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The Tradeoffs in Leaning Against the Wind

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ABSTRACT

Credit booms sometimes lead to financial crises which are accompanied with severe and persistent economic slumps. Does this imply that monetary policy should "lean against the wind" and counteract excess credit growth, even at the cost of higher output and inflation volatility? We study this issue quantitatively in a standard small New Keynesian dynamic stochastic general equilibrium model which includes a risk of financial crisis that depends on "excess credit". We compare monetary policy rules that respond to the output gap with rules that respond to excess credit. We find that leaning against the wind may be attractive, depending on several factors, including (1) the severity of financial crises;(2) the sensitivity of crisis probability to excess credit; (3) the volatility of excess credit; (4) the level of risk aversion.

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1 Introduction

Following the Global Financial Crisis of 2008, policymakers around the world have made it a priority to reduce the risk of future crises. New prudential and regulatory policies have been developed to promote financial stability. But the question of whether financial stability concerns should play a role in the setting of monetary policy remains controversial. In this paper we investigate the wisdom of what has come to be known as "leaning against the wind" (LAW), that is having monetary policy react to perceived financial imbalances such as excess credit growth, which has been found empirically to predict financial crises.[1]

One argument against LAW is that financial stability could be better delivered by an appropriate set of macroprudential policies, that is making prudential and regulatory policies respond to the state of the economy, which would leave monetary policy free to focus on its usual inflation and output stability objectives.[2] While this separation is attractive in principle, we believe it is often difficult to implement practically (as recently explained by Dudley (2015)). Many countries such as the United States have a limited set of macro-prudential tools, and suffer from a dispersion of regulatory authorities. The tools are difficult and slow to adjust, and their effects remain fairly uncertain. Monetary policy has broad effects (it "gets in all the cracks" as Stein (2013) famously noted) while macro-prudential tools are perhaps too narrow (e.g. they lead to a migration of activities from the regulated banking system to the unregulated shadow banking system). These considerations motivate our focus on monetary policy.

The second main argument against LAW is that under inflation targeting, stabilizing inflation is sufficient to stabilize the macroeconomy, as argued by Bernanke and Gertler (1999).[3] Even if there is a trade-off, monetary policy has likely small effects on the likelihood of financial crises, so that having a meaningful effect on this likelihood would require a large interest rate change, at the cost of a large deviation of output and inflation relative to what could be achieved. This argument

[1] See Schularick and Taylor (2012).

[2] For instance, see Korinek and Simsek (2016) and Farhi and Werning (2016).

[3] A distinct argument states that it is preferable to "mop up after the crash", but this argument seems less compelling now in light of the difficulties in stabilizing the economy in the aftermath of the most recent financial crises - for instance, the zero lower bound and reduced potency of monetary policy when agents want to deleverage.

has been made most clearly by Svensson (2016).

Our starting point is that financial crises are very costly. As Reinhart and Rogoff (2009) and Cerra and Saxena (2008) emphasized even before the most recent crisis, recovery from crises are typically slow so that the hangover from a crisis is different than from a regular recession. Figure 1 shows GDP since the crisis and suggests that there has been a permanent drop in the level of GDP amounting to about 13 percent. More studies since then have documented that financial crises have very persistent effects.[4] Preventing a crisis may, therefore, bring different benefits than those associated with smoothing out inefficient business cycle fluctuations (Barro (2009)). This consideration features prominently in our analysis.

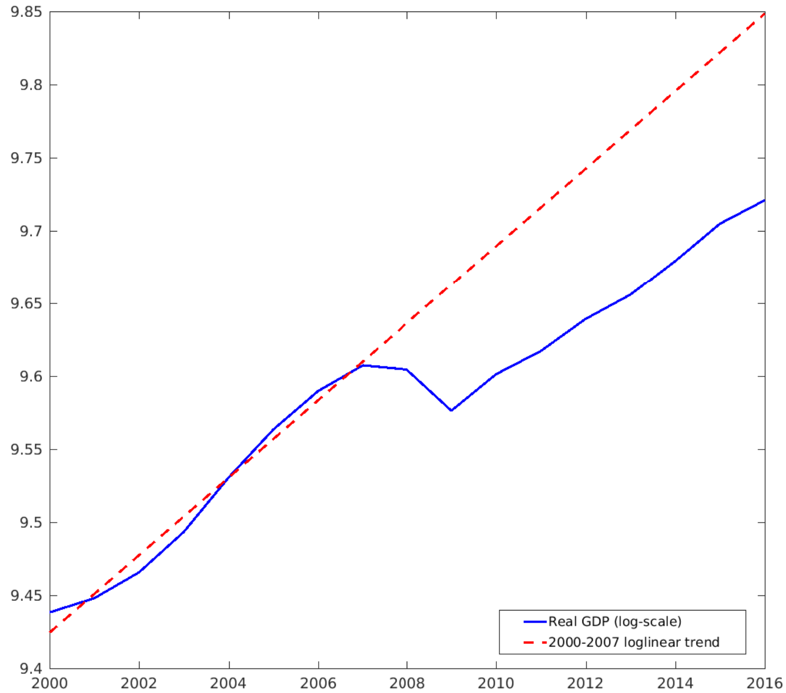
Our main contribution is to propose a stylized dynamic stochastic general equilibrium (DSGE) model to assess the efficacy of LAW. We depart from the usual model in two ways. First, we follow Gourio (2013) and introduce a standard capital structure choice in which debt has a tax subsidy, but creates the risk of costly bankruptcy (that is avoided for an all equity financed firm). Capital is accumulated by firms that face costs of issuing equity. We introduce a "financial shock" in this economy by assuming that the tax benefit varies over time. As we explain below, this is a shorthand for various forms of inefficient credit use. We view the tradeoff theory as providing a compact way to introduce variation in the use of debt financing (that could in fact arise for many reasons).

Our second modification is to introduce the possibility of a large financial crisis that can hit the economy. This is similar to the rare disasters that have received much attention recently in the asset pricing literature.[5] We assume that the financial crisis leads to a significant, permanent reduction in total factor productivity and a one-off shock to the capital stock. We view this modeling choice as a convenient device to capture that financial crises lead to large and highly persistent declines in output and consumption. Given that there is not much of a consensus as to why crises are so costly, this simplification is a reasonable way to model them without taking a stand on a particular reason why losses seem to be so persistent. In particular, as Figure 1 suggests, in the aftermath of the most recent crisis U.S. real GDP dropped permanently below the pre-crisis trend, and shows no sign of returning to the trend. As of 2016, real GDP was about 13 percent below the pre-crisis trend. Given this consideration, associating a permanent reduction in the production capacity with

[4]See Blanchard, Cerutti, and Summers (2015) and Martin, Munyan, and Wilson (2015).

[5]See Barro (2006), Gabaix (2012), Tsai and Wachter (2015) and Gourio (2012).

Figure 1: Real GDP and Its Pre-Crisis Trend



disaster-type crises is a convenient shortcut to replicate the crisis dynamics of real GDP.

We study two types of collapses. The first kind of financial crisis, as in Gourio (2012) and Gourio (2013), occurs exogenously. The second supposes that the probability of the crisis depends on the amount of inefficient credit. By comparing the two alternatives, we can understand how the policy consequences may differ when leaning against the wind can change the likelihood of a crisis.

The model allows for the usual productivity and demand shocks in addition to the financial shocks. The centerpiece of the analysis is a comparison of different monetary policy rules that vary with respect to the signals on which the central bank's policy rate is set. In our baseline, we compare policies that rely on perfectly measured variables and then in some extensions analyze what happens when the central bank must rely on imperfectly measured proxies. In this respect we follow in the long line of papers starting with Bernanke and Gertler (1999) and Gilchrist and Leahy (2002) that ask whether monetary policy should take account of asset price movements. A common conclusion in that literature is that after accounting for movements in inflation, and possibly output, there is no need to respond to asset prices. We explore whether the same conclusion holds in our environment.

Our main finding is that gains from responding to financial shocks depend importantly on the relative importance of the various shocks hitting the economy and the nature of the financial crisis risk. In some versions of the model, for instance when only productivity and demand shocks are present, the possibility of a crisis (endogenous or not) makes little difference for policy. In this environment, stabilizing inflation is optimal. Loosely speaking, once the central bank eliminates demand shocks and accommodates productivity shocks, it can stabilize inflation and simultaneously control crisis risk to the extent possible. In this setup, even if financial crises are endogenous it will make little difference for the policy choices because the central bank's control of demand will also control credit and limit crisis risk. This result is consistent with the previous literature, in particular Bernanke and Gertler (1999).

On the other hand, when there are also financial shocks, then failing to respond to credit build ups leads to larger crisis risk. Because crises are very costly, the optimal policy trades off leaning against the wind to reduce crisis risk against the costs of larger fluctuations in output and inflation. We emphasize that this result arises even though monetary policy is not a particularly powerful tool for managing the risk of financial crisis. The agents in our model are also not terribly risk averse. Nonetheless, by lowering the probability of financial crisis, the central bank generates welfare gains because of the large cost of financial crises. In general, the more risk averse are households and the larger is the size of the crisis, the stronger is the case for LAW. We describe these mechanisms in more detail below and provide a preliminary quantitative assessment.

The remainder of the paper proceeds as follows. In the next section, we provide a brief literature review. In section 3, we introduce the model. Most elements are very standard and are common to many New Keynesian models. In presenting the model, therefore, we concentrate on the two novel aspects mentioned above. Section 4 discusses the parameters used and examines basic properties of the model economy. Finally, in section 5, we compare the performance of a number of policy rules for different versions of the model, and illustrate how several key parameters affect our results. Section 6 concludes.

2 Literature Review

Smets (2014) provides an excellent survey of most of the research on leaning against the wind through 2014, so we summarize his main conclusions and then focus on a few notable papers written since his survey. Smets notes that the case for using monetary policy to promote financial stability depends in part on the availability and effectiveness of other tools. The paper then reviews a number of analyses, most notably Lim, Costa, Columba, Kongsamut, Otani, Saiyid, Wezel, and Wu (2011), that study the experience using macroprudential tools and reaches two important conclusions: that "the empirical literature tentatively supports the effectiveness of macroprudential tools in dampening procyclicality" and "to what extent such measures are effective enough to significantly reduce systemic risk is, however, as yet unclear."

Given the ambiguity over whether financial stability can be delivered without appealing to monetary policy, the paper then turns to the question of what the evidence says regarding the effectiveness of monetary policy in limiting the build up of financial vulnerabilities. Here again the evidence is mixed. On the one hand, there are a variety of studies that link higher risk-taking by banks with looser monetary policy. Smets stresses that the risk-taking can occur on both the asset-side of the banks' balance sheet as they reach for yield and through funding choices that entail extra reliance on short-term financing. He argues that although there is ample evidence of risk-taking, the question of whether actively using monetary policy to head it off creates too much collateral damage remains open. He cites several articles that suggest, for instance, that using monetary policy to forestall property price booms would have created a recession. Overall we read his paper as suggesting that there may be scope for leaning against the wind, but doing so would entail non-trivial risks.[6]

Perhaps the most prominent paper written after the Smets survey is Svensson (2016). This paper provides a simple and transparent framework for evaluating LAW policies. It starts with empirical estimates of the effects of higher interest rates on the likelihood of a crisis (obtained by combining estimates of the effect of interest rates on credit, and of credit growth on the likelihood of crisis (Schularick and Taylor (2012))) and on inflation and output in the short run as well as the cost of a financial crisis (a sharp, temporary recession). Svensson emphasizes that on the one hand, tighter policy reduces the risk of financial crisis in the short-run but increases it later on since the effect of tighter policy works through the growth rate of credit (and the long-term level of real credit is assumed to be independent of monetary policy because of long-run neutrality). On the

[6]Smets also stresses that if the central bank is given responsibility for financial stability and fails to achieve it, then the bank's monetary independence could be compromised. Though as Peek, Rosengren, and Tootell (2015) mention, central banks that are simply acting as a lender of last resort can also face this kind of pressure.

other hand, tighter policy reliably reduces growth and inflation in the short-run. Overall, the costs of slowing down the economy are much higher than the gains from only marginally reducing the risk of a crisis. Indeed, if one accounts for the fact that crises are to a certain extent inevitable and unavoidable, then a policy that steers the economy to be above potential during non-crisis periods is optimal. Hence, Svensson argues that a careful treatment of this problem calls for leaning *with* the wind.[7]

The IMF 2015 staff study (IMF (2015)) reaches similar conclusions to Svensson. On their reading of the empirical literature, a 100 basis point increase in the central bank policy rate for one year is needed to reduce the probability of a crisis by only 0.02 percentage point per quarter. There is obviously much uncertainty around this estimate, but they argue that even using the largest reported estimates of a 0.3 percentage point reduction per quarter in crisis risk, the costs of a slowdown are likely to exceed the gains from preventing a crisis. Ajello, Laubach, Lopez-Salido, and Nakata (2016) similarly argue that the optimal response is small for the median estimate of the effect of monetary policy on risk of crisis, but may be significant if the policymaker takes into account the uncertainty surrounding the estimate, and focuses on the worst-case scenario.[8]

Filardo and Rungcharoenkitkul (2016), in contrast, reach the opposite conclusion studying optimal monetary policy in an environment of recurring, endogenous financial booms and busts. In their environment leaning systematically over the whole cycle is justified because leaning not only influences the probability of a crisis, but also smooths the financial cycle, resulting in less virulent boom and bust episodes. The optimal monetary policy in this setting calls for progressively stronger leaning as financial imbalances grow but reducing the degree of leaning against the wind as a crisis becomes imminent. The persistence of the financial cycle and the degree to which monetary policy influences the amplitude and duration of booms and busts are key distinguishing features of the modelling approach.[9]

Our approach cannot be easily mapped into the Svensson style calculation. There are several critical differences. First, in terms of methodology we optimize a policy rule in a DSGE model

[7] Juselius, Borio, Disyatat, and Drehmann (2017) argue that one cost of low interest rates is an exacerbation of the financial cycle.

[8] See also Gerdrup, Hansen, Krogh, and Maih (2016) and Bauer and Granziera (2016) for recent studies of the effectiveness of monetary policy in LAW.

[9] Filardo and Rungcharoenkitkul (2016) solve for the optimal nonlinear policy rule using collocation method. This allows the intensity of leaning to change with the level of financial imbalances. Linear rules do not permit this possibility.

while Svensson conducts a one-time cost/benefit analysis. Second, our objective function is utility while he bases his analysis on a quadratic loss function. Third, we model crises as permanent effects on output while he considers them a temporary "gap" in unemployment or output. For instance, in our benchmark calculation the level of output drops by 10 percentage points in a crisis. Svensson assumes a five percentage points increase in unemployment for two years followed by a return to normal. The total loss in output in his baseline is, therefore, much smaller than in ours. Below we show that with much smaller crises a LAW policy is not welfare improving. Finally, there is a difference between the way the models approach long-run monetary neutrality. In our model, monetary policy shocks have only transient effects on credit and other variables, similar to Svensson. But Svensson's specification implies that lower credit growth reduces the probability of crisis in the short-run before increasing it in the medium run. In our model, LAW can deliver a lower probability throughout.

IMF (2015), like Smets, questions whether monetary policy is the right tool to address these problems and proposes a three part test that should be considered before monetary policy should be used to lean against the wind. First, are financial risks in the economy excessive? If they are not, then adjusting monetary policy is unnecessary. Second, can other tools be used, particularly macroprudential ones, be used instead of monetary policy? Finally, will monetary policy, if set in a conventional fashion based on inflation and output developments, take care of financial stability concerns?

Our model allows us to partially address two of the three considerations. We suppose that monitoring financial risks is challenging. Inefficient credit movements may not be observable, so we can study policies that can only be based on noisy indicators of financial risk. Our model has multiple shocks, so we can also study which ones give rise to scenarios where there is a genuine tradeoff between managing the near term inflation and output fluctuations and preventing crises; as will be clear, there are some shocks where a standard inflation targeting central bank will contain financial risks just as a by-product of following its mandate.

We do not discuss macroprudential tools. Partly, this is a tractability issue. There is no consensus model that integrates macroprudential policy levers in a standard monetary model. As Smets (2014) emphasizes even the empirical evidence how this might work is mixed. Developing that kind of framework is beyond the scope of our paper.

More importantly, in many countries the scope for deploying macroprudential tools is limited. The case study developed by Adrian, de Fontnouvelle, Yang, and Zlate (2015) highlights some of the challenges in the U.S. context. In their hypothetical scenario that they dub a "tabletop exercise", the Federal Reserve is facing a situation where commercial real estate prices are rising sharply, while its inflation and employment objectives are close to being met. Most of the funding fueling the boom are coming from small banks and through capital markets (via securitization).[10] When confronted with this scenario, the four Federal Reserve Bank Presidents who were attempting to implement policies to manage the situation concluded that "from among the various tools considered, tabletop participants found many of the prudential tools less attractive due to implementation lags and limited scope of application. Among the prudential tools, participants favored those deemed to pose fewer implementation challenges, in particular stress testing, margins on repo funding, and supervisory guidance. Nonetheless, monetary policy came more quickly to the fore as a financial stability tool than might have been thought before the exercise."

3 Model

The model economy consists of a representative household, a continuum of monopolistic competitors, a representative investment good producer, and a continuum of financial intermediaries that hold capital financed by debt and equity. All firms, including the intermediaries are owned by the household and therefore discount future cash flow using the stochastic discount factor of the representative household.

3.1 Households

The representative household has preferences

$$\mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} U(C_s, N_s)$$

[10] This funding constellation matters because in the U.S. the central bank can use some tools, such as stress tests, to steer decisions for very large banks. Restricting the behavior of small banks and stopping securitization is more difficult.

where

$$U(C_t, N_t) = \frac{{C_t}^{1-\tau}}{1-\tau} - \frac{{N_t}^{1+\upsilon}}{1+\upsilon}. \quad (1)$$

The household consumption bundle is made up of differentiated products,

$$C_t = \left(\int_0^1 C_t(i)^{\frac{1}{1-\eta}} di \right)^{1-\eta}.$$

The dual problem of cost minimization gives rise to a good-specific demand,

$$C_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\eta} C_t$$

where $P_t \equiv \left[\int_0^1 P_t(i)^{1-\eta} di \right]^{1/(1-\eta)}$.

The representative household earns wage income ($w_t N_t$), the profits of intermediate-goods firms (Π_t^F) and the profits of financial intermediaries (Π_t^I). (The investment good producer makes zero profits due to perfect competition and constant return to scale.) The household saves by holding securities issued by financial intermediaries and government bonds (B_t^G), which are zero in net-supply. The bonds issued by the intermediaries are unsecured risky bonds. We denote the price of a bond by q_t. If the bond issuer avoids default, the bond returns one unit of consumption tomorrow. In default, the household receives a partial payment. Since there is a continuum of issuers, the law of large number applies and the household can form rational expectations about how many bonds fail and how many deliver the promised payment. We denote the probability of default by H_t and the average recovery rate conditional upon default by R_t^D. We can then express the budget constraint of the household as

$$C_t = w_t N_t + \Pi_t^F + \Pi_t^I - q_t B_t + [(1 - H_t) + H_t R_t^D] B_{t-1} + R_{t-1} B_{t-1}^G - B_t^G. \quad (2)$$

We denote the Lagrangian multiplier associated with the budget constraint by Λ_t. The household's efficiency conditions are summarized as:

$$C_t : \Lambda_t = U_C(C_t, N_t), \quad (3)$$

$$N_t : \Lambda_t w_t = -U_N(C_t, N_t), \tag{4}$$

$$B_t^G : 1 = \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} R_{t+1} \right] \tag{5}$$

and

$$B_t : q_t = \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} (1 - H_{t+1}) + H_{t+1} R_t^D \right]. \tag{6}$$

A few remarks are in order. First, the two static FOCs together also imply the following efficiency condition.

$$w_t = -\frac{U_N(C_t, N_t)}{U_C(C_t, N_t)}. \tag{7}$$

Second, we assume that the economy is subject to the risk premium shock of Smets and Wouters (2007). Following Fisher (2015), we interpret this as the shock to the demand for safe asset.[11] We denote the shock by Ξ_t and modify the FOC as

$$1 = \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} \Xi_t R_{t+1} \right]. \tag{8}$$

These shocks do not affect the flexible economy and hence are an inefficient source of business cycle fluctuations.

Third, the FOC for intermediary bond holding plays the role of the pricing equation for intermediary problem. We will provide more details on this, including the determinants of the recovery rate R_t^D, when we discuss the intermediary problem. For later purposes, we define the stochastic discount factor of the household as

$$M_{t,t+1} \equiv \beta \frac{\Lambda_{t+1}}{\Lambda_t}. \tag{9}$$

3.2 Investment Goods Producers

We assume that there exists a continuum of competitive firms indexed by $k \in [0, 1]$. These firms produce an identical composite good I_t using a linear technology subject to an adjustment cost related to changing the level of investment. We parameterize the costs to be $\kappa/2 \left(I_t/I_{t-1} - 1 \right)^2 I_{t-1}$.

[11] In this interpretation, the shock Ξ_t can be viewed as a disturbance to demand for money and hence can also be thought of as shifting nominal aggregate demand.

The composite good I_t is sold at a price Q_t to be used in the production of capital. Production of the composite good requires the use of all varieties of intermediate goods. Since the industry is competitive, the size of an individual firm is indeterminate. Hence we assume a representative firm that is a price taker. The profit maximization problem of the investment goods producers can be cast as choosing the input level given the cost of adjusting investment level, i.e.,

$$\max_{I_s} \mathbb{E}_t \sum_{s=t}^{\infty} M_{t,s} \left\{ Q_s I_s - \left[I_s + \frac{\kappa}{2} \left(\frac{I_s}{I_{s-1}} - 1 \right)^2 I_{s-1} \right] \right\}.$$

The FOC of the problem is given by

$$Q_t = 1 + \kappa \left(\frac{I_t}{I_{t-1}} - 1 \right) - \mathbb{E}_t \left\{ M_{t,t+1} \frac{\kappa}{2} \left[\left(\frac{I_{t+1}}{I_t} \right)^2 - 1 \right] \right\}. \tag{10}$$

3.3 Retailers

There exists a continuum of monopolistic competitors indexed by $i \in [0, 1]$. These retailing firms combine labor and capital using a Cobb-Douglas production technology

$$Y_t(i) = Z_t K_t(i)^\alpha N_t(i)^{1-\alpha}$$

where Z_t is the aggregate technology. Following Rotemberg (1982), we assume that the retailers are subject to quadratic costs of adjusting prices

$$\frac{\varphi}{2} \left(\frac{P_t(i)}{P_{t-1}(i)} - 1 \right)^2 Y_t = \frac{\varphi}{2} \left(\Pi_t \frac{p_t(i)}{p_{t-1}(i)} - 1 \right)^2 Y_t,$$

where $p_t(i) \equiv P_t(i)/P_t$ and $\Pi_t \equiv P_t/P_{t-1}$ is aggregate inflation. Hence, the firm's static profit is given by

$$\Pi_t(i) = p_t(i) Y_t(i) - w_t N_t(i) - r_t^K K_t(i) - \frac{\varphi}{2} \left(\frac{p_t(i)}{p_{t-1}(i)} \Pi_t - 1 \right)^2 Y_t.$$

where $w_t \equiv W_t/P_t$ is the real wage. The retailers are owned by the representative household, and hence discount future cash flow using the stochastic discount factor of the household. Pricing maximizes the present value of expected profits

$$\mathcal{L} = E_t \sum_{s=t}^{\infty} M_{t,s}\{\Pi_s(i) + \mu_s(i)[Z_s K_s(i)^\alpha N_s(i)^{1-\alpha} - Y_s(i)] + \nu_s(i)[p_s(i)^{-\eta} Y_s - Y_s(i)]\}$$

where $\nu_s(i)$ and $\mu_s(i)$ are the shadow values of the demand constraint and technological constraints. The efficiency conditions in a symmetric equilibrium (where all firms choose an identical relative price) are:

$$w_t = (1-\alpha)\mu_t \frac{Y_t}{N_t}, \tag{11}$$

$$r_t^K = \alpha \mu_t \frac{Y_t}{K_t}, \tag{12}$$

$$\nu_t = 1 - \mu_t \tag{13}$$

and

$$0 = 1 - \varphi \Pi_t \left(\Pi_t - 1\right) - \eta \nu_t + \varphi \mathbb{E}_t \left[M_{t,t+1} \Pi_{t+1} \left(\Pi_{t+1} - 1\right) \frac{Y_{t+1}}{Y_t} \right]. \tag{14}$$

3.4 Financial Intermediaries

This part of the model follows the setup in Gourio (2013). We assume that there exists a continuum of financial intermediaries indexed by $s \in [0,1]$. The financial intermediaries combine debt and equity capital to invest in physical capital. From now on we omit the intermediary index.

If intermediary invests $Q_t K_{t+1}$ at time t, then at time $t+1$ its return on the asset will be

$$\varepsilon_{t+1} R_{t+1}^K = \varepsilon_{t+1} \frac{r_{t+1}^K + (1-\delta) Q_{t+1}}{Q_t},$$

where ε_{t+1} is an idiosyncratic risk associated with the intermediary. The shocks are iid across time and producers, have a cdf $H(\cdot)$, and a pdf $h(\cdot)$. (In practice we assume that ε_{t+1} follows a lognormal destribution, $\log \varepsilon_{t+1} \sim N(-0.5\sigma^2, \sigma^2)$).

The intermediary here can be thought of integrating a set of financially unconstrained borrowers with a banking system. In a more complete set up where even borrowers are subject to financial constraints, we could have richer financial accelerator mechanism that comes both from the borrowers and the lenders. Here we collapse the actors together so that when the banks expand, they directly create more physical capital (as in Gertler and Karadi (2011)).

The choice of debt vs. equity is driven by the standard trade-off model from corporate finance. For now, we assume that debt is set in real terms[12] and has a tax advantage $\chi_t > 1$. This means that for each unit of debt issued at time t, the corporation receives a subsidy equal to $\chi_t - 1 > 0$. This subsidy is a stand-in for many considerations that make debt issuance attractive. For instance, it is commonly argued that the presence of debt is beneficial as it gives stronger incentives on managers to maximize profits, and to avoid engaging in empire building. One can view χ_t as a shortcut for such an "agency benefit" to debt. On the other hand, if there are no benefits to debt but simply issuance costs, χ_t could be less than unity. Critical for our purpose is the assumption that χ varies over time. One could think of χ varying because of unmodeled changes in the ease of placing debt issues. The intermediary's problem is to choose capital and debt (and hence equity) to maximize its expected present discounted value.

We also assume that the issuance of equity is costly and that the cost per-unit of equity issuance is an increasing function of the equity share relative to the size of the project:

$$\gamma_t = \gamma\left(\frac{S_t}{Q_t K_{t+1}}\right), \quad \gamma(0) = 0, \ \gamma'(\cdot) \geq 0 \text{ and } \gamma''(\cdot) \geq 0$$

where S_t is equity issuance today.[13] The maximization problem of the intermediary can then be expressed as

$$\max_{B_{t+1}, S_t, Q_t K_{t+1}} \mathbb{E}_t[M_{t,t+1} \max\left(V_{t+1} - B_{t+1}, 0\right)] - \left[1 + \gamma\left(\frac{S_t}{Q_t K_{t+1}}\right)\right] S_t. \tag{15}$$

where $V_{t+1} = \varepsilon_{t+1} R^K_{t+1} Q_t K_{t+1}$ is the value at time $t+1$. The maximization is subject to the funding constraint:

$$Q_t K_{t+1} = \chi_t q_t B_{t+1} + S_t, \tag{16}$$

[12] This is rather innocuous since our financial crises will not have deflation, so changing this assumption would not materially affect the results.

[13] This equation assumes that the producer only maximizes its one-period ahead value. It is easy to see that this corresponds to maximizing its long-term value because the present value of rents is zero due to free entry.

where q_t is the price of the bonds and the debt pricing equation is given by

$$q_t = \mathbb{E}_t\left[M_{t,t+1}\left(1_{V_{t+1}<B_{t+1}}\zeta\frac{V_{t+1}}{B_{t+1}} + 1_{V_{t+1}\geq B_{t+1}}\right)\right]. \tag{17}$$

$1_{V_{t+1}<B_{t+1}}$ is a dummy indicating default, and ζ is the recovery rate. The intermediary decides on debt and capital, recognizing that higher leverage will lead to lower bond prices.

To derive the efficiency conditions of the problem, first, we rewrite the bond pricing function as

$$q_t B_{t+1} = \mathbb{E}_t M_{t+1}[\Omega(\varepsilon^*_{t+1})\zeta R^K_{t+1} Q_t K_{t+1} + (1 - H(\varepsilon^*_{t+1}))B_{t+1}], \tag{18}$$

where $\Omega(x) \equiv \int_0^x \varepsilon dH(\varepsilon) = xh(x)$, and $\varepsilon^*_{t+1} \equiv \frac{B_{t+1}}{R^K_{t+1}Q_t K_{it+1}}$, i.e., the default threshold.[14] Substituting (16) and (18) into (15), we reexpress the objective function as

$$\begin{aligned}\max_{B_{t+1},K_{t+1}} \; & \mathbb{E}_t M_{t+1}[(1-(1-\chi_t\zeta)\Omega(\varepsilon^*_{t+1})) - (1-\chi_t)(1-H(\varepsilon^*_{t+1}))\varepsilon^*_{t+1}]R^K_{t+1}Q_t K_{t+1} \\ & - Q_t K_{t+1}\left[1+\gamma\left(\frac{S_t}{Q_t K_{t+1}}\right)\frac{S_t}{Q_t K_{t+1}}\right]\end{aligned} \tag{19}$$

Dividing (18) by the size of the balance sheet $Q_t K_{t+1}$, we define

$$L\left(\frac{B_{t+1}}{Q_t K_{t+1}}\right) \equiv \frac{q_t B_{t+1}}{Q_t K_{t+1}} = \mathbb{E}_t M_{t+1}[\Omega(\varepsilon^*_{t+1})\zeta R^K_{t+1} + (1-H(\varepsilon^*_{t+1}))\varepsilon^*_{t+1}R^K_{t+1}]. \tag{20}$$

Using (16) and (20), we transform the second line of (19) into an expression that does not depend on the amount of equity:

$$\begin{aligned}& Q_t K_{t+1}\left[1+\gamma\left(\frac{S_t}{Q_t K_{t+1}}\right)\frac{S_t}{Q_t K_{t+1}}\right] \\ &= Q_t K_{t+1}\left\{1+\gamma\left[1-\chi_t L\left(\frac{B_{t+1}}{Q_t K_{t+1}}\right)\right]\left[1-\chi_t L\left(\frac{B_{t+1}}{Q_t K_{t+1}}\right)\right]\right\} \\ &\equiv Q_t K_{t+1}\Gamma\left(\frac{B_{t+1}}{Q_t K_{t+1}}\right).\end{aligned}$$

Importantly, $\Gamma(B_{t+1}/Q_t K_{t+1})$ depends only on leverage and not separately on $Q_t K_{t+1}$. Hence,

[14] Note that the recovery rate that appears in the household problem can be expressed as $R^D_{t+1} = \frac{\Omega(\varepsilon^*_{t+1})\zeta R^K_{t+1}Q_t K_{t+1}}{H(\varepsilon^*_{t+1})B_{t+1}}$.

the FOC for capital can be expressed as

$$1=\Gamma\left(\frac{B_{t+1}}{Q_tK_{t+1}}\right)^{-1}\mathbb{E}_t\left(M_{t+1}R^K_{t+1}\lambda_{t+1}\right) \tag{21}$$

where

$$\lambda_{t+1}=1+\left(\chi_t-1\right)\varepsilon^*_{t+1}\left(1-H\left(\varepsilon^*_{t+1}\right)\right)-\left(1-\zeta\chi_t\right)\Omega\left(\varepsilon^*_{t+1}\right). \tag{22}$$

The efficient level of leverage is determined by

$$0=\mathbb{E}_tM_{t+1}\left[(\chi_t-1)(1-H(\varepsilon^*_{t+1}))-(1-\chi_t\zeta)\varepsilon^*_{t+1}h(\varepsilon^*_{t+1})-(\chi-1)\varepsilon^*_{t+1}h(\varepsilon^*_{t+1})\right]-\Gamma'\left(\frac{B_{t+1}}{Q_tK_{t+1}}\right).$$

This expression can be shown equivalent to

$$\begin{aligned}&\mathbb{E}_t\left\{M_{t+1}\left(1-H\left(\varepsilon^*_{t+1}\right)\right)\left[\frac{\chi_t-1}{\chi_t}+\gamma\left(\frac{S_t}{Q_tK_{t+1}}\right)+\gamma'\left(\frac{S_t}{Q_tK_{t+1}}\right)\right]\right\}\\&=\left(1-\zeta_t\right)\mathbb{E}_t\left\{M_{t+1}\varepsilon^*_{t+1}h\left(\varepsilon^*_{t+1}\right)\left[1+\gamma\left(\frac{S_t}{Q_tK_{t+1}}\right)+\gamma'\left(\frac{S_t}{Q_tK_{t+1}}\right)\right]\right\}.\end{aligned} \tag{23}$$

3.5 Financial Crises

We now describe how we introduce financial crises into the model. We assume that aggregate technology Z_t evolves over time as the sum of a standard AR(1) shock and a unit root process affected by rare downward jumps:

$$Z_t=Z^r_tZ^p_t,\quad \log Z^r_t=\rho_Z\log Z^r_{t-1}+\sigma_Ze_{Z,t},\quad \frac{Z^p_{t+1}}{Z^p_t}=e^{-X_{t+1}b_c}, \tag{24}$$

where X_{t+1} is the "financial crisis" shock; specifically $X_{t+1}=0$ with probability $1-p_t$ an $X_{t+1}=1$ with probability p_t. When a crisis occurs, the level of technology drops by b_c percent. We assume the following reduced-form law of motion for the probability of a crisis:

$$\log p_t=b_0+b_1\log(B_t/B^f_t) \tag{25}$$

where B^f_t is the efficient level of credit that prevails in an economy without price distortions. The reduced-form assumes that the probability of a crisis is an increasing function of the level of inefficient credit. This framework directly implies an "externality" since higher debt increases the probability of a crisis, which is not internalized by financial intermediaries.[15] We refer to this as "inefficient credit" and hence implicitly assume that the steady-state distortion that favors debt (that, is the steady-state tax subsidy $\chi > 1$) does not create a risk of financial crisis.

We also assume that the capital accumulation process is affected by the financial crisis in the same fashion: financial intermediaries invest I_t and "expect" to obtain

$$K_t^w = (1-\delta)K_t + I_t,$$

but their capital stock that is realized at beginning of time $t+1$ is actually

$$K_{t+1} = K_t^w e^{-X_{t+1}b_c}.$$

That is, in the (unlikely) event of a financial crisis, the capital stock is not what the intermediaries expected it to be. This amounts to assuming a "capital quality" shock that is perfectly correlated with the productivity shock. This assumption is made largely for technical reasons in our case: it allows using a simpler solution method as we explain below.

Finally we further assume that the utility function is affected by a crisis realization. We do this because the preferences we use are not compatible with balanced growth, so that a one-time decline in productivity may lead to a change in hours. For tractability, we assume that

$$U(C_t, N_t) = \frac{C_t^{1-\tau}}{1-\tau} - J_t^{1-\tau}\frac{N_t^{1+\upsilon}}{1+\upsilon}$$

where J_t is the cumulative disaster effect,

$$J_t = e^{-X_t b_c} J_{t-1}.$$

We then redefine variables by detrending by Z_t, e.g. $\widetilde{Y}_t = Y_t/Z_t$, etc. Under the assumptions above,

[15]While this is a convenient short-cut, Cairo and Sim (2016) provides a structural model that delivers the same prediction. In order to study the relationship between price stability and financial stability, Cairo and Sim (2016) endogenize the production and income distribution in the financial crisis model of Kumhof, Ranciere, and Winant (2015). Cairo and Sim (2016) also allows for nominal rigidities and labor market frictions. Cairo and Sim (2016) shows that in this structural model of financial crisis, the correlation between debt and the probability of financial crisis is as high as 0.92. This is one way to justify our reduced form specification for the crisis risk.

Table 1: Structural Parameters

Parameters	Interpretation	Value
β	Discount factor	0.99
$\bar{\gamma}$	Quadratic cost of equity issuance	0.167
α	Capital share	0.36
τ	Constant relative risk aversion	2
κ	Investment adjustment cost	5
δ	Depreciation rate	0.025
η	Elasticity of substitution between goods	2.0
$\bar{\chi}$	Steady state tax benefit	1.005
ζ	Recovery rate	0.50
υ	Inverse of Frisch elasticity of labor supply	1/3
$\bar{\Pi}$	Gross inflation rate target	1
φ	Price adjustment cost	130
σ	Idiosyncratic volatility	0.2007
p_{ss}	Average probability of financial crisis	0.005
b_1	Sensitivity of log prob to credit deviation	5
b_c	Size of output drop if financial crisis	0.10
ρ_Z	Persistence of the technology shock	0.90
ρ_χ	Persistence of the financial shock	0.90
ρ_Ξ	Persistence of the demand shock	0.90
σ_Z	Volatility of the technology shock	0.01
σ_χ	Volatility of the financial shock	0.0097
σ_Ξ	Volatility of the demand shock	0.0035

the system of equations of detrended variables does not depend on X_t. That is, the detrended system has no jumps. This implies that it can be solved using standard perturbation techniques. For the details of transforming the original system of equations into the detrended system, see the appendix. Also see Gourio (2012), Isoré and Szczerbowicz (2015) and Gabaix (2011) for detailed detrending methodology for this kind of model.[16]

4 Basic model properties

We first discuss the parameters used for our model, then illustrate the model dynamics using impulse response analysis.

4.1 Calibration

Table 1 summarizes the calibration of the model parameters. We set the time discount factor $\beta = 0.99$ simplying annual real rate of 4 percent. Capital share of production α is set equal to

[16]Note that we also need to assume that financial crisis affects the investment goods production function so that the producer's adjustment cost is not affected by the disaster realization.

0.36 as is standard in the literature. The depreciation rate δ is calibrated equal to 0.025. We set investment adjustment cost κ equal to 5 to produce reasonable investment volatility.

We assume risk aversion of 2 and an inverse Frisch elasticity of labor supply of 1/3. Regarding the elasticity of substitution between goods, we choose $\eta = 2$, consistent with the results in Broda and Weinstein (2006). With this choice, we set the price adjustment cost $\varphi = 130$ to match the fact that micro studies suggest that prices adjust about once a year.

We set the "tax benefit" parameter to a relatively low value of $\bar{\chi} = 1.005$, to take into account that debt incurs issuance costs as well as tax benefits, as discussed above. We choose the bankruptcy cost of default to be $\zeta = 0.5$. This value allows us to match the recovery rate on U.S. corporate bonds. Regarding the functional form of the equity issuance cost, we assume a quadratic form:

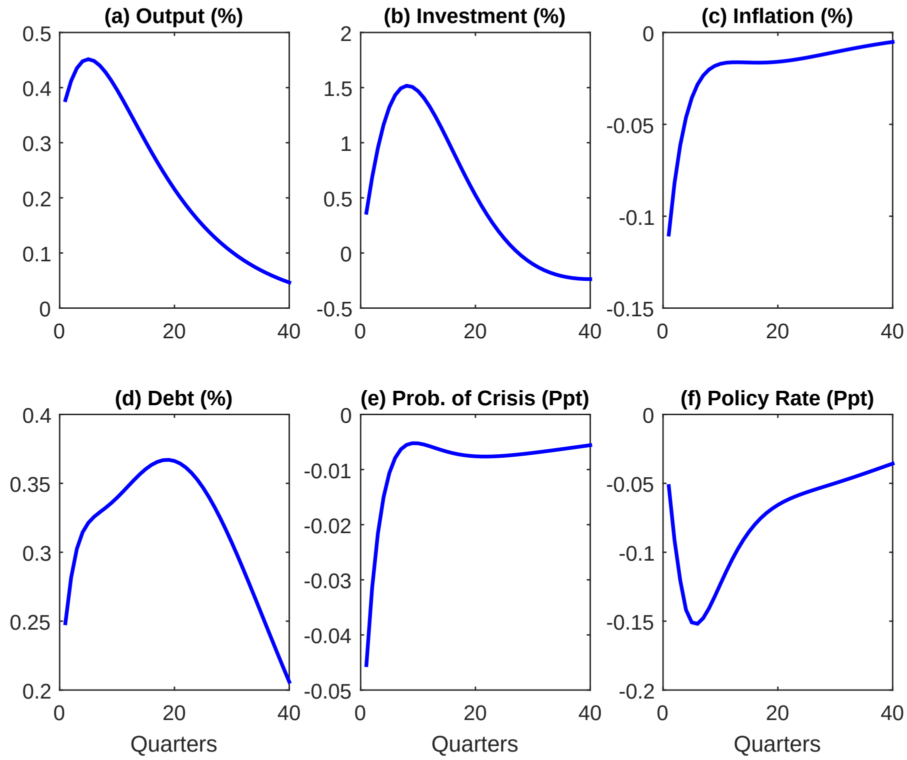
$$\gamma\left(\frac{S_t}{Q_t K_{t+1}}\right) = \bar{\gamma}\left(\frac{S_t}{Q_t K_{t+1}}\right)^2.$$

We next calibrate the two parameters σ and $\bar{\gamma}$ (the volatility of idiosyncratic shocks to firms and the equity issuance cost) to match a probability of default of 15% per year and average leverage of around 0.65. This implies that $\sigma = 0.2007$ and $\bar{\gamma} = 0.167$.

Steady state probability of a financial crisis is set to 2% per year or 0.5% per quarter, corresponding to two crises per century. The size of the output drop is set to 10%. This number is significantly smaller than the values typically used in the asset pricing literature on disasters. This number is also smaller than the recent US experience, as discussed in the introduction. The sensitivity of the financial crisis probability to excess credit is 5, so that a 20% increase in inefficient credit doubles the probability of financial crisis. We study extensively the sensitivity of our results to these parameters below.

Regarding the aggregate shock processes, we take an agnostic approach and set all the persistence parameters equal to 0.9. We calibrate the standard deviation of technology shock to equal to 0.01. We then choose the other shock volatilities so that the variance decomposition of output can be allocated to technology shock, demand shock and financial shock with 42.5,42.5, and 15 shares, respectively. The 15% share for financial shocks is at the lower end of the estimates implied by Christiano, Ilut, Motto, and Rostagno (2010) and Fuentes-Albero (2014). We study the sensitivity of the results to the importance of the financial shocks as well.

Figure 2: Impulse Response to Productivity Shock: Baseline



4.2 Model Properties With a Standard Policy Rule

As a first step, we illustrate how our model economy behaves in response to the three fundamental impulses that we consider - a productivity shock, an aggregate demand shock, and the financial shock. As a further diagnostic we also report the effect of a monetary policy shock. To solve the model, we assume a standard inertial Taylor (1999) rule:

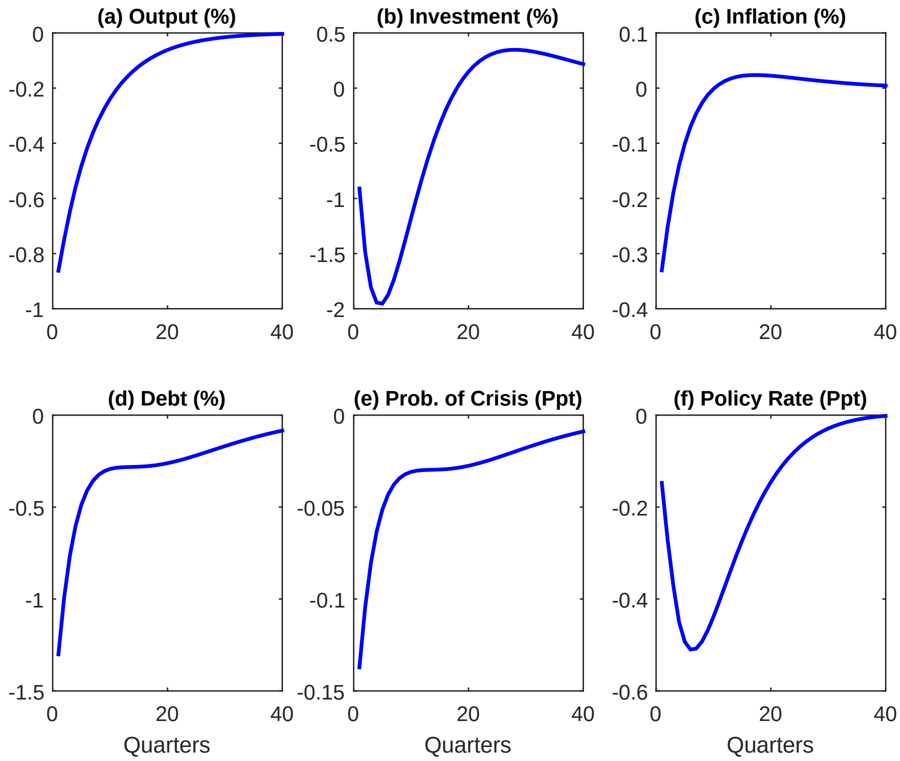
$$R_t = 0.85 \times R_{t-1} + 0.15 \times (R^* + 1.5 \times (\pi_t - \pi^*) + \widetilde{y}_t) \tag{26}$$

where $\widetilde{y}_t$ is the output gap,[17] and π_t is the year-over-year inflation rate. We summarize the main mechanisms in the model by explaining what happens to output, investment, inflation, debt, the policy rate, and the probability of a crisis.

A productivity shock, shown in Figure 2, leads to higher output and lower inflation as is common in New Keynesian models. The policy rule leads the central bank to cut the policy rate but not sufficiently to stabilize inflation or to allow output to rise in line with potential. Put differently,

[17] We define this gap to be the difference between the level of output and the one that would prevail in an economy without nominal rigidities and without financial shocks.

Figure 3: Impulse Response to Demand Shock: Baseline



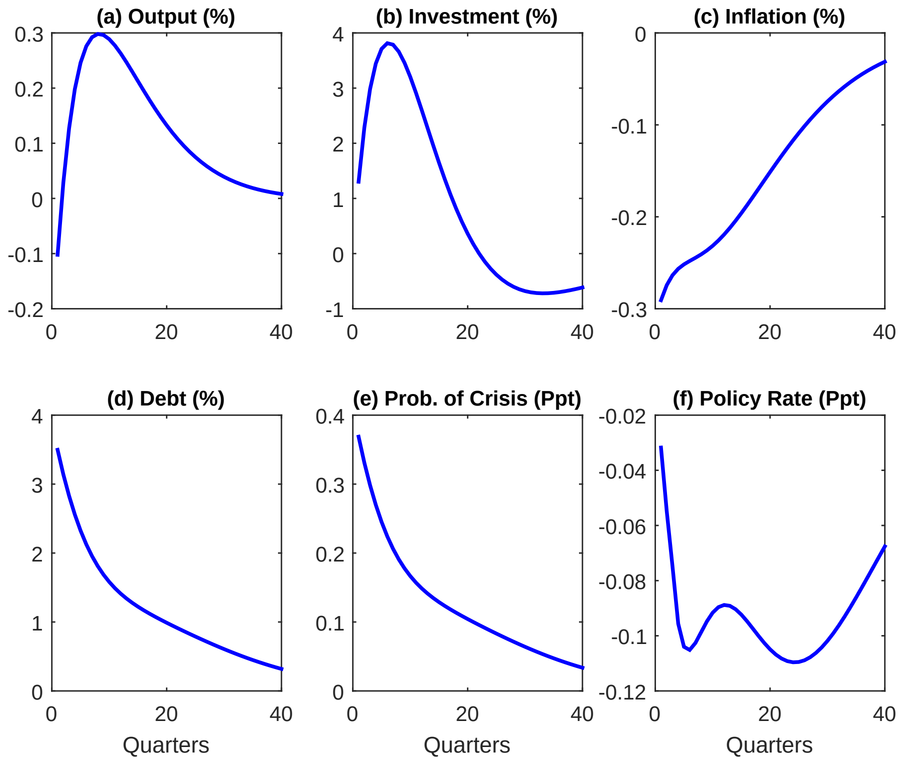
lower inflation reflects the decline in current and future marginal costs that arise from higher productivity and the fact that monetary policy does not bring demand in line with this higher supply.

The output surge leads to higher borrowing to finance investment, but because output does not keep up with the growth in potential, credit actually rises less than in the frictionless benchmark. As a result, the annualized probability of crisis falls modestly (by 4 basis points, so that the probability drops from 2% per year to 1.96%).

The response to a negative demand shock is shown in Figure 3. A negative demand shock leads to lower output and inflation; the shock also leads to a lower policy rate, but the assumed policy rule does not respond enough to offset completely the effects of the shock. Lower output in turn leads to lower debt and lower risk of financial crisis. Since the shock does not affect the flexible economy and the credit thereof, probability reduction due to deleveraging is sizable in this case.

Next, in Figure 4, we show the effect of a financial shock, which reflects an inefficient shock to credit supply. This type of shock leads to a large expansion of credit which reduces the user cost of capital and leads to a boom in investment and, to a lesser extent, also in output. The lower user

Figure 4: Impulse Response to Financial Shock: Baseline



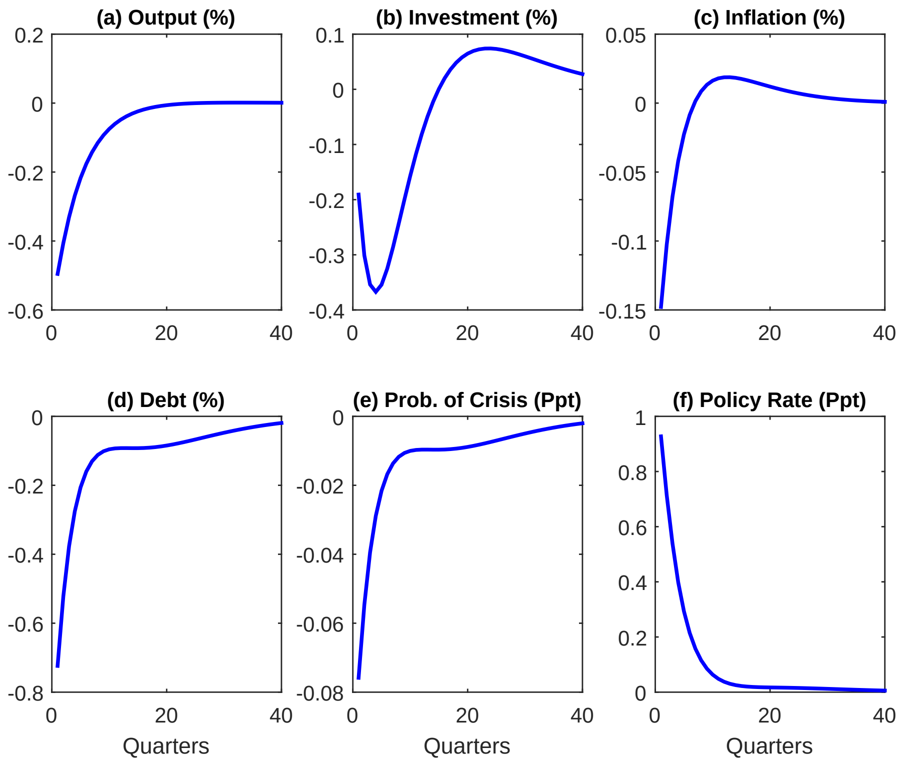
cost feeds through to lower inflation. The spike in debt (that is permitted with this policy rule) significantly increases the risk of financial crisis, from 2% per year to 2.37% per year.

Finally we illustrate how a "monetary shock" affects this model economy. Although we are most interested in optimal monetary policy rules, showing the impact of a deviation from the rule is informative about certain aspects of the model. Figure 5 displays the responses of our main variables to a 100 basis point (1%) increase in the policy rate. One important takeaway from the figure is that the shock leads to a decline in output and inflation.[18] The output drop leads to a decline of credit and hence the probability of crisis.

An important conclusion from this exercise is that the sensitivity of the risk of crisis to an increase in the policy rate is by no means extreme - this fairly large monetary shock only generates on impact a reduction of 8 basis points in the annual probability of crisis, i.e. moving it from 2% to 1.92%. This is magnitude of the change is consistent with the empirical estimates reviewed by IMF (2015). We share the view of IMF (2015) that these estimates are quite uncertain, but it

[18]Our model does not generate hump-shapes in response to this shock because it lacks some of the propagation mechanisms introduced by Christiano Eichenbaum and Evans (2005) or Smets and Wouters (2007) such as inflation indexation or consumer habits. We believe this is not critical for our results.

Figure 5: Impulse Response to Monetary Policy Shock: Baseline



is important to note that our subsequent conclusions about the desirability of leaning against the wind are not driven by a presumption that monetary policy has powerful effects on the risk of a crisis.

5 Optimal simple rules

Having established the basic model properties, we consider policy rules that specify the interest rate as a function of last period's interest rate, inflation, the output gap and/or the "credit gap", that is, B_t/B_t^f, the deviation of credit from the level that would prevail with only productivity shocks and flexible prices. Previous research shows that such rules typically perform well in models like ours. Because real time measurement of the output and credit gaps is difficult, we also study rules that rely on imperfectly measured version of these variables, namely deviations of output and credit from their steady state values.[19] Our goal is to establish the conditions when responding to credit may be beneficial. The benchmark for comparisons is the welfare of a representative consumer. This consumer cares not only about the usual fluctuations in output and inflation, but

[19]See, among many others, Orphanides and Williams (2002) and Edge and Meisenzahl (2011).

also about risks that bring large persistent drops in output and consumption. As we will see, in some configurations of the model, the central bank finds it preferable to respond to credit gap rather than the output gap, even though this leads to higher output *and* inflation volatility.

Our main result is that leaning against the wind can be beneficial provided that three conditions are met: (1) financial crises have important output effects; (2) financial shocks are important, i.e. the variance of the financial shocks and the associated swing in inefficient credit are large enough, and (3) financial crises are endogenous, i.e. they are caused in part by inefficient credit. In contrast, if there are no financial shocks, even with other financial imperfections present, we obtain the standard result that stabilizing inflation is a sufficient condition for maximizing welfare. In this latter case, a simple Taylor rule that puts enough weight on the output gap can maximize welfare.[20] If there are financial shocks, but financial crises are exogenous, a simple rule that puts weight on the output gap still outperforms credit-based rules, because targeting the output gap is a more direct way to eliminate undesirable fluctuations in output and inflation.

Obviously, these results depend on parameter choices. For instance, it is clear that if financial crises have small effects, or the variance of financial shocks is small, responding to output may still be preferable to responding to credit. In the results that follow we have calibrated the financial shocks so that they account for 15% of the variance of output, and demand and productivity shocks equally account for the remainder (i.e., 42.5% each). We discuss some robustness exercises after we introduce our main findings. However, because we have not estimated the model, we view these results as being indicative rather than dispositive. Put differently, rather than giving a definitive answer to the question of whether leaning against the wind is desirable, we think our framework is useful precisely because it permits us to understand, within a fairly standard DSGE model, which parameters and model features govern whether responding to credit conditions is beneficial.

5.1 Methodology

We consider policy rules of the following form:

$$R_t = \rho R_{t-1} + (1-\rho)(R^* + \phi_\pi(\pi_t - \pi^*) + \phi_y \tilde{y}_t + \phi_b b_t)$$

[20] This result is sometimes called "divine coincidence". The same outcome can be achieved by maximizing the inflation coefficient. Of course, in the presence of price markup shocks, this result breaks down.

Table 2: Benchmark Model

	Output gap only	Credit gap only	Both gaps
Welfare	-143.35	-143.15	-143.14
Consumption equivalent (%)	0	0.177	0.185
Coefficient ϕ_y	100	–	80.09
Coefficient ϕ_b	–	1.90	100.0
400×SD(Π)	1.45	2.41	2.36
100×SD(Y)	2.20	4.57	4.30
400×E(P)	2.06	1.98	1.99
400×SD(P)	0.83	0.29	0.29

where π_t is again the year-over-year inflation rate, $\widetilde{y}_t$ is the output gap and b_t is the credit gap, i.e. $\log\left(B_t/B_t^f\right)$. Note that b_t is the variable which determines the probability of a financial crisis, as given by equation (25). Throughout this exercise we set $\rho = 0.85$ and $\phi_\pi = 1.5$. Our motivation for imposing these restrictions is to make analysis transparent, and to require that the policy rule resembles the kind that broadly describes actual central bank decisions. We then consider the welfare consequences of policy rules with different coefficients for ϕ_y or ϕ_b. Specifically, we rank rules according to the utility they provide to the representative consumer and find the value of ϕ_y and/or ϕ_b that maximizes this expected utility.[21,22] We first consider the simple case where the central bank responds to only one gap so that $\phi_b = 0$ or $\phi_y = 0$. We then discuss results when we optimize over ϕ_b and ϕ_y jointly.

5.2 Main Result

Table 2 summarizes our main finding. When we select the best rule that depends solely on a correctly measured output gap, the optimal sensitivity is very high,[23] around 100, so that monetary policy eliminates all inefficient fluctuations of output. As can be seen, this monetary policy rule generates also a relatively small volatility of inflation. The standard deviation of the probability

[21]In contrast, many papers maximize a quadratic loss function of inflation and unemployment. In our case this approach would not capture the cost of financial crises, which permanently lower productivity. It is also a priori attractive to use a micro-founded welfare criterion.

[22]In practice, we first rewrite the system of equations that determines the equilibrium around the stochastic trend induced by disaster. This system can then be solved using standard perturbation methods since it has no jumps. We then use a second-order approximation of the utility to obtain conditional welfare, that is the utility obtained by the agent if the state variables are at their nonstochastic steady-state values. The result with unconditional welfare (the average utility in the new steady-state) are quite similar however. See appendix for details, and https://sites.google.com/site/fgourio/ for the code used to solve the paper.

[23]We set an upper bound of 100, and a lower bound of 0, to ensure that the optimization problem is well-posed. Allowing for values higher than 100 does not materially alter the results.

of crises is 0.83 percent. Crises occur about 2.06 percent of the time, which differs from 2 percent owing to Jensen's inequality.[24] As a result, households face the risk that crises can be more frequent than that. When we select the best rule that depends solely on the correctly measured credit gap, we obtain a coefficient of 1.90 on the credit gap. This rule generates significantly greater volatility of output and inflation than the one based on the output gap.[25] Yet, the credit-gap based rule outperforms the output-gap based rule in terms of welfare. The difference in utility is equivalent to a permanent increase of consumption of 0.18%, a significant number. For comparison, if one were to follow Lucas (1987) and compute the welfare gain of exogenously removing all business cycle volatility of consumption, the benefits amount to 0.058%.[26] In contrast, the same Lucas-style calculation yields a benefit of 5.50% of exogenously removing all disasters.[27]

In all of the comparisons that follow, we report the consumption equivalent change between a rule based only on the output gap and those that depend on the credit gap or both gaps; by this convention, the consumption equivalent for the rule that focusing on output gap only is always zero.

The gain in welfare occurs because the LAW policy is sacrificing cyclical volatility in order to limit the financial crisis risk: the probability of a financial crisis is now both smaller and substantially less volatile. The reduction in the mean probability of crisis is driven, in part, by the functional form we use to insure that the crisis probability lies between zero and one.[28] While this effect may seem at first mechanical, it reflects the reality that the financial crisis probability is bounded below (by zero). As such, decreasing the volatility of financial crisis leads to lower mean because the mean is driven by the occasional upswings.

Figures 6, 7 and 8 depict the response of macroeconomic aggregates to the three fundamental shocks under the standard Taylor (the solid blue line), the rule that responds only to the output gap (the dotted green line), and the rule that responds only to the credit gap (the dashed red line). Our

[24] The level of crisis probability is given by $p_t = \exp[b_0 + (B_t/B_t^f)^{b_1}]$. As a result, the average value of crisis probability is affected by the volatility of excess credit.

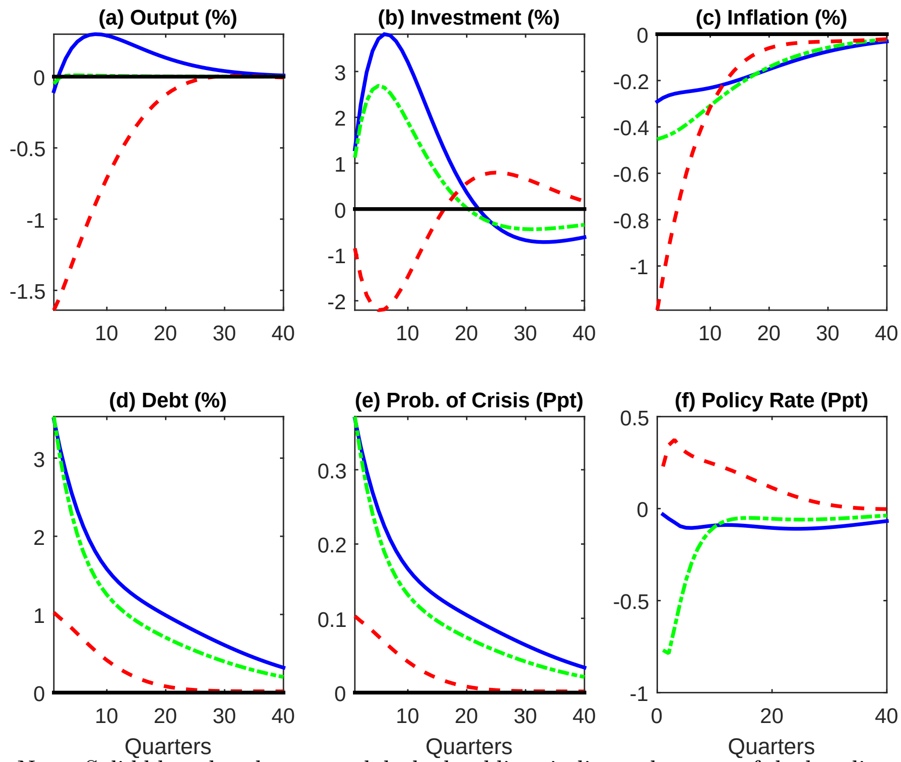
[25] The output volatility measure does not take into account financial crises.

[26] This calculation is based on the benefits of removing consumption volatility starting from the standard Taylor (1999) rule.

[27] The benefit obtained from reducing the disaster probability exogenously from 2.06ppt to 1.98ppt is 0.23%. Hence our result is in line with the Lucas calculation. We obtain smaller gains because our gains come at a cost of higher business cycle volatility. Moreover, our model incorporates other costs of volatility, including inflation and labor. And, as discussed in Lester, Pries, and Sims (2014), there may be gains from higher volatility as well.

[28] We specify a process for the log of the probability and that implies that lower volatility also brings a lower mean.

Figure 6: Impulse Response to Financial Shock: Optimal Simple Rule

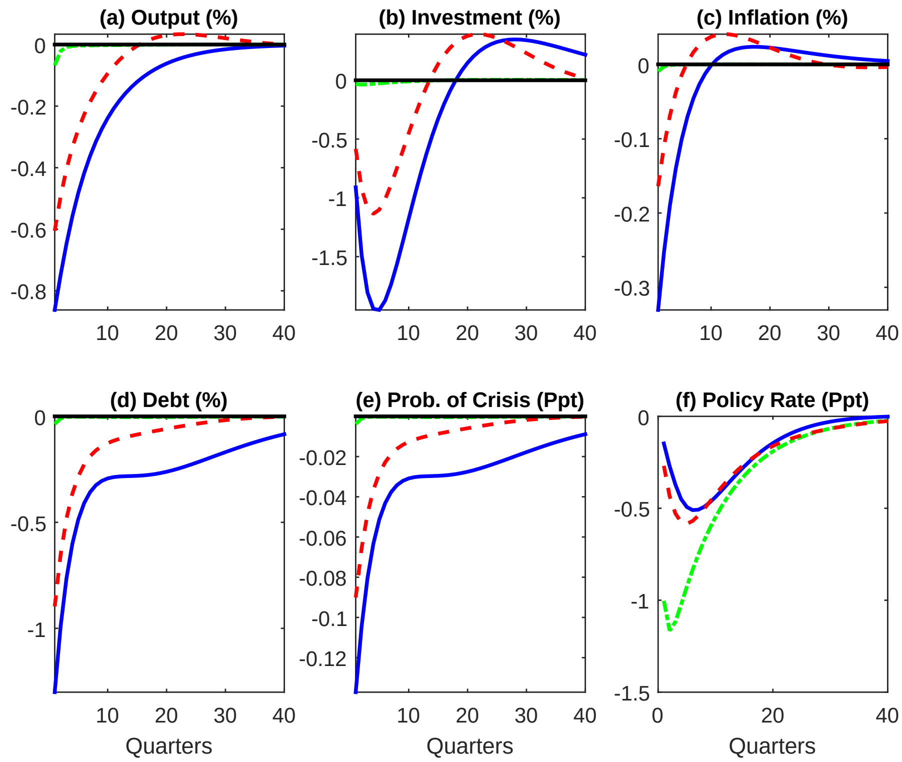


Note: Solid blue, doted green and dashed red lines indicate the cases of the baseline monetary policy rule, eq. (26), optimized output-gap rule and optimized credit-gap rule (LAW), respectively.

main conclusion is best understood by comparing what the different rules imply for policy in the aftermath of a financial shock in figure 6. The credit-gap rule tightens policy, which leads to a much lower debt expansion and consequently a lower risk of a crisis. The cost of this policy is large in terms of the deviation of inflation and output from target. This policy, nevertheless, delivers higher welfare because it meaningfully lowers the probability of a financial crisis. In contrast, the output gap based policy cuts interest rates because inflation is low and lower rates help keep output close to its target. The cost of this choice is a rise in the financial crisis risk. Finally, following a standard Taylor rule leads the central bank to gradually cut rates as it trades off inflation undershooting against a modest output boom. In this case, debt also accumulates so that the crisis probability rises even more substantially.

Figures 7 and 8 show the performance of the different rules in face of demand and productivity shocks. Another cost of the credit-gap policy rule is that it does less well than the output-gap based rule in response to standard demand and productivity shocks. While the output-gap based policy offsets completely the demand shock and accommodates almost perfectly the productivity

Figure 7: Impulse Response to Demand Shock: Optimal Simple Rule



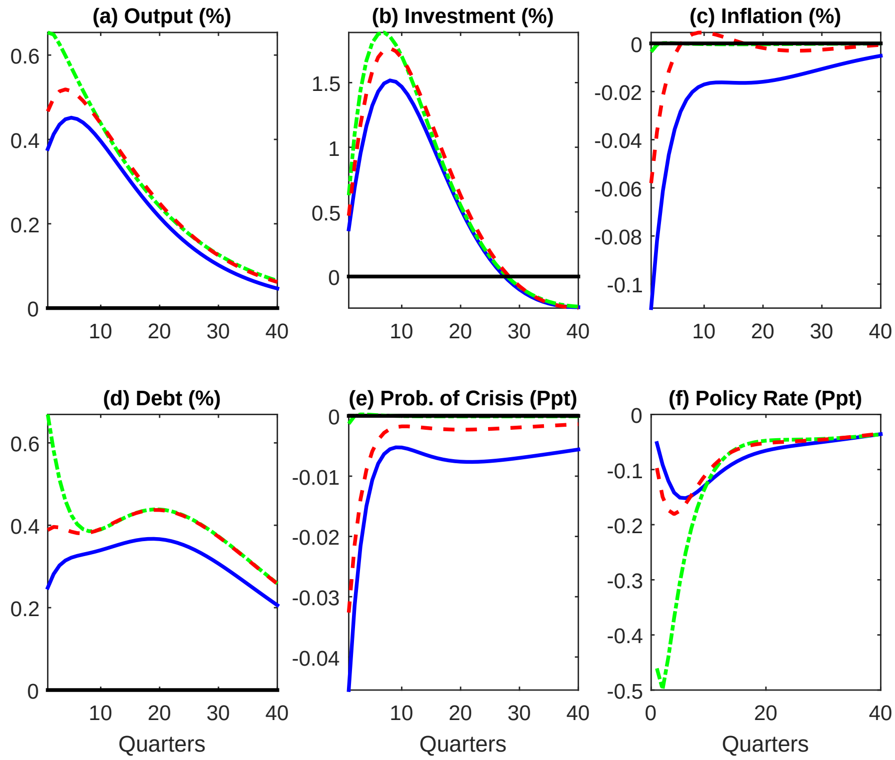
Note: Solid blue, doted green and dashed red lines indicate the cases of the baseline monetary policy rule, eq. (26), optimized output-gap rule and optimized credit-gap rule (LAW), respectively.

shock, the credit-gap based policy responds less aggressively to both of these shocks. The relatively passive response implied by the optimized credit rule for these shocks is because if it were more aggressive in these cases, it would also be even more responsive to financial shocks: i.e., a higher coefficient on the credit gap would help in responding to these shocks, but would exaggerate even more the output and inflation deviations in response to the financial shock.

5.3 Understanding the results

To confirm the interpretation that we have offered for the main findings, it is instructive to shutdown various features of the model to see how doing so changes the results. A particularly helpful experiment is to turn off the financial shocks (i.e. set $\sigma_\chi = 0$) and make the financial crises exogenous events (e.g. $b_1 = 0$). The environment then amounts to a standard New Keynesian model that includes a debt-equity tradeoff in capital structure and exogenous crises. The main findings are summarized in Table 3. In this environment, the optimal policy is one that responds enough to either the output or credit gap, and essentially perfectly stabilizes inflation. After

Figure 8: Impulse Response to Technology Shock: Optimal Simple Rule



Note: Solid blue, doted green and dashed red lines indicate the cases of the baseline monetary policy rule, eq. (26), optimized output-gap rule and optimized credit-gap rule (LAW), respectively.

a demand shock, monetary policy offsets the shock to fully stabilize output and inflation. On the other hand, when a productivity shock occurs, the policy keeps inflation on target and lets output respond fully to the shock. This result is standard in New Keynesian models - the divine coincidence property (Blanchard and Gali (2007)) applies and so there is no trade-off between output and inflation volatility, and this optimal policy can be (approximately) implemented by either simple rule provided they are sufficiently aggressive.[29]

To further build intuition, we now relax the assumption of exogenous financial crises. The main results are reported in Table 4. The findings are nearly identical to the prior case. This is because there is no reason to offset the credit fluctuations driven by the productivity shock, which are efficient and do not contribute to financial risk. As for demand shocks, the credit fluctuations they create are actually eliminated once output volatility is eliminated. Hence, there is no trade-off between credit stabilization and output/inflation stabilization, and the same policies

[29]Note that there is no intrinsic reason as to why one simple rule should perform better than the other in terms of welfare in this case; indeed the welfare difference we find is extremely small, about 0.2 basis point. Also note that output and inflation volatility as well as mean and standard deviation of financial crisis probability are quite close.

Table 3: No Financial Shocks, Exogenous Financial Crises

	Output gap only	Credit gap only	Both gaps
Welfare	-142.98	-142.99	-142.98
Consumption equivalent (%)	0	-0.002	0
Coefficient ϕ_y	100	–	100
Coefficient ϕ_b	–	96.89	0
400×SD(Π)	0.01	0.01	0.01
100×SD(Y)	2.20	2.19	2.20
400×E(P)	2	2	2
400×SD(P)	0	0	0

Table 4: No Financial Shocks, Endogenous Financial Crises

	Output gap only	Credit gap only	Both gaps
Welfare	-142.98	-142.98	-142.98
Consumption equivalent (%)	0.00	-0.00	0.00
Coefficient ϕ_y	100	–	100
Coefficient ϕ_b	–	97.28	100
400×SD(Π)	0.01	0.01	0.01
100×SD(Y)	2.19	1.66	2.20
400×E(P)	2.00	2.00	2.00
400×SD(P)	0.01	0.01	0.01

as in the previous case can implement an efficient allocation without creating any inefficient credit movements.

As a third point of comparison, we now reintroduce financial shocks, though unlike in the benchmark we suppose that crises are exogenous. In this version of the model the output gap rule does slightly better than LAW. The main findings are summarized in Table 5. The novelty compared to the previous cases is that the response to the output gap is diminished. This occurs because the response that would be required to offset demand and productivity shocks is not consistent with the response needed to respond to the financial shock. But the credit gap rule suffers from the same issue and has to trade off the response against the different shocks.[30] Overall, the LAW policy underperforms because the volatility it induces by stabilizing credit shocks does not lower the crisis risk. However, combining the credit and output gap allows a slightly better outcome.

[30] In some environments where the financial frictions are sufficiently severe, LAW can dominate an output gap rule even if financial crises are exogenous. For such an example, see Kiley and Sim (2017). In our model, this result also seems to be possible.

Table 5: Financial shocks, Exogenous Financial Crises

	Output gap only	Credit gap only	Both gaps
Welfare	-143.08	-143.14	-143.07
Consumption equivalent (%)	0	-0.050	0.017
Coefficient ϕ_y	4.11	–	2.69
Coefficient ϕ_b	–	0.47	0.47
400×SD(Π)	1.28	1.97	1.60
100×SD(Y)	2.21	3.20	2.32
400×E(P)	2	2	2
400×SD(P)	0	0	0

Table 6: Effect of Financial Crisis Size on Optimal Credit Policy

Financial crisis size (b_c)	6%	8%	10% (benchmark)	12%	14%
Optimal coeff. on credit ϕ_b	1.20	1.58	1.90	2.14	2.32
Consumption equivalent (%)	0.06	0.115	0.177	0.247	0.324
SD(Y) under LAW	4.06	4.37	4.57	4.69	4.78
SD(Π) under LAW	2.29	2.37	2.41	2.44	2.46
Mean(P) under LAW	1.993	1.987	1.980	1.983	1.982
Mean(P) under output gap rule	2.058	2.059	2.060	2.060	2.061
SD(P) under LAW	0.39	0.32	0.29	0.26	0.25
SD(P) under output gap rule	0.82	0.83	0.83	0.83	0.83

5.4 When is leaning against the wind optimal?

We next ask how certain parameters affect the desirability of leaning against the wind. For simplicity, in these comparisons we focus here on rules that depend either only on the (correctly measured) output gap or credit gap.

5.4.1 The cost of financial crises

Our benchmark model assumes that a financial crisis leads to a permanent decline in the level of GDP of 10%. Table 6 illustrates how our results change as we vary this cost from 6% to 14% with all other parameters kept constant. Several points emerge. First, the welfare benefit of targeting the credit gap rather than the output gap increases monotonically with the size of the financial crisis. Second, the bigger is the crisis, the stronger is the response to credit, with the coefficient rising from 1.20 to 2.32. Third, the volatility of inflation and output rise modestly as the responsiveness to credit rises, though the probability of the crisis is hardly moving across the different scenarios.

Table 7: Effect of Sensitivity of Crisis to Excess Credit on Optimal Policies

Sensitivity of crisis to excess credit (b_1)	2	4	5 (benchmark)	6	8
Optimal coeff. on credit ϕ_b	0.42	1.13	1.90	2.69	4.06
Consumption equivalent (%)	-0.05	0.04	0.17	0.37	0.91
SD(Y) under LAW	3.15	4.00	4.57	4.89	5.22
SD(Π) under LAW	1.94	2.28	2.41	2.49	2.55
Mean(P) under LAW	1.987	1.989	1.984	1.982	1.979
Mean(P) under output gap rule	1.987	2.019	2.060	2.115	2.271
SD(P) under LAW	0.27	0.32	0.29	0.27	0.26
SD(P) under output gap rule	0.34	0.66	0.83	0.99	1.33

5.4.2 The sensitivity of crises to excess credit

Another key parameter for our results is b_1, which measures how much excess credit affects the likelihood of financial crises. A large value of b_1 means that excess credit has a strong effect on the risk of crisis and hence on welfare. This naturally gives rise to a stronger motive to lean against excess credit. Table 7 confirms this intuition. First, for low values of b_1, LAW is outperformed by the output gap rule. Second, the optimal coefficient on credit rises with b_1. This change in the coefficient partially offsets the increase in the volatility of financial crisis probability that would otherwise occur mechanically. Third, this policy is chosen despite a clear cost in terms of higher output and inflation volatility.

5.4.3 The importance of financial shocks

Perhaps most basically, the magnitude of the (inefficient) financial shocks is critical for our results. We already illustrated that if there are no financial shocks, leaning against the wind brings no benefits relative to standard policies. Table 8 provides more details on the importance of this consideration. Here too, we see that the welfare difference between the best credit gap policy and the best output gap policy is increasing in the variance of financial shocks. The effects on output and inflation volatility as well as the financial crisis probability are more subtle because they result both from (i) the higher variance of financial shocks and (ii) the change in policy rule in response to this higher variance. Nevertheless, when the financial shocks are more important, the LAW policy delivers more volatility for output and inflation than the output gap rule and a lower probability of a crisis.

Table 8: Effect of Standard Deviation of Financial Shocks on Optimal Policy

Standard dev. of financial shocks (relative to benchmark)	33%	66%	100% (benchmark)	133%	166%
Optimal coeff. on credit ϕ_b	4.97	2.35	1.90	1.74	1.67
Consumption equivalent (%)	0.01	0.07	0.18	0.32	0.51
SD(Y) under LAW	2.71	3.58	4.57	5.63	6.75
SD(Π) under LAW	0.87	1.65	2.41	3.18	4.96
Mean(P) under LAW	1.999	1.992	1.980	1.974	1.962
Mean(P) under output gap rule	2.007	2.027	2.060	2.106	2.165
SD(P) under LAW	0.09	0.19	0.29	0.38	0.48
SD(P) under output gap rule	0.28	0.55	0.83	1.01	1.38

Table 9: Risk Aversion and Leaning Against the Wind

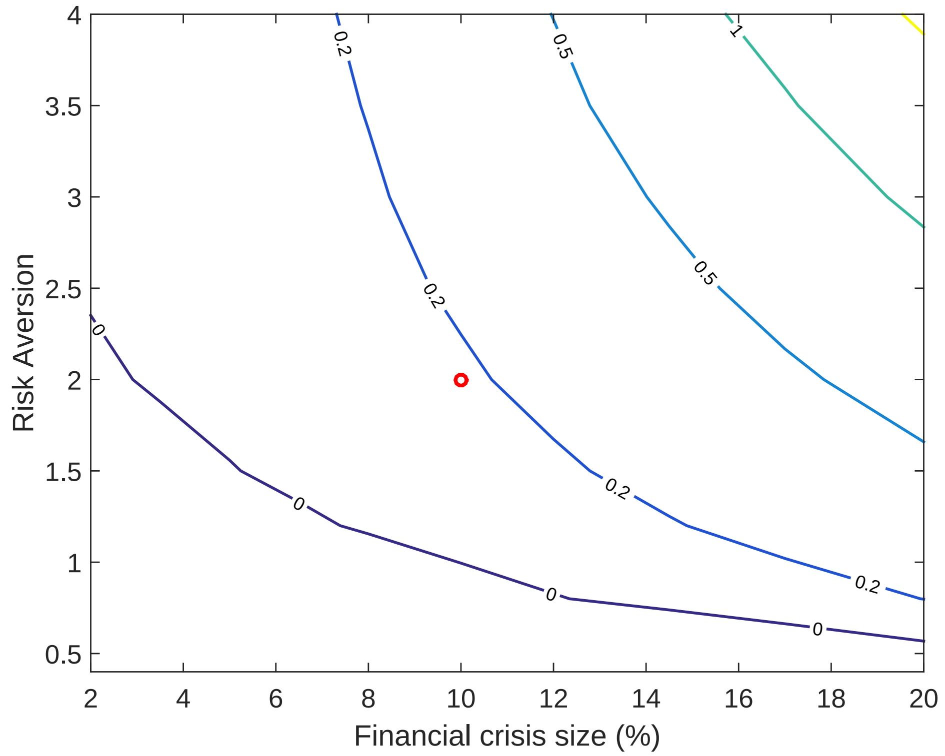
CRRA	0.5	1.5	2 (benchmark)	3	4
Optimal coeff. on credit ϕ_b	0.74	1.35	1.90	3.23	4.76
Consumption equivalent (%)	-0.30	0.12	0.18	0.27	0.35
SD(Y) under LAW	7.81	4.98	4.57	4.00	3.63
SD(Π) under LAW	2.60	2.41	2.41	2.40	2.39
Mean(P) under LAW	1.92	1.98	1.98	1.99	1.99
Mean(P) under output gap rule	2.084	2.066	2.060	2.049	2.041
SD(P) under LAW	0.49	0.36	0.29	0.20	0.15
SD(P) under output gap rule	0.89	0.84	0.83	0.80	0.78

5.4.4 The role of risk aversion

We next explore how the willingness of households to bear macroeconomic risk affects our results. On one side, higher risk aversion makes agents more fearful of financial crises. On the other hand, higher risk aversion also makes agents less willing to tolerate the higher business cycle volatility implied by LAW. Moreover, with our assumed preferences, a higher risk aversion implies a lower elasticity of substitution, which affects the response of the economy to monetary policy (as well as the dynamics of the model more generally). Table 9 reveals that the first effect seems to dominate - the higher the risk aversion, the larger the benefits from leaning against the wind. With a risk aversion of 0.5, an output-gap rule outperforms a credit-gap rule, but the benefits of using the credit gap rule rise with risk aversion. The optimal policy largely stabilizes fluctuations in financial crisis risk.

Figure 9 summarizes many of the central findings of the paper. On the horizontal axis, we vary the size of the financial crisis. On the vertical axis we vary risk aversion. The lines that are drawn trace out isoquants in units of equivalent consumption between the best LAW policy (that

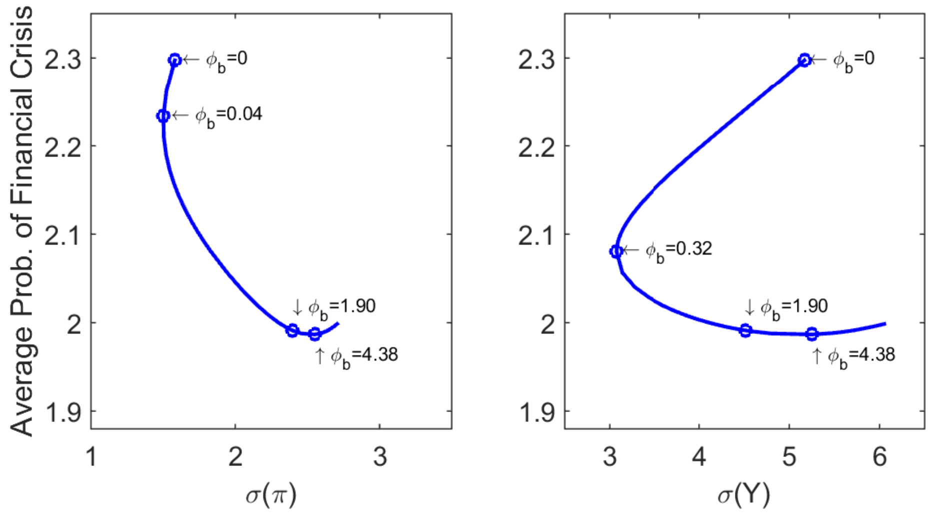
Figure 9: Welfare Gain from LAW: the Effects of Risk Aversion and the Size of Financial Crisis



responds only to the credit gap and inflation) and the best monetary policy rule that responds only to the output gap (and inflation).[31] The zero consumption equivalence curve traces out all the combinations of the size of the crisis and the representative household's level of risk aversion where the two policies deliver equivalent welfare. Points to the right and above the zero curve show the regions where LAW delivers higher welfare and below and to the left show combinations where the output gap rule performs better. The outcome for the benchmark model, described in Table 2 with risk aversion of two and a crisis that brings a permanent ten percent output loss, is indicated by the red dot. The results from Table 6 described how welfare varied when we fixed risk aversion at two and varied the size of the crisis. This figure fills in the rest of the parameter space. Not surprisingly, as risk aversion rises, LAW's relative performance improves. For most combinations, LAW is advantageous. However, if risk aversion is lower, say one, then a crisis that drops output by 10 percent is not enough to justify a LAW policy.

[31]Each policy is optimized with respect to the coefficient on the credit gap or output gap, as in the exercises above.

Figure 10: Tradeoff between Financial Stability and Traditional Mandates



5.5 Trading off financial stability vs. macroeconomic stability

Our model results demonstrate a significant trade-off between the traditional mandates of monetary policy – output and inflation stability – and financial stability - stabilizing, and if possible reducing the probability of financial crisis.

To illustrate this trade-off, we present a "policy frontier" in Figure 10. The policy frontier depicts the range of outcomes that can be implemented by a LAW policy. The frontier is obtained by solving the model for many possible values of ϕ_b. In particular, in the left panel of Figure 10, we change the LAW coefficient from 0 to 100 to see what happens to the mean probability of financial crises (on the vertical axis) and the standard deviation of the inflation rate (on the horizontal axis). In the right panel, we show the relationship between the mean probability of financial crisis and the stability of economic activity as measured by the standard deviation of output.[32] In a standard New Keynesian DSGE model, it is common to represent the policy frontier as the pairs of volatility of output and inflation that can be obtained. Here, we show how these measures vary with the average probability of a financial crisis.

The two panels indicate that for low values of the LAW coefficient, there can be a region where the central bank can improve upon both financial stability and traditional monetary policy objectives. This is possible because a rule that sets interest rates based only on inflation is sub-optimal and putting a little weight on the credit gap unambiguously improves outcomes. The

[32] The figure is nearly identical when one uses the output gap instead of output.

panels also show that after a certain point, the central bank can reduce the probability of financial crises only by sacrificing the traditional mandates. The LAW coefficient where the tradeoff begins differs for output and inflation. This is not surprising since the distortionary effects of responding to financial shocks differs for inflation and output. Nonetheless, the cost of a crisis is large enough that utility is maximized (at $\phi_b = 1.90$) by driving down the probability of a crisis even though doing so substantially raises inflation and output volatility. This choice reflects the improvement in the distribution of outcomes due to the lower risk of crisis. The welfare maximization challenge is to balance these gains against the losses from the increased volatility of the economy. The analysis suggests that this is an important potential consideration that is often omitted from stabilization discussions.

5.6 Mismeasurement

An important practical consideration is that neither the output gap nor the credit gap is actually observable. In practice efficient movements in credit cannot easily be separated from inefficient ones. In our model, inefficient movements come from demand or financial shocks while efficient ones come from technology shocks. In reality deregulation, changes in property rights and many other factors could also lead to a benign surge in credit and a central bank would need to be able to separate those swings from the inefficient ones.

To quantify this, we search again for the best policy rules in our baseline specification where the central bank is restricted to just observing actual output and credit - that is, it uses the deviation from the steady-state rather than the deviation from the efficient benchmark. The results are shown in Table 10 (and these should be compared to the findings in Table 2). The mismeasured output gap rule now eliminates all fluctuations in output, including the efficient ones. This leads to higher inflation volatility and noticeably lower welfare. Relying on the mismeasured credit gap still leads to a similar tradeoff as in the baseline model. The central bank delivers less frequent and less volatile crises, in exchange for higher inflation and output volatility. The relative performance of the rule based on mismeasured credit is bigger in this scenario than in the one with both gaps are perfectly measured. In fact, the best rule when both gaps are considered puts almost no weight on the output gap (and the welfare is about the same as when only the credit gap is used).

The welfare level is actually slightly higher when the mismeasured credit gap is used instead

Table 10: Optimal Policy Rules with Mismeasured Gaps

	Output gap only	Credit gap only	Both gaps
Welfare	-143.54	-143.25	-143.25
Consumption equivalent (%)	-0.17	0.09	0.09
Coefficient ϕ_y	100	0.00	0.00
Coefficient ϕ_b	0	1.61	1.61
400×SD(Π)	1.77	2.50	2.50
100×SD(Y)	0.09	3.98	3.98
400×E(P)	2.10	2.01	2.01
400×SD(P)	0.90	0.42	0.42

of the perfectly measured output gap; this conclusion depends on all the foregoing factors that have been shown to determine the relative attractiveness of leaning against the wind. For instance, in parameter configurations where the gains from leaning against the wind are low to begin with, then tying the policy rate to mismeasured credit gap would not necessarily lead to higher welfare than a rule that can be set based on a perfectly measured output gap. In these cases, however, the mismeasured credit gap rule would still outperform the mismeasured output gap rule. One caveat is that in our simple model, most of the credit variation is inefficient, so that the mismeasurement problem is not very significant.

5.7 Robustness

A concise way to summarize the findings from our baseline specification is as follows. The advantage of LAW depends on whether financial shocks are responsible for some non-trivial amount of economic fluctuations and whether they influence the probability of a financial crisis that delivers a long-lived slowdown. When these shocks are not important for macro outcomes, then LAW delivers similar outcomes to a conventional Taylor style monetary policy rule. When they are present, but they do not influence the probability of a crisis, a policy rule that reacts to them delivers worse outcomes. This deterioration comes because off-setting the credit shocks worsens inflation and output stabilization without any corresponding benefit. The case when LAW is preferred arises because dampening the financial fluctuations reduces the probability of a crisis enough to overcome the higher level of output and inflation variability. The success of LAW in this case depends neither on perfectly observing how much of the credit fluctuations are inefficient nor on agents being extremely risk averse.

Our results all assume that the monetary policy rule has a fixed coefficient on inflation. If instead that coefficient is also optimized, the same broad conclusions hold; that is, a monetary rule that responds to inflation and credit gap optimally outperforms one that responds to inflation and output gap.

These basic conclusions are present in several other variants of the model where we altered the nature of the financial fluctuations and the way that they influence a crisis. One set of alternatives that we considered is the possibility that a crisis depends on the level of debt relative to either output or capital (rather than the level of debt itself), again compared to the efficient level of the ratio. That kind of a specification is closer to some of the empirical literature that uses scaled debt movements to predict crises. When we change the model in this direction, and recalibrate appropriately, our main conclusions are unaffected. One issue that arises in the alternative specifications is that leaning against the wind now depends on both movements in the numerator and the denominator of the financial variable. This complicates the interpretation of what one would expect to some shocks that move the numerator and denominator in different directions or at different horizons. That is the main reason for presenting the specification that we featured.

We also experimented with more extreme variants of the financial frictions. As mentioned earlier, we think of χ as standing in for fluctuations in firms' ability to place debt. Our baseline calibration supposes that there are benefits to debt finance, say through tax subsides or reductions in agency problems with managers that prevent the squandering of funds. The quantitative results are, however, very similar if we suppose that each dollar of debt issued returns less than a dollar in available funds. This would be the case if we assumed that χ was standing in for the floatation costs of issuing debt and these costs were fluctuating.

6 Conclusion

Conventional discussions about the links between monetary policy and financial stability typically start by saying that one can appeal to different tools for different jobs. Macro-prudential regulation can address stability concerns, while monetary policy can attend to managing inflation. We agree that this would be the ideal arrangement, however, in practice in many countries this is easier said than done. Macro-prudential policymaking is in its infancy and for some countries the tools barely exist. These practical concerns motivate our analysis.

On the question of whether central banks should alter monetary policy to contain financial stability risks IMF staff study (IMF (2015)) says “Based on our current knowledge, and in present circumstances, the answer is generally no.” We believe this conclusion is premature.

The model we have presented is highly stylized and the parameters are not estimated. Nonetheless, we believe it does capture the ingredients that many of the advocates, and opponents, of leaning against the wind accept as important. In particular, the model presumes that financial crises are very costly, and are partly driven by credit conditions which monetary policy can affect, but at the cost of missing on its traditional inflation and output objectives. The model can easily uncover circumstances where leaning against the wind is welfare improving.

The model points to a number of factors that will determine the efficacy of leaning against the wind. Our main hesitations in endorsing the conclusion of IMF staff study (IMF (2015)) are that many of these factors are difficult to measure and that existing empirical work still do not provide much guidance about how to calibrate certain of these key elasticities. Perhaps subsequent work will confirm the IMF conclusion but for now we believe it is too early to say that the question is settled.

One powerful conclusion from the model is that the case for leaning against the wind likely rests on accepting higher volatility of inflation and output, in exchange for reducing the risk of crises. If central banks are going to embrace this policy, they will need to invest substantially in explaining this tradeoff to the public and to legislatures.

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Appendices

The system has 31 variables:

$$\mathbf{Y}_t = \begin{bmatrix} \nu_t & \lambda_t^K & \mu_t & C_t & L_t & \Pi_t & l_t & \Omega_t & M_{t-1,t} & \Lambda_t \\ N_t & w_t & \Xi_t & R_t & Q_t & K_t & I_t & Y_t & R_t^K & S_t^K \\ q_t & B_t & \varepsilon_t^* & \chi_t & K_t^w & r_t^K & Z_t & h_t & z_t^* & H_t \\ \Gamma_t & & & & & & & & & \end{bmatrix}$$

The corresponding system of equations are:

$$\nu_t = 1 - \mu_t \tag{.27}$$

$$0 = 1 - \varphi \Pi_t (\Pi_t - 1) - \eta \nu_t + \varphi \mathbb{E}_t \left[M_{t,t+1} \Pi_{t+1} (\Pi_{t+1} - 1) \frac{Y_{t+1}}{Y_t} \right] \tag{.28}$$

$$M_{t-1,t} = \beta \frac{\Lambda_t}{\Lambda_{t-1}} \tag{.29}$$

$$\Lambda_t = C_t^{-\tau} \tag{.30}$$

$$\Lambda_t w_t = N_t^{\upsilon} \tag{.31}$$

$$1 = E_t \left(M_{t,t+1} \Xi_t \frac{R_t}{\Pi_{t+1}} \right) \tag{.32}$$

$$K_t^w = (1 - \delta) K_t + I_t \tag{.33}$$

$$K_{t+1} = e^{X_{t+1} b} K_t^w \tag{.34}$$

$$C_t + I_t = Y_t - \frac{\psi}{2} \left(\Pi_t - \overline{\Pi} \right)^2 Y_t \tag{.35}$$

$$w_t = (1 - \alpha) \mu_t \frac{Y_t}{N_t} \tag{.36}$$

$$r_t^K = \alpha \mu_t \frac{Y_t}{K_t} \tag{.37}$$

$$Y_t = Z_t K_t^{\alpha} N_t^{1-\alpha} \tag{.38}$$

$$R_t^K = \frac{(1 - \delta) Q_t + r_t^K}{Q_{t-1}} \tag{.39}$$

$$S_t^K = Q_t K_t^w - \chi_t q_t B_{t+1} \tag{.40}$$

$$\varepsilon_t^* = \frac{B_t}{R_t^K Q_{t-1} K_t} \tag{.41}$$

$$z_t^* = \sigma^{-1}(\log \varepsilon_t^* + 0.5\sigma^2) \tag{.42}$$

$$H_t = \Phi(z_t^*) \tag{.43}$$

$$h_t = \phi(z_t^*) \tag{.44}$$

$$\Omega_t = \Phi(z_t^* - \sigma_t) \tag{.45}$$

$$q_t = E_t \left(M_{t+1} \left(1 - H(\varepsilon_{t+1}^*) + \frac{\zeta}{B_t} R_{t+1}^K Q_t K_{t+1} \Omega(\varepsilon_{t+1}^*) \right) \right) \tag{.46}$$

$$\Gamma_t = E_t \left(M_{t+1} R_{t+1}^K \lambda_{t+1}^K \right) \tag{.47}$$

$$\lambda_t^K = 1 + (\chi_t - 1)\, \varepsilon_t^* \left(1 - H\left(\varepsilon_t^*\right)\right) - (1 - \zeta \chi_t)\, \Omega\left(\varepsilon_t^*\right) \tag{.48}$$

$$\Gamma_t = 1 + \gamma \left(1 - \chi_t L\left(l_t\right)\right) \left(1 - \chi_t L\left(l_t\right)\right) \tag{.49}$$

$$L\left(l_t\right) = E_t M_{t+1} [\Omega(\varepsilon_{t+1}^*) \zeta R_{t+1}^K + (1 - H(\varepsilon_{t+1}^*)) \varepsilon_{t+1}^* R_{t+1}^K] \tag{.50}$$

$$\begin{aligned} &E_t \left\{ M_{t+1} \left(1 - H\left(\varepsilon_{t+1}^*\right)\right) \left[\frac{\chi_t - 1}{\chi_t} + \gamma \left(\frac{S_t^K}{Q_t K_{t+1}} \right) + \gamma' \left(\frac{S_t^K}{Q_t K_{t+1}} \right) \right] \right\} \\ &= (1 - \zeta)\, E_t \left\{ M_{t+1} \varepsilon_{t+1}^* h\left(\varepsilon_{t+1}^*\right) \left[1 + \gamma \left(\frac{S_t^K}{Q_t K_{t+1}} \right) + \gamma' \left(\frac{S_t^K}{Q_t K_{t+1}} \right) \right] \right\} \end{aligned} \tag{.51}$$

$$Q_t = 1 + \kappa \left(\frac{I_t}{I_{t-1}} - 1 \right) - \mathbb{E}_t \left\{ M_{t,t+1} \frac{\kappa}{2} \left[\left(\frac{I_{t+1}}{I_t} \right)^2 - 1 \right] \right\} \tag{.52}$$

$$l_t = \frac{B_t}{Q_t K_t^w} \tag{.53}$$

$$\log R_t = (1 - \rho_R) \log R_{t-1} + \rho_R [\log R + \rho_\Pi \log(\Pi_t / \bar{\Pi}) + \rho_Y \log(Y_t / Y_t^F)] \tag{.54}$$

$$\log \chi_t = (1 - \rho_\chi) \log \chi + \rho_\chi \log \chi_{t-1} + \sigma_\chi \epsilon_{\chi,t} \tag{.55}$$

$$Z_{t+1} = e^{X_{t+1} b} e^{\xi_{t+1}} Z_t \tag{.56}$$

$$\log \Xi_t = (1 - \rho_\Xi) \log \Xi + \rho_\Xi \log \Xi_{t-1} + \sigma_\Xi \epsilon_{\Xi,t} \tag{.57}$$

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