a v_t$, $v_t \sim N(0, 1)$.

The intermediate-goods producer issues state-contingent claims S_t to a financial intermediary, and use the proceeds to finance capital purchases, $Q_t K_{t+1}$. A no-arbitrage condition implies that the price of the state-contingent claim must be equal to Q_t such that $Q_t S_t = Q_t K_{t+1}$. After the production and sale of products, the firm sells its undepreciated capital at the market value, returns the profits and the proceeds of the capital sale to the intermediary. The competitive industry structure implies that the firm's static profit per capital is determined by the capital share of revenue, i.e., $r_t^K = (1-\alpha)P_t^M Y_t^M / K_t$, where P_t^M is the price level of the intermediate goods. Hence the after-tax return for the intermediary is given by

$$1 + r_t^A = \frac{(1 - \tau_c)(1 - \alpha)P_t^M Y_t^M / K_t + [1 - (1 - \tau_c)\delta]Q_t}{Q_{t-1}}. \quad (10)$$

We assume costs of adjusting investment at the aggregate level to allow for time-variation

⁸Other recent studies of intermediaries, notably [Gertler and Karadi \(2011\)](#) and [Gertler and Kiyotaki \(2010\)](#), adopt a similar assumption.

in the price of installed capital (K_t) relative to investment. More specifically, we assume that there is a competitive industry producing new capital goods combining the existing capital stock and consumption goods using a quadratic adjustment cost of investment, $\chi_t/2(I_t/I_{t-1} - 1)^2 I_{t-1}$. We allow for stochastic variation in χ as a means to include shocks to the investment first-order condition, as in [Smets and Wouters \(2007\)](#).

2.2.2 Households

We assume that the consumption utility of the household sector has a property of “catching up with the Joneses”—that is, an external habit formation a la [Abel \(1990\)](#). Preferences over hours worked H_t are standard.

Formally, household preferences can be summarized by

$$\sum_{s=0}^{\infty} \beta^s \left[\frac{1}{1-\gamma} [(C_{t+s}(j) - hC_{t+s-1}(j))^{1-\gamma} - 1] - \frac{1}{1+\nu} H_{t+s}^{1+\nu} \right], \quad (11)$$

where $C_t(j)$ is consumption, H_t is hours worked, β is the time discount factor, γ governs the curvature in the utility function, h is the habit parameter, and ν is the inverse of the Frisch elasticity of labor supply.

We assume that each household invests in a perfectly diversified portfolio of intermediary debt such that $B_t(j) = \int [1 - m_{t-1}(i, j)] Q_{t-1} S_{t-1}(i, j) di$. Since all households make the same choice, $\int B_t(j) dj = B_t$ trivially. In the interest of space, we do not derive the efficiency conditions for households’ financial investment decisions here. The technical appendix shows that the participation constraint (2) for the intermediary problem is equivalent to the efficiency condition for households’ intermediary bond investment. It also shows that investment in the equity shares of the financial intermediary satisfies the equilibrium condition

$$1 = \mathbb{E}_t \left[M_{t,t+1} \frac{\mathbb{E}_{t+1}^\epsilon [\max\{D_{t+1}, 0\} + (1 - \varphi) \min\{D_{t+1}, 0\}] + P_{t+1}^S}{P_t^S} \right] \quad (12)$$

where P_t^S is the ex-dividend price of an intermediary share. This is a standard dividend-price

formula for the consumption CAPM, taking into account the effect of the equity issuance cost. Note that in our symmetric equilibrium, $P_t^S(i) = P_t^S = \mathbb{E}_t[M_{t,t+1} \cdot J_{t+1}]$ for all $i \in [0, 1]$, and thus the ex-dividend value is equalized for all intermediaries. Finally, note that in general equilibrium, the existing shareholders and the investors in the new shares are the same entity, the representative household. Hence, costly equity financing does not create a wealth effect for the household, but affects the aggregate allocation through the marginal efficiency conditions of the intermediaries.⁹

Finally, we assume that the representative household has access to a nominal bond whose one-period return equals the policy interest rate set by the central bank, R_t , adjusted for an exogenous aggregate “risk” premium Ξ_t (reflecting un-modeled distortions between the central bank and households). Under these assumptions, the condition linking households stochastic discount factor and the policy interest rate is given by

$$1 = \mathbb{E}_t [M_{t,t+1} R_t \Xi_t] \quad (13)$$

We assume that the “risk premium” follows a Markov process, $\log \Xi_t = \rho_\Xi \log \Xi_{t-1} + \sigma_\Xi w_t$, $w_t \sim N(0, 1)$. Other models, most notably [Smets and Wouters \(2007\)](#) and [Chung, Kiley, and Laforte \(2010\)](#), have also used this aggregate risk premium shock to explain economic fluctuations. In particular, this shock is a pure shock to the natural rate of interest (e.g., [Woodford \(2003\)](#)) and represents a “nominal aggregate demand” disturbance – that is, it has no effect on economic activity under flexible prices, as it would simply pass through to nominal interest rates, but has important effects when prices are rigid and nominal rates influence demand. We turn to nominal rigidities in the next subsection.

⁹To see that there is no wealth transfer to the household, one can rewrite the flow of funds constraint for the intermediary (3) at time $t + 1$ as $D_{t+1} - \varphi \min\{0, D_{t+1}\} = N_{t+1} - m_{t+1}Q_{t+1}S_{t+1}$, and observe

$$D_{t+1} = \begin{cases} N_{t+1} - m_{t+1}Q_{t+1}S_{t+1} & \text{if } D_{t+1} \geq 0 \\ (N_{t+1} - m_{t+1}Q_{t+1}S_{t+1})/(1 - \varphi_{t+1}) & \text{if } D_{t+1} < 0 \end{cases}$$

Hence $\max\{D_{t+1}, 0\} + (1 - \varphi) \min\{D_{t+1}, 0\} = N_{t+1} - m_{t+1}Q_{t+1}S_{t+1}$ always. This shows that the households do not face any consequences on their wealth from the equity market friction because they would get the same aggregate dividends $N_{t+1} - m_{t+1}Q_{t+1}S_{t+1}$ as if there were no dilution effects, i.e., $\varphi = 0$.

2.2.3 Nominal Rigidity and Monetary Policy

We include nominal rigidity in the goods market.¹⁰ We assume that a continuum of monopolistically competitive firms take the intermediate outputs as inputs and transform them into differentiated retail goods $Y_t(k)$, $k \in [0, 1]$. To generate nominal rigidity, we assume that the retailers face a quadratic cost in adjusting their prices $P_t(k)$ given by $\chi^p/2 (P_t(k)/P_{t-1}(k) - (\bar{\Pi}^{1-\kappa}\Pi_{t-1}^\kappa))^2 P_t Y_t$, where Y_t is the CES aggregate of the differentiated products with an elasticity of substitution ε_t , $\bar{\Pi}$ is the steady state inflation rate, and κ is a parameter governing the extent to which adjustment costs depend on the steady-state inflation rate or lagged inflation. The stochastic variation in ε_t introduces markup shocks to the New-Keynesian Phillips curve.

In order to make the equilibrium of our model in the absence of nominal price rigidity and financial frictions “first best”, we further assume that a system of distortionary subsidies to producers and households offsets the (steady-state) price and wage markups associated with monopolistic competitions.

Monetary policy is governed by a simple rule for the nominal interest rate,

$$R_t = R_t^{\rho_R} \left[\frac{\bar{\Pi}}{\beta} \left(\frac{\Pi_t}{\bar{\Pi}} \right)^{r_\Pi} \left(\frac{Y_t - Y^*}{Y^*} \right)^{r_{y^*}} \left(\frac{Y_t}{Y_{t-1}} \right)^{r_{\Delta Y}} \right]^{1-\rho_R} \exp(e_t^R) \quad (14)$$

where inertia in interest rate adjustments is governed by ρ_R , r_Π and $r_{\Delta Y}$ are the coefficients on inflation and output growth, respectively, r_{y^*} is the coefficient on the production-based output gap ($\frac{Y_t - Y^*}{Y^*}$, which is proportional to hours worked, see [Kiley \(2013\)](#)), and e_t^R is the error term or monetary policy shock (which is i.i.d.).

2.2.4 Fiscal Policy

In our baseline model, the fiscal policy is simply dictated by the period-by-period balanced budget constraint. The revenues for government come from two sources: corporate income

¹⁰We do not consider nominal wage rigidity, in part because modeling nominal wages appears to largely be an exercise in modeling measurement error, according to [Justiniano, Primiceri, and Tambalotti \(2013\)](#)

tax of the financial intermediaries and lump sum tax on households. The proceeds from the corporate income tax are assumed to be transferred back to the financial intermediaries in a lump sum fashion as this taxation is employed mainly for creating an incentive to take leverage in the steady state. We also assume that the distortionary subsidies on product prices and wages are funded by the lump sum tax on the households. Later, we will introduce leverage tax/subsidy on the financial intermediaries. Any proceeds (outlays) from the leverage taxation (subsidy) will be transferred back to the intermediaries (or funded by the lump sum tax in the case of subsidy). In addition, fluctuations in government purchases are a source of autonomous demand shocks, as in [Smets and Wouters \(2007\)](#).

2.3 Calibration and Estimation

Our approach involves calibration of certain parameters and estimation of others – we assign parameters to each category based on the degree to which observed fluctuations in the data are likely to be informative about parameter values.

2.3.1 Calibration

The calibrated parameters related to preferences and technology are summarized in table [1](#). The discount factor β is set to 0.985. We set the labor share in production α to 0.60 and the depreciation rate δ to 0.025. (These choices have essentially no effect on results, and have a long history – e.g., [Cooley and Prescott \(1995\)](#)).

The parameters governing the strength of financial frictions have important effects on the properties of the model – in particular, these parameters contribute to the steady-state level of leverage assumed by financial intermediaries and help govern the response of the economy to shocks. The corporate income tax rate creates an incentive for intermediaries to assume leverage to exploit the tax shield on interest expenses. We set the tax rate equal to 20 percent, a reasonable choice given that we abstract from other taxes such as interest income tax and capital gain tax for simplicity.

Table 1: Baseline Calibration

Description	Calibration
Preferences and production	
Time discounting factor	$\beta = 0.985$
Value added share of labor	$\alpha = 0.6$
Depreciation rate	$\delta = 0.025$
Financial Frictions	
Liquidation cost	$\eta = 0.05$
Corporate income tax	$\tau_c = 0.20$
Long run level of uncertainty	$\bar{\sigma} = 0.03$

We set the uncertainty regarding idiosyncratic returns to lending projects equal to 3 percent consistent with the standard deviation of return on assets across the top 100 commercial banks in U.S. since 1986. This level of volatility also has effects on leverage – at near zero idiosyncratic risk, leverage would approach 100 percent (as there is no risk that outside equity will be required) and leverage decreases, for a time, as uncertainty increases; however, at some point, leverage would rise again with further increases in uncertainty, as the value of the default option rises more rapidly than the risk of needing to raise outside equity. Finally, the bankruptcy cost reduces the advantage of debt financing as a funding source because the cost is a welfare loss mutually detrimental to both sides of the contract. We choose a modest bankruptcy cost – 5 percent of project value – reflecting the fact that we are modeling large intermediaries which, in the “real world”, fund diversified projects.

2.3.2 Estimation

We estimate the model to recover plausible parameterizations for the degree of financial frictions, the importance of different disturbances such as the shocks to the New-Keynesian natural rate of interest and to the volatility of intermediary (idiosyncratic) returns, and for the parameters governing monetary policy. All of these parameters will be important when gauging the role for interactions between monetary and counter-cyclical macroprudential

policy.

Our estimation is informed by eight macroeconomic time series. The first six are among those in [Smets and Wouters \(2007\)](#), given below.

$$\text{Change in output per capita} = \Delta \hat{y}_t$$

$$\text{Change in consumption per capita} = \Delta \hat{c}_t$$

$$\text{Change in investment per capita} = \Delta \hat{i}_t$$

$$\text{Change in hours worked per capita} = \Delta \hat{l}_t$$

$$\text{GDP price inflation} = \hat{\Pi}_t$$

$$\text{Nominal federal funds rate} = \hat{r}_t$$

In each case, lower-case letters refer to the natural logarithm of a variable, and we remove the mean from the series prior to estimation.¹¹

The last two time series used in estimation are data on long-run expected inflation from the Survey of Professional Forecasters and the excess bond premium from [Gilchrist and Zakrajsek \(2012\)](#), which we link to the model by:

$$\text{Expected inflation } E_t \Pi_t^{40} = \frac{1}{40} \sum_{j=1}^{40} E_t [\hat{\Pi}_{t+j}].$$

$$\text{Excess bond premium (EBP)} = \frac{1}{20} \sum_{j=1}^{40} E_t [\hat{R}_{t+j}^L - \hat{R}_{t+j}].$$

Our estimation sample spans the periods from 1965 to 2008. We do not include the zero-lower bound period to avoid dealing with this non-linearity during estimation.

We employ likelihood-based methods to estimate the model. First, we solve the model for a (locally) unique rational expectations equilibrium, and derive the state-space representation of the system and resulting likelihood function of the data. The objective is to estimate the

¹¹The latter point implies that we do not impose the balanced growth restrictions across consumption, investment, and output.

parameter vector θ . Under the Bayesian approach, a prior distribution, represented by the density $p(\theta|\mathcal{M})$ is combined with the likelihood function $p(\mathcal{Y}^o|\theta, \mathcal{M})$ for the observed data $\mathcal{Y}^o(= \{y_t\}_{t=1}^T)$, to obtain, via Bayes rule, the posterior:

$$p(\theta|\mathcal{Y}^o, \mathcal{M}) \propto p(\mathcal{Y}^o|\theta, \mathcal{M})p(\theta|\mathcal{M}).$$

The assumed priors for parameters and estimation results are presented in the appendix and the estimation code is available on request.

To facilitate estimation, we must access the posterior $p(\theta|\mathcal{Y}^o, \mathcal{M})$. Unfortunately, the posteriors are analytically intractable, owing to the complex ways θ enters the likelihood function. To produce draws from the posteriors, we resort to Markov-Chain Monte Carlo (MCMC) methods for the expanded suite of models in the robustness section. Detailed information on MCMC for DSGE models can be found in [Herbst and Schorfheide \(2013\)](#) and [An and Schorfheide \(2007\)](#). All our estimation procedures use Dynare ([Adjemian, Bastani, Juillard, Mihoubi, Perendia, Ratto, and Villemot \(2011\)](#)).

2.3.3 Results

Parameter Estimates. Table 2 presents posterior moments of key parameters that govern equilibrium responses to shocks and the accompanying effects on economic welfare. As is typical of DSGE models, preferences over consumption exhibit a moderate intertemporal elasticity of substitution (e.g., γ is somewhat larger than one) and habit persistence, both of which provide for substantial consumption-smoothing motives.

Our estimates suggest an important degree of financial friction, in that the mean dilution cost associated with outside equity is about 24 percent (0.24) – in the middle of the range spanned by [Gomes \(2001\)](#) and [Cooley and Quadrini \(2001\)](#). In our case, this parameter largely governs the degree to which fluctuations in the the excess bond premium responds to different shocks.

The estimates of nominal price rigidities suggest important price stickiness: This result, typical of DSGE models, will contribute to the findings on good policy design, as these frictions will contribute to the central role of price stability in our welfare analysis. As is typical in large DSGE model, the degree of inertia in prices, as gauged by the role of indexation, is minor.

Finally, monetary policy shows substantial inertia, a sizable response to inflation, and a large response to output growth (as in [Smets and Wouters \(2007\)](#)). Each of these features is crucial to good monetary policy design in New-Keynesian models, as recently emphasized in [Chung, Herbst, and Kiley \(2014\)](#).

Table 2: Posterior Moments of Key Parameters

Parameter	Mean	[0.05, 0.95]
Preferences		
γ	1.57	[1.41 1.72]
h	0.37	[0.30 0.44]
ν	0.95	[0.63 1.27]
Financial frictions		
$\bar{\varphi}$	0.24	[0.20 0.28]
χ	4.44	[3.76 5.13]
Nominal rigidities		
ε	51.69	[41.14 59.06]
κ	0.07	[0.01 0.12]
Monetary policy		
ρ_R	0.72	[0.68 0.75]
r_{y^*}	0.02	[-0.01 0.06]
$r_{\Delta y}$	0.53	[0.41 0.64]
r_{Π}	0.72	[0.59 0.84]

To gauge the relative importance of the structural disturbances to productivity, investment adjustment costs, the natural rate of interest, the volatility of intermediary (idiosyncratic) risk, price markups, and monetary policy (including the time-varying inflation target and transitory shifts affecting the interest rate rule), [table 3](#) presents the contributions of these shocks to the the variances of the variables we use in estimation.

Turning first to the effects of financial shocks, the combination of the financial risk shock and the shock to the natural rate of interest explain all of the variation in the excess bond premium. This is as expected— these shocks drive a wedge between the risk-free interest rate (set by the monetary authority) and the interest rate paid by the private sector, and the excess bond premium is a measure of this spread. However, the financial risk shock accounts for less than 10 percent of the variance of activity measures. In part this is because such shocks lead to opposite-signed responses of consumption and investment (as will be apparent in impulse responses presented below), but this lack of co-movement is only a partial explanation, as the investment-adjustment cost shock, which also leads to opposite-sign responses for consumption and investment, accounts for more of economic fluctuations. (The investment adjustment cost shocks is a shock to the investment first-order condition, which can be viewed as a Tobin’s Q shock.)

It is instructive to think about the mechanisms that lead the financial risk shock to play a relatively small role in our model relative to the financial shock in [Jermann and Quadrini \(2012\)](#), which drives a significant share of output fluctuations in the analysis of those authors. There are two key differences between our financial risk shock and their financial shock. First, our financial risk shock governs the risk facing financial intermediaries in our model, whereas the financial shock in [Jermann and Quadrini \(2012\)](#) is a disturbance affecting the financial frictions facing non-financial firms. This distinction is important, as our model include a natural rate of interest shock that, in combination with the financial risk shock, affects the financial frictions facing non-financial firms; in this respect, we follow the [Smets and Wouters \(2007\)](#) model closely.¹² Note that the combination of the financial risk shock and the natural rate of interest shock explain substantially more of output fluctuations than the financial risk shock alone. Second, [Jermann and Quadrini \(2012\)](#) assume that the

¹²In contrast, [Jermann and Quadrini \(2012\)](#) include a discount factor shock rather than a natural rate of interest shock; such a shock was present in early working paper versions of [Smets and Wouters \(2007\)](#), but was later replaced by the natural rate of interest shock. This distinction is important, as the natural rate of interest shock affects the spread between the borrowing rate facing non-financial firms and the (risk-free) monetary-policy interest rate, whereas the discount factor shock does not affect this spread.

Table 3: Variance Decomposition for Observable Variables

	Financial volatility	Nat Rate of Int.	Tobin's. Q	Techn- ology	Markup	Nominal Int. Rate	Infl. Target	Auto. demand
Δy	2.2	15.5	17.2	3.3	27.0	7.5	0.4	27.0
Δc	10.6	38.0	5.3	5.8	13.3	18.3	0.6	8.0
Δi	11.5	4.0	50.6	1.6	29.1	1.9	1.3	0.1
Δh	1.2	11.8	13.3	27.7	20.2	5.7	0.2	20.0
EBP	41.0	51.7	0.0	0.1	2.2	4.3	0.6	0.0
R	0.1	0.1	0.1	0.0	0.0	0.0	99.7	0.0
Π	0.0	0.0	0.0	0.0	0.1	0.0	99.9	0.0
$E\Pi^{40}$	0	0	0	0	0	0	100	0

financial frictions facing non-financial firms directly affect their choice of labor input because labor input is financed with working capital and working capital is subject to the financial friction. (Jermann and Quadrini (2012) emphasize the importance of this role several times in their analysis, including in the discussion of their equation (4).) We do not include a working capital channel, which lowers the role of financial frictions. Overall, future analyses combining frictions facing financial firms (which we consider) and those facing non-financial firms (which Jermann and Quadrini (2012) consider) is an important topic.

Turning to the other important shocks, changes in the inflation target account for all of the (long-run) variation in nominal variables. This is because these shocks are extremely persistent – at short horizons, other shocks are important for nominal fluctuations as well. For changes in output, the key drivers are the natural rate of interest, investment adjustment costs, technology, and autonomous demand – a mix that is familiar in estimated models of this type.

2.4 Model Dynamics

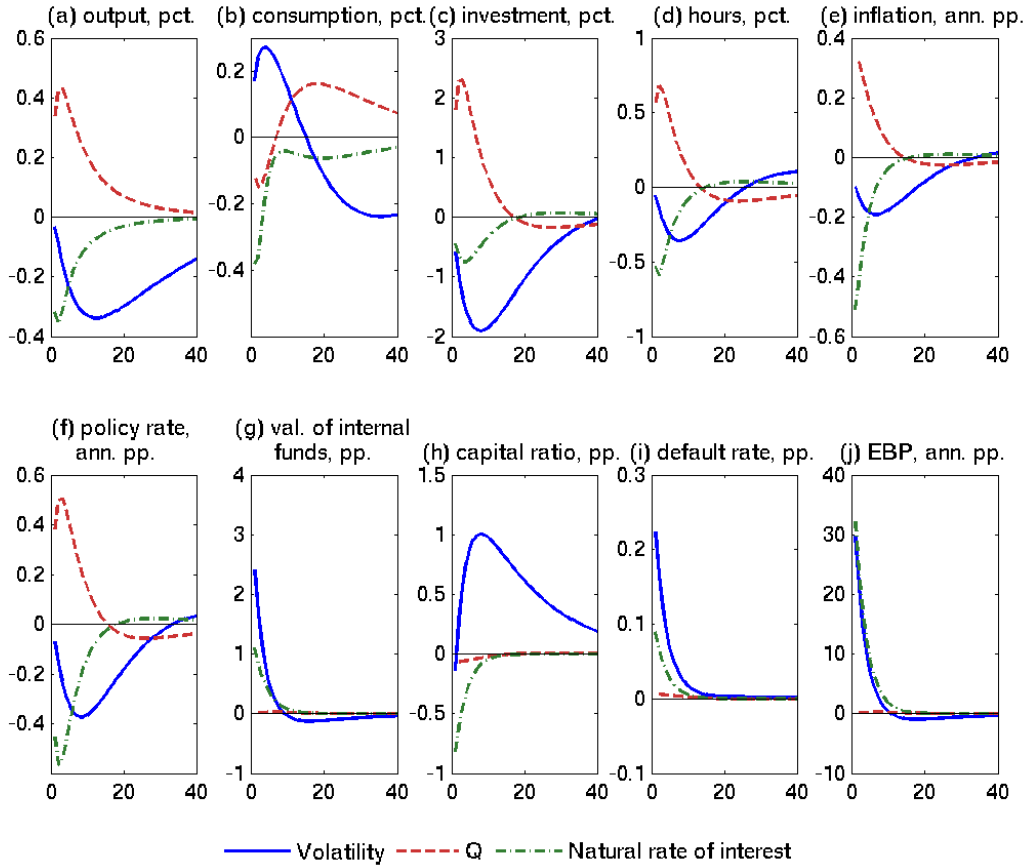
To see the role of “financial” shocks more clearly, we present impulse responses to the volatility shock, the natural rate of interest (risk premium) shock, and the shock to Tobin’s Q for a set of key variables in figure 2. These responses will also illuminate some of the properties of the model important for policy design. (The response of key variables to the

other shocks in the model are reported in an appendix).

The dashed-dotted (green) line presents the response following an increase in the risk premium (which depresses the nominal natural rate of interest). This shock raises financing costs economy-wide, boosting the excess bond premium by about 30 basis points (as shown in the last column of the bottom row), leading intermediaries to reduce their equity capital while at the same time cutting lending so as to reduce the size of their balance sheet during the period of high external financing costs. Importantly, the aggregate risk premium also affects the intertemporal substitution of consumption directly, and hence consumption falls with investment. This co-movement between consumption and investment, combined with the sizable effect on spreads of borrowing over the risk-free interest rate, differentiate the aggregate risk premium shock from the volatility or Tobin’s Q shock.

These differences are apparent when looking at the responses following the volatility shock (the blue solid lines). As in the case of the risk premium shock, financing costs rise, boosting the excess bond premium by a bit more than 30 basis points. Intermediaries deleverage, as shown by the rise in the capital ratio reported in the middle panel of the bottom row, because higher volatility implies a higher risk of shortfalls in internal funds. This boosts the value of internal funds (the second panel in the bottom row), leading to the precautionary motives to cut lending and hence falling investment, as shown in the middle panel of the top row. However, the volatility shock primarily depresses investment in the short run, and consumption rises (partially reflecting the decline in nominal (and real) interest rates (which is illustrated by the combination of the first panel in the bottom row and the last panel in the top row)). This lack of co-movement between consumption and investment is a common feature of “investment-specific” shocks. Moreover, the deleveraging dynamics associated with intermediaries’ high valuation of internal funds leads to a very protracted decline in investment and output—much more protracted than for the other shocks; this result is interesting in light of the literature emphasizing how recoveries in output following “credit crunches” have typically been slow (e.g., [Reinhart and Rogoff \(2014\)](#)).

Figure 2: The Effects of Shocks to Financial Variables: One S.D. Shocks



Note: Responses to shocks as indicated in legend at posterior mean of estimated parameters.

The final (red dashed) set of impulse responses shown in figure 2 present outcomes following a shock to Tobin's Q or the "investment adjustment cost" shock (e.g., [Smets and Wouters \(2007\)](#)). The shock lowers the price of installed capital relative to investment (Tobin's Q), creating an expected capital gain from holding physical capital. Such a shock drives a wedge between investment and consumption. As a result, investment rises but consumption falls on impact. These spending responses are similar (albeit opposite-signed) to those following the volatility shock. However, the shock to Tobin's Q has little effect on financial intermediaries and hence does not affect the excess bond spread; in our estimation approach, these differences contribute to how the model assesses the relative importance of different shocks for economic fluctuations – that is, shocks to Tobin's Q are associated with movements in

investment that are independent of credit spreads.

Overall, the information presented by the variance decompositions and impulse responses present a clear summary of how the model assigns relative importance to different financial shocks. In particular, the natural rate of interest shock is associated with rising lending spreads and declines in consumption and investment; shocks to intermediation, as embodied in the volatility shock, boost lending spreads, depress lending and investment, and only depress consumption with a lag; and (contractionary) shocks to Tobin's Q depress investment, boost consumption, and have little effect on lending spreads. Because our estimation strategy includes both the traditional data on macroeconomic variables and the excess bond premium from [Gilchrist and Zakrajsek \(2012\)](#), the model can assess the relative importance of the various disturbances, which has important implications for counter-cyclical macroprudential policy design.

3 Optimal Policy

We consider two approaches to optimal policy. The first is the Ramsey approach. The Ramsey planner maximizes the welfare of the representative household given by equation 11 above, subject to the equilibrium conditions of the private sector. In the second approach, we assume that the policymaker chooses a simple rule for its policy instruments to maximize household welfare.

3.1 A Macroprudential Policy Framework

In order to judge the role for macroprudential policy to assist monetary policy in improving economic welfare or stabilizing inflation and hours worked, we need to augment our model with a macroprudential instrument. The related literature has considered several possible instruments, including instruments that have some historical precedent or are important within the modeling framework adopted: For example, the use of loan-to-value (LTV) re-

quirements is common in work emphasizing frictions related to housing’s role as collateral (e.g., [Kannan, Rabanal, and Scott \(2012\)](#) and [Lambertini, Mendicino, and Punzi \(2013\)](#)). This approach might suggest, in our framework emphasizing balance-sheet risk associated with leverage and maturity transformation within the intermediary sector, a focus on capital or reserve requirements. However, such an approach would necessarily involve introducing an occasionally binding constraint, with associated computational challenges; indeed, such challenges should, in principle, be relevant in other related studies, including those involving LTV constraints just mentioned, but the literature has typically ignored this challenge and assumed such constraints always bind.¹³

Rather than follow such an approach, we choose a policy instrument that affects decisions at the margin. Specifically, we assume policymakers can adjust a proportional tax on intermediary leverage, denoted by τ_t^m . While such a tax is not a standard element of policymakers’ toolkit, it can be implemented via time-varying reserve requirements as shown by [Kashyap and Stein \(2012\)](#). Moreover, the approach is common in the literature (e.g., [Jeanne and Korinek \(2013\)](#) and [Farhi and Werning \(2016\)](#)) and some countries employ taxes on intermediaries balance sheets ([Cerutti, Claessens, and Laeven \(2015\)](#)). We assume that the tax proceeds are transferred to the intermediaries in a lump-sum fashion. Finally, the analysis of optimal policy focuses on the optimum given this policy instrument, and does not examine the type of policy instrument that may be optimal.

With the introduction of the leverage tax, the flow of funds constraint of the intermediaries is modified into

$$0 = [m_t + \tau_t^m(1 - m_t)]Q_t S_t + N_t - D_t + \varphi \min\{0, D_t\}. \quad (15)$$

When an intermediary invests in the risky asset, the accounting marginal cost of investment

¹³Because private contracts between intermediaries and their debt holders endogenously lead to a time-varying constraint on leverage in our framework (where the time-variation owes to changing levels of risk and other factors), a regulatory constraint may be less binding than the privately-optimal constraint during some periods, implying an occasionally-binding constraint. Such constraints impose computational challenges (e.g., the discussion in [Jermann and Quadrini \(2012\)](#)).

is given by its capital ratio m_t because the intermediary's balance sheet is levered. However, the economic marginal cost of such investment is $\mathbb{E}_t^\epsilon[\lambda_t]m_t$, which can deviate from the accounting cost m_t because the expected shadow value of one dollar is not always equal to one dollar, particularly when a financial intermediary faces a difficulty in raising external funds. $\mathbb{E}_t^\epsilon[\lambda_t]$ summarizes the liquidity condition of a given intermediary. Inefficient fluctuations in liquidity conditions can then distort the efficient balance of the marginal costs and benefits of investment projects. For instance, during good times, the shadow value of internal funds may be unusually low, prompting over-investment, which then lead to a further improvement in the liquidity condition due to rising asset prices. During bad times, the same mechanism applies, but in the opposite direction.

The idea of the macroprudential leverage tax is to offset the distortions from such fluctuations in liquidity conditions, thereby breaking the link between the liquidity and investment. With the leverage tax (and subsidy, when negative), the economic cost is modified to

$$\mathbb{E}_t^\epsilon[\lambda_t][m_t + \tau_t^m(1 - m_t)] \begin{cases} \geq \\ \leq \end{cases} \mathbb{E}_t^\epsilon[\lambda_t]m_t \quad \text{if } \tau_t^m \begin{cases} \geq \\ \leq \end{cases} 0.$$

The economic cost of investment increases when the tax rate is positive, and decreases when negative. Under this policy, the intermediary's asset pricing equation is modified to

$$1 = \mathbb{E}_t \left[M_{t,t+1} \frac{\mathbb{E}_{t+1}^\epsilon[\lambda_{t+1}]}{\mathbb{E}_t^\epsilon[\lambda_t]} \cdot \left(\frac{1 + \tilde{r}_{t+1}^A - (1 - m_t)[1 + (1 - \tau_c)r_{t+1}^B]}{m_t + \tau_t^m(1 - m_t)} \right) \right] \quad (16)$$

One can see easily that the leverage tax policy reduces (increases) the leverage effect on the return on equity from $1/m_t$ to $1/[m_t + \tau_t^m(1 - m_t)]$ when the tax rate is positive (negative). (A very similar equation arises when the macroprudential instrument is a reserve requirement.)

Given the macroprudential instrument, we consider two possible approaches to adjusting the policy instrument: A Ramsey social planner following the optimal rule, which responds to all state variables in the model, and an optimal simple rule, in which a policy instrument responds to a small number of endogenous variables. In each case, the optimal rule is the

rule that maximizes household welfare. Note that, in each case, we do not consider the optimal level of the leverage tax; instead, we assume a steady-state level of zero for the tax, and examine how adjustments in the instrument contribute to stabilization objectives. Consideration of the optimal level of the leverage tax would involve assessing the role of frictions (e.g., the tax advantage of debt) and services (e.g., the liquidity services associated with deposits) that attend intermediary leverage (as in, for example, [Begenau \(2015\)](#)). As stabilization properties are of independent interest, we leave examination of the optimal level of a macroprudential instrument to other research, although we are cognizant of the possibility that incorporation of additional features relevant in a study of the optimal level of a macroprudential instrument may also affect the desirability of alternative stabilization approaches.

We consider welfare under a variety of combinations of Ramsey and simple rules, including

- The baseline estimated model (e.g., estimated monetary policy rule and no leverage tax).
- The optimal simple monetary policy rule (and no leverage tax)
- The optimal simple monetary and leverage tax rule.
- The Ramsey monetary rule (and no leverage tax).
- The Ramsey leverage tax rule (and estimated monetary policy rule).
- The Ramsey monetary and leverage tax rules.

Table 4 reports the results for welfare under alternative instruments under this approach. In order to aid intuition, the welfare comparison reports the loss in welfare relative to the Ramsey policy with both optimal monetary and macroprudential policies in consumption units – that is, the per-period percent loss in consumption that would result in the same welfare level.

Table 4: Welfare Under Alternative Policy Settings

	Loss (%)
Baseline (no macroprudential policy)	-0.40
Optimized simple rules	
Instrument: r_t and τ_t^m	-0.19
Instrument: r_t	-0.28
Ramsey policy with	
Instrument: r_t and τ_t^m	0
Instrument: r_t	-0.22
Instrument: τ_t^m	-0.04

Note: Welfare under Ramsey policies were computed with the planner Lagrange multipliers set equal to their steady state values. Losses are measured in consumption equivalent units as a percent of steady-state consumption relative to the welfare level under joint Ramsey monetary and macroprudential policies.

Table 4 illustrates several results. As in the New-Keynesian literature, there are important gains from a Ramsey monetary policy (on the order of 0.2 percent of consumption). A simple (optimized) rule can achieve an important fraction of the gains from optimal monetary policy. Optimal Ramsey macroprudential policy, via a leverage tax, can nearly achieve the welfare level of joint-Ramsey monetary and macroprudential policy *even if monetary policy is set via a simple rule*. The consumption loss from combining Ramsey macroprudential policy with simple monetary policy is only 0.04 percent of consumption. This result simply reinforces the notion that a simple approach to monetary policy is “nearly” optimal. A simple leverage tax rule has moderate benefits, on the order of 0.1 percent of consumption—but these benefits are only about 1/3 as large as those associated with a Ramsey approach to the leverage tax.

3.2 Gains from A Macroprudential Instrument Under Ramsey Policy

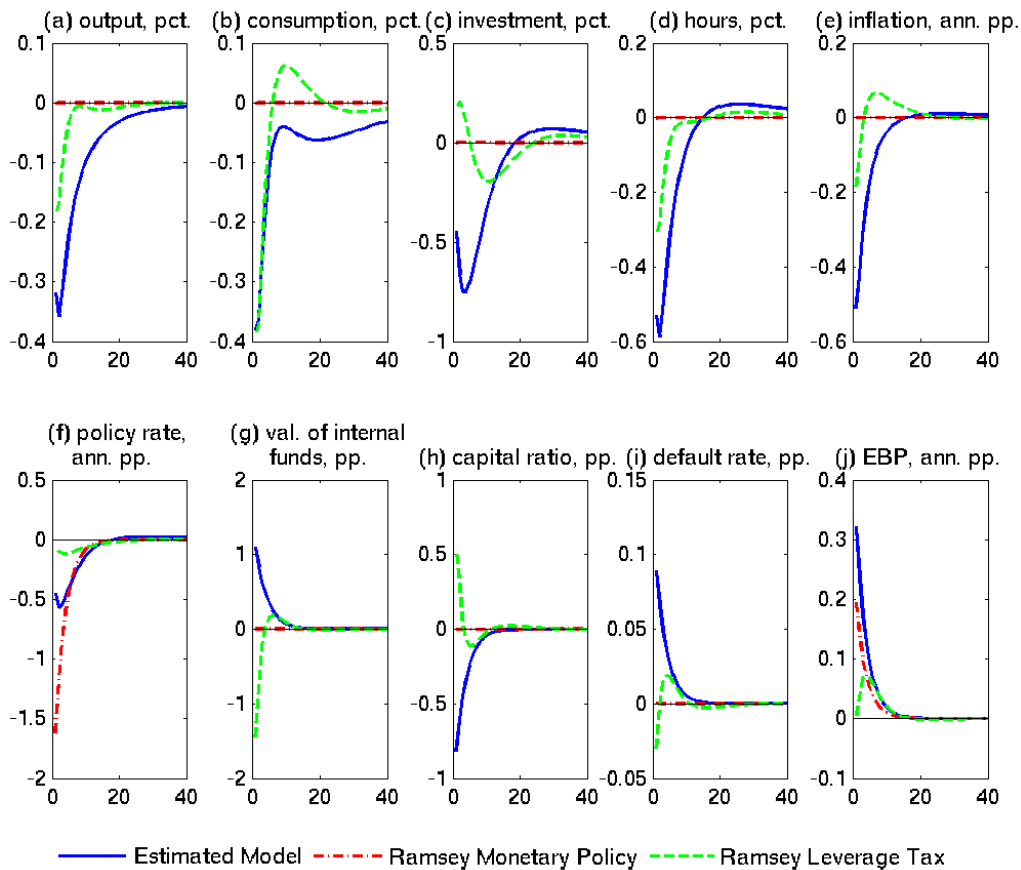
The Ramsey approach assumes that policymakers follow a complex rule, responding to all state variables in the model, to maximize household welfare. Further insight into the source of welfare gains can be gleaned by considering the response of the economy to key shocks

under both Ramsey approaches. Consider first the risk-premium or natural rate of interest shock: As emphasized by [Woodford \(2003\)](#), such a shock, reflecting shifts in the demand for nominal risk-free bonds and hence having no implications for real allocations in the absence of nominal rigidity, should be neutralized by the policymaker. As shown in [figure 3](#), complete neutralization can be accomplished via a Ramsey approach to monetary policy through adjustments in the nominal interest rate (the dashed-red line), a standard result (and hence the term “natural rate of interest shock”). Ramsey macroprudential policy is not effective following a natural rate of interest shock – there remain substantial fluctuations in output, consumption, hours, and inflation (the green-dashed line). Macroprudential policy affects the wedge between spending reliant on lending (i.e., investment) and consumption, and hence cannot perfectly offset a shock that does not drive a wedge between consumption and investment decisions.

The situation is quite different following a shock to volatility: In this case, the shock drives a wedge between spending reliant on lending and consumption, and hence stabilization is well suited to a macroprudential approach. As illustrated in [figure 4](#), a Ramsey macroprudential policy that reduces the leverage tax (i.e, subsidizes lending) following such a shock substantially mitigates the effect of the shock on output, consumption, hours, and inflation. In contrast, monetary policy cannot mitigate these affects nearly as well—as is apparent in the movements in consumption and investment and was emphasized in [Gilchrist and Leahy \(2002\)](#).

The welfare implications of Ramsey policies do not only reflect how such policies stabilize the effects of financial shocks – the influence of all shocks is important. For example, it is well-known that output and investment tend to expand too little following an improvement in technology in New-Keynesian models, as the fall in inflation following such shocks tends to increase real interest rates and attenuate incentives to invest during the period of high productivity. As shown in [figure 5](#), both Ramsey monetary and macroprudential approaches ameliorate the inefficiency associated with the estimated policy interest rate rule – with

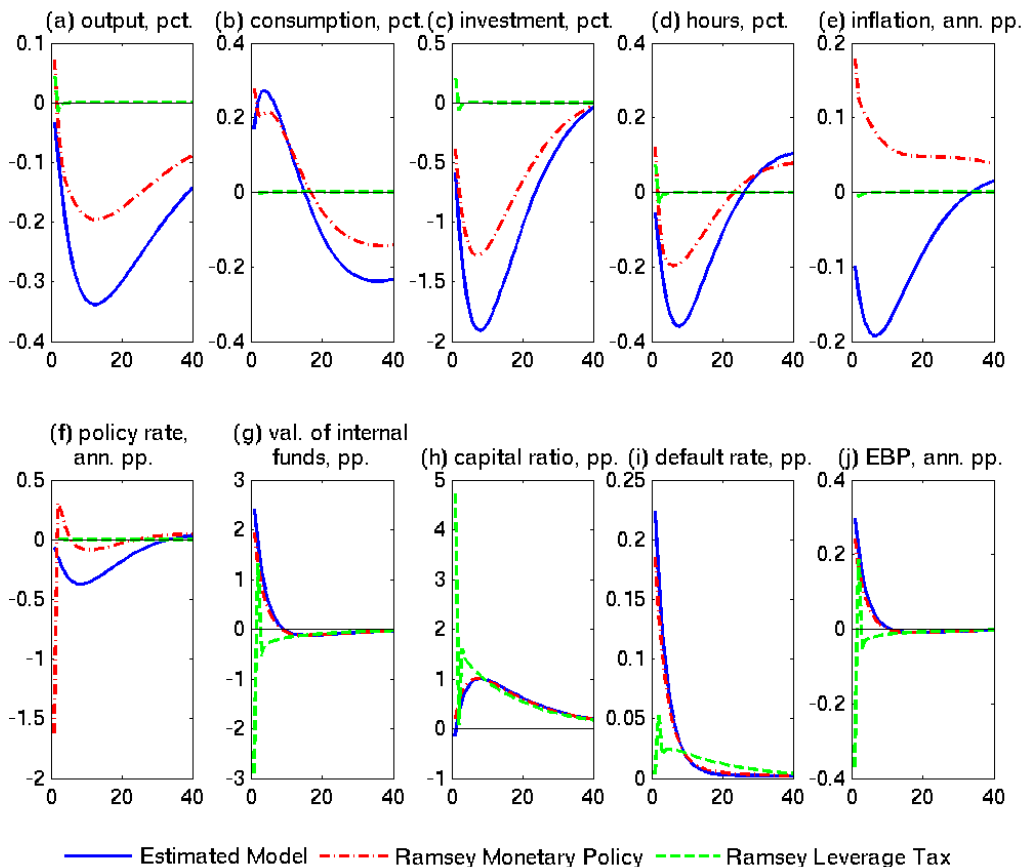
Figure 3: Impulse Response to Natural Rate of Interest Shock Under Ramsey Policies



Note: Responses under policies indicated in legend at posterior mean of estimated parameters. Ramsey monetary policy assumes no leverage tax, and Ramsey leverage tax assumes monetary policy follows estimated rule.

investment and output increasing more, and inflation somewhat higher over the balance of the response period following a productivity improvement than in the case under the estimated rule. That said, monetary policy is the more effective instrument of the two – because the inefficiency reflects nominal rigidities, adjustments in the nominal interest rate push the economy toward the efficient outcome through inflation stabilization. In contrast, the macroprudential policy is less effective in stabilizing inflation.

Figure 4: Impulse Response to Volatility Shock Under Ramsey Policies

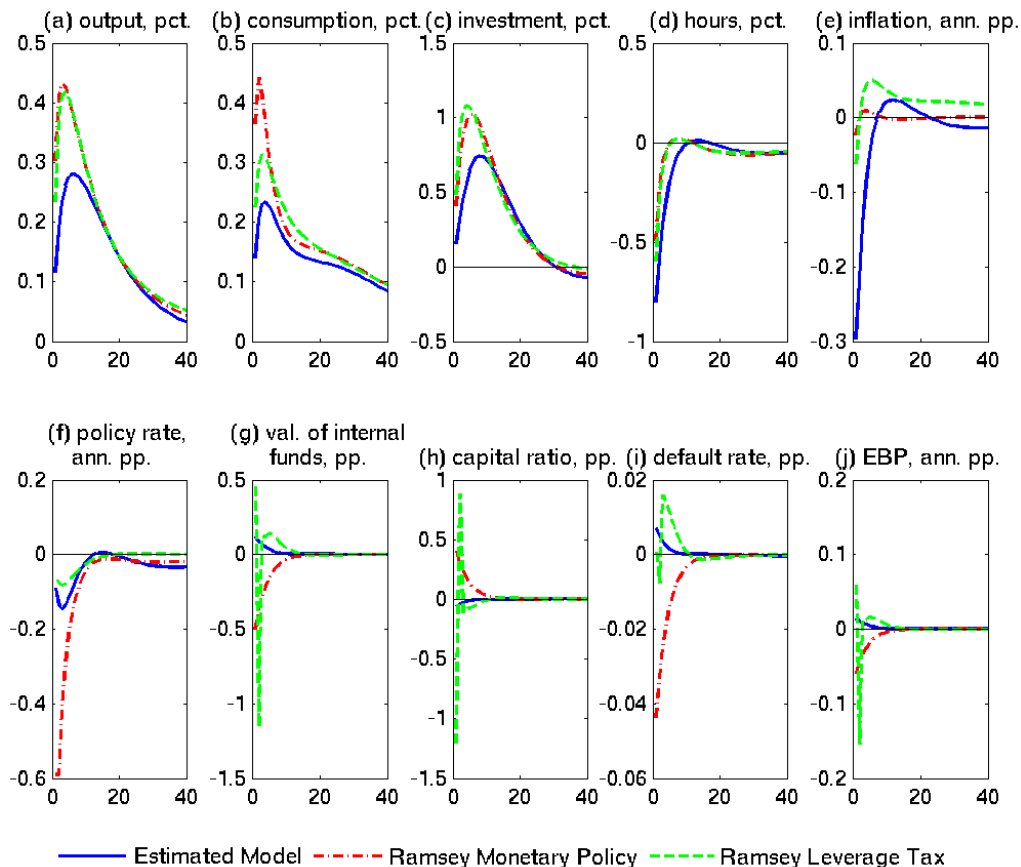


Note: Responses under policies indicated in legend at posterior mean of estimated parameters. Ramsey monetary policy assumes no leverage TWX, and Ramsey leverage tax assumes monetary policy follows estimated rule.

3.3 Gains from Macroprudential Policy Under Simple Rules

The performance of simple rules is even more dependent on the importance of different shocks to economic fluctuations. While a Ramsey approach can respond differently to movements in endogenous variables depending on the structural shock driving the movement, a simple rule (in our implementation) responds to the endogenous movement and does not differentiate movements by the source of shock. For example, a simple rule response to credit (on the part of either the monetary instrument or the leverage tax) cannot differentiate between an increase in credit driven by an improvement in productivity or an increase in credit driven by a decline in volatility—even though it would like to differentiate in this case, as a technology-

Figure 5: Impulse Response to Technology Shock Under Ramsey Policies

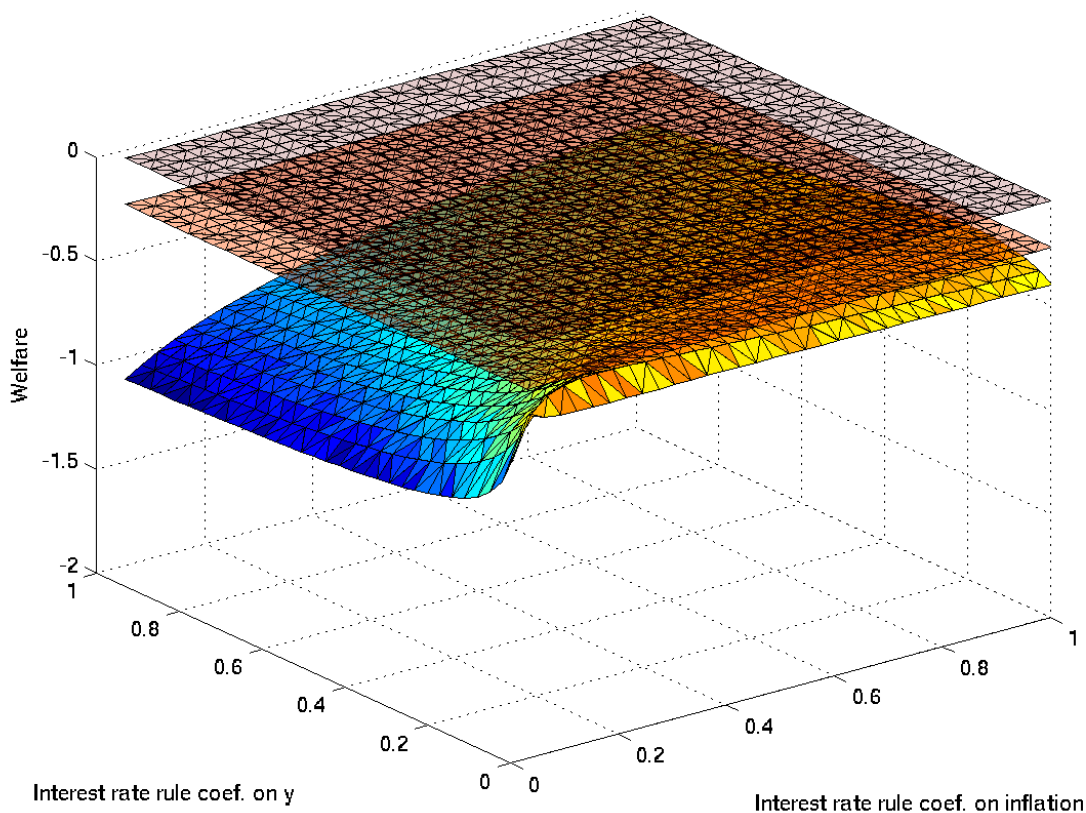


Note: Responses under policies indicated in legend at posterior mean of estimated parameters. Ramsey monetary policy assumes no leverage TWX, and Ramsey leverage tax assumes monetary policy follows estimated rule.

induced increase in credit is efficient whereas a volatility-induced increase in credit decreases welfare through excessive volatility.

Some intuition for the importance of this issue can be seen by examining the welfare surface for alternative coefficient combinations in simple rules. For example, figure 6 presents the welfare surface for the simple rule in which the change in the nominal interest rate depends on the deviation of inflation from its target and the production-function output gap. The rule is specified in change form as a coefficient of one on the lagged nominal interest rate is essentially the optimal simple rule in our model, as in much of the New-Keynesian literature (e.g. [Chung, Herbst, and Kiley \(2014\)](#); note that we abstract from the lower bound on nominal interest rates). The upper surface, at a value of zero, is the

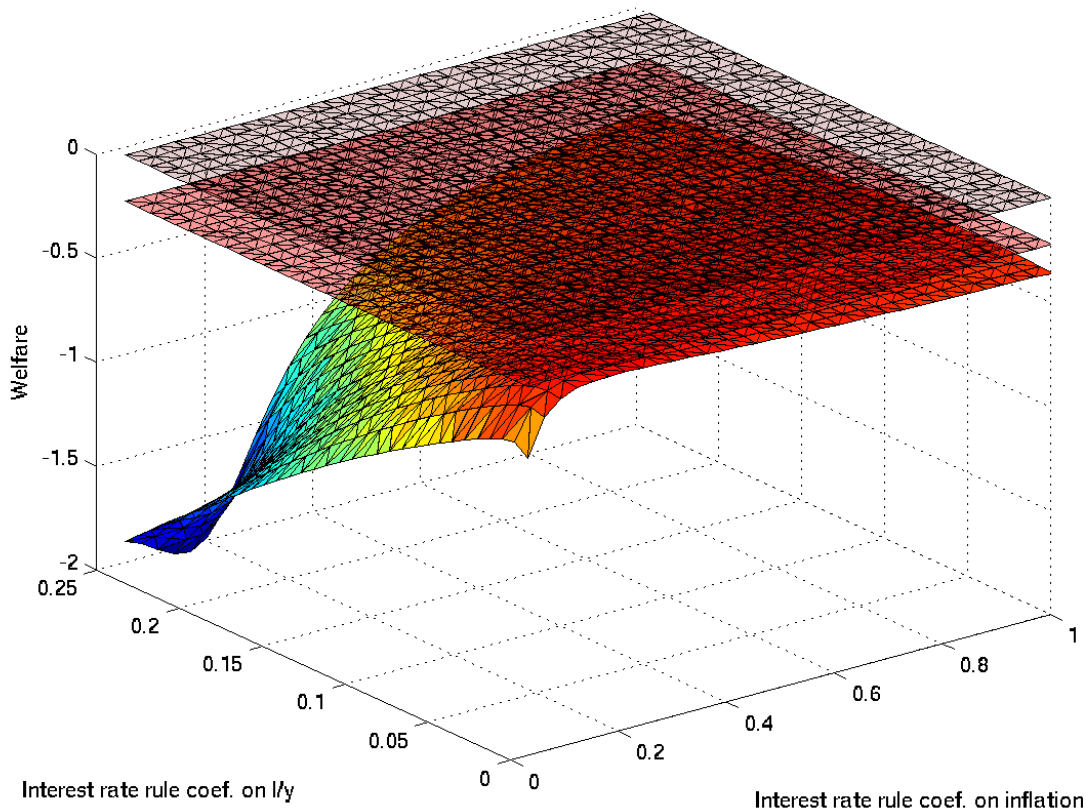
Figure 6: Welfare Under A Simple Monetary Policy Rule (Inflation and Output Gap Coefficients)



Note: Welfare surfaces under different approaches. The top surface (at zero) is the benchmark of welfare under Ramsey monetary policy and leverage tax settings. The middle surface (at -0.2) is the loss relative to the benchmark under Ramsey monetary policy (with no leverage tax). The bottom surface is welfare under a simple monetary policy rule as a function of the rule coefficients on the x-axis (inflation response) and the y-axis (output gap response). As in table 4, losses are in consumption equivalents as a percent of steady-state consumption.

comparison point (given by welfare under the Ramsey monetary and leverage tax rules, the same benchmark in table 4). The surface underneath this is the Ramsey monetary policy level of welfare, about 0.2 percent of consumption below the joint Ramsey welfare level. And the curved surface at the bottom is the level of welfare under alternative pairings of the coefficients on inflation and the output gap. As this surface makes clear, a focus on price stability—that is, a strong response to inflation and at most a moderate response to the output gap—approaches the Ramsey level of welfare for monetary policy. In contrast, a

Figure 7: Welfare Under A Simple Monetary Policy Rule (Inflation and Credit/Output Coefficients)

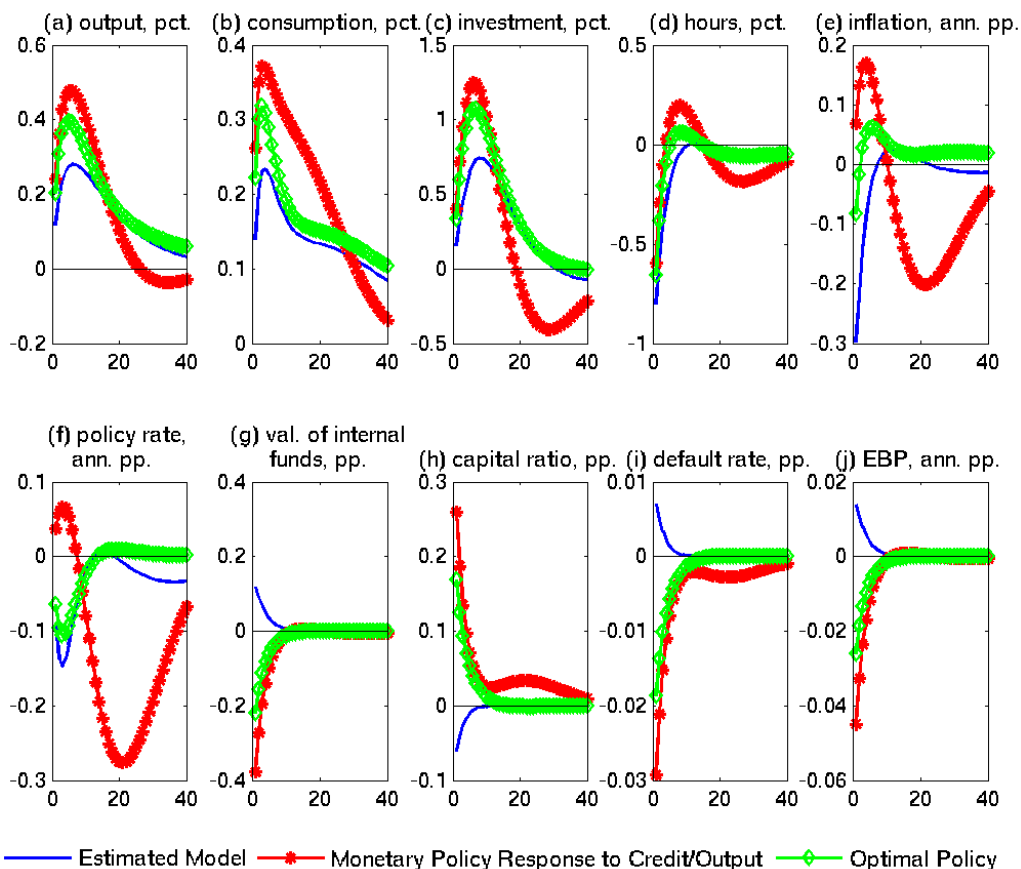


Note: Welfare surfaces under different approaches. The top surface (at zero) is the benchmark of welfare under Ramsey monetary policy and leverage tax settings. The middle surface (at -0.2) is the loss relative to the benchmark under Ramsey monetary policy (with no leverage tax). The bottom surface is welfare under a simple monetary policy rule as a function of the rule coefficients on the x-axis (inflation response) and the y-axis (credit/output response). As in table 4, losses are in consumption equivalents as a percent of steady-state consumption.

strong response to the output gap (as measured by the production function gap) tends to lower welfare.

Results are even more stark in the case in which the monetary instrument, the nominal interest rate, considers responding directly to the (natural logarithm of the) ratio of credit to output. Figure 7 presents the welfare surfaces in this case. The simple monetary rule includes responses to inflation and credit relative to output, with the coefficient on the output gap set to the value which maximizes welfare in figure 6 (i.e., essentially zero). As can be

Figure 8: Impulse Response to Technology Shock Under Alternative Simple Rules for Monetary Policy)

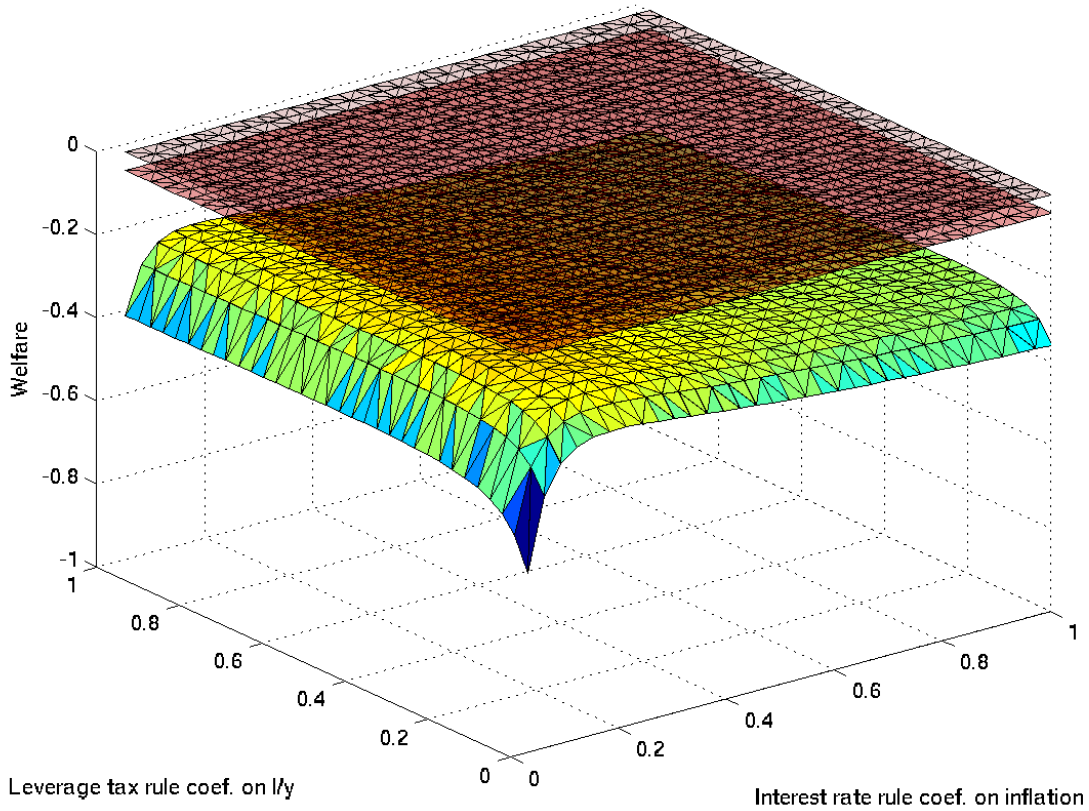


Note: Responses under policies indicated in legend at posterior mean of estimated parameters. Simple monetary policies assume no leverage TWX.

seen along the z-axis, a response of monetary policy to credit is very detrimental to welfare (despite the finding above that monetary policy, under the Ramsey approach, can stabilize credit, inflation, and output to some degree following shocks to volatility).

The detrimental effect associated with a response of monetary policy to credit arises for two reasons. First, an important fraction of credit movements reflect efficient investment opportunities associated with, for example, technology shocks. Leaning against such movements lowers welfare. In addition, credit moves out of phase with output, and a buildup in credit—associated with changes in technology or other factors—implies a high ratio of credit to output for years following the initial movement. As a result, a strong response to the

Figure 9: Welfare Under A Simple Monetary and Leverage-Tax Rule



Note: Welfare surfaces under different approaches. The top surface (at zero) is the benchmark of welfare under Ramsey monetary policy and leverage tax settings. The middle surface (at -0.2) is the loss relative to the benchmark under a Ramsey leverage tax (with a simple rule for monetary policy). The bottom surface is welfare under a simple leverage tax rule as a function of the rule coefficients on the x-axis (inflation response in monetary rule) and the y-axis (credit/output response). As in table 4, losses are in consumption equivalents as a percent of steady-state consumption.

ratio of credit to output induces undesirable cycles in inflation, output, and investment. This result is illustrated in figure 8, which shows the responses following a technology shock in the estimated model (the blue line), under the optimal simple monetary policy rule (the green, circles/line), and under a monetary policy with a strong response to credit (the red, stars/line). The deterioration in inflation performance is notable, and highlights why deviations from the pursuit of price stability in the setting of monetary policy may be welfare reducing.

The finding that a simple-rule approach to monetary policy is poorly suited to the pursuit

of macroprudential objectives suggests that a macroprudential instrument may be valuable. The Ramsey results strongly hint at this finding, and our consideration of a simple-rule approach suggests some promise to this approach. As shown in figure 9, a macroprudential instrument is valuable—welfare increases with a response of the leverage tax to the credit-to-output ratio. But these gains remain far below those associated with a Ramsey leverage tax (the surface above the simple rule surface) or a joint Ramsey monetary/leverage tax approach (the top surface). As with monetary policy, responding to the credit cycle in a manner that improves welfare requires an ability to distinguish “good” and “bad” credit, and simple rules responding to credit cannot make such distinctions.

4 Conclusion

We have investigated the gains from adopting optimal macroprudential regulation in a model with frictions associated with financial intermediation.

We have shown that an additional macroprudential instrument set optimally (in the sense of Ramsey) offers sizable gains in terms of welfare and stabilization of macroeconomic activity following shocks to intermediation. However, a simple rule for a leverage tax can deliver only a fraction of the gain associated with an optimal, Ramsey approach to the leverage tax.

The results partially reflect the empirical importance of shocks to intermediation identified via our estimation procedure. In particular, our analysis uses data on credit spreads and the standard macroeconomic variables used in empirical work following [Smets and Wouters \(2007\)](#) to identify financial shocks well-suited to monetary stabilization (risk-premium, or natural rate of interest shocks) and those more well-suited to a macroprudential approach (e.g., shocks to intermediation, as captured by volatility shocks in our model). While both types of shocks are important for credit-spread fluctuations, the shocks to intermediation play a secondary role in economic fluctuations, and hence the gains from a (simple) macroprudential rule are limited. If intermediation shocks were very important, leaning against

credit via a leverage tax would be very valuable.

Relative to previous work, our multiple-shock and Ramsey/simple-rule comparison illustrates the constraints that arise when using either macroprudential or monetary-policy adjustments to promote welfare – constraints that are not apparent in smaller, calibrated models that emphasize one (or few) shocks or the Ramsey approach.

This finding suggests avenues for further work. First, subsequent policy analysis using general equilibrium analyses needs to have firm empirical grounding to assess the quantitative importance of different factors. Calibrated work assuming a large role for factors amenable to macroprudential approaches, as in much of the literature, may be misleading. In addition, we focused on counter-cyclical policies around a stable steady state: While this approach is valuable and most-readily amenable to analysis using quantitative general equilibrium models, analysis of macroprudential policies may more fruitfully focus on how to present large adverse shocks or nonlinear dynamics that resemble crises and credit crunches, as suggested by [Blanchard \(2014\)](#).

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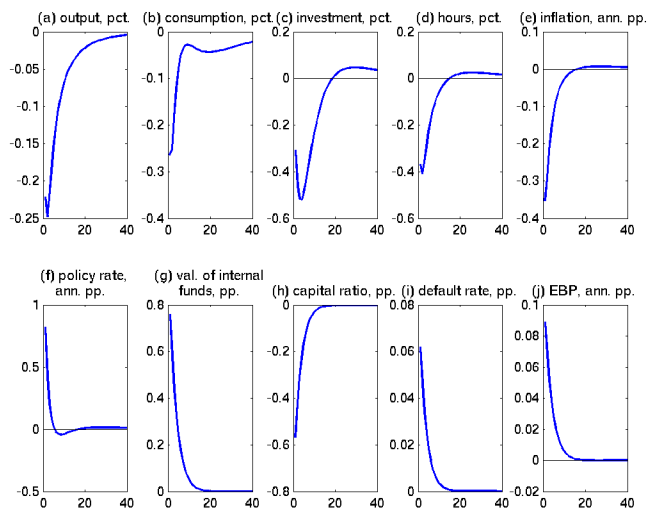
Appendices

A Prior and Posterior Distribution of Estimated Parameters

Table 5 summarizes the prior and posterior distributions of the estimated parameters, excluding those associated with the exogenous shock processes; table 6 summarizes the prior and posterior distributions of the estimated parameters associated with the exogenous shock processes.

B Impulse Response Functions of the Estimated Model

Figure 10: The Effects of One S.D. Shock to Monetary Policy



	Prior distribution	Prior mean	Prior s.d.	Posterior mean	Posterior s.d.	0.05 quantile	0.95 quantile
				Financial frictions and investment adj. costs			
$\bar{\varphi}$	Normal	0.300	0.0330	0.240	0.0254	0.1984	0.2825
χ	Normal	4.000	0.5000	4.442	0.4137	3.7554	5.1224
				Household preferences			
γ	Normal	3.000	0.2500	1.570	0.1079	1.4097	1.7188
h	Normal	0.750	0.1250	0.372	0.0416	0.3042	0.4405
ν	Normal	1.000	0.2500	0.950	0.1962	0.6332	1.2757
				Nominal rigidities and monetary policy			
ε	Normal	200.000	25.0000	51.687	6.5286	41.1368	59.0553
κ	Beta	0.500	0.2000	0.071	0.0387	0.0112	0.1249
ρ_R	Beta	0.750	0.1000	0.718	0.0202	0.6847	0.7510
r_{y^*}	Normal	0.000	0.1250	0.024	0.0192	-0.0074	0.0554
$r_{\Delta y}$	Normal	0.000	0.1250	0.531	0.0704	0.4116	0.6434
r_{Π}	Normal	0.500	0.1250	0.716	0.0782	0.5872	0.8432

Table 5: Results from Metropolis-Hastings (parameters excluding shock processes)

	Prior distribution	Prior mean	Prior s.d.	Posterior mean	Posterior s.d.	0.05 quantile	0.95 quantile
$\sigma_{in.fl.target}$							
σ_R	Inv. Gamma	0.100	2.0000	0.055	0.0042	0.0481	0.0618
ρ_ε	Inv. Gamma	0.100	2.0000	0.280	0.0181	0.2505	0.3091
σ_ε	Beta	0.500	0.1000	0.848	0.0213	0.8132	0.8826
	Inv. Gamma	0.100	2.0000	5.729	0.7997	4.3919	6.9235
				Technology, natural rate of interest, and autonomous demand			
ρ_a	Beta	0.500	0.1000	0.893	0.0216	0.8573	0.9282
σ_a	Inv. Gamma	0.100	2.0000	0.598	0.0331	0.5420	0.6504
ρ_Ξ	Beta	0.500	0.1000	0.719	0.0319	0.6668	0.7712
σ_Ξ	Inv. Gamma	0.100	2.0000	0.402	0.0541	0.3130	0.4875
ρ_g	Beta	0.500	0.1000	0.902	0.0212	0.8685	0.9370
σ_g	Inv. Gamma	0.100	2.0000	2.687	0.1459	2.4412	2.9165
				Financial frictions and investment adj. costs			
ρ_χ	Beta	0.500	0.1000	0.462	0.0624	0.3596	0.5653
σ_χ	Inv. Gamma	0.100	2.0000	5.605	0.7615	4.3341	6.8247
ρ_σ	Beta	0.500	0.1000	0.945	0.0074	0.9348	0.9529
σ_σ	Inv. Gamma	0.250	2.0000	23.392	2.4924	19.0819	27.5240

Table 6: Results from Metropolis-Hastings (autocorrelations and standard deviation of structural shocks)

Figure 11: The Effects of One S.D. Shock to Volatility

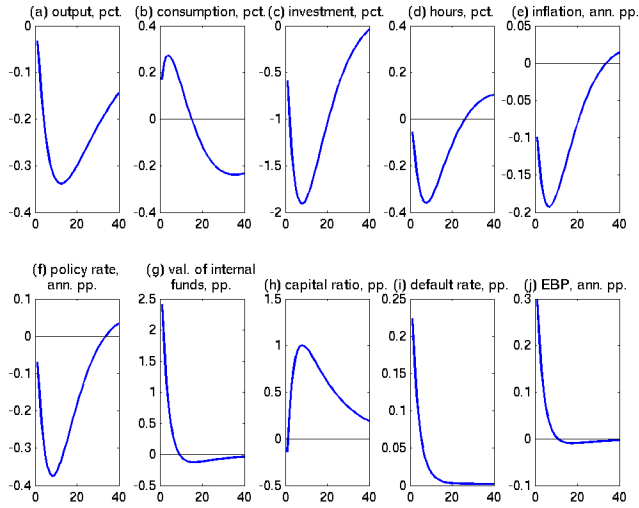


Figure 12: The Effects of One S.D. Shock to Technology

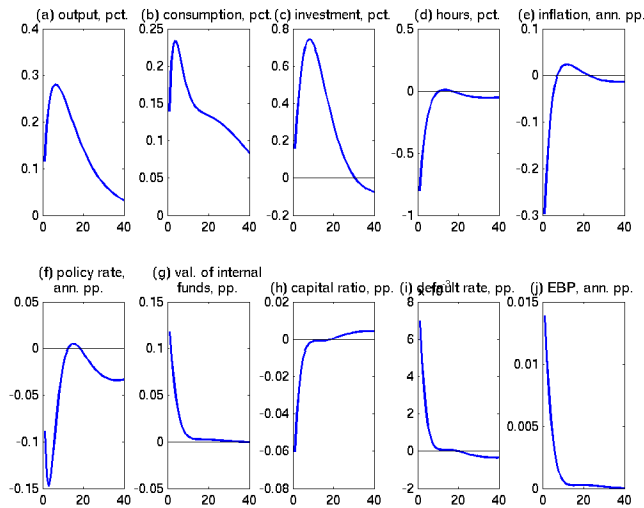


Figure 13: The Effects of One S.D. Shock to Price Markup

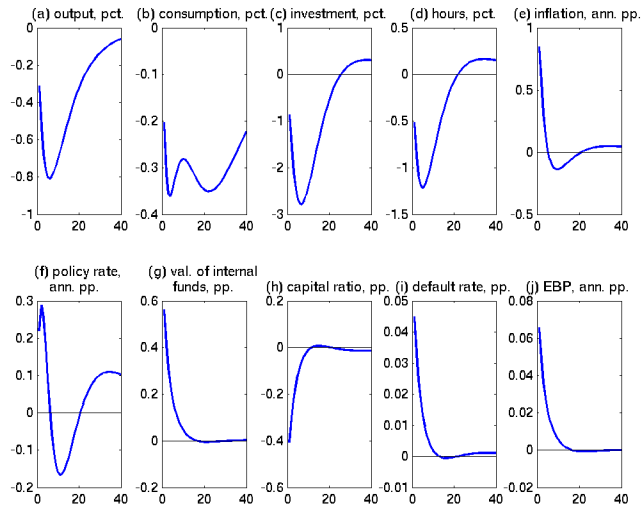


Figure 14: The Effects of One S.D. Shock to Autonomous Demand

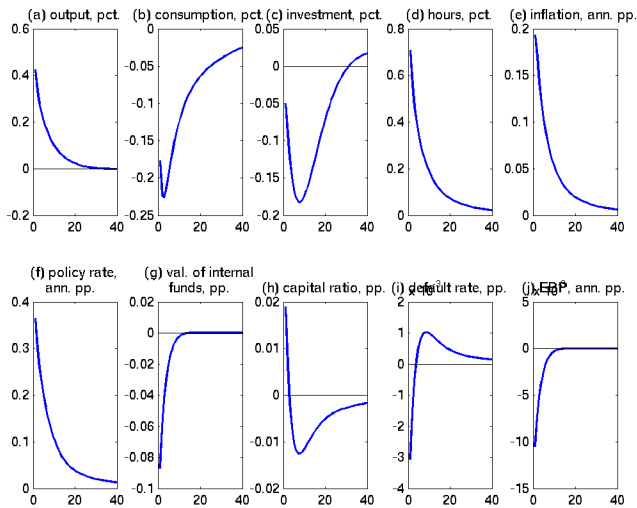


Figure 15: The Effects of One S.D. Shock to Risk Premium/Natural Rate of Interest

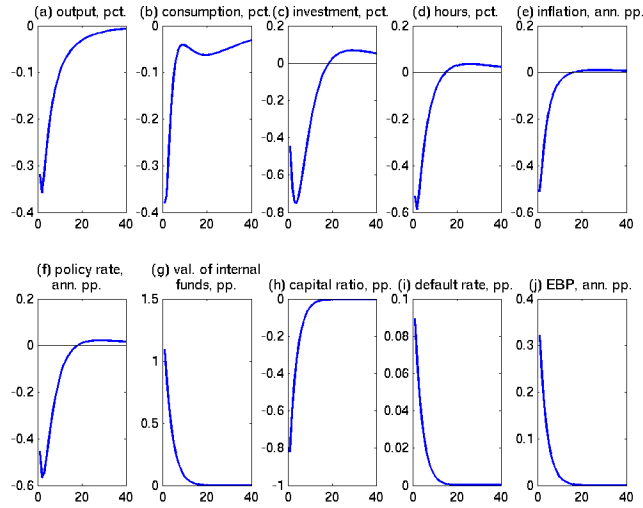


Figure 16: The Effects of One S.D. Shock to Tobin's Q

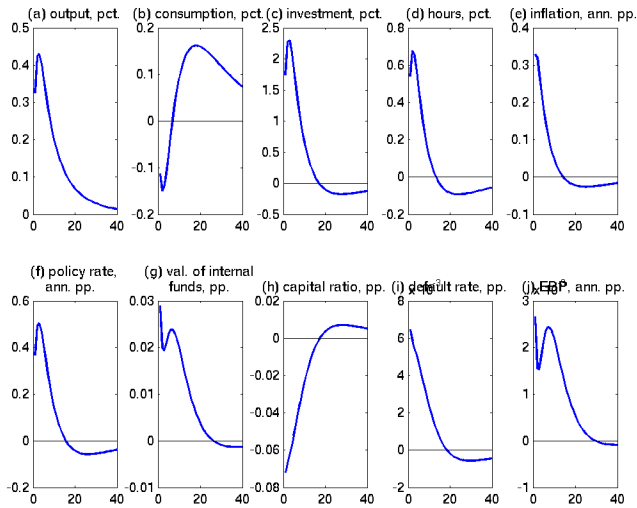
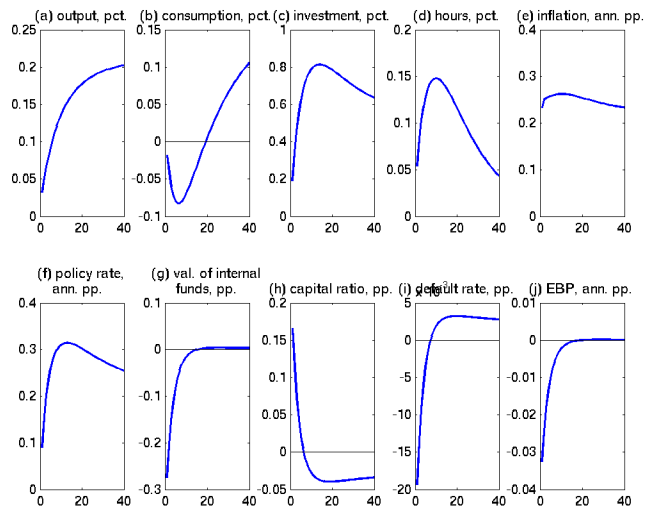


Figure 17: The Effects of One S.D. Shock to Inflation Target



C Intermediary Debt Contract

Without the Pigouvian tax, the flow of funds constraint for an intermediary is given by

$$Q_t S_t = (1 - m_t) Q_t S_t + N_t - D_t + \varphi \min\{0, D_t\}, \quad (\text{C.1})$$

where the net-worth of the intermediary is now defined as

$$N_t = \epsilon_t (1 + r_t^A) Q_{t-1} S_{t-1} - [1 + (1 - \tau_c) r_t^B] (1 - m_{t-1}) Q_{t-1} S_{t-1}. \quad (\text{C.2})$$

Using the limited liability condition, one can write the net-worth as

$$N_t = \max\{0, \epsilon_t (1 + r_t^A) Q_{t-1} S_{t-1} - [1 + (1 - \tau_c) r_t^B] (1 - m_{t-1}) Q_{t-1} S_{t-1}\}. \quad (\text{C.3})$$

A default is assumed to occur when the value of net-worth falls below zero. This means that a default occurs when

$$\epsilon_{t+1} \leq \epsilon_{t+1}^D \equiv (1 - m_t) \left[\frac{1 + (1 - \tau_c) r_{t+1}^B}{1 + r_{t+1}^A} \right] \quad (\text{C.4})$$

Using the definition of the modified default threshold, the expression for the net-worth can be simplified into

$$\begin{aligned} N_t &= \max\{0, \epsilon_t (1 + r_t^A) - \epsilon_t^D (1 + r_t^A)\} Q_{t-1} S_{t-1} \\ &= \max\{0, \epsilon_t - \epsilon_t^D\} (1 + r_t^A) Q_{t-1} S_{t-1} \\ &= [\max\{\epsilon_t, \epsilon_t^D\} - \epsilon_t^D] (1 + r_t^A) Q_{t-1} S_{t-1}, \end{aligned}$$

which is the same as the one for the case without the reserve requirement policy.

The intermediary debt pricing equation is then modified into

$$1 - m_t = \mathbb{E}_t \left\{ M_{t,t+1} \left[\int_{\epsilon_{t+1}^D}^{\infty} (1 - m_t) \frac{1 + r_{t+1}^B}{1 + \pi_{t+1}} dF_{t+1} + (1 - \eta) \int_0^{\epsilon_{t+1}^D} \frac{\epsilon_{t+1} (1 + r_{t+1}^A)}{1 + \pi_{t+1}} dF_{t+1} \right] \right\} \quad (\text{C.5})$$

Solving (C.4) for r_{t+1}^B yields $r_{t+1}^B = (1 - \tau_c)^{-1} [\epsilon_{t+1}^D (1 + r_{t+1}^A) / (1 - m_t) - 1]$. Finally, substituting the expression for r_{t+1}^B in (2) yields

$$\begin{aligned} 0 &= \mathbb{E}_t \left\{ M_{t,t+1} \left[\int_0^{\epsilon_{t+1}^D} (1 - \eta) \epsilon_{t+1} dF_{t+1} + \int_{\epsilon_{t+1}^D}^{\infty} \frac{\epsilon_{t+1}^D}{1 - \tau_c} dF_{t+1} \right] (1 + r_{t+1}^A) \right\} \\ &\quad - (1 - m_t) \left\{ 1 + \mathbb{E}_t \left[M_{t,t+1} \left(\frac{\tau_c}{1 - \tau_c} [1 - F_{t+1}(\epsilon_{t+1}^D)] \right) \right] \right\}. \end{aligned} \quad (\text{C.6})$$

D Intermediary Value Maximization Problem

It is useful to formulate the problem as a set of saddle point problems as follows. The intermediary solves

$$\begin{aligned} J_t &= \min_{\theta_t} \max_{Q_t S_t, m_t, \epsilon_{t+1}^D} \left\{ \mathbb{E}_t^\epsilon [D_t] + \mathbb{E}_t [M_{t,t+1} \cdot \mathbb{E}_{t+1}^\epsilon [V_{t+1}(N_{t+1})]] \right. \\ &\quad + \mathbb{E}_t^\epsilon \left[\lambda_t \left(N_t - D_t + \varphi \min\{0, D_t\} - m_t Q_t S_t \right) \right] \\ &\quad + \theta_t Q_t S_t \mathbb{E}_t \left[M_{t,t+1} \left((1 - \eta) \Phi(s_{t+1}^D - \sigma_{t+1}) + \frac{\epsilon_{t+1}^D}{1 - \tau_c} [1 - \Phi(s_{t+1}^D)] \right) (1 + r_{t+1}^A) \right. \\ &\quad \left. \left. - (1 - m_t) \left(1 + \frac{\tau_c}{1 - \tau_c} \mathbb{E}_t [M_{t,t+1} [1 - F_{t+1}(\epsilon_{t+1}^D)]] \right) \right] \right\} \end{aligned} \quad (\text{D.1})$$

before the realization of the idiosyncratic shock, and

$$V_t(N_t) = \min_{\lambda_t} \max_{D_t} \left\{ D_t + \mathbb{E}_t[M_{t,t+1} \cdot J_{t+1}] + \lambda_t \left[N_t - D_t + \varphi \min\{0, D_t\} - m_t Q_t S_t \right] \right\} \quad (\text{D.2})$$

after the realization of the idiosyncratic shock, where $s_{t+1}^D \equiv \sigma_{t+1}^{-1}[\log \epsilon_{t+1}^D + 0.5\sigma_{t+1}^2]$, a standardization of the default threshold.

D.1 Efficiency Conditions of the Intermediary Problem

The efficiency conditions of the problem are given by

$$Q_t S_t : \quad 0 = -m_t \mathbb{E}_t^\epsilon[\lambda_t] + \mathbb{E}_t \left\{ M_{t,t+1} \cdot \mathbb{E}_{t+1}^\epsilon \left[V'_{t+1}(N_{t+1}) \frac{\partial N_{t+1}}{\partial Q_t S_t} \right] \right\} \quad (\text{D.3})$$

$$m_t : \quad 0 = -\mathbb{E}_t^\epsilon[\lambda_t] + \theta_t \left\{ 1 - \mathbb{E}_t \left[M_{t,t+1} \left((1-\eta)r_t^m \Phi(s_{t+1}^D) - \frac{\tau_c - r_t^m}{1-\tau_c} [1 - \Phi(s_{t+1}^D)] \right) \right] \right\} \quad (\text{D.4})$$

$$\epsilon_{t+1}^D : \quad 0 = \mathbb{E}_t \left\{ M_{t,t+1} \cdot \mathbb{E}_{t+1}^\epsilon \left[V'_{t+1}(N_{t+1}) \frac{\partial N_{t+1}}{\partial \epsilon_{t+1}^D} \right] \right\} \frac{1}{Q_t S_t} \quad (\text{D.5})$$

$$+ \theta_t \mathbb{E}_t \left\{ M_{t,t+1} \left[(1-\eta) \frac{\phi(s_{t+1}^D - \sigma_{t+1})}{\sigma_{t+1} \epsilon_{t+1}^D} + \frac{1}{1-\tau_c} \left(1 - \Phi(s_{t+1}^D) - \frac{\phi(s_{t+1}^D)}{\sigma_{t+1}} \right) \right] (1 + r_{t+1}^A) \right\}$$

$$+ \theta_t (1 - m_t) \mathbb{E}_t \left\{ M_{t,t+1} \frac{\phi(s_{t+1}^D)}{\sigma_{t+1} \epsilon_{t+1}^D} \frac{\tau_c}{1-\tau_c} \right\}$$

$$D_t : \quad \lambda_t = \begin{cases} 1 & \text{if } D_t \geq 0 \\ 1/(1-\varphi) & \text{if } D_t < 0 \end{cases} \quad (\text{D.6})$$

D.1.1 FOC for Investment ($Q_t S_t$)

Using (D.6), we obtain $\mathbb{E}_t^\epsilon[\lambda_t] = \Pr(D_t \geq 0) \mathbb{E}_t^\epsilon[\lambda_t | D_t \geq 0] + \Pr(D_t < 0) \mathbb{E}_t^\epsilon[\lambda_t | D_t < 0]$. Hence,

$$\mathbb{E}_t^\epsilon[\lambda_t] = [1 - \Phi(s_t^E)] + \frac{\Phi(s_t^E)}{1-\varphi} = 1 + \mu \Phi(s_t^E) \quad (\text{D.7})$$

where $\mu \equiv \varphi/(1-\varphi)$, $s_t^E \equiv \sigma_t^{-1}[\log \epsilon_t^E + 0.5\sigma_t^2]$ and ϵ_t^E is the equity issuance threshold (see the main text for the definition).

Using Benveniste-Scheinkman formula, we have $V'(N_t) = \lambda_t$. Hence

$$\mathbb{E}_{t+1}^\epsilon \left[V'_{t+1}(N_{t+1}) \frac{\partial N_{t+1}}{\partial Q_t S_t} \right] = \mathbb{E}_{t+1}^\epsilon [\lambda_{t+1} (\max\{\epsilon_{t+1}, \epsilon_{t+1}^D\} - \epsilon_{t+1}^D) (1 + r_{t+1}^A)]$$

Using this and dividing the FOC for investment through by $m_t \mathbb{E}_t^\epsilon[\lambda_t]$, one can rewrite the FOC as

$$1 = \mathbb{E}_t \left[M_{t,t+1} \frac{\mathbb{E}_{t+1}^\epsilon[\lambda_{t+1}]}{\mathbb{E}_t^\epsilon[\lambda_t]} \frac{1}{m_t} [1 + \tilde{r}_{t+1}^A - (1-m_t)(1 + (1-\tau_c)r_{t+1}^B)] \right] \quad (\text{D.8})$$

where we use $\epsilon_{t+1}^D(1 + r_{t+1}^A) = (1-m_t)[1 + (1-\tau_c)r_{t+1}^B]$ and the modified asset return $1 + \tilde{r}_{t+1}^A$ is defined as

$$1 + \tilde{r}_{t+1}^A \equiv \frac{\mathbb{E}_{t+1}^\epsilon[\lambda_{t+1} \max\{\epsilon_{t+1}, \epsilon_{t+1}^D\}]}{\mathbb{E}_{t+1}^\epsilon[\lambda_{t+1}]} (1 + r_{t+1}^A)$$

$$= \left\{ \frac{\mathbb{E}_{t+1}^\epsilon[\lambda_{t+1} \epsilon_{t+1}]}{\mathbb{E}_{t+1}^\epsilon[\lambda_{t+1}]} + \frac{\mathbb{E}_{t+1}^\epsilon[\lambda_{t+1} \max\{0, \epsilon_{t+1}^D - \epsilon_{t+1}\}]}{\mathbb{E}_{t+1}^\epsilon[\lambda_{t+1}]} \right\} (1 + r_{t+1}^A)$$

The first term inside the curly bracket can be evaluated as

$$\begin{aligned} E_{t+1}^\epsilon[\lambda_{t+1}\epsilon_{t+1}] &= \int_0^{\epsilon_{t+1}^E} \frac{\epsilon_{t+1}}{1-\varphi} dF_{t+1} + \int_{\epsilon_{t+1}^E}^\infty \epsilon_{t+1} dF_{t+1} \\ &= \frac{1}{1-\varphi} \Phi(s_{t+1}^E - \sigma_{t+1}) + 1 - \Phi(s_{t+1}^E - \sigma_{t+1}) = 1 + \mu \Phi(s_{t+1}^E - \sigma_{t+1}). \end{aligned}$$

Similarly, we can derive the analytical expression for the second term as

$$\begin{aligned} \mathbb{E}_{t+1}^\epsilon[\lambda_{t+1} \max\{0, \epsilon_{t+1}^D - \epsilon_{t+1}\}] &= \int_0^{\epsilon_{t+1}^D} \frac{\epsilon_{t+1}^D - \epsilon_{t+1}}{1-\varphi} dF_{t+1} \\ &= \frac{1}{1-\varphi} [\epsilon_{t+1}^D \Phi(s_{t+1}^D) - \Phi(s_{t+1}^D - \sigma_t)] \end{aligned}$$

where we use the fact that $\lambda_{t+1} = 1/(1-\varphi)$ when $\epsilon_{t+1} \leq \epsilon_{t+1}^D < \epsilon_{t+1}^E$. Combining the two expressions yields

$$1 + \tilde{r}_{t+1}^A \equiv \left[\frac{1 + \mu \Phi(s_{t+1}^E - \sigma_{t+1})}{1 + \mu \Phi(s_{t+1}^E)} + \frac{\epsilon_{t+1}^D \Phi(s_{t+1}^D) - \Phi(s_{t+1}^D - \sigma_t)}{(1-\varphi)[1 + \mu \Phi(s_{t+1}^E)]} \right] (1 + r_{t+1}^A) \quad (\text{D.9})$$

D.1.2 FOC for default threshold (ϵ_{t+1}^D)

To transform the FOC for ϵ_{t+1}^D into a form that is more convenient for computation, we need to evaluate the following differentiation

$$\begin{aligned} &\mathbb{E}_t \left[M_{t,t+1} \cdot \frac{\partial N_{t+1}}{\partial \epsilon_{t+1}^D} V'_{t+1}(N_{t+1}) \right] \frac{1}{Q_t S_t} \\ &= \mathbb{E}_t \left[M_{t,t+1} \frac{\partial \max\{\epsilon_{t+1}, \epsilon_{t+1}^D\} - \epsilon_{t+1}^D}{\partial \epsilon_{t+1}^D} (1 + r_{t+1}^A) V'_{t+1}(N_{t+1}) \right] \\ &= \mathbb{E}_t \left\{ M_{t,t+1} \mathbb{E}_{t+1}^\epsilon \left[\lambda_{t+1} \left(\frac{\partial \max\{\epsilon_{t+1}, \epsilon_{t+1}^D\}}{\partial \epsilon_{t+1}^D} - 1 \right) \right] (1 + r_{t+1}^A) \right\} \end{aligned}$$

where we used the envelope condition $V'_{t+1}(N_{t+1}) = \lambda_{t+1}$ and the law of iterated expectation in the third line. To that end, first, we think of $\max\{\epsilon_{t+1}, \epsilon_{t+1}^D\}$ as a function of a ‘variable’ ϵ_{t+1}^D for a given ‘parameter’ ϵ_{t+1} and take a differentiation of $\max\{\epsilon_{t+1}, \epsilon_{t+1}^D\}$ with respect to ϵ_{t+1}^D as follows

$$\frac{\partial \max\{\epsilon_{t+1}, \epsilon_{t+1}^D\}}{\partial \epsilon_{t+1}^D} = \begin{cases} 0 & \text{if } \epsilon_{t+1}^D \leq \epsilon_{t+1} \\ 1 & \text{if } \epsilon_{t+1}^D > \epsilon_{t+1} \end{cases}.$$

Second, we now think of the above as a function a ‘variable’ ϵ_{t+1} for a given ‘parameter’ ϵ_{t+1}^D since we now need to integrate this expression over the support of ϵ_{t+1} . Reminding that the shadow value is equal to $1/(1-\varphi)$ when $\epsilon_{t+1} \leq \epsilon_{t+1}^D < \epsilon_{t+1}^E$, one can see immediately that

$$\mathbb{E}_{t+1}^\epsilon \left[\lambda_{t+1} \frac{\partial \max\{\epsilon_{t+1}, \epsilon_{t+1}^D\}}{\partial \epsilon_{t+1}^D} \right] = \int_0^{\epsilon_{t+1}^D} 1 \cdot \frac{dF_{t+1}}{1-\varphi} = \frac{\Phi(s_{t+1}^D)}{1-\varphi}.$$

Combining this expression with the FOC (D.5) yields

$$\begin{aligned}
0 = & \mathbb{E}_t \left\{ M_{t,t+1} \left[\frac{\Phi(s_{t+1}^D)}{1-\varphi} - [1 + \mu\Phi(s_{t+1}^E)] \right] (1 + r_{t+1}^A) \right\} \\
& + \theta_t \mathbb{E}_t \left\{ M_{t,t+1} \left[(1-\eta) \frac{\phi(s_{t+1}^D - \sigma_{t+1})}{\sigma_{t+1} \epsilon_{t+1}^D} + \frac{1}{1-\tau_c} \left(1 - \Phi(s_{t+1}^D) - \frac{\phi(s_{t+1}^D)}{\sigma_{t+1}} \right) \right] (1 + r_{t+1}^A) \right\} \\
& + \theta(1-m_t) \mathbb{E}_t \left\{ M_{t,t+1} \frac{\phi(s_{t+1}^D)}{\sigma_{t+1} \epsilon_{t+1}^D} \frac{\tau_c}{1-\tau_c} \right\} \tag{D.10}
\end{aligned}$$

E The Case with the Pigovian Tax

When the Pigovian tax is introduced, the flow of funds constraint facing the intermediaries becomes

$$0 = -[m_t + \tau_t^m(1-m_t)]Q_t S_t + T_t + N_t - D_t + \varphi_t \min\{0, D_t\} \tag{E.1}$$

where T_t is the lump sum transfer of the proceeds from the leverage taxation. In equilibrium $\tau_t^m(1-m_t)Q_t S_t = T_t$, though T_t is taken as given by the intermediaries. The default threshold is now given by

$$\epsilon_{t+1} \leq \epsilon_{t+1}^D \equiv (1-m_t) \left[\frac{1 + (1-\tau_c)r_{t+1}^B}{1 + r_{t+1}^A} \right] \tag{E.2}$$

and the participation constraint of the intermediary is modified into

$$\begin{aligned}
0 = & \mathbb{E}_t \left\{ M_{t,t+1} \left[\int_0^{\epsilon_{t+1}^D} (1-\eta)\epsilon_{t+1} dF_{t+1} + \int_{\epsilon_{t+1}^D}^{\infty} \frac{\epsilon_{t+1}^D}{1-\tau_c} dF_{t+1} \right] (1 + r_{t+1}^A) \right\} \\
& - (1-m_t) \left\{ 1 + \frac{\tau_c}{1-\tau_c} \mathbb{E}_t [M_{t,t+1}[1 - F_{t+1}(\epsilon_{t+1}^D)]] \right\}. \tag{E.3}
\end{aligned}$$

Following the same steps, one can derive the following efficiency conditions:

$$Q_t S_t : \quad 1 = \mathbb{E}_t \left[M_{t,t+1} \frac{\mathbb{E}_{t+1}^{\epsilon}[\lambda_{t+1}]}{\mathbb{E}_t^{\epsilon}[\lambda_t]} \frac{1}{m_t + \tau_t^m(1-m_t)} [1 + \tilde{r}_{t+1}^A - (1-m_t)[1 + (1-\tau_c)r_{t+1}^B]] \right] \tag{E.4}$$

$$m_t : \quad 0 = -(1-\tau_t^m)\mathbb{E}_t^{\epsilon}[\lambda_t] + \theta_t \left\{ 1 + \frac{\tau_c}{1-\tau_c} \mathbb{E}_t [M_{t,t+1}[1 - \Phi(s_{t+1}^D)]] \right\} \tag{E.5}$$

$$\begin{aligned}
\epsilon_{t+1}^D : \quad 0 = & \mathbb{E}_t \left\{ M_{t,t+1} \left[\frac{\Phi(s_{t+1}^D)}{1-\varphi} - [1 + \mu\Phi(s_{t+1}^E)] \right] (1 + r_{t+1}^A) \right\} \\
& + \theta_t \mathbb{E}_t \left\{ M_{t,t+1} \left[(1-\eta) \frac{\phi(s_{t+1}^D - \sigma_{t+1})}{\sigma_{t+1} \epsilon_{t+1}^D} + \frac{1}{1-\tau_c} \left(1 - \Phi(s_{t+1}^D) - \frac{\phi(s_{t+1}^D)}{\sigma_{t+1}} \right) \right] (1 + r_{t+1}^A) \right\} \\
& + \theta_t(1-m_t) \mathbb{E}_t \left\{ M_{t,t+1} \frac{\tau_c}{1-\tau_c} \frac{\phi(s_{t+1}^D)}{\sigma_{t+1} \epsilon_{t+1}^D} \right\} \tag{E.6}
\end{aligned}$$

F Household's Optimization Conditions

We denote the total outstanding of intermediary debts by B_t . In equilibrium, $B_t = \int [1 - m_{t-1}(i)] Q_{t-1} S_t(i) di = (1 - m_{t-1}) Q_{t-1} K_t$, where $i \in [0, 1]$ is an index for intermediary. The last equality is due to the symmetric equilibrium and the no-arbitrage condition mentioned in the main text. The realized aggregate return on intermediary debts, denoted by $1 + \tilde{r}_t^B$, is given by

$$1 + \tilde{r}_t^B \equiv \left[\int_0^{\epsilon_t^D} (1 - \eta) \epsilon_t dF_t + \int_{\epsilon_t^D}^{\infty} (1 - m_t)(1 + r_t^B) dF_t \right] \frac{1 + r_t^A}{1 - m_{t-1}}.$$

Using $1 + \tilde{r}_t^B$, we can express the household's budget constraint as

$$0 = W_t H_t + (1 + \tilde{r}_t^B) B_t - B_{t+1} - P_t C_t - \int_0^1 P_t^S(i) S_{t+1}^F(i) di + \int_0^1 [\max\{D_t(i), 0\} + P_{t-1,t}^S(i)] S_t^F(i) di$$

where W_t is a nominal wage rate, H_t is labor hours, and $S_t^F(i)$ is the number of shares outstanding at time t . $P_{t-1,t}^S(i)$ is the time t value of shares outstanding at time $t - 1$. $P_t^S(i)$ is the ex-dividend value of equity at time t . The two values are related by the following accounting identity, $P_t^S(i) = P_{t-1,t}^S(i) + X_t(i)$ where $X_t(i)$ is the value of new shares issued at time t . The costly equity finance assumption adopted for the financial intermediary implies that $X_t(i) = -(1 - \varphi) \min\{D_t(i), 0\}$. Using the last two expressions, one can see that the budget constraint is equivalent to

$$\begin{aligned} 0 = & W_t H_t + (1 + \tilde{r}_t^B) B_t - B_{t+1} - P_t C_t - \int_0^1 P_t^S(i) S_{t+1}^F(i) di \\ & + \int_0^1 [\max\{D_t(i), 0\} + (1 - \varphi) \min\{D_t(i), 0\} + P_t^S(i)] S_t^F(i) di. \end{aligned}$$

The household's FOCs for asset holdings are summarized by two conditions,

- FOC for B_{t+1} : $1 = \mathbb{E}_t [M_{t,t+1}(1 + \tilde{r}_{t+1}^B)]$
- FOC for $S_{t+1}^F(i)$: $1 = \mathbb{E}_t \left[M_{t,t+1} \frac{\mathbb{E}_{t+1}^\epsilon [\max\{D_{t+1}, 0\}] + (1 - \varphi) \mathbb{E}_{t+1}^\epsilon [\min\{D_{t+1}, 0\}] + P_{t+1}^S}{P_t^S} \right]$.

where $E_{t+1}^\epsilon [\max\{D_{t+1}, 0\}] = \int_0^1 \max\{D_t(i), 0\} di$ and $E_{t+1}^\epsilon [\min\{D_{t+1}, 0\}] = \int_0^1 \min\{D_t(i), 0\} di$.