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Systemic Risk: A New Trade-Off for Monetary Policy?*

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Abstract

We introduce time-varying systemic risk (à la He and Krishnamurthy, 2014) in an otherwise standard New-Keynesian model to study whether simple leaning-against-the-wind interest rate rules can reduce systemic risk and improve welfare. We find that while financial sector leverage contains additional information about the state of the economy that is not captured in inflation and output leaning against financial variables can only marginally improve welfare because rules are detrimental in the presence of falling asset prices. An optimal macroprudential policy, similar to a countercyclical capital requirement, can eliminate systemic risk raising welfare by about 1.5%. Also, a surprise monetary policy tightening does not necessarily reduce systemic risk, especially during bad times. Finally, a volatility paradox a la Brunnermeier and Sannikov (2014) arises when monetary policy tries to excessively stabilize output.

JEL Classification: E3, E52, E58, E44, E61, G2, G12

Keywords: Monetary Policy, Endogenous Financial Risk, DSGE models, Non-Linear Dynamics, Policy Evaluation.

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1. Introduction

Prior to the great financial crisis the mainstream view held among central banks was that using interest rate policy to counteract financial exuberance (such as asset price bubbles) was costly or ineffective (Bernanke and Gertler [9], Gilchrist and Leahy [27], Greenspan [29]).[1] The global financial crisis (GFC), however, has put this "benign neglect" approach into question, bringing the issue of whether monetary policy should explicitly include financial stability as an independent objective and use (some) specific financial variables as intermediate targets to the forefront of the policy debate (Borio [11]). There is now, indeed, the widely held belief that the current financial architecture is inherently fragile and that widespread externalities—stemming from some form of asset price corrections—can have a *systemic* impact on the financial sector, disrupting financial intermediation and, in turn, jeopardizing the normal functioning of the real economy (Adrian et al. [2]).

We re-assess the monetary policy conduct when the financial intermediation sector can be subject to disruptions which would then trigger adverse effects for the real economy. These system-wide financial disruptions are rare but highly damaging. To capture them appropriately we use a framework that accommodates potentially highly non-linear behavior of financial variables and their two-way interaction with the real economy. As a result, it is important to assess monetary policy in a model in which systemic risk is endogenously latent in the intermediary sector and a financial crisis may be triggered by a series of bad shocks where both the real economy and the solidity of the financial sector deteriorate feeding on each other. More specifically, we introduce time-varying systemic risk in an otherwise standard New-Keynesian model that can approximate data for macroeconomic and financial variables. In particular, following He and Krishnamurthy [33] we include two financial frictions: 1) there is a separation between ownership and management of financial intermediaries which induces an excessively pro-cyclical risk-taking behavior of the financial sector; 2) there is an equity constraint which makes raising funds difficult for financial intermediaries during periods of financial stress. The latter friction, by interacting with the first friction, is relevant only in bad states and can, thus, introduce not only an amplification of real shocks but also a substantial asymmetry between good and bad times. Bad states can morph into a financial crisis due to a negative feedback loop effect: an initial drop in asset prices that induces

[1] Moreover, the additional information brought about by financial variables relatively to the one already incorporated in inflation and output gap was considered minimal and occasional financial disruptions could be dealt with by following the traditional lender-of-last-resort function (Bagehot [7]).

a sufficient fall in the return on equity of the financial sector makes raising equity difficult which, in turn, implies that the intermediary sector will bear more risk in its portfolio and both the Sharpe ratio and equity premium will rise—akin to a rise in risk aversion. The higher equity premium, in turn, pushes down the real rate but also asset prices, and, thus, investment to deliver the higher expected returns on capital propagating the financial stress to the real economy. As the capital stock adjusts, however, the marginal productivity of capital increases which breaks the vicious circle and posing the premises for a recovery.

Extending He and Krishnamurthy [33] and following Adrian and Shin [1], our baseline calibration assumes that financial intermediaries expand their balance sheet by borrowing rather than raising equity, which results in a positive co-movement between leverage and asset prices.[2] Empirical evidence suggests that financial sector leverage is indeed pro-cyclical, although results vary across sectors and over time. For example, using pre-crisis aggregate financial accounts data, Adrian and Shin [1] find that leverage increases with total assets for broker-dealers. This result is confirmed by Nuno and Thomas [38], who extend data up to 2011 and find evidence that leverage is procyclical for both broker dealers and for commercial banks. Finally, Kalemli-Ozcan et al. [34] use pre-crisis microdata and find that leverage is procyclical for investment banks and for large commercial banks; similar to Greenlaw et al. [28] (who look at a few individual banks). Our model is rich enough to qualitatively replicate the cross-correlation between leverage and output found in the data. Specifically, leverage lags output and is more persistent over the business cycle.[3]

Finally, we rely on a third order perturbation method to solve the model and capture changes in risk premia and, thus, systemic risk. While perturbation methods have their own limitations (Brzoza-Brzezina et al. [12] and Aruoba et al. [6]), this approach strikes a balance between precision and machine time, while still capturing *movements* in risk premia that, in periods of financial stress, are crucial to properly account for the effect of the financial sector on the economy and evaluating the welfare costs related to systemic risk.

We use our model as a laboratory to analyze the effect of *simple* monetary policy rules on the stochastic properties of financial variables, systematic risk and, more generally, welfare. We

[2] See BIS [8] for a detailed survey of alternative transmission channels between the financial and the real sectors. Risk taking in our framework occurs on the liability side of banks. Another interesting margin of risk taking is asset quality. For an example of a DSGE model with a search-for-yield among banks see Cociuba, Shukayev and Ueberfeldt [19].

[3] Some commentators have noted that the asynchronicity of business cycle fluctuations and the financial cycle (defined as fluctuations in some chosen financial variables) poses a challenge to monetary policy (see Borio [11]).

limit our analysis to simple rules to proxy a monetary policy behavior which could be, in principle, sufficiently predictable and learnable in a more general context—i.e., we proxy a central bank operating in a framework that is consistent with the general principles of a flexible inflation targeting framework. This leads us to focus our analysis on observable measures of systemic risk such as leverage. As a benchmark we derive an optimal macroprudential instrument rule where a state contingent tax (subsidy) is levied on financial intermediaries.

The findings of our analysis can be summarized as follows:

First, a monetary policy tightening *surprise* does not necessarily reduce systemic risk, particularly when the state of the financial sector is fragile. The negative impact of the surprise tightening on output, inflation, asset prices, and the rise of funding costs for financial intermediaries implies a reduction in profitability of the financial sector without altering their risk taking behavior.

Second, risk taking behavior is affected by *systematic* monetary policy reaction. Systematic policy based on a simple (Taylor type) policy rule that includes financial variables such as leverage, can improve welfare by striking a balance between inflation and output stabilization on the one hand and reducing the likelihood of financial stress on the other. A simple policy reaction to leverage, however, is too simplistic: When leverage increases because of a fall in asset prices, an increase in policy interest rates exacerbates the initial asset price correction. Leaning against leverage without clearly distinguishing why leverage is increasing could therefore lead to a policy mistake that exacerbates incipient financial stress, possibly inducing a full blown crisis. Alternative financial variables such as measures of mis-pricing of risk have more appealing properties since risk aversion (i.e., asset price undervaluation) always increases in crisis times. However, they are not directly observable and the varying ability of the policy rate to influencing them across the cycle lead to only modest welfare improvements. These results are only mildly sensitive to the cyclical properties of leverage: Even when leverage is countercyclical (i.e. ,low during booms and, thus, restraining investment from reaching its efficient level) a too loose monetary policy aimed at raising leverage towards its mean level would increase the vulnerability of the system to adverse shocks (i.e., systemc risk).

Third, the optimal macroprudential policy can be derived as an instrument rule which acts similarly to a counter-cyclical capital requirement (making it more costly to raise debt during good times and vice versa). The optimal macroprudential rule, by severing the vicious link between financial sector risk and investment, re-establishes a Modigliani-Miller world.

Finally, even though price stability is no longer optimal and a moderate reaction to output reduces systemic risk and improve welfare, an excessive stabilization of output leads to a compression of risk premia, higher asset prices, investment levels, and, thus, leverage (which is necessary to finance the higher investment levels). When the financial system faces sharper negative shocks, however, the higher leverage becomes a vulnerability leading to sharper downturns. This feature is analog to the *volatility paradox* described in Brunnermeier and Sannikov [13].[4] In this context, a monetary policy reaction to output over and above the one warranted in the absence of financial frictions leads to lower welfare.

In relation to the literature most existing studies have found little or no welfare benefit from monetary policy targeting (or "leanings against") financial variables.[5] However, differently from ours, these studies are subject to several limitations: credit frictions affect only *non-financial* borrowers (as in models a la Kiyotaki and Moore [36], Carlstrom and Fuerst [14], Carlstrom, Fuerst, and Paustian [15] or Bernanke and Gertler and Gilchrist [10]); asset price deviations from fundamentals or, more generally, financial shocks are assumed to be exogenous; and the solution techniques that have been used remove non-linear dynamics which are crucial for describing the impact of crisis and to accurately assess welfare implications (e.g., Woodford [49]). A notable exception is Brunnermeier and Sannikov [13] who put financial frictions at the center of the monetary policy transmission mechanism. However, given that financial frictions are the *only* source of inefficiencies in their model, the trade-off with traditional monetary policy goals such as inflation and output gap stabilization is removed by assumption. An approach similar in spirit and possibly complementary is provided by Gertler et al. [26] who analyzes a model where banks endogenously choose their leverage. The analysis, however, does not rely directly on *endogenous* movements in risk premia, as the model is solved to a 2nd order approximation capturing business cycle amplifications rather than the buildup of systemic risk. Their framework, however, can be thought of as complementary to ours as it focuses more squarely on banks (and credit) while ours is better suited to capture financial intermediaries more broadly defined.[6] Finally, some analyses (such as Svensson [46] and

[4]The volatility paradox can be described by the following passage: "Paradoxically, lower exogenous risk can lead to more extreme volatility spikes in the crisis regime. This happens because low fundamental risk leads to higher equilibrium leverage." (Brunnermeier and Sannikov [13])

[5]In addition to Bernanke and Gertler [9], papers that have found small or no welfare benefits from leaning-against financial variables include Ajello et al [3], Angeloni and Faia [5], Faia and Monacelli [23], De Groot [20], Quint and Rabanal [40], and Svensson [46].

[6]The literature considering endogenous and occasionally binding leverage constraints for banks in dynamic equilibrium models is small but growing rapidly, see e.g. Akinci and Queralto [4], and Ozhan [39] for complementary work.

Ajello et al. [3]), focus on the effect of a monetary policy *surprises* on systemic risk finding little or negligible welfare gains. In the present paper, instead, we will place more emphasis on how a systematic monetary policy reaction to financial variables, which is fully internalized by private agents, can affect welfare, while broadly confirming the results of Svensson [46] and Ajello et al. [3] in relation to a surprise policy tightening.[7] [8]

The rest of the paper is organized as follows. We present the model in section II and calibrate the model and describe how the model matches the data for key macro and financial variables in section III. We discuss model properties and perform welfare analysis for alternative policy rules in section IV before concluding with a summary of our results in section V

2. The Model

The specification of the macroeconomic block of the model follows standard New-Keynesian DSGE models (Christiano et al., [18]; Smets and Wouters [44]) whereas the financial sector is modeled as in He and Krishnamurthy [33]. Time is discrete and indexed by t. The economy has three sectors: households, financial intermediation, and goods production. We assume that the capital stock is owned by financial intermediaries which are run by a manager. We interpret the intermediaries to include both commercial banks, as well as non-banks (such as investment banks, hedge funds and private equity funds).

2.1. Household Sector

A representative household maximizes the expected utility flow:

$$U_t = E_0 \sum_{t=0}^{\infty} \beta^t u\left(C_t, L_t\right), \tag{2.1}$$

where β is the discount factor and C_t and L_t denotes consumption and labor effort respectively. The instantaneous utility function is specified as in Greenwood et al. [30], eliminating the wealth effect on labor supply

$$u\left(C_t, L_t\right) = \frac{\left(C_t - hC_{t-1} - \psi L_t^{1+\phi_L}/(1+\phi_L)\right)^{1-\sigma} - 1}{1-\sigma}, \tag{2.2}$$

[7] It is also important to note that as opposed to Svensson [46] and Ajello et al. [3] the severity of financial stress and its welfare implications are endogenous in our setup.

[8] See also Silva (2017) for a survey on the literature on systemic financial risk.

where σ the inverse of inter-temporal elasticity of substitution, $1/\phi_L$ is the Frisch elasticity of labor supply. The parameter $\psi > 0$ is used for accounting for the steady state of L_t, while h captures external habit formation on consumption.

Households maximize their objective function subject to an intertemporal budget constraint which is given by:[9]

$$W_t = w_t^n L_t - P_t C_t + \tilde{R} V_{t-1} + R_{t-1}^f B_{t-1} + D_t^k - 0.5\phi_{cw}\pi_{w,t}^2 \overline{Y}, \tag{2.3}$$

where W_t is financial wealth and $w_t = w_t^n/P_t$ is the real wage expressed in terms of final consumption, P_t is the price of the final consumption bundle while the last term represents nominal wage adjustment costs. Households are assumed not to be able to directly own the capital stock—even though they own capital producers which rebate their profits D_t^k to households. Instead, households invest their wealth in risky and risk-free assets issued directly by the financial sector. More precisely, a *minimum* fraction of household wealth λ is channeled into risk-free deposits, B_t, for transaction and liquidity services that earn a gross (real realized) return $(1+i_{t-1})/(1+\pi_t)$—where i_{t-1} is the nominal risk-free rate. The risk-free rate governs the consumption-saving choice of the households through a standard Euler equation:

$$\beta E_t \frac{u_{c,t+1}}{u_{c,t}} \frac{1+i_t}{1+\pi_{t+1}} = 1, \tag{2.4}$$

and

$$R_t^f = 1/[\beta E_t \frac{u_{c,t+1}}{u_{c,t}}],$$

where π_t is the inflation rate of consumption prices P_t while the marginal utility of consumption is given by $u_{c,t} = [C_t - hC_{t-1} - \psi L_t^{1+\phi_L}/(1+\phi_L)]^{-\sigma}$.

The other fraction $1-\lambda$ is invested either in risky financial assets V_t which earn a stochastic return $\tilde{R}_t$ or in deposits. Both returns are taken as given. The portfolio choice of investing in risky financial liabilities of a financial intermediary depends on the "reputation", e, acquired by the financial intermediary. We assume that for each intermediary the following relation holds (where $\overline{W}$ is steady state wealth)[10]

$$V_t = \min\{e_{t-1}, (1-\lambda)\overline{W}^{\gamma_0} W_t^{1-\gamma_0}\}, \tag{2.5}$$

[9] The budget constraint, before the wage adjustment cost, can also be written as $W_t = P_t(w_t L_t - C_t) + R_t^w W_{t-1} + D_t^k$,where $R_t^w = [R_t^f(1-\alpha_{t-1}) + \tilde{R}_t \alpha_{t-1}]$ is a weighted average of the risk-free and risky return with weight $\alpha_{t-1} = V_t/W_t$.

[10] The household portfolio allocation between risky and safe assets is price insensitive. Implicitly, we are assuming

When $\gamma_0 = 1$, during good times the share of household wealth invested in risky asset is constant, $\alpha_t \equiv V_t/W_t = 1-\lambda$. In bad times, however, when the financial sector is perceived fragile the equity share α_t falls with e_t. As we will see, choosing $\gamma_0 = 1$ is consistent with the empirical observation that financial sector leverage is procyclical. While the functional form used in (2.5) is appealing, it is not suited for most local perturbation methods; hence, we will actually replace it with a differentiable function that retains the same salient features (see equation 3.1).

Finally, we describe wage setting and labor supply. The marginal rate of substitution between consumption and leisure, mrs, is defined by the ratios of marginal utilities

$$mrs_t \equiv \psi L_t^{\phi_L} \tag{2.6}$$

Following the New-Keynesian tradition, we assume the households have market power in setting their nominal wages such that the nominal wage expressed in final consumption goods price is a markup over the household marginal rate of substitution

$$w_t^n = \mu_{w,t} mrs_t \tag{2.7}$$

while evolution of the wage markup $\mu_{w,t}$ is determined by nominal rigidities in setting wages such that the following wage Phillips curve governs wage inflation $\pi_{w,t} = \pi_t w_t / w_{t-1}$

$$\pi_{w,t} = (1-\gamma_w) E_t \pi_{w,t+1} + \gamma_w \pi_{w,t-1} - \kappa_w (\mu_{w,t} - \mu_{ss}). \tag{2.8}$$

The cost of wage inflation is born by the household and amounts to a loss of resources equal to $0.5\phi_{cw}\pi_{w,t}^2\overline{Y}$. The parameter ϕ_{cw} is a function of κ_w such that in a first order approximation adjustment costs à la Rotemberg and Calvo would give the same dynamics (see Lombardo and Vestin [37]).

2.2. Real Sector (Production)

Following the New-Keynesian framework, there is a continuum of monopolistic firms that produce differentiated goods according to the technology

$$Y_t = A_t L_t^{\alpha} K_{t-1}^{1-\alpha} - \Psi \overline{Y}, \tag{2.9}$$

that there are limits to arbitrage and deposits and intermediary equity are not close substitute. Hence, there is no direct arbitrage equation linking the return on equity and the return on risk-less deposits. As we will see, asset prices (the price of physical capital) equilibrate demand and supply of risky funds to the financial sector. The consumption-saving choice, however, is still captured by the Euler equation on bonds where the demand for individual firm's output is given by $y_t^* = (p_t^*/P_t)^{-\epsilon} Y_t$ and Ψ is a fixed cost of production, while p_t^* and y_t^* are firm-specific variables—in a symemtric equilibrium it will be $p_t^* = P_t$ and $y_t^* = Y_t$. The law of motion for physical capital is given by

$$K_t = (1-\delta)K_{t-1} + I_t, \tag{2.10}$$

however, since firms are owned by intermediaries the investment decision, I_t, is actually driven by financial intermediaries (see next section).

Labor demand is given by

$$w_t = mc_t \alpha A_t L_t^{\alpha-1} K_t^{1-\alpha}. \tag{2.11}$$

Firms face price adjustment costs a la Rotemberg, $\phi_{cp}\pi_t^2\overline{Y}/2$, expressed in terms of steady state output $\overline{Y}$, governed by the parameter $\phi_{cp} \geq 0$, which imply the following non-linear Phillips curve for price inflation[11]

$$\phi_{cp}\pi_t(1+\pi_t)\overline{Y} + (\epsilon-1)Y_t = \epsilon mc_t Y_t + \beta E_t \phi_{cp}\pi_{t+1}(1+\pi_{t+1})\overline{Y}. \tag{2.12}$$

The parameter ϕ_{cp} is a function of parameter of a traditional New-Keynesian Phillips curve, κ_p, such that in a first order approximation adjustment costs à la Rotemberg and Calvo would give the same dynamics (see Lombardo and Vestin [37]). The marginal cost mc_t is function of the factor prices (wage and rental rate of capital) and TFP:

$$mc_t = \frac{w_t^\alpha r_{k,t}^{1-\alpha}}{A_t \alpha^\alpha (1-\alpha)^{1-\alpha}}. \tag{2.13}$$

Total factor productivity is a stationary exogenous process governed by a temporary and persistent shock ε_t^A and ε_t^g,respectively

$$\begin{aligned} A_t &= g_t + \rho_A A + (1-\rho_A) A_{t-1} + \sigma_A \varepsilon_t^A, \\ g_t &= \rho_g g_{t-1} + \sigma_g \varepsilon_t^g. \end{aligned} \tag{2.14}$$

Capital goods producers Capital goods producers, owned by households, buy output Y_t^I to produce investment goods (new capital), I_t, which are sold to the intermediary sector at a price

[11] We assume firms are risk neutral when it comes to the price-setting decision, instead of discounting the future using the intermediary discount factor. This assumption has no implication since we introduce both wages and prices Phillips curve in a first order approximation to reduce the potential instability of the system.

Q_t. Technology is such that output is transformed one-to-one into capital investment, $I_t = Y_t^I$, but only up to an adjustment cost $\Phi(I_t/K_t, K_t)$. Given $q_t = Q_t/P_t$, investment is chosen to solve

$$\max_{I_t} q_t I_t - I_t - \Phi(I_t/K_t, K_t),$$

where $\Phi(I_t/K_t, K_t) = 0.5\kappa(I_t/K_t - \delta)^2 K_t$ is the functional form of the adjustment cost that depends on aggregate capital. Optimality implies[12]

$$I_t/K_t = \delta + \frac{(q_t - 1)}{\kappa}. \tag{2.15}$$

Since there is no difference between new and old capital, the real value of the capital stock is simply $q_t K_t$, where $q_t = Q_t/P_t$. This means that, in equilibrium, it is the intermediary sector's valuation of capital, q_t, that drives investment. Finally, capital producers rebate their profits to households (which are zero only in the deterministic steady state):[13]

$$D_t^k = q_t I_t - I_t - \Phi(I_t/K_t, K_t) = (q_t - 1)(\delta + \frac{q_t - 1}{2\kappa})K_t. \tag{2.16}$$

2.3. Financial Sector

There is a separation between the ownership and control of an intermediary, and a manager makes all investment decisions of the intermediary. The manager raises funds from households in two forms, equity and debt $W_t = V_t + B_t$ which are used to purchase capital. The goal of the manager is to maximize his reputation which is determined by the history of realized returns on intermediary equity

$$e_t = e_{t-1}\gamma_t \tilde{R}_t, \tag{2.17}$$

where $\gamma_t > 0$ is a possibly time-varying process describing the risk aversion of the manager and $\tilde{R}_t$ is the intermediary's real return on equity which is a combination of the return on investment and the cost of funds

$$\tilde{R}_t = \theta_{t-1}R_t - (\theta_{t-1} - 1)(1 + \tau_{t-1})\frac{1 + i_{t-1}}{1 + \pi_t} = R_t + (\theta_{t-1} - 1)\left[R_t - (1 + \tau_{t-1})\frac{1 + i_{t-1}}{1 + \pi_t}\right], \tag{2.18}$$

where $\theta_t > 1$ is the financial intermediaries leverage which amplifies the return on investment R_t. In other words, θ_t is the ratio of assets and the equity raised by an intermediary while $\theta_t - 1$ is the

[12] Notice that the relation between investment and q is the same as the one prevailing in presence of capital adjustment costs in a traditional real business cycle model (Hayashi 1982).

[13] It is straightforward to see that profits are positive if and only if $q_t > 1$.

debt-to-equity ratio. In equilibrium, we have that $\theta_t = W_t/V_t$ and $\theta_t - 1 = B_t/V_t$. As far as the equity premium is positive $E_t R_{t+1} - R_t^f > 0$ higher leverage is expected to increase the financial intermediary's return on equity. A macroprudential tool, τ_t, is available to the government and will be described below.

Optimal leverage is determined by maximizing the manager's expected life-time (log) reputation, given his risk aversion, γ_t. Under log-normality of the return on investment this is equivalent to a mean-variance portfolio strategy.[14] We, thus, assume that the financial intermediary solves

$$\max_{\theta} E_t \tilde{R}_{t+1} - \gamma_t \text{var}_t(\tilde{R}_{t+1}).$$

The optimal necessary condition for leverage is, indeed, consistent with the traditional mean–variance portfolio strategy[15]

$$\theta_t = \frac{E_t R_{t+1} - R_t^f (1 + \tau_t)}{\gamma_t \text{var}_t (R_{t+1})}, \tag{2.19}$$

where $\gamma_t = \gamma + \upsilon_t$ and $\upsilon_t = \rho_\upsilon \upsilon_{t-1} + \varepsilon_t^\upsilon$ can be interpreted as a demand or financial shock which follows a first order autoregressive process. The realized return on investment is given by

$$R_t = \frac{q_t K_t + D_t}{q_{t-1} K_{t-1}}. \tag{2.20}$$

Where D_t are dividends from firms $D_t = Y_t - \delta K_t - w_t L_t$.[16]

It is instructive to consider the amplifying effects of a binding the capital constraint. If $e_{t-1} < (1-\lambda)\overline{W}^{\gamma_0} W_t^{1-\gamma_0}$, then the intermediary sector only raises e_{t-1} of equity. The effect of negative shock in this state reduces $W_t = q_t K_t$, but it also feeds back on e_t through two channels. First, since the intermediary sector is levered the return on equity is a multiple of the underlying return on the intermediary sector's assets. Second, reputation, e_t, moves more than one-for-one with the return on equity since the risk aversion of the financial intermediary, γ_t, is larger than one ($e_t = e_{t-1} \gamma_t \tilde{R}_t$). Hence, negative shocks are amplified and cause leverage to actually rise when the capital constraint binds. Higher leverage implies a higher Sharpe ratio on capital investment,

[14] See He and Krishnamurthy [33] on how to derive the problem of the financial intermediary.

[15] For simplicity, we assume that the financial intermediary disregard inflation volatility as a source of risk for the real return. This is a reasonable approximation for countries with credible inflation targeting regimes where no major burst in inflation is expected.

[16] It is also possible to define the Sharpe ratio as the risk premium on an investment divided by its risk, $S_t^a = \gamma_t \theta_t \sigma_{t+1}^R$,where $\sigma_{t+1}^R = \sqrt{var_t (R_{t+1})}$. The Sharpe ratio is equal to the riskiness of the intermediary portfolio, $\theta_t \sigma_{t+1}^R$, times the risk aversion of the financial intermediary γ_t. If the intermediary sector bears more risk in its portfolio the Sharpe ratio will rise.

S_t^a, which in turn implies that the price of capital, q_t, must be lower in order to deliver the higher expected returns (from 2.20). A lower price of capital will in turn further depress investment which depends on q_t.

We can define the mis-pricing of risk as

$$\omega_t = \beta E_t \frac{u_{c,t+1}}{u_{c,t}} (R_{t+1} - R_t^f) = E_t m_{t,t+1} R_{t+1} - 1, \tag{2.21}$$

where $m_{t,t+1}$ is the socially relevant stochastic discount factor. Notice that in the absence of financial frictions $\omega_t = 0$ at all times (see Appendix). The mispricing of risk is counter-cyclical in that there is overpricing of risk during bad times (in particular during crises) and vice versa. This distortion is also a key feature of the model that helps understand why risks can buildup during good times. Also the equity premium, EP_t, can be written as $EP_t = -R_t^f[cov(m_{t,t+1}, R_{t+1}) - \omega_t]$: An increase in the misprising of risk reflects a excessively high equity premium that the financial sector requires to invest in risky assets.

2.4. Monetary Policy

We assume that the monetary authority sets the short-term nominal interest rate according to a simple Taylor-type rule (Taylor [48]) where the risk-free nominal rate responds to its lagged value, price and wage inflation, a measure of economic activity x_t, and a zero-mean measure of financial vulnerability (leverage or mispricing of risk) ϑ_t,

$$\begin{aligned} i_t &= \phi_i i_{t-1} + (1 - \phi_i)(\phi_\pi \pi_t^c + \phi_x x_t + \phi_\theta \vartheta_t) + \epsilon_t^m, \qquad (2.22) \\ \pi_t^c &= (1 - \phi_w)\pi_t + \phi_w \pi_t^w, \end{aligned}$$

where π_t^c is a composite wage and price inflation index.[17] We take x_t to be the log-deviations of output from its slow moving trend, similarly for the measure of financial vulnerability. Hence, the output gap x_t and the measure of financial vulnerability ϑ_t are both expressed in deviations from their unconditional mean.[18] We also append a monetary policy shock ϵ_t^m, which is possibly autocorrelated, when we study the transmission mechanism of monetary policy.

[17] In models with both sticky prices and wages it can be proved that under some conditions it is optimal to respond to the composite inflation index. In our baseline setup, a parameter $\phi_w \simeq 0.5$ gives a good welfare performance. The expected mispricing of risk will be an exception (see Section 5.4).

[18] For a target variable $\widehat{z} = \{x, \vartheta\}$, we define $\widehat{z}_t = z_t - \overline{z}_t$, where $\overline{z}_t = \varsigma \overline{z}_{t-1} + z_t$, where ς should be high but consistent with the choice of the simulation's burn-in—we use $\varsigma = 0.975$, consistent with a convergence to the stationary distribution after about 300 periods. This is a way of targeting deviations from unconditional mean which can prove to vary substantially from the non-stochastic steady state.

2.5. Macroprudential Policy

Within our framework there are two related motives for a macro-prudential policy that encourages banks to use outside equity and discourages the use of short term debt. First, households do not fully internalize the systemic effect of their portfolio allocation choices and their investment in equity is price insensitive. Second, investment decision by financial intermediaries are driven by the objective of maximizing total returns in a way that does not fully capture the household preference for risk and their externality on asset prices. The two distortions imply that risk is mispriced and, thus, asset prices are distorted. We assume that a macro prudential policy instrument, τ_t, is available which is akin to a tax or subsidy on the financial intermediary return on assets, R_t. In section 5.5 we will derive the optimal macro-prudential policy.[19]

2.6. Equilibrium conditions and Aggregation

Goods market clearing implies that output is either consumed or invested

$$Y_t = C_t + I_t + \frac{1}{2}\kappa \left(i_t - \delta\right)^2 K_t + 0.5(\phi_{cp}\pi_t^2 + \phi_{cw}\pi_{w,t}^2)\overline{Y}. \tag{2.23}$$

The value of the financial sector portfolio has to be equal to the overall households' financial investment in the financial intermediaries: $Q_t K_t = W_t = V_t + B_t$.

Finally, aggregating reputation e_t across financial intermediaries, $\mathbf{S}_t$, since a given manager may die at any date at a constant Poisson intensity of $\eta > 0$, the law of motion of the aggregate health (reputation) of the financial sector $\mathbf{S}_t$ is

$$\mathbf{S}_t = \mathbf{S}_{t-1}\left(\gamma_t \tilde{R}_t - \eta\right), \tag{2.24}$$

hence, in equilibrium, the overall financial sector equity is given by

$$V_t = \min\left(\mathbf{S}_{t-1}, (1-\lambda)\,\overline{W}^{1-\gamma_0} W_t^{\gamma_0}\right). \tag{2.25}$$

[19] The macroprudential policy rule applies to all financial intermediaries. There are several practical issues related to using macroprudential policy that go beyond the scope of this paper. See, for example, Gelati and Moessner [24] for a discussion of issues such as risks shifting from one part of the financial system to another, which could potentially undermine the objectives of the policy measure. Also, we abstract from potential moral hazard issues related to the macro-prudential policy.

3. Quantitative analysis

In this section we show that the model has reasonable quantitative properties. We then use the model to evaluate the performance of alternative monetary policy rules.[20] Non-linear models should preferably be solved with global methods. Due to the curse of dimensionality, however, these can be applied only to relatively small models with a limited number of state variables. Following Dewatcher and Wouters [21] we replace the occasionally binding constraint (2.25) with a differentiable function[21]

$$V_t = V(W_t, \mathbf{S}_{t-1}) \equiv \frac{(1-\lambda)\overline{W}^{\gamma_0} W_t^{1-\gamma_0}}{1+\gamma_1 \left(\frac{\overline{W}^{\gamma_0} W_t^{1-\gamma_0}}{\mathbf{S}_{t-1} - \underline{\mathbf{S}}} \right)^3}, \tag{3.1}$$

where $\underline{\mathbf{S}}$ is a constant. Equation (3.1) captures the essential features of the equity constraint, which is higher cost of raising equity during bad times.[22] While it is debatable whether or not this approach can well approximate the original kink, it does generate a system where the elasticity of equity to reputation is about zero in normal times and about 1 when reputation falls below a certain value—which is about 0.6 under our calibration (Figure 9).

3.1. Calibration

The two Tables below list the choice of parameter values for our model. There are [20] main parameters. Seventeen are conventional. Three λ, γ_0, γ are specific to our model. We follow the literature as closely as possible to choose our parameters (see He and Krishnamurthy [33] and Dewachter and Wouters [21]) with the exception of γ_0 which governs the procyclicality of leverage and is set to 1 in the baseline analysis. The annual discount rate, β, is set at 0.96 and the steady-state returns are defined consistently with this parameter. The depreciation rate, δ, is assumed to be 10%. The elasticity of intertemporal substitution for the households, σ, and the inverse of the

[20] The simulation outcomes are generated with the third-order perturbation procedures available in Dynare 4.4.3.

[21] An alternative interpretation of equation (3.1) would be the one of a penalty function (in the same spirit of Rotemberg and Woodford [41] and Kim et al [35]). It is also worth noting that both formulations (the original non-differentiable equity constraint and its differentiable version) can be thought of as reduced forms; hence, there is no obvious *direct* metric to assess which one of them is more realistic but it is only indirectly possible to look at the macroeconomic properties of the model.

[22] Dewatcher and Wouters [21] performs a comprehensive study of the performance of function $V(W_t, S_{t-1})$. Their study shows that the approximation of the HK's original occasionally binding constraint is quite sastisfactory and Figure 9 and Table 7 of their paper show the asymmetry and amplification that the model with the differentiable V function is able to produce.

Frisch labor elasticity, ϕ_L, are both set equal to one. The habit parameter is equal to 0.3. The output elasticity to labor, α, is set at 0.6. The capital adjustment cost is set at a value of 25 which produces a realistic relative volatility of consumption and investment in our model. The price and the wage inflation have a moderate sensitivity to their respective markups with wages behaving more sticky ($\kappa_w = 0.02$) than prices ($\kappa_\pi = 0.10$). Wages are partially indexed to price inflation $\gamma_w = 0.5$. The fixed cost in production is equal to 20% of output and this choice also determines the average markup in price setting and the corresponding elasticity of substitution between individual goods. Fixed costs and nominal stickiness are important in the model as determinants of the amount of operational risk, that is the risk directly related to the volatility of the dividend flow paid out by the firms. Finally, in the baseline case monetary policy is responding to the inflation composite deviations from target with an elasticity of 1.5.

Parameter	Value	Description
β	0.99	Discount factor
h	0.3	Habit
ψ	1	Steady state labor
ϕ_L	1	Inverse Frisch labor elasticity
σ	1	Intertemporal. elasticity of substitution
γ_w	0.5	Wage indexation
δ	0.10	Depreciation of capital a.r.
α	0.6	Output elasticity of labor
Ψ	0.2	Fixed cost in production
η	0.10	Financial interm. exit rate
λ	0.55	Liquidity service share
γ	3.75	Manager risk aversion
γ_0	1	Leverage cyclicality
κ_p	0.10	Price stickiness
κ_w	0.02	Wage stickiness

We calibrate the exogenous processes to match data moments of macroeconomic variables. We use postwar US data from 1960Q1 to 2014Q2, for PCE inflation, real GDP, private consumption, and private business fixed investment to match growth rate volatilities with the ones implied by the model.[23] The model is able to replicate, to some extent given its stylized nature, the standard deviations of key macro variables during normal times and during recessions (defined using the *NBER* recession dating) and the fall in average growth between normal times and recessions (see

[23] We simulate the model, starting from the deterministic steady state, for 1,000 periods. We discard the first 600 periods as a burn-in to eliminate the transition from the deterministic steady state of the model to the ergodic distribution of the state variables.

Table 1).[24]

Parameter	Value	Description
ρ_A	0.92	Temporary Technology Process, persistence
ρ_g	0.75	Persistent Technology Process, persistence
ρ_υ	0.65	Financial Shock Driving Process, persistence
σ_A	0.00430	Temporary Technology shock, standard dev.
σ_g	0.00070	Persistent Technology shock, standard dev.
$corr_{A,g}$	1	Temporary-Persistent Technology shock, correlation
σ_υ	0.30000	Financial shock, standard dev.
σ_m	0.00125	Monetary policy shock standard dev.

[Table 1. Summary Statistics]

We also choose our parameter γ_0 such that the correlation between leverage and the value of financial intermediaries' portfolio W_t is as in the data during normal times and during crisis periods. As documented by Adrian and Shin [1] changes in debt are correlated with changes in the value of total assets while changes in equity are mostly uncorrelated to total assets. The interpretation is that financial intermediaries expand their balance sheet by issuing debt rather than raising equity. The exception is severe financial crisis periods when fire sales reduce the value of assets while the value of liabilities is mostly unchanged. If equity is marked to market then the value of equity follows the reduction in total assets. Table 2 shows that the model is able to replicate these salient features of the data for broker dealers. As pointed out in the literature, however, the procyclicality of commercial bank leverage (and the change in the size of their balance sheet) is substantially lower. As we will see, results are not particularly sensitive to the leverage's degree of cyclicality.

[Table 2 Cyclical properties of leverage, debt, and equity.].

Following He and Krishnamurthy [33] we define systemic crisis as periods where the equity constraints bind. In this situation the elasticity of equity to reputation is equal to 1 ($V_t = \mathbf{S}_t$). Our use of a differentiable function makes the definition of a systemic crisis slightly more arbitrary since the equity elasticity is defined over a continuum. Hence, we define *recessions* as periods of moderate to strong financial stress when the elasticity is greater than 0.5 which implies a threshold for reputation of $e_t < 0.8$. We define a *systemic crisis* when reputation is below 0.5 which implies an elasticity of equity to reputation close to one. Under the baseline calibration the probability

[24] Bad times are defined using the NBER recession dating. Standard deviations for both normal and bad times are centered around the unconditional sample mean.

of a systemic crisis is about 3 percent, i.e. systemic crisis occur approximately every thirty years on average. This probability is chosen to reflect the observation that there have been three major financial crises in the US over the last 100 years. Finally, a severe systemic crisis could be defined as a situation when equity falls below a certain threshold which, in our third order approximation, can be for negative values for equity. When a sufficiently negative value for equity is reached the system becomes explosive. Under our chosen approximation of the equity investment constraint, we usually pass the point of no return when $e_t < 0.1$ and equity is close to zero or negative.

4. Model Analysis

In this section we will explore how the model behaves under the baseline calibration. Since we use a third-order approximation, we also consider how impulse response functions change with the state of the economy: between a state with average reputation and a state with low reputation (a "bad" state).

4.1. Financial cycle vs. business cycle

Empirical literature has documented that the business cycle and the financial cycle (defined according to the choice of some financial variables) are not perfectly aligned (see e.g. Claessens et al. [16] and Borio [11]). This observation has often been brought forward as evidence of a trade-off between systemic risk and output and inflation stabilization goals. Table 2 shows the auto- and cross-correlation between de-trended output and leverage in the model and in the data (both in percent). Under the baseline calibration we find that leverage is more persistent than de-trended output and lags the business cycle. In the data, broker-dealer leverage is also positively and significantly correlated with the output gap, with the highest correlation at one-quarter lagged output gap.

4.2. Impact of TFP and financial shocks to the financial sector and the amplification mechanism

Figure 1 shows how technology shocks affect macroeconomic and financial variables. A negative productivity shock in the real sector reduces realized returns in the financial sector and its perception of health which, in turn, reduces risk appetite leading to excess pricing of risk. The corresponding lower asset price valuations, in a vicious feedback loop, imply lower investment and output. The same mechanism is amplified by the equity constraint in a bad state when financial sector reputation is already low. In this case we observe a sudden and persistent drop in the capacity of the financial sector to bear risk that exacerbates the initial reduction in investment and output. The equity premium (asset prices) increases (decrease) more substantially while leverage *increases* rather than decreasing in the baseline state.

[Figure 1. Negative Total Factor Productivity Shock]

Similarly, the demand-financial shock (Figure 2) shows how a risk-aversion shock in the financial sector can generate movements in leverage and risk premia that affect real sector variables.

[Figure 2. Negative Demand-Financial Shock]

Figure 3 highlights the asymmetry and amplification generated by the financial sector by comparing the same simulation under the 3rd and the 1st order approximation. As shocks occur when reputation is already low the reduction in investment and, thus, GDP is substantially magnified. The return on equity, $\tilde{R}_t$, during normal times is higher under the 3rd order approximation since the capital stock is lower than the efficient one (which is also reflected in a sizeable output gap, see Table 4). During crises, however, $\tilde{R}_t$, drops more substantially in the 3rd order approximation.

[Figure 3. Amplification: 3rd vs. 1st order approximation]

4.3. Impact of a monetary policy shock on the financial sector

A surprise monetary policy tightening has a negative impact on output, inflation, and asset prices. Coupled with an increase in funding costs and the equity premium, this implies a reduction in the financial sector return on investment which reduces its reputation at impact. In general, the monetary policy shock leads to a modest increase in leverage. However, if the surprise happens during a bad state the more persistent fall in asset prices (and, thus, investment)—coupled with a deeper fall in inflation—triggers a sharper reduction in financial equity which leads to a sharp increase in leverage and in the mis-pricing of risk. The monetary policy surprise leads to losses without persistently altering risk taking behavior in the financial sector, which are more affected by the systematic monetary policy behavior (see below). The impact on systemic risk is, thus, mixed and is state dependent. In the bad state, reputation deteriorates substantially and persistently after a surprise monetary policy tightening increasing the fragility of the financial sector for about 2 years.

[Figure 4. Monetary Policy Tightening Shock]

5. Welfare Analysis

Following Faia and Monacelli [23] and Gertler and Karadi [25], among others, we express the household utility function recursively:[25]

$$U_t = u(C_t, L_t) + \beta E_t U_{t+1} \tag{5.1}$$

where $U_t = E_t \sum_{j=0}^{\infty} \beta^j u\left(C_{t+j}, L_{t+j}\right)$ denotes the utility function. We take a third-order approximation of U_t around the deterministic steady state. Using the third-order solution of the model, we then calculate the unconditional expectation of the utility $U = E\left[U_t\right]$ (i.e., welfare, where E denotes the unconditional expectations operator) in each of the separate cases of monetary and macroprudential policies. We rank alternative policies in terms of a steady state consumption equivalent, Δ, given by the fraction of consumption *loss* required to equate welfare in the deterministic steady state, $U^{ss}(\Delta)$, to one resulting from using monetary and macroprudential policies, U^*. Hence the measure of welfare we use is the consumption equivalent value required for the household to be indifferent between $U^{ss}(\Delta)$ and U^*.[26] A higher (less negative) Δ implies a lower consumption equivalent value is required for the household to be indifferent between the alternatives and hence indicates that the policy is more desirable from a welfare point of view.[27] By imposing $U^{ss} = u(\Delta\overline{C}, \overline{L})/(1-\beta) = U^*$ we have[28]

$$\Delta = \frac{1}{(1-h)\overline{C}} \left\{ \left[1 + (1-\sigma)(1-\beta)U^*\right]^{\frac{1}{1-\sigma}} + \frac{\psi \bar{L}^{1+\phi_L}}{(1+\phi_L)} \right\} \tag{5.2}$$

[25] Given that it is a representative household model, the welfare function coincides with the household overall utility function.

[26] We actually measure the welfare loss, for each succesful simulation i, in relation to the first best allocation such that $U^* = U^{ss} - (U^{fp} - U)$, where U^{fp} is the utility under first best and U is the utility reached under the rule in consideration.

[27] An alternative, to be explored in future research, would be to compare the optimal simple rule's welfare and interest rate policy to the one of a Ramsey planner that can use the policy rate and or a macroprudential tool.

[28] We will present the results in terms of $100 \times (\Delta - 1)$. Notice also that since the steady state is distorted it is possible, in principle, to obtain a $\Delta > 0$.

To find the optimal simple monetary and macroprudential policy rules, we then search numerically in the grid of parameters $\{\phi_i, \phi_p, \phi_x, \phi_\theta\}$ where we use the following grid $\phi_i = 0$, $\phi_p = [1, 3]$, $\phi_x = [0, 2]$, $\phi_\theta = [0, 0.5]$, that optimizes U in response to the shocks.

To compute welfare, we simulate the model for 100 years (400 quarters) after dropping the first 500 observations and compute the average value of U_t. If during the simulation reputation drops below a point of no return (about $\mathbf{S}_t < 0.5$, see Figure 9) we record the outturn as failures and move on to draw another seed. We then compare welfare only across commonly successful simulations. We drop rules with a failure rate higher than 20% from the welfare comparison, also to avoid self-selecting few benign simulations.[29]

5.1. Results in absence of systemic risk or in presence of the optimal macro-prudential policy

The standard New Keynesian results prevail in presence of the optimal macroprudential rule which neutralizes the effect of financial frictions on the real economy and aggregate demand. In particular, since the model includes nominal wage rigidities, it is optimal for the central bank to target a composite index which takes into account also wage inflation (see e.g. Erceg et al. [22]).[30] Also, once the composite inflation index is sufficiently stabilized, reacting to the level of output is not welfare improving (see Figure 5).[31] Hence, we confirm the results in Schmitt-Grohé and Uribe [43] who also find that it is welfare reducing to respond to output. Since traditional results were derived in a linear-quadratic approach, our findings suggest that, in the Modigliani-Miller world, time-varying risk premia and higher order non-linearities do not alter the traditional policy prescription.

[29] Alternatively, since some policy rules dramatically change the stability properties of the model, we penalized instability by adjusting welfare and define adjusted (weighted) welfare as the average computable welfare times a fraction l_w of the frequency of stable simulations—where l_w represents the welfare loss given by failure. When $l_w = 0$, we recover the unweighted welfare comparison, when $l_w = 1$, the welfare loss is equivalent to 100% of steady state consumption. Results presented are robust to values of l_w that ranges between 0.02 and 1.

[30] The reason is that fluctuations in both wage and price inflation and the output gap, generate a resource misallocation and a welfare loss. Hence, optimal policy should strike the right balance between stabilization of those three variables. The optimal policy can be approximated by a policy that stabilizes a weighted average of price and wage inflation, where the appropriate weights are function of the relative stickiness of prices and wages.

[31] An intuition for why a policy of responding to output is not appropriate in response to supply shocks such as a technology shock, is that under such policy the nominal interest rate rises whenever output rises. This increase in the nominal interest rate in turn hinders prices falling by as much as marginal costs causing markups to increase. With an increase in markups, output does not increase as much as it would have otherwise, preventing the efficient rise in output.

We will take these results as our benchmark against which we evaluate how the optimal simple rule can be augmented with financial variables once the financial sector is introduced.

[Table 3. Welfare: Baseline with optimal macro pru]

5.2. Reacting to output: the volatility paradox

Reacting to output (in addition to the usual prescription of the model without financial frictions) implies a reduction of macroeconomic volatilities, such as output volatility, during periods or relatively mild shocks—at the cost of higher inflation volatility. We find $\phi_x = 0.51$ and $\phi_p = 1.78$ to be optimal (Table 4).[32] Compressing macroeconomic volatility, however, by reducing risk premia, also generates lower real rates which in turn increase asset prices and, thus, investment and capital stock above their efficient levels—average output is indeed higher. As a result, the financial sector has to finance, through borrowing and higher leverage, a larger investment portfolio. Even though apparently in better shape because of higher asset prices the financial sector is actually more vulnerable to boom-bust cycles when a series of benign shocks, which further increase leverage and compress risk premia, is followed by a series of negative shocks. Overall, depending on the severity of the crisis, welfare can be negatively affected by the intensification of tail events (Figure 5). Indeed, the number of simulations where reputation drops below its lower bound threshold increases as ϕ_x increases. Hence, a reaction to output over and above the optimal reaction is not warranted mainly because its financial stability implications in addition to inflation destabilization.

[Figure 5. Volatility Paradox: Distribution of Output, Inflation and Leverage]

5.3. Reacting to leverage: risk of financial dominance and unintended consequences

A systematic reaction to leverage improves welfare in normal times. However the improvement is small: a modest reaction to leverage, with $\phi_\theta \simeq 0.05$, which would typically induce a change in the policy rate that is about 1 bps larger than otherwise, improves welfare by about 0.05 percent in terms of steady state consumption equivalent, under the baseline calibration (Table 4). Indeed, a modest systematic monetary policy of leaning against the wind implies a reduction in both inflation and output volatility and in the severity of crises (output's skewness is mitigated, especially relative to

[32] Substantial lower values for ϕ_π and/or higher values for ϕ_x lead to higher failure rates and are thus discared from the welfare comparison.

strict inflation targeting) but at the cost of a lower output gap. When leverage is indeed procyclical, $\gamma_0 = 1$, a higher weight on leverage in the monetary policy rule increases the frequency of the failure rate—i.e., possibly severe crises (see Figure 6). As a result, even if the unadjusted welfare increases with a higher weight on leverage, the welfare measure adjusted for the probability of crisis eventually decreases as the weight on leverage increases. The reason is that crises are periods of sharp drops in asset prices, which lead to a reduction in equity greater than the reduction in debt—putting upward pressure on leverage. Hence, a policy rule that reacts to increases in leverage in these circumstances can exacerbate a crisis, penalizing our adjusted welfare metric. Indeed, even though the mass of leverage is more concentrated around a lower value, the tails of the distribution are actually larger (Figure 7 Panel B vs. Panel A). Finally, an even higher weight of leverage in the monetary policy rule results in higher (centered) volatility of inflation as its mean falls below target by about 0.88 p.p. (annual rates). Reacting to systemic risks therefore results in a trade-off between the traditional inflation mandate of monetary policy.

These results are only mildly sensitive to parametrization. When leverage is acyclical, $\gamma_0 = 0$, the optimal reaction to leverage in the policy rule is still positive, $\phi_\theta \simeq 0.07$ (similarly when leverage is countercyclical, $\gamma_0 = -1$) (Figure 6 bottom charts).[33] The reason is that as γ_0 falls, leverage becomes excessively low during normal times driving investment below its potential. A small positive policy rate's reaction to the leverage gap ϑ (which is now *negative* during good times), reduces interest rates and stimulates investment towards its potential level. At the same time, even though the cross-correlation with output decreases as γ_0 falls the one with inflation increases reducing the trade-off of targeting leverage versus stabilizing inflation around its target. Even when leverage is countercyclical, though, a too loose monetary policy would increase the vulnerability of the system to adverse shocks (i.e., systemic risk).

[Figure 6. Monetary Policy Trade-Offs]

[Figure 7. Distribution of leverage]

5.4. Reacting to mispricing of risk: a modest effect

The reaction to the mis-pricing of risk, $\vartheta_t = E_t\omega_{t+1} - \omega_t$, entails less destabilization and the optimal coefficient found is 4.83 (Table 4 and Figure 6). Even though increasing the reaction does not lead to

[33] Setting $\gamma_0 = 0$ ($\gamma_0 = -1$), during good times (no financial crises), the leverage-output correlation is not significant (negative) while the correlation with inflation increases relatively to the baseline case $\gamma_0 = 1$.

increased instability of the system, the benefits in terms of welfare are relatively small. The reason is that even if the mis-pricing of risk is the right target, the simple (i.e., constant coefficients) interest rate rule is still not particularly effective in lowering its mean and mitigating its volatility. This shows how the policy rate ability to affect the financial distortions varies across states. This seems to point to a limit that simple interest rate rules have in mitigating financial risk.[34]

5.5. Robustness: Policy Intertia

The introduction of policy intertia in the monetary policy rule, $\phi_i > 0$, does not alter the main results qualitatively. Some degree of policy intertia improves stability and welfare, however, a higher degree, $\phi_i > 0.6$, induces instability in the system (Figure 8 top left chart): A policy rate that takes too long to react to changing economic conditions allows leverage and bank reputation to depart excessively from their stationary values and, thus, makes the system more vulnerable to shocks. Even though the optimal policy intertia coefficient is around 0.45, the optimal reaction to leverage found in section 5.3 is mostly unaltered (Figure 8).

[Figure 8. Policy Intertia]

5.6. Macroprudential policy

It is instructive to derive the optimal macroprudential policy rule as an instrument rule. The optimal levy on debt, τ_t, imposes a countercyclical tax on financial intermediaries (similar to a countercyclical capital requirement), thus, increasing the cost of funding when it is low and leverage is high. By re-establishing a fair pricing of risk ($\omega_t = 0$), it severs the link between the financial sector and the real economy and re-establishes a Modigliani-Miller world. The optimal targeting rule can be derived by manipulating equation 2.19 and imposing $\omega_t = 0$:

$$\begin{aligned} \tau_t &= \frac{EP_t - \theta_t \gamma_t \mathrm{var}_t\left(R_{t+1}\right)}{R_t^f} \\ 1 &= E_t m_{t,t+1} R_{t+1} \end{aligned} \tag{5.3}$$

which implies

[34] Reacting to the level of the mis-pricing of risk gives lower welfare improvements. Contrary to macroprudential policy, monetary policy alone is not able to implement the allocation without financial frictions since it leads to indeterminacy of the system.

$$\tau_t = -cov(m_{t,t+1}, R_{t+1}) - \frac{\theta_t \gamma_t \text{var}_t (R_{t+1})}{R_t^f} \tag{5.4}$$

The macro-prudential instrument is increased as the equity premium increases since it reflects a higher underlying risk of the economy. However, crises are averted by subsidizing the financial sector when leverage shoots up due to a fall intermediary financial equity. Table 3 and 4 show that the macroprudential policy relative to interest rate policy gives a relative welfare benefit up to 1.5% of steady state consumption equivalent. The sizeable gain is explained by the fact that the macroprudential policy breaks the negative feedback loop which links equity availability to the financial sector and asset prices (low returns-low equity-low asset prices-low returns). In comparison a policy rate that reacts to leverage is a blunt tool which, in an effort to stabilize leverage, tends to destabilize inflation and reduce output. Indeed, the welfare increase from the optimal macroprudential policy does not derive mainly from stabilizing the economy only in good times but by raising the level of investment rate while still mitigating the probability and severe downturns.

6. Conclusions

To analyze the benefit of simple monetary policy rules in the presence of systemic risk, we have developed a model where systemic risk arises endogenously and the behavior of macroeconomic and financial variables approximates data. The findings of our analysis can be summarized as follows: A monetary policy tightening *surprise* does not necessarily reduce systemic risk, particularly when the state of the financial sector is fragile. The negative impact of the surprise tightening on output, inflation, asset prices, and the rise of funding costs for financial intermediaries implies a reduction in profitability of the financial sector without altering their risk taking behavior. Risk taking behavior is affected by *systematic* monetary policy reaction. The negative effects of a monetary policy surprise are mitigated when the financial sector is strong and the surprise is small.

Systematic policy based on a simple (Taylor type) policy rule that includes financial variables such as leverage, can improve welfare by striking a balance between inflation and output stabilization on the one hand and reducing the likelihood of financial stress on the other. A simple policy reaction to leverage, however, implies a relatively tighter policy when a shock induces a decline in asset prices which drives leverage up, exacerbating the initial asset price correction. Leaning against leverage without clearly distinguishing why leverage is increasing could therefore lead to a policy mistake that exacerbates incipient financial stress, possibly inducing a full blown crisis. This result suggests that the monetary policy reaction should go beyond the simple rule described here. Alternative rules could incorporate a non-linear response that differentiates between leaning against the wind in normal times and crisis response one the economy is moving towards financial stress. Alternative financial variables such as measures of mis-pricing of risk have more appealing properties which make them preferable to react to in a simple rule. However, they are less affected by monetary policy, leading to only modest welfare improvements. This seems to point to a limit that simple interest rate rules have in mitigating financial risk. Finally, the optimal macroprudential policy can be derived as an instrument rule which acts similarly to a counter-cyclical capital requirement (making it more costly to raise debt during good times and vice versa). The optimal macroprudential rule, by severing the vicious link between financial sector risk and investment, re-establish a Modigliani-Miller world and improve welfare substantially.

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Appendix

6.1. The Efficient Allocation

We will solve for the (constrained) efficient allocation when the financial sector is a veil and all nominal rigidities are eliminated.

Household Sector (no financial sector) A representative household maximizes the expected utility flow:

$$U_t = E_0 \sum_{t=0}^{\infty} \beta^t u\left(C_t, L_t\right),$$

where β is the discount factor and C_t and L_t denotes consumption and labor effort respectively. The instantaneous utility function is specified as in the text while the intertemporal budget constraint which is given by:

$$C_t + q_t I_t = w_t L_t + r_t^k K_{t-1} + Div_t^{cp} + Div_t,$$

Capital producers rebate their profits Div_t^{cp} to households which are assumed to invest directly in the capital stock, I, and rent it to firms for a return r^k. New capital is purchased at a price q from capital producers. The law of motion of physical capital is

$$K_t = (1-\delta)K_{t-1} + I_t \tag{6.1}$$

The optimal intertemporal condition for capital accumulation provides the following intertemporal condition.

$$q_t = \beta E_t \frac{u_{c,t+1}}{u_{c,t}}[(1-\delta)q_{t+1} + r_{t+1}^k] \tag{6.2}$$

When the price of capital is expected to raise, capital gains adds to the rental rate of capital.

The labor supply is given by

$$w_t = -u_{l,t}/u_{c,t} = \psi L_t^{\phi_L} \tag{6.3}$$

Household (explicit financial sector) It is possible to split the household problem in introduce a financial sector. Assume household do not accumulate physical capital directly but own financial intermediaries which, in turn, invest in physical capital and own final goods firms. The household budget constraint is modified to include the possibility of buying banks' shares and in risk-free debt with banks:

$$C_t + p_t^s x_t + B_t = w_t L_t + (p_t^s + d_t)x_{t-1} + (1 + r_{t-1})B_{t-1} + Div_t^{cp},$$

The household maximization problem gives two equations in addition to the consumption-leisure choice:

$$p_t^s = \beta E_t \frac{u_{c,t+1}}{u_{c,t}} [p_{t+1}^s + d_{t+1}] \tag{6.4}$$

$$1/(1+r_t) = \beta E_t \frac{u_{c,t+1}}{u_{c,t}} \tag{6.5}$$

It is also possible to define $V_t = p_t^s x_t$,$\widetilde{R}_{t+1} = (p_{t+1}^s + d_{t+1})/p_t^s$ and $W_t = V_t + B_t$ such that we have

$$C_t + W_t = w_t L_t + \widetilde{R}_t V_{t-1} + (1+r_{t-1})B_{t-1} + Div_t^{cp},$$

$$1 = \beta E_t \frac{u_{c,t+1}}{u_{c,t}} [\widetilde{R}_{t+1}] \tag{6.6}$$

Accumulation of physical capital is done by banks. Since q_t is the price of (new and old) installed capital, the value of total capital is $q_t K_t$. The bank can issue shares and one-period debt. The bank maximizes current and future dividends per share using the discount factor $m_{t,t+j}$:[35]

$$E_0 \sum_{t=0}^{\infty} m_{0,t} d_t,$$

subject to

$$\begin{aligned} D_t &= d_t x_{t-1} = r_t^k K_{t-1} + Div_t + B_t + p_t^s \Delta x_t - q_t I_t - (1+r_{t-1})B_{t-1} \\ K_t &= (1-\delta)K_{t-1} + I_t \end{aligned}$$

The consolidated budget constraint is also identical to the previous one. We define the adjusted discount factor as $\tilde{m}_{t,t+1} = m_{t,t+1} x_{t-1}/x_t$.The first order conditions, after some algebra, are analog

[35] The timing is as follows: banks can use debt and cash flow from physical capital to pay dividends to the current shareholders $d_t x_{t-1} + Nd_t = r_t^k K_{t-1} + Div_t + B_t - (1+r_{t-1})B$, where $Nd_t \geq 0$ are non distributed dividends (retained earnings). After that, new shares are potentially issued to investment together with retained earnings $q_t I_t = p_t^s \Delta x_t + Nd_t$. Hence, new shares will receive tomorrow's dividends consistently with the convention used in the household problem to determined demand for shares. Only when the constraint is binding $Nd_t = 0$ the two problems differ. We assume it does not bind.

to 6.2

$$\begin{aligned} p_t^s &= E_t \tilde{m}_{t,t+1}[p_{t+1}^s + d_{t+1}] & (6.7)\\ q_t &= E_t \tilde{m}_{t,t+1}[(1-\delta)q_{t+1} + r_{t+1}^k] & (6.8)\\ 1 &= E_t \tilde{m}_{t,t+1}[1 + r_t] & (6.9)\end{aligned}$$

If the bank is rasing capital to finance investment then it discounts more future returns. If $m_{t,t+1} = \beta \frac{u_{c,t+1}}{u_{c,t}}$, equilibrium in the bond market implies that $E_t \tilde{m}_{t,t+1} = E_t m_{t,t+1} x_{t-1}/x_t = E_t m_{t,t+1}$, which implies $x_t = x_{t-1}$. Hence, allocation is the same as above and the banking sector is a veil.

6.2. Real Sector (Production)

Following the NK framework, there is a continuum of monopolist firms that produce differentiated goods according to the technology

$$Y_t = F(L_t, K_t^d) - \Phi_Y = A_t L_t^{\alpha} K_{t-1}^{1-\alpha} - \Phi_Y \tag{6.10}$$

where the demand for individual firm's output is given by $y_t^* = (p_t^*/P_t)^{-\epsilon} Y_t$, while they pay wages w and rental rates r^k for labor and capital. We already impose the equilibrium condition that demand for capital is equal to the supply $K_t^d = K_t$.The marginal cost mc_t is function of the factor prices (wage and rental rate of capital) and TFP. In equilibrium, since prices are flexible, is equal to the inverse of the markup $\mu_p = \epsilon/(\epsilon - 1)$.

$$mc_t = \frac{w_t^{\alpha} r_{k,t}^{1-\alpha}}{A_t \alpha^{\alpha}(1-\alpha)^{1-\alpha}} = 1/\mu_p$$

The labor demand is given by

$$\begin{aligned} w_t &= \alpha A_t (K_{t-1}/L_t)^{1-\alpha}/\mu_p & (6.11)\\ r_t^k &= (1-\alpha) A_t (L_t/K_{t-1})^{\alpha}/\mu_p \\ Div_t &= (Y_t - \overline{Y})/\epsilon \end{aligned}$$

We choose $\Phi = \overline{Y}/(\epsilon - 1)$ to guarantee zero profits in the non-stochastic steady state.[36]

[36] Notice that total costs are equal to marginal costs times output gross of the fix cost: $TC = mc(Y + \Phi)$.

Capital goods producers Capital goods producers, owned by households, produce investment goods (new capital) which are sold to the intermediary sector at a price q_t.[37] Hence, the intermediary sector's valuation of capital, q_t, also drives investment. Given q_t , investment is chosen to solve,

$$\max_{i_t} q_t I_t - I_t - \Phi\left(I_t/K_{t-1}, K_{t-1}\right).$$

where $\Phi\left(I_t/K_{t-1}, K_t\right) = 0.5\kappa(i_t - \delta)^2 K_t$ is a cost function which depends on aggregate capital and include capital adjustment costs. Optimality implies[38]

$$I_t/K_t = \delta + \frac{(q_t - 1)}{\kappa} \tag{6.12}$$

In the deterministic steady state capital producers earn zero profit, however, when $q_t > 1$ ($q_t < 1$) we they earn positive (negative) profits: $Div_t^{cp} = (q_t - 1)(\delta + \frac{q_t - 1}{2\kappa})K_t$.

Resource Constraint (Equilibrium) The equilibrium in the capital market implies that $K_t^d = K_{t-1}$.The equilibrium in the good market implies that output is[39]

$$Y_t = C_t + I_t + \Phi\left(I_t/K_{t-1}, K_{t-1}\right)$$

[37] In the deterministic steady state capital producers make zero profits. A $q > 1$ ($q < 1$) implies positive (negative) profits: $\text{div}_t = (q_t - 1)(\delta + \frac{q_t - 1}{2\kappa})K_t$

[38] Notice that the relation between investment and q_t is the same as the one prevailing in presence of capital adjustment costs in a traditional real business cycle model (Hayashi [32]).

[39] It is straightforward to derive the resource constraint from budget constraint of the household.

Tables and Figures

Table 1. Summary Statistics (in percent)

Data

Moments based on NBER Recessions (1960Q1 - 2014Q2)			
	Std Dev Recession	Std Dev Non-Recession	Mean Resession - Mean Non-Recession
Real GDP Growth Rate	5.58	2.94	-5.39
Private Consumption	4.57	2.34	-3.67
Private Business Fixed investment	14.98	7.12	-14.91
Hours worked	6.92	2.74	-4.76

Baseline Simulation.

Model based moments			
	Std Dev Recession	Std Dev Non-Recession	Mean Resession - Mean Non-Recession
Real GDP Growth Rate	6.00	4.07	-4.06
Private Consumption	2.87	2.38	-1.62
Private Business Fixed investment	17.50	10.48	-12.68
Hours worked	4.62	2.93	-2.93

Note: Standard deviations are centered on the sample mean. The third column represents the difference in average growth rates between recession and non-recession periods. We define recessions as periods of moderate to strong financial stress when the elasticity is greater than 0.5 which implies a threshold for reputation of 0.8.

Table 2 Cyclical properties of leverage, debt, and equity.

		Model	Data
Slope	(ΔV, ΔW)	-0.25	0.08
	(ΔB, ΔW)	1.3***	1.1***
Auto-corr.	Y	0.90	0.90
	θ	0.95	0.70
Cross-corr.	(θ,Y(t-j))	0.4, j=7	0.3, j=1

Note: Slopes based on regressing changes in total financial assets (ΔW) versus changes in equity (ΔV) and debt (ΔB) in the model and in the data for broker-dealers from financial accounts. Stars (***) denote significance at 1 percent. Data sample is 1960Q1-2014Q2. Autocorrelations and cross-correlations of de-trended output (Y) and leverage (θ) in the model and the data. Data is HP-filtered (lambda=1600) real GDP and broker-dealer leverage 1980Q1-2014Q2.

Table 3 Welfare: Interest Rate Rules under optimal macro-pru policy

[ϕ(π),ϕ(x)]	Welfare Δ	σ(π)	σ(x)	Failure Rate
[30,0]	-0.0424	0.00081	0.0052	0
[40,0]	-0.0425	0.00083	0.0051	0
[20,0]	-0.0425	0.00080	0.0053	0
[1.75, 0.5]	-0.0851	0.00180	0.0051	0

Note: Welfare is in deviation from first best welfare and expressed in terms of steady state consumption equivalent. Linear 10x10 grid $\in [\phi_\pi, \phi_x] \in [1,2]x[0,2]$ then a coarser grid $[\phi_\pi, \phi_x] \in [2,50]x[2,5]$. Macro prudential policy implemented as described in Section 5.5.

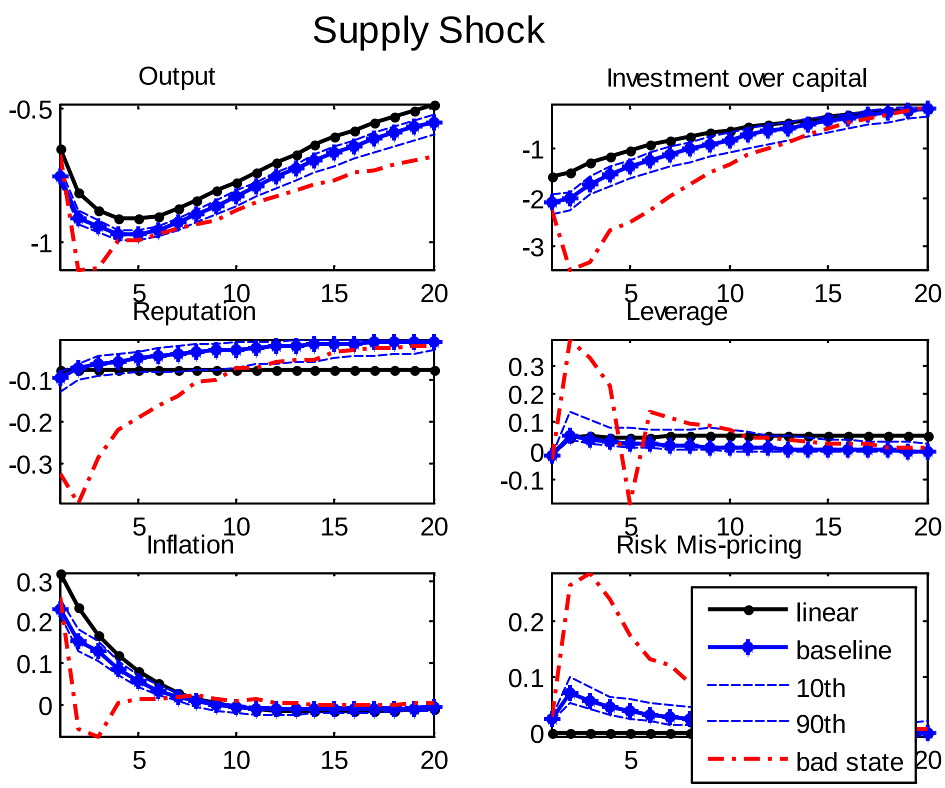
Table 4 Welfare: Optimal Interest Rate Rules

[ϕ(π),ϕ(x)]	Welfare Δ	Failure Rate	σ(π)	σ(x)	μ(π)	μ(x)	*skew(x)*
[30,0]	-2.1056	0	0.0008	0.0086	0	-0.1038	-0.343
[1.78, 0.51]	-1.6190	0	0.0021	0.0069	-0.0009	-0.0775	-0.122
ϕ(ω) = 4.83	-1.5674	0.032	0.0019	0.0072	-0.0022	-0.0797	-0.092
ϕ(θ) = 0.03	-1.5672	0.05	0.0019	0.0071	-0.0021	-0.0794	-0.119

Note: Welfare is in deviation from first best welfare and expressed in terms of steady state consumption equivalent. Linear 50x50 grid $\in [\phi, \phi_x] \in [1.3,3]x[0,2]$. The optimal weight for ϕ(ω) and ϕ(θ) is calculated keeping $[\phi_\pi, \phi_x] =$[1.78, 0.51]. The (fine) grid for ϕ(θ) and ϕ(ω) is [-0.5, 0.5] and [0, 8], respectively.

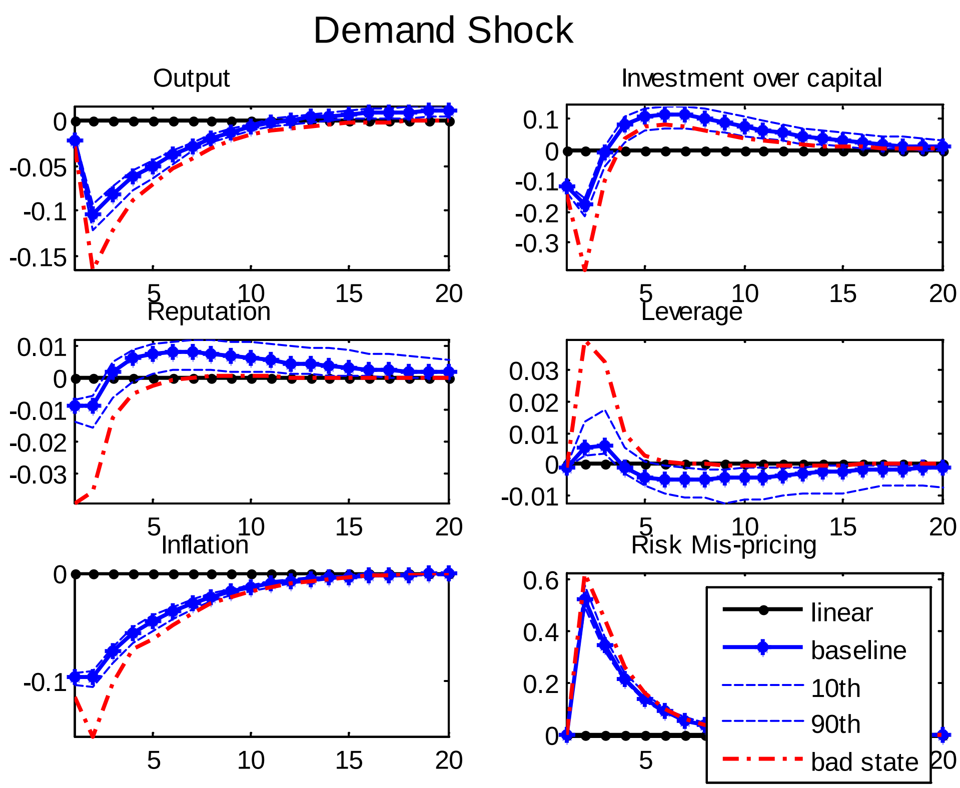
Figures

Figure 1. Negative Total Factor Productivity Shock



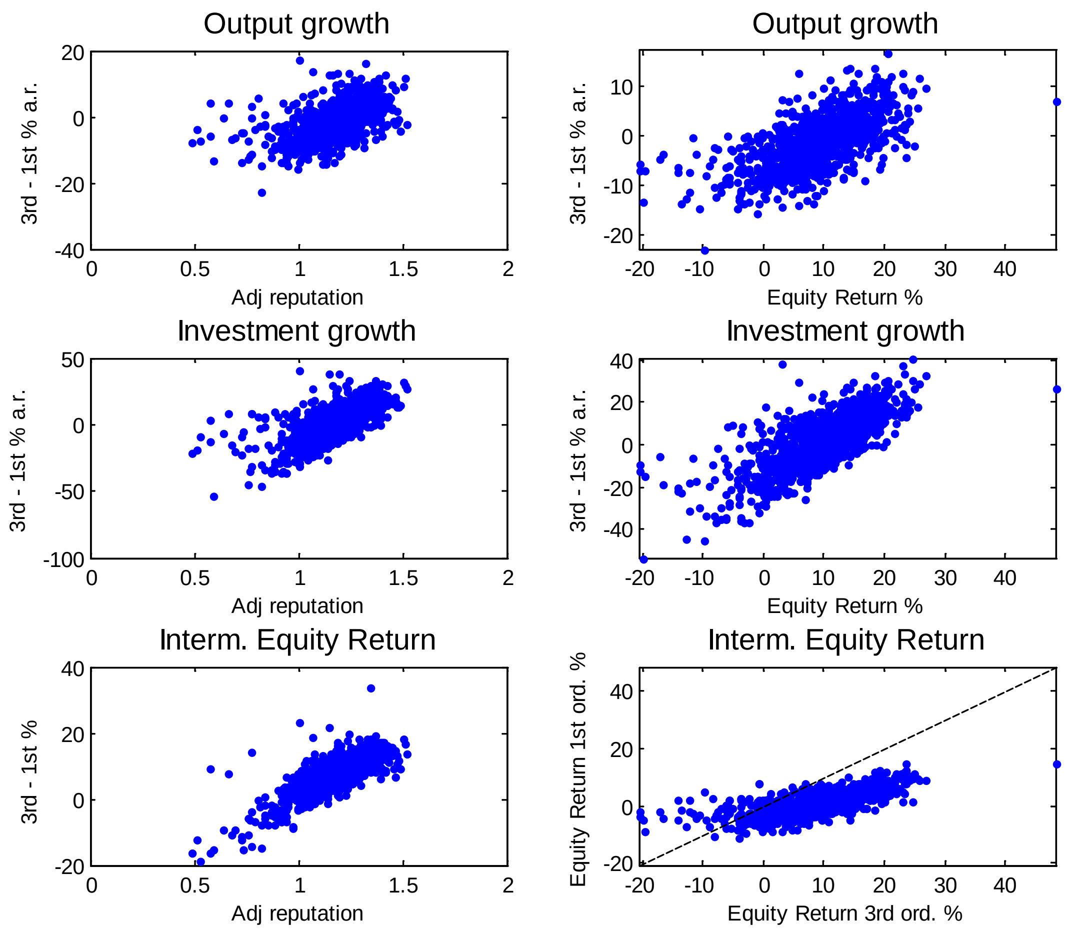
Note: Response to a one st. dev. negative TFP shock under the baseline. A bad state refers to a state with low reputation. A bad state impulse response function is defined as the mean reaction conditional to the 4-quarter average of reputation being below its 2.5th percentile. The average state impulse response function is defined as the unconditional mean reaction. Dashed blue lines are confidence bands. The black lines are the IRFs under the 1st order approximation.

Figure 2. Negative Demand/Financial Shock



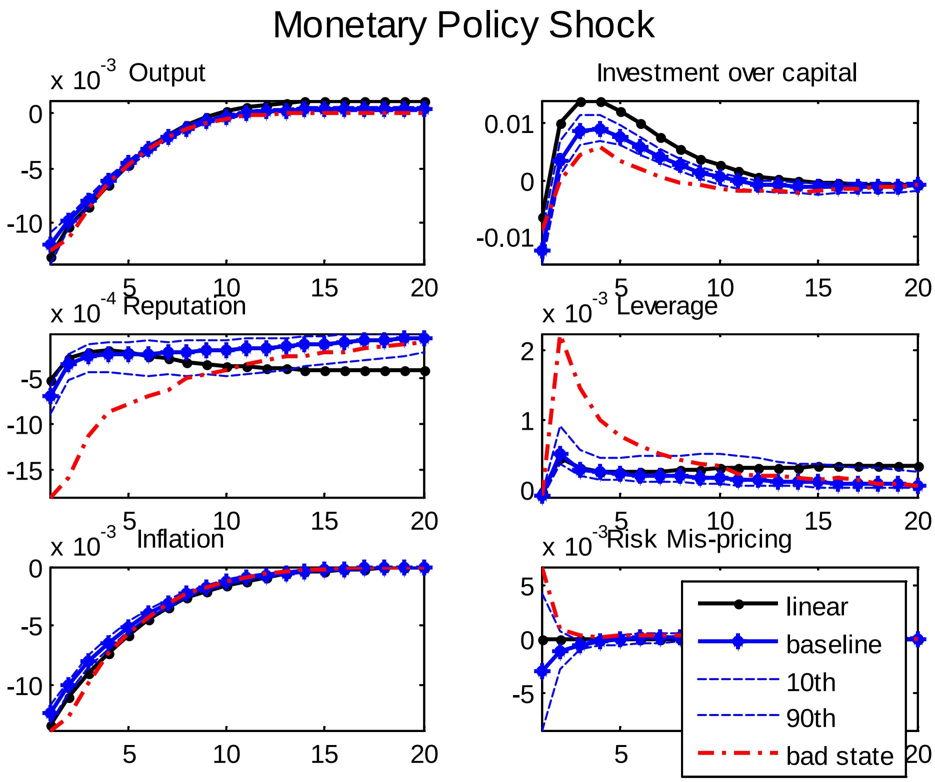
Note: Note: Response to a one st. dev. negative demand shock under the baseline. A bad state refers to a state with low reputation. A bad state impulse response function is defined as the mean reaction conditional to the 4-quarter average of reputation being below its 2.5th percentile. The average state impulse response function is defined as the unconditional mean reaction. Dashed blue lines are confidence bands. The black lines are the IRFs under the 1st order approximation.

Figure 3. Amplification: 3rd vs. 1st order approximation



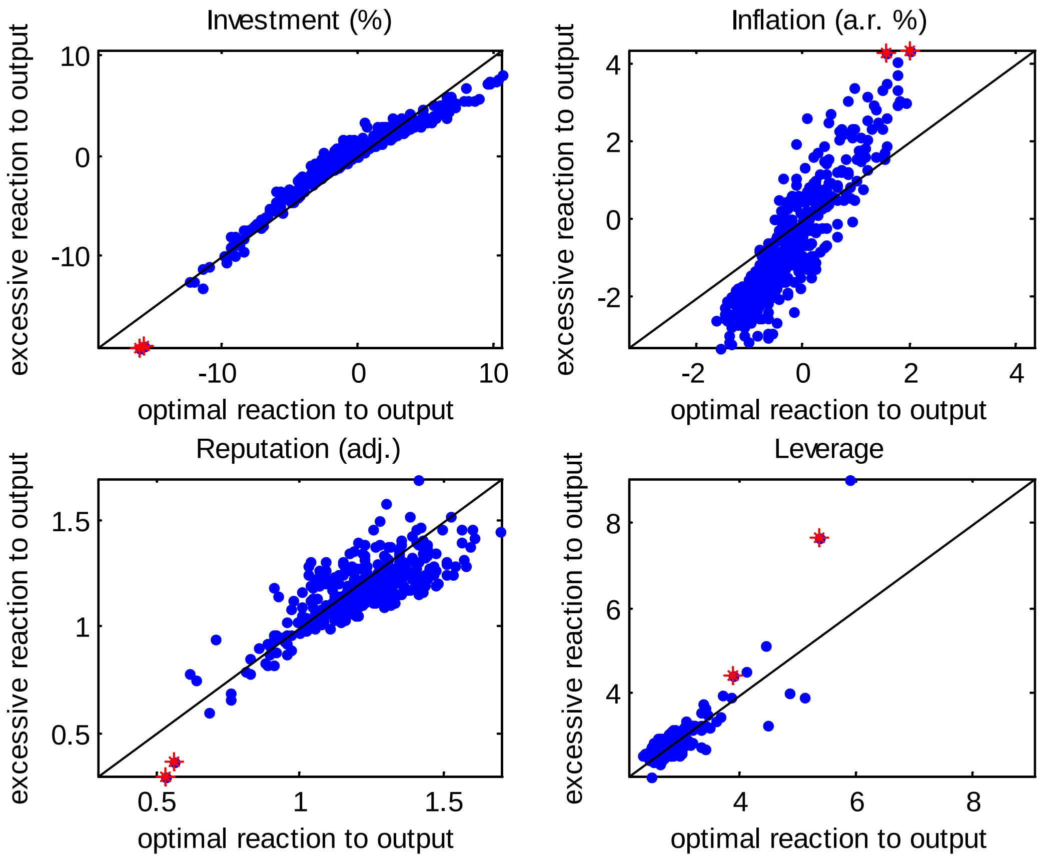
Note. All charts (excluding the bottom right) shows the difference, under the baseline calibration, for a set of variables, between the 3rd and 1st order approximation relative to values for reputation-capital ratio (adj. reputation), on the left side, and the financial intermediary return on equity. The bottom right chart shows the return on equity under the 1st order approximation relative to the 3rd order. Using the same seed for both 3rd and 1st order approximation, the simulation length is 1000 periods with 600 periods of burn-in.

Figure 4. Monetary Policy Tightening Shock



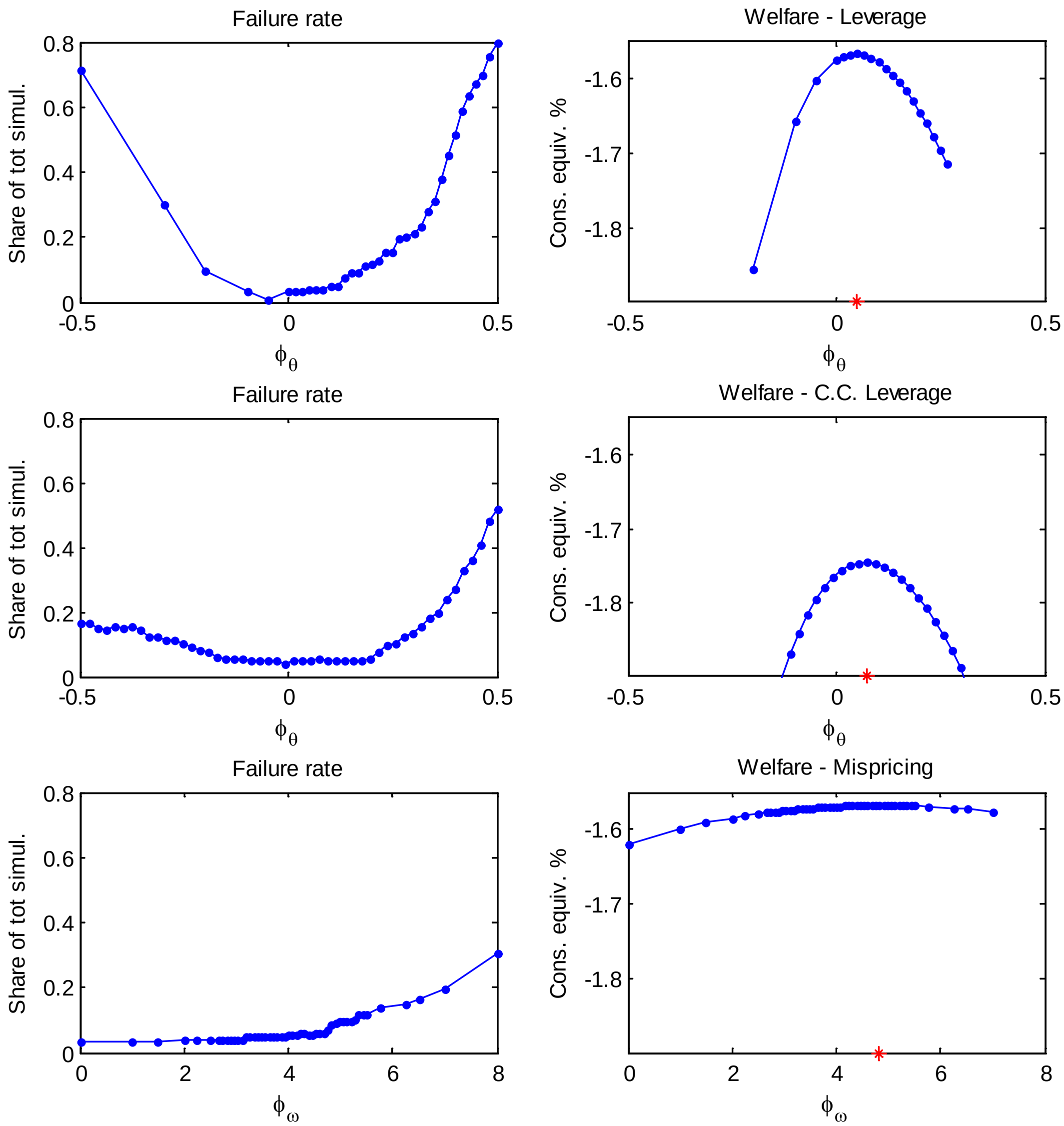
Note: Response to a one st. dev. monetary policy tightening shock under the baseline. A bad state refers to a state with low reputation. A bad state impulse response function is defined as the mean reaction conditional to the 4-quarter average of reputation being below its 2.5th percentile. The average state impulse response function is defined as the unconditional mean reaction. Dashed blue lines are confidence bands. The black lines are the IRFs under the 1st order approximation.

Figure 5. Volatility Paradox: Investment, Inflation, Reputation, and Leverage



Note: Simulations (1000 periods and 600 periods of burn-in) with optimal reaction to inflation and output $\phi_x = 0.51$ and $\phi_\pi = 1.78$ (x-axis) and with $\phi_x = 2$ (y-axis). Red stars denote low reputation values. Adjusted reputation is reputation divided by capital. Investment is expressed in percent log-deviations from steady state while inflation is ARP percent.

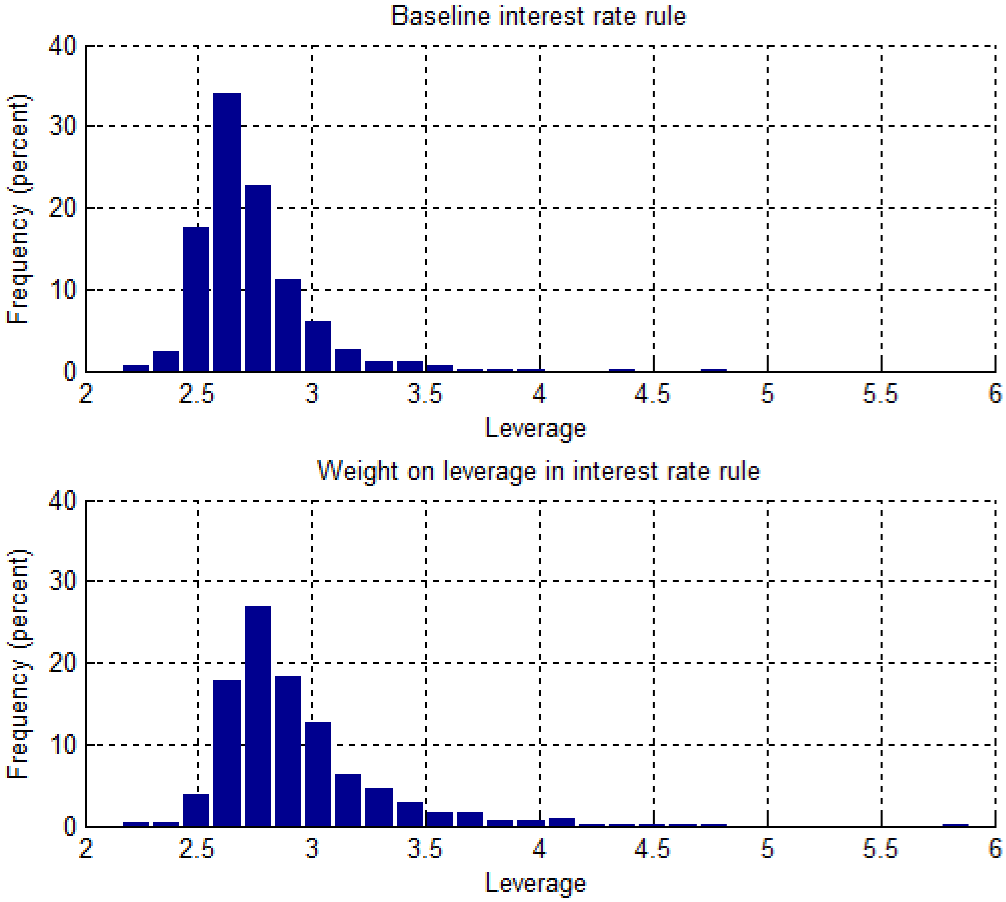
Figure 6. Monetary Policy Trade-Offs: Leaning against Leverage



Note: Top charts show the failure rate and welfare for rules reacting to pro-cyclical leverage ($\gamma_0 = 1$) while middle charts assume leverage is counter-cyclical in normal times ($\gamma_0 = 0$). Bottom charts show the failure rate and welfare when rules react to the mispricing of risk. Welfare is expressed in steady state consumption equivalent. Simulations' length is 1000 periods with a 600 periods burn-in. Rules with a failure rate above 20% have been dropped from welfare comparison to use a comparable subset of successful simulations across all rules. Red asterisks denote the peak.

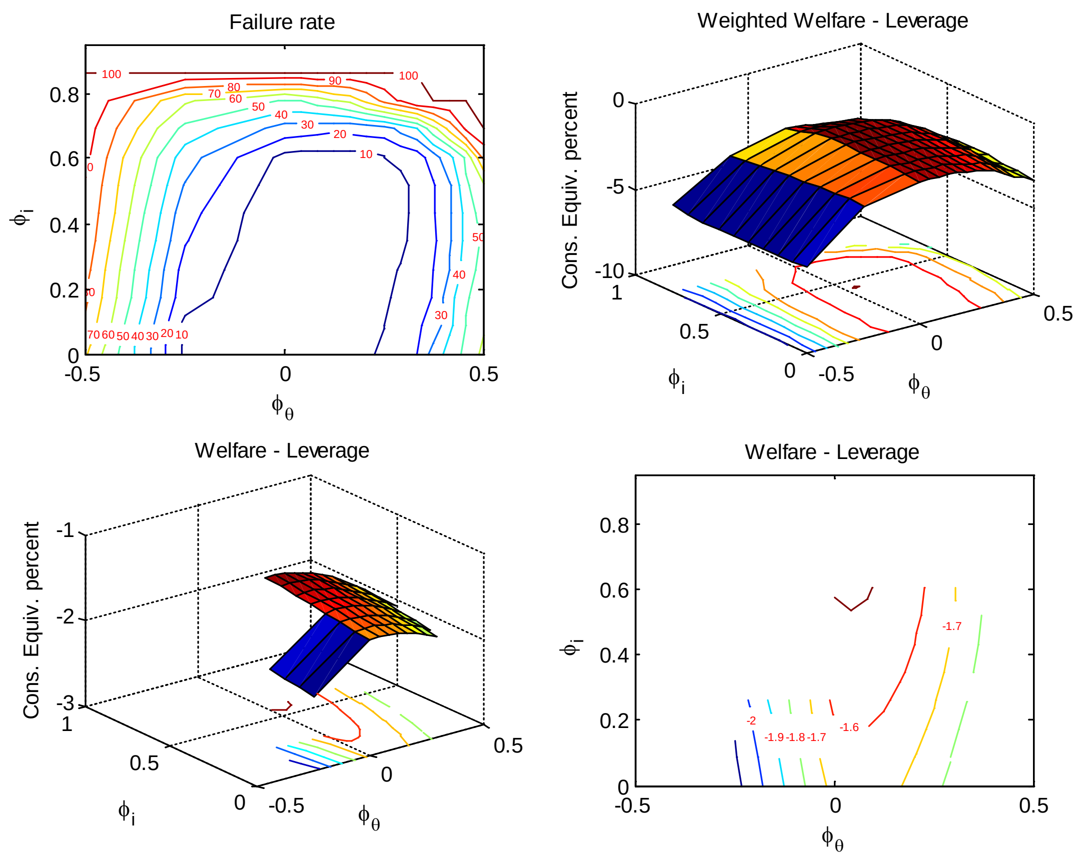
Figure 7. Distribution of leverage

Baseline vs. leverage in interest rate rule



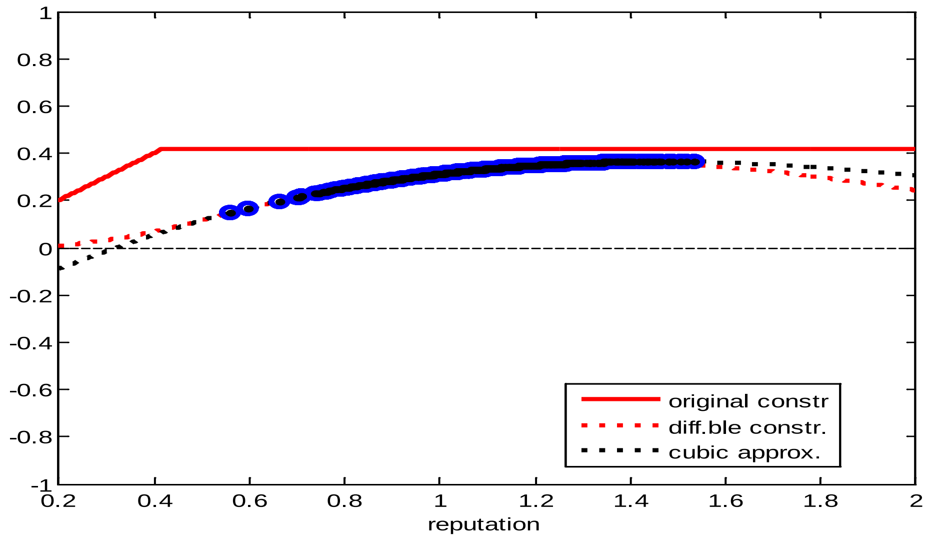
Note: Histograms of leverage for a path of the simulated economy with the baseline monetary policy rule ($\phi_\theta = 0$) and with a monetary policy rule with a higher weight on leverage ($\phi_\theta = 0.25$). The simulation length is 1000 periods with 600 periods of burn-in

Figure 8. Monetary Policy Trade-Offs: The Role of Interest Rate Smoothing



Note: Charts show the failure rate and welfare for rules reacting to leverage while varying the interest rate smoothing parameter in the range [0, 0.95]. The top right chart shows the welfare weighted by failure rate while the bottom charts show the (unweighted) welfare both are expressed in steady state consumption equivalent. Simulations' length is 1000 periods with a 600 periods burn-in. For the bottom charts, rules with a failure rate above 20% have been dropped from welfare comparison to use a comparable subset of successful simulations across all rules. Red asterisks denote the peak.

Figure 9 Approximation of the Equity Constraint



Note. The chart shows equity as function of reputation under various assumptions: The red line represents the theoretical relation, the dashed red line the non-polynomial approximation, and the black dashed line polynomial approximation. Blue circles represent actual realization from a 1000 periods simulation under the baseline calibration.

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Bayesian forecast combination for VAR models 2007:216
by Michael K. Andersson and Sune Karlsson

Do Central Banks React to House Prices? 2007:217
by Daria Finocchiaro and Virginia Queijo von Heideken

The Riksbank's Forecasting Performance 2007:218
by Michael K. Andersson, Gustav Karlsson and Josef Svensson

Macroeconomic Impact on Expected Default Freqency 2008:219
by Per Åsberg and Hovick Shahnazarian

Monetary Policy Regimes and the Volatility of Long-Term Interest Rates 2008:220
by Virginia Queijo von Heideken

Governing the Governors: A Clinical Study of Central Banks 2008:221
by Lars Frisell, Kasper Roszbach and Giancarlo Spagnolo

The Monetary Policy Decision-Making Process and the Term Structure of Interest Rates 2008:222
by Hans Dillén

How Important are Financial Frictions in the U S and the Euro Area 2008:223
by Virginia Queijo von Heideken

Block Kalman filtering for large-scale DSGE models 2008:224
by Ingvar Strid and Karl Walentin

Optimal Monetary Policy in an Operational Medium-Sized DSGE Model 2008:225
by Malin Adolfson, Stefan Laséen, Jesper Lindé and Lars E. O. Svensson

Firm Default and Aggregate Fluctuations 2008:226
by Tor Jacobson, Rikard Kindell, Jesper Lindé and Kasper Roszbach

Re-Evaluating Swedish Membership in EMU: Evidence from an Estimated Model 2008:227
by Ulf Söderström

Stylized (Arte) Facts on Sectoral Inflation 2011:254
by Ferre De Graeve and Karl Walentin

Hedging Labor Income Risk 2011:255
by Sebastien Betermier, Thomas Jansson, Christine A. Parlour and Johan Walden

Taking the Twists into Account: Predicting Firm Bankruptcy Risk with Splines of Financial Ratios 2011:256
by Paolo Giordani, Tor Jacobson, Erik von Schedvin and Mattias Villani

Collateralization, Bank Loan Rates and Monitoring: Evidence from a Natural Experiment 2012:257
by Geraldo Cerqueiro, Steven Ongena and Kasper Roszbach

On the Non-Exclusivity of Loan Contracts: An Empirical Investigation 2012:258
by Hans Degryse, Vasso Ioannidou and Erik von Schedvin

Labor-Market Frictions and Optimal Inflation 2012:259
by Mikael Carlsson and Andreas Westermark

Output Gaps and Robust Monetary Policy Rules 2012:260
by Roberto M. Billi

The Information Content of Central Bank Minutes 2012:261
by Mikael Apel and Marianna Blix Grimaldi

The Cost of Consumer Payments in Sweden 2012:262
by Björn Segendorf and Thomas Jansson

Trade Credit and the Propagation of Corporate Failure: An Empirical Analysis 2012:263
by Tor Jacobson and Erik von Schedvin

Structural and Cyclical Forces in the Labor Market During the Great Recession: Cross-Country Evidence 2012:264
by Luca Sala, Ulf Söderström and AntonellaTrigari

Pension Wealth and Household Savings in Europe: Evidence from SHARELIFE 2013:265
by Rob Alessie, Viola Angelini and Peter van Santen

Long-Term Relationship Bargaining 2013:266
by Andreas Westermark

Using Financial Markets To Estimate the Macro Effects of Monetary Policy: An Impact-Identified FAVAR* 2013:267
by Stefan Pitschner

DYNAMIC MIXTURE-OF-EXPERTS MODELS FOR LONGITUDINAL AND DISCRETE-TIME SURVIVAL DATA 2013:268
by Matias Quiroz and Mattias Villani

Conditional euro area sovereign default risk 2013:269
by André Lucas, Bernd Schwaab and Xin Zhang

Nominal GDP Targeting and the Zero Lower Bound: Should We Abandon Inflation Targeting?* 2013:270
by Roberto M. Billi

Un-truncating VARs* 2013:271
by Ferre De Graeve and Andreas Westermark

Housing Choices and Labor Income Risk 2013:272
by Thomas Jansson

Identifying Fiscal Inflation* 2013:273
by Ferre De Graeve and Virginia Queijo von Heideken

On the Redistributive Effects of Inflation: an International Perspective* 2013:274
by Paola Boel

Business Cycle Implications of Mortgage Spreads* 2013:275
by Karl Walentin

Approximate dynamic programming with post-decision states as a solution method for dynamic economic models *by Isaiah Hull* 2013:276

A detrimental feedback loop: deleveraging and adverse selection 2013:277
by Christoph Bertsch

Distortionary Fiscal Policy and Monetary Policy Goals 2013:278
by Klaus Adam and Roberto M. Billi

Predicting the Spread of Financial Innovations: An Epidemiological Approach 2013:279
by Isaiah Hull

Firm-Level Evidence of Shifts in the Supply of Credit 2013:280
by Karolina Holmberg

SPEEDING UP MCMC BY DELAYED ACCEPTANCE AND DATA SUBSAMPLING 2015:307
by MATIAS QUIROZ

Modeling financial sector joint tail risk in the euro area 2015:308
by André Lucas, Bernd Schwaab and Xin Zhang

Score Driven Exponentially Weighted Moving Averages and Value-at-Risk Forecasting 2015:309
by André Lucas and Xin Zhang

On the Theoretical Efficacy of Quantitative Easing at the Zero Lower Bound 2015:310
by Paola Boel and Christopher J. Waller

Optimal Inflation with Corporate Taxation and Financial Constraints 2015:311
by Daria Finocchiaro, Giovanni Lombardo, Caterina Mendicino and Philippe Weil

Fire Sale Bank Recapitalizations 2015:312
by Christoph Bertsch and Mike Mariathasan

Since you're so rich, you must be really smart: Talent and the Finance Wage Premium 2015:313
by Michael Böhm, Daniel Metzger and Per Strömberg

Debt, equity and the equity price puzzle 2015:314
by Daria Finocchiaro and Caterina Mendicino

Trade Credit: Contract-Level Evidence Contradicts Current Theories 2016:315
by Tore Ellingsen, Tor Jacobson and Erik von Schedvin

Double Liability in a Branch Banking System: Historical Evidence from Canada 2016:316
by Anna Grodecka and Antonis Kotidis

Subprime Borrowers, Securitization and the Transmission of Business Cycles 2016:317
by Anna Grodecka

Real-Time Forecasting for Monetary Policy Analysis: The Case of Sveriges Riksbank 2016:318
by Jens Iversen, Stefan Laséen, Henrik Lundvall and Ulf Söderström

Fed Liftoff and Subprime Loan Interest Rates: Evidence from the Peer-to-Peer Lending 2016:319
by Christoph Bertsch, Isaiah Hull and Xin Zhang

Curbing Shocks to Corporate Liquidity: The Role of Trade Credit 2016:320
by Niklas Amberg, Tor Jacobson, Erik von Schedvin and Robert Townsend

Firms' Strategic Choice of Loan Delinquencies 2016:321
by Paola Morales-Acevedo

Fiscal Consolidation Under Imperfect Credibility 2016:322
by Matthieu Lemoine and Jesper Lindé

Challenges for Central Banks' Macro Models 2016:323
by Jesper Lindé, Frank Smets and Rafael Wouters

The interest rate effects of government bond purchases away from the lower bound 2016:324
by Rafael B. De Rezende

COVENANT-LIGHT CONTRACTS AND CREDITOR COORDINATION 2016:325
by Bo Becker and Victoria Ivashina

Endogenous Separations, Wage Rigidities and Employment Volatility 2016:326
by Mikael Carlsson and Andreas Westermark

Renovatio Monetae: Gesell Taxes in Practice 2016:327
by Roger Svensson and Andreas Westermark

Adjusting for Information Content when Comparing Forecast Performance 2016:328
by Michael K. Andersson, Ted Aranki and André Reslow

Economic Scarcity and Consumers' Credit Choice 2016:329
by Marieke Bos, Chloé Le Coq and Peter van Santen

Uncertain pension income and household saving 2016:330
by Peter van Santen

Money, Credit and Banking and the Cost of Financial Activity 2016:331
by Paola Boel and Gabriele Camera

Oil prices in a real-business-cycle model with precautionary demand for oil 2016:332
by Conny Olovsson

Financial Literacy Externalities 2016:333
by Michael Haliasso, Thomas Jansson and Yigitcan Karabulut

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