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Monetary Policy Rules with Financial Instability*

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Abstract
To provide a rigorous analysis of monetary policy in the face of financial instability, we extend the standard dynamic stochastic general equilibrium model to include a financial system. Our simulations suggest that if financial stability affects output and inflation with a lag, and if the central bank has privileged information about financial stability, then monetary policy responding instantly to deteriorating financial stability can trade off more output and inflation instability today for a faster return to the trend than a policy that follows the traditional Taylor rule. This augmented rule leads in some parameterizations to improved outcomes in terms of long-term welfare, but the welfare impacts of such a rule are small.

1. Introduction

In a widely quoted paper, Taylor (1993) suggested that monetary policy could be explained by a rule that links the central bank's policy rate to contemporaneous deviations of inflation and output from their target and potential levels, respectively. Since then, this "traditional Taylor rule" has become a tool of choice for those modeling central bank responses to macroeconomic developments. However, the traditional Taylor rule and similar basic rules leave something to be desired. In broad literature surveys, such basic rules explain at most two thirds of the empirical variance of interest rate changes (Svensson, 2003). The unexplained part includes discretionary policymaking, but it can also be seen as measure of our ignorance about the actual rules used by policy makers.

In our paper, we examine the central bank response to episodes of financial instability as a source of deviations from the traditional Taylor rule. The motivation for doing so is that for some time now, central banks themselves have recognized the importance of timely response to financial instability, and have devoted substantial resources to monitoring financial stability, often with the help of confidential supervisory data. The liquidity injections by the major central banks during the 2007–09 global financial crisis have brought these issues to the spotlight.

How should changes in financial sector soundness affect monetary policy? In our article, we answer this question by addressing two simplifications in the standard monetary dynamic stochastic general equilibrium (DSGE) model: (i) the omission of a financial system, and (ii) the omission of forward-looking variables in the tra-

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ditional policy (Taylor) rule. Our paper is not the first one to introduce forward-looking elements into the Taylor rule (see, e.g., Berger, Kissmer, and Wagner, 2007 or Berg, Karam, and Laxton, 2006), but it provides a novel way of introducing the financial system into the DSGE model while augmenting the Taylor rule.

In our model, the central bank has privileged information about the health of the financial system, a reasonable assumption given that many central banks are involved in financial sector supervision, and even those that are not have access to a wealth of payment system data. Individual financial institutions would normally have better information about their financial health and the financial health of their clients, but they would not have such information at the systemic level. In contrast, the central bank's unique role in the payment system and usually its access to confidential prudential data gives it access to superior information about the health of the financial system as a whole (e.g., Padoa-Schioppa, 2002). There is active discussion in the empirical literature and in central bank reports on how exactly to define and measure financial instability (Čihák, 2006). In this article, we focus on the probability of default in the non-bank corporate sector because this is usually a key component of banks' credit risk and is a major source of financial instability. Also, the probability of default has been a rather popular way to approximate financial stability in the empirical literature.

To preview our findings, the simulations suggest that if financial instability (approximated by credit risk) affects output and inflation with a lag, and if the central bank has privileged information about credit risk, monetary policy responding instantly ("preventively") to increased financial instability can trade off more instability in output and inflation today for a faster return to the output and inflation trend than a policy that follows the traditional Taylor rule. In some parameterizations, this augmented rule leads to improved outcomes in terms of long-term welfare; however, the welfare impacts of such a rule appear to be negligible.

The findings provide a model-based justification for the central bank practice of intervening against a background of financial shocks. Therefore, the traditional (simple) Taylor rule is an inaccurate description of central bank behavior, underestimating actual policy changes under financial stress. The central bank following our augmented policy rule trades off more output and inflation instability today for a faster return to the trend path tomorrow. The simulations also suggest limits to the use of monetary policy instruments under these conditions: the bank seems capable only of a faster reaction to the financial instability shock, keeping the nature of monetary policy unchanged, and long-run consumption volatility remains practically identical under both rules. Moreover, monetary easing is unlikely to work in highly open economies with either fixed exchange rates or a strong exchange rate channel of monetary transmission.

Until recently, the DSGE models used for policy analysis have omitted the financial system. Such an omission was puzzling, given that many central banks have had financial stability as a policy goal (Crockett, 1997) and given that central bankers had devoted considerable time to discussing and analyzing the financial sector.[1]

[1] This attention has been illustrated by the proliferation of financial stability reports over the last decade (Čihák, 2006), and, more recently, by the aggressive policy response of many central banks during the global financial crisis.

There have been several recent attempts to introduce a financial sector into DSGE models and, in particular, into models designed for monetary policy analysis. Williamson (1987) constructs a business cycle model in which financial intermediation exists because of asymmetric information and costly monitoring. Stochastic disturbances to the riskiness of investment projects produce equilibrium business cycles in the presence of monitoring costs. The paper is close to ours in that a reduction in the amount of loans in the current period reduces the next period's output. However, the model does not incorporate nominal rigidities (sticky prices), and does not consider the role of monetary policy in smoothing fluctuations in the cycle.

Bernanke, Gertler, and Gilchrist (1999) develop a new Keynesian model that includes a partial equilibrium model of the credit market in order to study how credit market frictions amplify real and nominal shocks to the economy. The model does not incorporate, though, a concept of financial instability. This concept and empirical support for the financial accelerator model were introduced by Christiano, Motto, and Rostagno (2008). Brousseau and Detken (2001) study how the central bank designs monetary policy in order to stabilize the financial system. In this respect, the objective of their paper is closely related to ours. However, financial instability is not modeled explicitly but rather introduced into the model as a sunspot shock. Moreover, they discuss the specification of the optimal policy instead of considering the use of a Taylor rule. Berger, Kissmer, and Wagner (2007) do not model a financial sector explicitly but rather explore how optimal monetary policy is affected by shocks to asset prices when these assets serve as the collateral base for private-sector debt accumulation. The authors argue that – under forward-looking private expectations and public knowledge of the possibility of a future credit crunch – a pre-emptive monetary policy to the build-up of the crisis scenario is superior in welfare terms to a reactive monetary policy, in part because the public will expect such policy.

A number of recent empirical studies have found that central banks *do* react to financial sector instability by lowering interest rates. The studies also suggest that this reaction is asymmetric, nonlinear, and reflects the nature of the underlying shock. Examples of such papers are Borio and Lowe (2004) and Cecchetti and Li (2005). Bulíř and Čihák (2008) estimate a modified Taylor rule in a panel of 28 industrial and emerging market countries using seven different measures of financial instability, finding that instability has been associated with short-term interest rates below those implied by the traditional Taylor rule. Quantitatively, in a country with a floating exchange rate, the contemporaneous impact of a one standard deviation increase in the probability of crisis is associated with interest rates being 0.2 percentage points lower than what they would be otherwise.

The article is organized as follows. In Section 2, we build a DSGE model with financial intermediaries. In Section 3, we calibrate the model on U.S. data and present simulations for a range of policy-relevant shocks, analyzing an augmented policy rule. In Section 4, we present some robustness checks. Section 5 concludes.

2. The Model

Our model, which builds on Galí (2002), addresses two simplifications in the standard new Keynesian DSGE model: the omission of a financial system and the omission of forward-looking variables in the policy rule. We differ from a Galí-

-type DSGE model in two respects: (i) financial intermediaries supply external financing to some firms; and (ii) firms that are sensitive to the supply of loans and the interest rate are linked with the rest of the firms in the economy through a productivity nexus.

These adjustments capture seven stylized facts that have been absent from the typical DSGE model used in the literature:[2] (i) the credit channel works through a subset of firms that depend on external financing; (ii) small- and medium-size firms depend on banks for financing more than large firms; (iii) small, start-up firms perish easily if they cannot obtain external financing; (iv) small firms are driving technology and productivity improvements; (v) higher lending rates make both the marginal loan and the lending portfolio of the financial system more risky; (vi) the central bank observes changes in financial system health before the public does; and (vii) monetary policy actions have a limited impact on moral hazard in banks.

The economy contains five types of agents: households; goods-producing firms that are monopolistic competitors; innovative firms that are freely competitive; financial intermediaries, which are freely competitive as well; and a central bank. The following sections discuss the features and interactions of these agents; further details of the derivations are available upon request.

2.1 Households

The economy is populated with a continuum of infinitely-lived and identical households that derive utility from consumption of goods and leisure, and invest their savings in a financial intermediary that pays a nominal rate r_t for one-period deposits made at time t-1. Households consume a basket of all goods available according to

$$c_t = \left[\int_0^1 c_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}}$$

where c is the contemporaneous consumption of the representative household and ε is the elasticity of substitution between any two given goods indexed i and i'.

The problem of the representative household can be written as

$$\max_{c_t, n_t} \; E_0 \sum_{t=0}^{\infty} \beta^t U(c_t, n_t)$$

subject to its period-by-period, nominal budget constraint $P_t c_t + P_t d_t = P_t w_t n_t +$ $+ r_t P_{t-1} d_{t-1} + P_t \Pi_t + P_t T_t$, where d_t are one-period deposits, w_t is the wage rate, n_t is labor, Π_t are dividends, and T_t are lump sum taxes; all these variables are in real terms.

2.2 Goods Firms ("Firms That Do Not Need External Financing")

The first segment of the corporate sector is a continuum of infinitely-lived firms acting as monopolistic competitors. These firms produce a single perishable,

[2] These elements have been absent also from the models that preceded the DSGE models, including those used by most central banks. See Sims (2008) for a review.

differentiated good with a technology $y_t(j) = a_t n_t(j)$, where a_t is a technology shifter common to all firms. The economy-wide, competitive factor market guarantees that all firms pay the same nominal wage $W_t = P_t w_t$ for a unit of labor employed. The distinguishing feature of these firms is that they do not need to borrow from financial intermediaries, and are able to finance themselves through retained earnings. We imagine that these firms are "large".

Following Calvo (1983), we assume that these firms adjust their prices infrequently and that the opportunity to adjust prices follows an exogenous Poisson process. Each period there is a constant probability $1-\theta$ that the firm will be able to adjust its price, independently of past history. Inability to adjust prices every period is the source of nominal rigidities that make inflation distortionary.

2.3 Innovative Firms ("Firms That Need External Financing")

The non-financial corporate sector also contains firms that have to borrow from financial intermediaries to develop a project. These firms only live for two periods and operate under perfect competition. The key distinguishing feature of these firms is that, unlike the goods firms, they are dependent on external financing. (We also imagine that these firms are "smaller" than the goods firms, but it is the dependence on external funding, not size, which distinguishes the two groups of firms.) In period t such a firm invests in a project in order to obtain a return in period t+1. The technology is such that

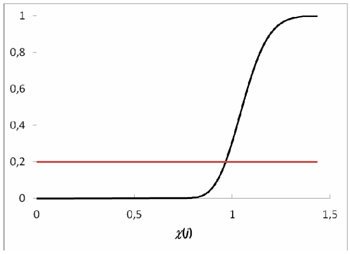
$$s_{t+1}(j) = \chi(j) s_t(j) \tag{1}$$

where $s_t(j)$ is the initial investment made by firm j in the project and $\chi(j)$ is the firm-specific return of the project.

Some of these firms survive and some do not. For simplicity, we assume that a constant fraction γ of these firms born in period t survive with probability one in period t+1. Moreover, to capture the trade-off between risk and return, we assume that firms that survive with probability one, i.e., "risk-free" firms, are the least profitable firms. The remaining firms may die at the beginning of period t+1 with probability δ_{t+1}, where δ_{t+1} is stochastic. A firm that does not survive obtains a zero return for its project. Finally, δ_{t+1} is realized only at the beginning of period t+1, after firms have applied for and received loans.

The returns of innovative firms are nonstochastic, firm-specific, and distributed according to a log-normal distribution with parameters μ and σ. We index firms according to their returns in the interval [0, 1], denoting with 0 the firm for which $\chi(j) = \chi^{min}$ and with 1 the firm for which $\chi(j) = \chi^{max}$. We establish a one-to-one correspondence between the firm's index and the lognormal cumulative distribution function. That is, firm j is such that a proportion j of firms obtain returns which are lower than $\chi(j)$. Then γ is both the proportion of firms that survive with probability one next period and the most profitable non-risky firm. *Figure 1* shows a stylized distribution of returns with parameters $\mu = 0.05$, $\sigma = 0.1$, and $\gamma = 0.2$. Firms that obtain returns higher than $\chi(\gamma) = 0.9664$ are risky, in the sense that they may die next

Figure 1 Distribution of Returns of Innovative Firms (Cumulative lognormal distribution of $\chi(j)$ with μ = 0.05 and σ = 0.1)



period with probability δ_{t+1}. On the contrary, firms with returns lower than χ (γ)= = 0.9664 survive with probability one. In Section 3 we will show results under different assumptions about γ.

2.4 Financial Intermediaries

The economy also contains a continuum of risk-neutral financial intermediaries that act as go-betweens for households and innovative firms. As there is free entry in the financial sector, banks obtain zero profits in equilibrium. These institutions receive deposits from households in period t and lend to innovative firms, charging them a lending rate z_t. At time t+1, firms that have survived repay their loans and intermediaries pay to households the return r_{t+1}, with zero recovery on loans to failed firms. We will assume that intermediaries are able to monitor whether a firm exists or not without a cost, but cannot distinguish between firms and thus have to charge the same loan rate z_t to all firms. However, a firm j has an incentive to ask for a loan only if its expected project return is higher than the lending rate. In other words, there is no moral hazard problem in the model.[3]

$$\chi(j) > z_t \tag{2}$$

We assume that $z_t < \chi^{max}\ \forall t$. Therefore, the marginal firm ω_t to ask for a loan will be such that $\chi(\omega_t) = z_t$. In *Figure 1*, the marginal-firm cutoff point ω_t can be interpreted as the proportion of innovative firms that have returns lower than z_t and, therefore, do not find it profitable to apply for a loan. Thus, due to the lack of funds, these firms will not be producing in period t+1. Conversely, the proportion of firms asking for loans will be $(1-\omega_t)$.

In this economy riskiness and the lending rate are positively related, in line with the existing literature (Ruckes, 2004).[4] Given the technology of innovative firms, they have an infinite demand for loans, and since banks cannot distinguish among borrowers, they will divide their loanable resources into equal parts, pro-

[3] Introducing moral hazard would complicate the algebra, without changing the results substantially. Given that lower rates reduce incentives for moral hazard (and thereby reduce risks in lending), the introduction of moral hazard would somewhat strengthen the case for lowering interest rates in situations of increased financial instability.

[4] In contrast, some economists have argued that lower interest rates tend to be associated with lower lending standards, increasing the overall riskiness of the bank portfolio; see, for example, Dell'Ariccia and Marquez (2006).

viding the same amount of loans to each firm that asks for one: $l_t = \frac{d_t}{1-\omega_t}$. Thus, the riskiness of the whole loan portfolio is increasing (more precisely, non-decreasing) in the lending rate. At higher rates fewer firms apply for a loan and the lending portfolio becomes more concentrated in the high-return and high-risk segment and thus more risky overall.[5]

Intermediaries' opportunity cost of a loan is a central bank bill that pays a nominal interest rate equal to i_t (the policy rate) and that is for all practical purposes equivalent to the rate on short-term treasury bills. Therefore, the return on lending to firms is equal to the return on investing in central bank paper and the loan rate will be determined as the rate such that the expected returns from loans are equal to the interest rate i_t.

$$i_t d_t = E_t\left(z_t \tilde{l}_{t+1}\right) \tag{3}$$

where $\tilde{l}_{t+1}$ are loans actually repaid in period t+1. Notice that, since banks do not know the probability of firms' survival when they lend to them, they compute the loan rate based on their expectations of the δ_{t+1} shock. The *ex post* deposit rate will thus be $r_{t+1} = z_t \tilde{l}_{t+1} / d_t$. In other words, if a smaller proportion of loans are repaid in t+1, the (*ex post*) deposit rate becomes smaller, which means an increase in the spread between the deposit rate on the one hand and the policy rate and the lending rate on the other hand.

2.5 Technology

The economy-wide total technology a_t consists of two components. One component is exogenous and stochastic and follows an autoregressive process $\hat{a}_t^s = \rho^a \hat{a}_{t-1}^s + \varepsilon_t^a$, where ε_t^a is an independent and identically distributed (i.i.d.) shock and $\hat{a}_t^s$ denotes log-deviations of a_t^s from steady state.

The other, additional components of technology are the projects developed by the innovative firms that asked for loans in period t–1 and survived in period t. The production function for this type of technology is $a_t^i = \left[\int_{\omega_{t-1}}^{1} \left(s_t(j)\delta_t^*(j)\right)^{\frac{\tau-1}{\tau}} dj\right]^{\frac{\tau}{\tau-1}}$,

where $\delta_t^*(j) = 1$ if the firm survived in period t and zero otherwise, and τ is the elasticity of substitution between any two projects j and j'. Substituting (1) into the last expression and rearranging, we obtain $a_t^i = \left[\int_{\omega_{t-1}}^{1} \left(\chi(j)\delta_t^*(j)\right)^{\frac{\tau-1}{\tau}} dj\right]^{\frac{\tau}{\tau-1}} \frac{d_{t-1}}{1-\omega_{t-1}}$.

Finally, total technology combines both the exogenous and endogenous components according to a Cobb-Douglas function, $a_t = a_t^{i\alpha} a_t^{s1-\alpha}$, where α is the con-

[5] Technically, it is possible for some combinations of parameters that the riskiness of the portfolio remains constant.

tribution of technology generated by innovative firms, a_t^i, to total technology. Thus, without innovative firms, productivity growth would be limited to the exogenous component only.

2.6 The Central Bank

The central bank seeks to stabilize the economy, which means that it responds to the productivity and survival shocks that hit the two types of firms (a_t^s and δ_t, respectively). We examine two central bank response functions, with and without regard for the state of the financial system.

First, we look at a central bank that sets its policy rate as per the traditional Taylor rule,

$$\hat{i}_t = \varphi_\pi \hat{\pi}_t + \varphi_x x_t \tag{4}$$

where i_t is the policy rate, $\hat{\pi}_t$ is inflation in period *t*, and x_t is the output gap, defined as the difference between actual output and natural output (that is, output in the flexible price allocation). In order to guarantee a unique equilibrium, the rule needs to be such that $\varphi_\pi > 1$. While this is a backward-looking rule, we test its robustness against a forward-looking rule that contains expected inflation (in $t+1$) instead of the current inflation (in *t*). While the latter rule is closer to the modeling practice in modern central banks, the resulting paths of inflation and output are fairly similar.

Second, we look at a central bank that continually monitors financial intermediaries and their counterparts to infer the state of the economy and the impact of financial institutions' health on the real economy. This information is likely to be collected through prudential supervision of financial intermediaries (many central banks have direct prudential powers; others have exclusive access to prudential data collected by prudential supervisory agencies), or through the central bank's role in the payment system. This information is confidential, that is, exclusive to the central bank on the systemic level.

Empirical studies suggest that if central banks have up-to-date prudential information on banks (e.g., from recent on-site supervisory visits), they can achieve better predictions of financial stability than is possible based on publicly available data, such as stock market prices.[6] If the central bank has this information, it can presumably use it to improve the stabilization outcome of its policies. When it observes no significant risk to financial stability, it can rely on the "traditional" Taylor rule. But when it detects a sizable threat to financial stability (i.e., in the context of our model, an adverse shock to the survival of borrowing firms), the central bank would employ its private information about the probability of default, δ_t, at the *beginning* of period *t*, possibly augmenting its rule-based decision with this information. This probability is forward-looking information that would ultimately help predict the future evolution of the output gap. The modified rule is applied in a non-

[6] Berger, Davies, and Flannery (2000) find that assessments based on freshly updated U.S. supervisory inspections tend to be more accurate than equity and bond market indicators in predicting performance of large bank holding companies. The predictive power of supervisory data is even higher in economies with limited public availability of bank soundness data; see Bongini, Laeven, and Majnoni (2002).

-continuous way, that is, only when the economy is hit with a shock to δ_t. The policy response function would look as follows:

$$\hat{i}_t = \begin{cases} \varphi_\pi \hat{\pi}_t + \varphi_x x_t & \text{if } \left(\delta_{t+1} - E_t \delta_{t+1}\right) < 0 \\ \varphi_\pi \hat{\pi}_t + \varphi_x x_t + \left(\varphi_\delta + v^\delta\right)\left(\delta_{t+1} - E_t \delta_{t+1}\right) & \text{otherwise} \end{cases} \tag{5}$$

where $\varphi_\delta < 0$ and v^δ is a shock to the sensitivity of the rule to movements in the probability of default, δ_t, capturing both the reporting lags and the policy maker's nonlinear and asymmetric response to these movements. The term v^δ (which can be thought of as white noise with standard deviation ε^v, unknown to the private agents) also limits the private sector participants' ability to infer δ_t from the interest rate set by the central bank, estimating φ_π, φ_x and φ_δ based on observations of the policy interest rate. In other words, we impose a limit on signal extraction by central bank observers.[7] This is realistic, because the sort of financial instability which we are capturing is a fundamentally new shock affecting the economy, not something that can be easily predicted based on past developments. Indeed, if economic agents knew the value of δ_t, the scope for loose monetary policy to "inflate away" a negative shock to financial stability would disappear.

The timing of events will be as follows: at the beginning of every period, after δ_t and a_t^s are realized, total technology a_t is observed. Households make their decisions on consumption, saving, and labor allocations, forming their expectations based on the information they possess at the time. The central bank sets the policy rate according to rule (4) in the benchmark scenario; while it employs the augmented rule (5) in the alternative scenarios, using also different values of this information in the rule (φ_δ). Therefore, in (5) the central bank uses information that other agents do not possess, and we want to study whether this informational advantage is relevant for the determination of the policy rate or not.

In what follows, we will calibrate the model and observe the effects of two shocks on the economy: (i) a pure technological shock; and (ii) a shock to the probability of default of firms. We will study two different scenarios for the central bank response. First, the benchmark ("Traditional Taylor Rule"), in which the central bank response is characterized by the Taylor rule defined as in (4), with the parameter values $\varphi_\pi = 1.5$ and $\varphi_x = 0.5$ used in Taylor (1993) and many of the subsequent papers. Second, we will examine an "Augmented Taylor Rule" scenario, in which the policy rule is as in (5) with $\varphi_\delta = -0.5$. This parameterization of φ_δ is somewhat arbitrary, but the results do not differ qualitatively if we use, for example, $\varphi_\delta = -0.25$ or $\varphi_\delta = -0.75$. What matters from a qualitative standpoint is that $\left(\varphi_\delta + v^\delta\right) < 0$.[8]

[7] One could also think that the central bank cannot perfectly foresee δ_t and that it only receives more information to compute the conditional expectation than the rest of the agents. Nevertheless, under this specification the qualitative implications of our setup remain unchanged.

[8] For the purpose of simplicity, we "shut down" the term v^δ in the simulations. Keeping v^δ as a white noise term with standard deviation ε^v does not materially affect the results as long as $\left(\varphi_\delta + v^\delta\right) < 0$.

3. Model Simulations

We calibrate the model and observe the effects of two shocks: a pure technological shock and a shock to the probability of default of firms. The time period is one quarter.

3.1 Parameterization

We calibrate the model using parameter values from Bernanke, Gertler, and Gilchrist (1999) and Galí (2001), both of which refer to the U.S. economy. We use the following utility function for households: $U\left(c_t, n_n\right) = \frac{c_t^{1-\sigma}}{1-\sigma} - \frac{n_t^{1+\varphi}}{1+\varphi}$ with $\sigma = \varphi = 1$. The probability of adjusting prices in a given period $1-\theta$ is set equal to 0.25, which implies an average price duration of one year, a value in line with survey evidence. The discount rate β is set to be 0.99. The serial correlation for the technology process, ρ^a, is assumed to be 0.95.

The process for the probability of small-firm survival is $\delta_t = \delta + \rho^\delta \delta_{t-1} + \varepsilon_t^\delta$, where ε_t^δ is an i.i.d. process. Given the average duration of post-war U.S. recessions of 11 months, we choose ρ^δ to be 0.25, and the annual rate of business failure, δ, is equal to 0.03, approximating the data. The share of firms that survive for sure, γ, is set to be 0.2, which implies a quarterly steady-state spread between loan and deposit rates of 0.76 percent and an annual loan rate of 7.28 percent.

The variances of the technological shock and probability-of-survival shocks, σ^a and σ^δ, are assumed to be 0.01 and 0.0025, respectively. The last two parameters, the participation of a_t^i in the creation of technology and the elasticity of substitution between any two projects *j* and *j'*, are set to equal $\alpha = 0.05$ and $\tau = 4/3$, respectively. That is, we are assigning a comparatively small role of a_t^i in the creation of total technology, but – based on U.S. data – we expect sizeable effects from shocks to the probability of default.

To assess the robustness of the results, we have calculated our simulations for a range of different distributions of returns to innovative firms. The results do not vary substantially. For exposition purposes, we choose a lognormal distribution with $\mu = 0.05$ and $\sigma = 0.1$.

3.2 Simulation Results

3.2.1 An Exogenous Technology Shock

First, we simulate an exogenous technology shock, that is, a positive shock to a_t^s equal to one standard deviation thereof (ε^a). *Figure 2*, as well as all other figures, shows the trajectory of the shock as a percentage deviation from the steady state. *Figure 3* shows the response of output, the output gap, inflation, and labor.[9] *Figure 4* shows the evolution of the main interest rates (policy rate, deposit rate, loan

[9] In the simulations, the impulse response of consumption is the same as the trajectory of output, and is therefore not shown separately.

Figure 2 Shock to Exogenous Technology
(One standard deviation of the technology shock, ε^a)

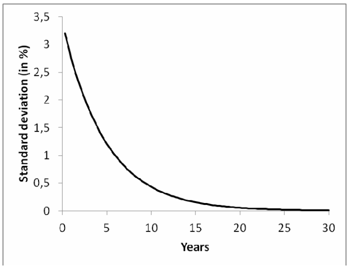
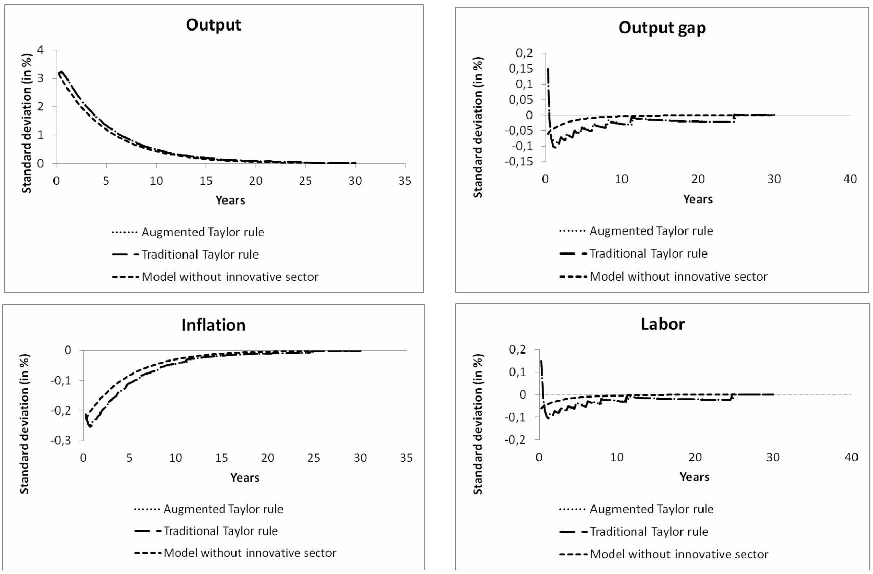


Figure 3 Shock to Exogenous Technology: Response of Output, Output Gap, Inflation, and Labor
(One standard deviation of the technology shock, ε^a)



rate, and effective (*ex post*) deposit rate). *Figure 5* shows the evolution of loan applications (ω_{t-1}) and endogenous and total technology. Both in *Figure 3* and in *Figure 4* we compare the results from our model (with both specifications of the Taylor rule given in equations (4) and (5)) with what is obtained in a standard model without the innovative sector. This last case has been studied in the literature, and will serve as a benchmark for comparison purposes. In *Figure 5*, we do not show results for the benchmark model since the variables graphed do not appear in such a framework.

A positive exogenous technology shock in an economy with sticky prices, imperfect competition, and no innovative sector generates lower employment, higher output, and opening of the output gap. While all firms experience a decrease in their marginal costs, not all can adjust their prices in this period (Galí, 2001).Thus, the consequent changes in the aggregate price level and demand will be proportionately less than the initial increase in productivity.

Figure 4 Shock to Exogenous Technology: Response of Policy Rate, Real Interest Rate, Loan Rate, and Effective Deposit Rate (One standard deviation of the technology shock, ε^a)

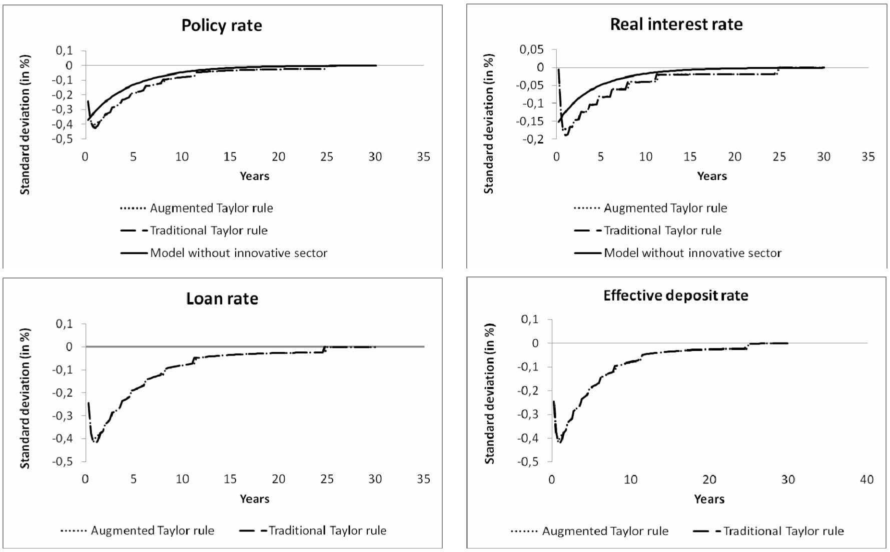
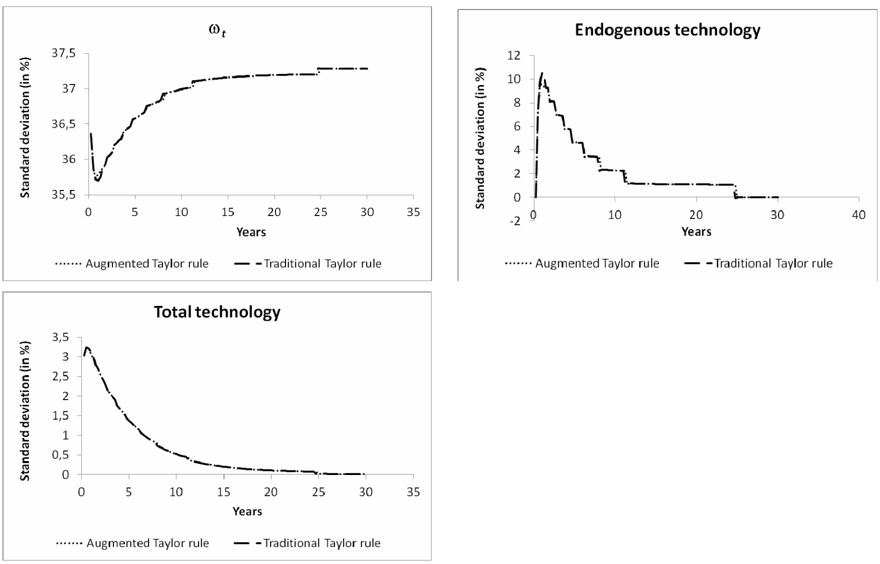


Figure 5 Shock to Exogenous Technology: Response of Loan Applications (ω_t), Endogenous Technology and Total Technology (One standard deviation of the technology shock, ε^a)



In the above economy, the responses of the variables to an exogenous technology shock are both different from the "traditional Taylor rule" benchmark model and more pronounced. Despite the differences explained below, from period 2 on the *qualitative* response of all variables is identical in all three scenarios. The response of labor and the output gap in the first period is positive, becoming negative only from the second period onwards. This result follows from the initial monetary loosening based on the central bank's private information. The path of the variables is not as smooth as before, and for some variables such as labor and the output gap the response is not even monotonic. This result follows from the impact of the lending conditions on the evolution of endogenous technology.

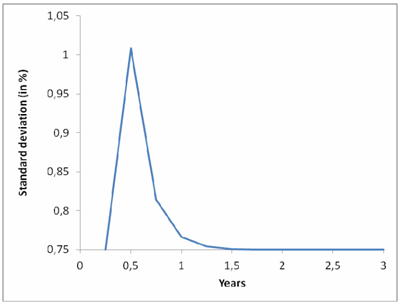
Increased volatility results from the presence of endogenous technology and bank lending. Recall that $a_t^i = \left[\int_{\omega_{t-1}}^{1} \left(\chi(j)\delta_t^*(j) \right)^{\frac{\tau-1}{\tau}} dj \right]^{\frac{\tau}{\tau-1}} \frac{d_{t-1}}{1-\omega_{t-1}}$. From this expression, we can observe that the creation of endogenous technology in period t depends on the proportion of firms applying for a loan ω_{t-1} and deposits d_{t-1}. The higher the level of deposits, the higher the amount of the loan received by each firm and, consequently, the higher the contribution of technology generated by innovative firms, a_t^i. The effect of ω_{t-1} on a_t^i is a priori indeterminate: while a lower ω_{t-1} implies that more firms are obtaining loans and thus the term in brackets increases, the total amount of deposits has to be divided over a higher number of borrowers and $\frac{d_{t-1}}{1-\omega_{t-1}}$ decreases.

More specifically, the decrease in the policy rate due to the negative response of inflation causes loan applications, $1-\omega_t$, to increase, whereas deposits, d_{t-1}, increase as well because of the better expectations of future consumption. The full impact on endogenous technology is positive, but the effect only takes place in period 2. This translates into a higher expectation of output (and consequently, consumption) for period 2, which causes period 1 consumption to increase more than what is accounted for by the period 1 increase in exogenous technology. Thus, labor increases, causing the output gap to increase as well. From period 2 onward the higher level of endogenous technology is added to the original effect of the exogenous technology shock, which explains the amplified response of all variables to the shock.

As the technology shock dies out, both loan applications and deposits decrease until they reach their steady state values. Nevertheless, the path of a_t^i is not monotonic: while the overall trend is downward sloping, in some periods it increases with respect to its value in the previous period. This is so because the process for a_t^i has no memory (there is no transmission from a_{t-1}^i to a_t^i as innovative firms live for two periods only) and the effect of ω_{t-1} on a_t^i is indeterminate a priori.

The economy with the innovative sector behaves much in the same way under both rules proposed. This is due to the fact that a technology shock does not generate financial instability: $\delta_t - E_t\delta_t = 0 \quad \forall\, t$ and thus the reaction of the central bank to the shock will be identical under all scenarios. For the case with no contribution to technology generated by the innovative sector, $\alpha = 0$, our model nests the bench-

Figure 6 Shock to Probability of Default
(One standard deviation of the shock to the default probability, ε^{δ})



mark model without the innovative sector. Deviating from the benchmark scenario by setting $\alpha = 0.05$, the model departs from the standard results, as can be seen in the differences between the dashed and solid lines in *Figures 3* to *5*, due to a small difference in the numerical solution of the model under the two specifications. These differences are, nonetheless, of a very small magnitude and do not alter the thrust of the results.

3.2.2 A Shock to the Default Probability

Second, we consider a negative shock to the probability of survival (δ_t) of one standard deviation (ε^{δ}) (*Figure 6*). Unlike the long-lasting technology shock, this shock is assumed to be much less persistent than the previous shock, dying out in approximately 4 quarters. The economy is described in *Figures 7* to *10* (note that in all three figures, time on the horizontal axis is shown in years, i.e. $t = 1$ corresponds to 4 quarters since the shock).

Since the two specifications of the Taylor rule that we consider generate very different dynamics for the variables of interest, we will first describe their evolution when the central bank sets the policy rate according to the traditional Taylor rule. The benchmark model does not have an innovative sector and thus no simulations for this shock can be generated.

The adverse shock to the probability of default in period 0 results in a decline in output in period 1 (*Figure 7*). The shock translates into fewer firms surviving the next period and less generation of endogenous technology in period 1 (*Figure 10*). Following the same logic as in the previous case, aggregate demand decreases less than the fall in the natural level of output (the output gap is negative) and inflation increases. The adverse default shock alters significantly the responses in the first period from the ones in period 2 onwards. In period 1, the negative performance of current (and future) output impacts negatively on the supply of deposits and the higher default rate increases ω_1. These two elements depress further the creation of endogenous technology in period 2, causing labor and the output gap to increase above its steady-state level. From period 2 onwards, the variables behave similarly to what is obtained in the benchmark model for a negative technology shock.

We observe that when the central bank follows the "traditional Taylor rule," it fails to react in period 1 to the next-period shock to the probability of survival, δ_t,

Figure 7 Shock to Probability of Default: Response of Output, Output Gap, Inflation, and Labor (One standard deviation of the shock to the default probability, ε^{δ})

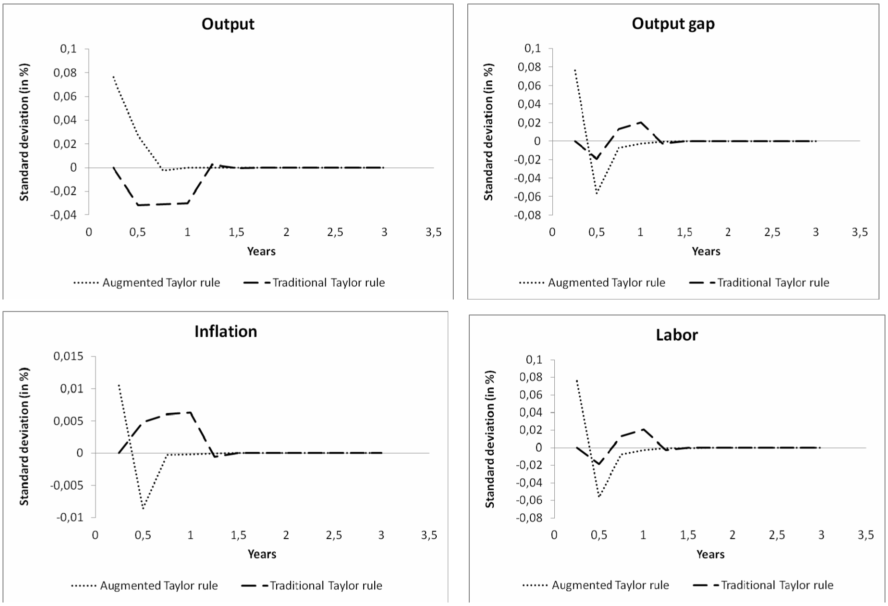


Figure 8 Shock to Probability of Default: Response of Policy Rate, Real Interest Rate, Loan Rate, and Effective Deposit Rate (One standard deviation of the shock to the default probability, ε^{δ})

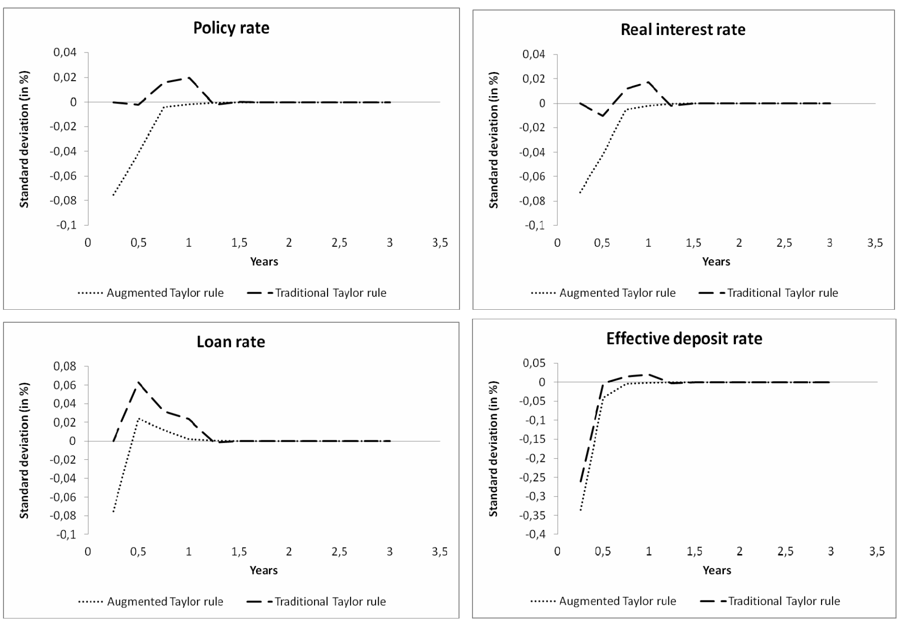


Figure 9 Shock to Probability of Default: Response of the Spread between Loan and Deposit Rates

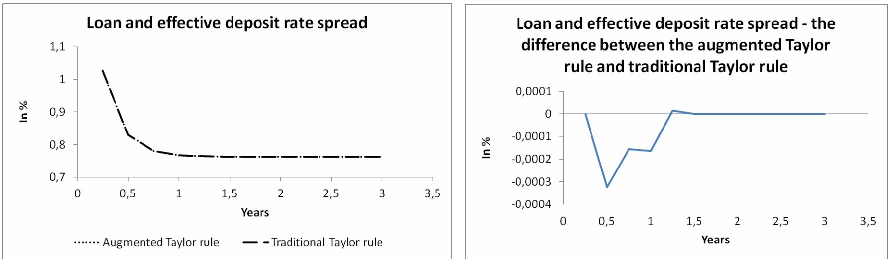
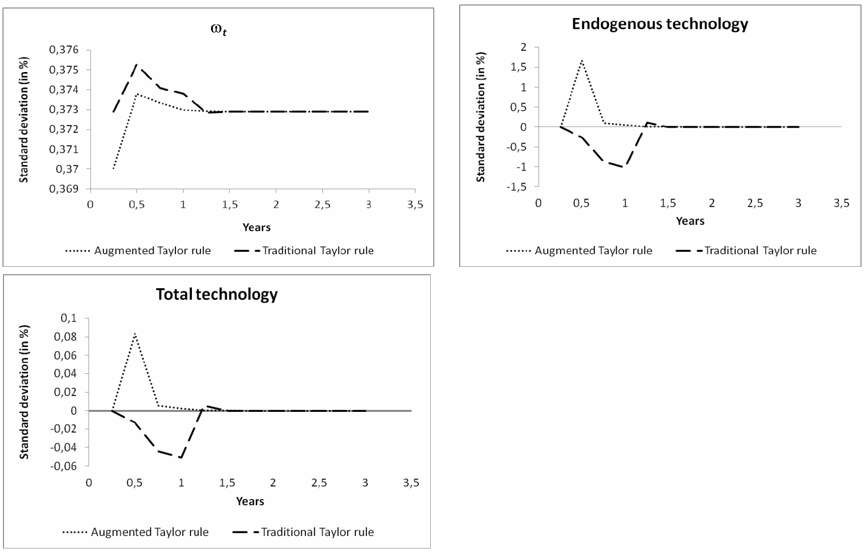


Figure 10 Shock to Probability of Default: Response of Loan Applications (ω_t), Endogenous Technology, and Total Technology (One standard deviation of the technology shock, ε^{δ})



even though it possesses this information (*Figure 8*). The central bank reacts only from period 2 onwards, when the shock has already affected the economy, widening the output gap and increasing inflation. At this point, the rule dictates that the central bank increase the policy rate, inducing a decline in aggregate demand and thus softening the effects of the shock.

What would happen if the central bank adjusted the policy before the shock affected total technology according to the augmented rule? Given that the central bank knows δ_t in period 1, foreseeing the negative effects on the economy caused by a higher default rate, it can decrease the policy rate in period 1, in turn lowering the loan rate (*Figure 8*). The change in the expected deposit rate mimics the change in the policy rate, thus stimulating aggregate demand. Moreover, the decrease in the policy rate implies a lower cutoff point for the first-period marginal firm, ω_1, and it generates positive expectations about future activity and stimulates deposits. These two elements have a positive effect on endogenous technology in period 2, more than offsetting the negative effect of δ_t. The deposit and loan rates follow the evolution of the policy rate by decreasing in period 1 and increasing gradually in subsequent periods (*Figure 8*). *Figure 9* illustrates the impact that this alternative policy rate response has on the spread between loan and deposit rates: under both the Taylor rule and the augmented Taylor rule, the spread goes up in the initial after-shock period and tapers off thereafter. Under the augmented rule, however, the increase in the spread is slightly lower than it would be under the "traditional Taylor rule."

Our simulations suggest that a central bank responding to financial sector instability (approximated here as an unexpected increase in the probability of default) is able to trade off higher initial inflation for more stable output and inflation later on. Under the traditional Taylor rule, the cost of ignoring information about δ is more pronounced, resulting in a longer-lasting output decline and higher inflation. Of course, monetary policy is useful in reacting to financial stability shocks only to the extent private agents' signal extraction is limited – only the central bank has information on δ_{t+1} at the beginning of period t.

3.3 Welfare Calculations

Despite the observable result of more stable output under the augmented Taylor rule, it does not translate into sizable welfare gains. Large sensitivity of the policy maker to financial distress in the augmented rule results in welfare losses relative to the traditional rules, while smaller sensitivity results in welfare gains. However, the gains/losses are barely noticeable. To this end we used the traditional measure of welfare losses used in the real business cycle literature – the variance of consumption – introduced by Lucas (1987). To assess the robustness of our results, we also carried out welfare calculations using a quadratic loss function (Section 4).

The Lucas welfare differential is calculated as ½ times the risk aversion coefficient (σ) times the difference in the variance of the constant elasticity of substitution (CES) consumption. The intuition behind the welfare comparison is that we want to assess how much trend consumption the household would give up in order to receive a smoother trajectory of output and inflation under the augmented rule. This simulation was evaluated over 300 periods (exposing technology and the default probability to simultaneous shocks every period), and the whole procedure was repeated 100 times.

The results are robust with respect to the weight of financial instability in the policy rule (φ_δ). For example, assuming the benchmark value, $\varphi_\delta = -0.5$, the standard deviations of consumption under the traditional and augmented rules are 0.05915 and 0.05947, respectively. Whereas the welfare losses under the augmented rule are marginally higher than under the traditional rule, this difference is barely noticeable. Similarly, for a less aggressive rule, $\varphi_\delta = -0.1$, the standard deviations are 0.05899 and 0.05892, respectively. The long-term effects of the augmented Taylor rule can thus be either welfare enhancing or welfare worsening depending on the parameterization of the rule. The economy stabilizes faster under the augmented Taylor rule, but the output and consumption paths are more volatile initially than under the traditional rule. Indeed, in *Figure 7*, we observe much larger initial, two-period departures from the trend in both the output and output gap simulations under the augmented rule than under the traditional rule. In other words, the central bank trades off more instability today for a faster return to the trend path tomorrow. Introduction of the financial sector and shocks thereto in the DSGE model does not change the nature of monetary policy; it only brings forward the eventual policy reaction.

4. Robustness Checks

We performed a series of robustness checks to assess what happens to the main results if we alter some of our key assumptions. Specifically, we assessed robustness with respect to (i) the size and persistency of the default probability shock; (ii) the welfare function; (iii) replacement of the backward-looking benchmark specification of the Taylor Rule by a forward-looking specification; and (iv) the inclusion of interest rate smoothing.

As the first robustness check, we increased the standard deviation of the default probability shock (from 0.0025 to 0.005) and increased its persistency (from $\rho^{\delta} = 0.25$ to $\rho^{\delta} = 0.5$). Predictably, larger and more persistent shocks result in more output and inflation fluctuations and a more pronounced policy response. However, the impact is broadly linear. The charts of the impulse response functions are available upon request.

Second, to test the robustness of our welfare calculations, we replaced the Lucas measure by the often-used quadratic loss function:

$$L = \alpha\left(\pi_t - \pi_T^*\right)^2 + (1-\alpha)\left(y_t - y_t^*\right)^2 \tag{6}$$

where $\pi_t - \pi_T^*$ is the difference between the log of inflation and its steady state value (defined to be equal to 0), and $x_t = y_t - y_T^*$ is the output gap (in logs). The parameter α characterizes the relative weights of inflation and output in the loss function.

Assuming that the central bank is mostly concerned about inflation, we set $\alpha =$ $= 0.75$ (for the motivation, see Kotlán and Navrátil, 2003). Our simulations yield a mean welfare loss of 0.01881 for the traditional Taylor rule and of 0.03765 for the augmented Taylor rule in the baseline calibration. The quadratic loss function calculation penalizes departures from the inflation and output trends more than that of Lucas, where only the impact of these departures on consumption matters, and we find that the traditional rule is preferable in the long run to the augmented rule. As before, we simulated the economy 100 times for a time span of 300 periods (applying shocks to technology and the default probability contemporaneously in every period). We computed the welfare loss each of the 100 times, and then computed the mean of the losses.

Third, we replaced the backward-looking Taylor rule (with the actual inflation rate in period *t*) by a forward-looking rule (with an expectation of the inflation rate in period *t*+1). The rule can be written as:

$$\hat{i}_t = \varphi_\pi E_t \hat{\pi}_{t+1} + \varphi_x x_t \tag{4'}$$

and the policy rate obeys

$$\hat{i}_t = \begin{cases} \varphi_\pi \hat{\pi}_{t+1} + \varphi_x x_t & \text{if}\left(\delta_{t+1} - E_t\delta_{t+1}\right) < 0 \\ \varphi_\pi \hat{\pi}_{t+1} + \varphi_x x_t + \left(\varphi_\delta + v^\delta\right)\left(\delta_{t+1} - E_t\delta_{t+1}\right) & \text{otherwise} \end{cases} \tag{5'}$$

Evaluating both versions of the rule using the quadratic loss function (6), we obtain the following mean losses for the traditional and augmented rule: 0.02453 and

0.02387, respectively. This result suggests that the augmented rule generates marginally smaller welfare losses in a forward-looking framework, but these differences are too small to declare the augmented rule as the rule of choice.

Finally, what if the policy rule were to include an interest rate smoothing element? The policy rule described in (5), i.e., the augmented rule with the reaction to the probability to default, requires the central bank to move the interest rate immediately in response to a change in the default probability. As we have shown in section 3, this aggressive response to financial instability leads to increased volatility of output and inflation in the short term, while ensuring a faster return to trend in the longer term. Should the central bank's policy rule include an interest rate smoothing element, its response to an observed financial stability shock would be muted, other things being equal, because the policy maker would wait for more information before moving the rate from its last-period level. As a result, short-run volatility in output and inflation would be relatively lower, but the return to trend would take relatively longer than under the augmented rule with the probability of default, as described in (5). The higher the weight on the last-period interest rate in the rule, the closer the interest setting process will be to the traditional rule.

5. Conclusions

In view of its macroeconomic costs, financial instability deserves to be taken seriously – something recognized by central banks in their policy documents, but not in the literature on modeling monetary policy responses. Much of the literature still relies on policy rules that do not include the financial sector, and often include only the contemporaneous output gap and inflation. To contribute to bridging this gap we enrich the standard new Keynesian model with a financial system and firms that require external financing. We then introduce a proxy for financial instability as a forward-looking element into the Taylor rule. Under the augmented policy rule the central bank monitors the financial system, responding to deterioration in the financial system's health with monetary loosening.

We find that, when faced with a short-lived financial instability shock, a forward-looking central bank will choose to prop up the banking system with monetary easing, limiting the short-term fall in the level of output and consumption as compared to the traditional Taylor rule. The central bank following the augmented rule trades off more output and inflation instability today for a faster return to the trend path tomorrow. The long-run welfare impact depends on the parameterization of the model and on the type of the welfare function, but the welfare benefits of the augmented rules appear to be negligible in numerical simulations.

Underlying our results is the assumption that the central bank has privileged information on financial stability. Many central banks have access to confidential information on banks' financial soundness as part of banking supervision and virtually all of them have unique access to data stemming from their role in the payment system. Theoretically at least, it is possible to consider what would happen if the central bank made all the relevant information publicly available. In the context of our model, the answer is straightforward: if the adverse shock to the probability of default became public knowledge, the trade-off between short-term output and inflation volatility and the speed of return to trend would disappear. There would be no incentive for the central bank to deviate from the "traditional Taylor rule," because the private sector would already incorporate the relevant information on financial instability (probability of default) into its decisions. It remains a theoretical consideration, however. Although central banks have indeed started releasing reports on financial stability to the general public, these are far from "reveal-it-all" documents (Čihák, 2006). The policy maker may want to retain at least some privileged information for reasons ranging from legal protection of confidentiality, through difficulty in communicating clearly on such a complex subject, to fears that adverse information about financial soundness might trigger bank runs, further weakening the financial system. For these reasons, it is quite realistic to assume that some relevant information will never be released into the public domain.

In future research, the model presented here can be extended in many interesting directions. Possible extensions include considering other specifications of the Taylor rule, such as non-linear responses of the central bank to changes in the probability of default. Furthermore, it would be interesting to study the case of open economies. Finally, the model can also be extended to allow the innovative sector to hire labor.

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