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## Leaning Against Windy Bank Lending

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## **Leaning Against Windy Bank Lending**

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July 2014



# Leaning Against Windy Bank Lending\*

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2nd July 2014

## Abstract

Using a dynamic stochastic general equilibrium model with banking, this paper first provides evidence that, during the Great Moderation, monetary policy leaned against the wind blowing from the loan market in the US. It then shows that the extent to which this occurred delivers a small welfare loss relative to the optimised simple interest-rate rule that features only a response to inflation. The source of business cycle fluctuations is crucial for the optimality of a leaning-against-the-wind policy. In fact, the pro-cyclical nature of lending creates a trade-off between inflation and financial stabilisation when supply shocks are prevalent.

*Keywords:* lending relationships, augmented Taylor rule, Bayesian estimation, optimal policy.

*JEL Codes:* E32, E44, E52

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# 1 Introduction

The role of central banks in promoting financial stability, in addition to inflation stability, has been debated well before the Great Recession. The so-called “Greenspan doctrine”, which objects to the policy of *leaning* against the wind blowing from asset-price bubbles, and favours the policy of *cleaning* after asset-price bubbles burst, greatly influenced the central banking world before the crisis. However, in the aftermath of the Great Recession, the need to protect the banking sector from periods of unduly high or excessively low credit growth has led to a renewed interest in the “lean” versus “clean” role for monetary policy. For instance, Aksoy et al. (2013) show that monetary policy can play an important role in terms of macroeconomic stabilisation if a leaning-against-the-wind policy is implemented within Dynamic Stochastic General Equilibrium (DSGE) models featuring credit market imperfections.

Mishkin (2011) distinguishes between two types of asset-price bubbles: (i) a credit-driven bubble; and (ii) an irrational exuberance bubble. He argues that credit-driven bubbles are easier to detect and pose much more risk to the economic system and, as a result, he advocates policies contrasting them. Indeed, the important role of credit market conditions in affecting business cycle fluctuations emerges also from the Basel III framework, aiming at protecting the financial sector from periods of excessive credit growth, often associated with growth in systemic risk. On this aspect, Jordà et al. (2013) document that, in a sample of 14 countries and a period between 1870 and 2008, more credit-intensive expansions tended to be followed by deeper recessions and slower recoveries. Their measure of “excess credit” build-up during expansions is the rate of change of bank loans to GDP, in deviation from its mean. Furthermore Bordo and Haubrich (2012) provide empirical evidence that bank lending significantly affects GDP fluctuations in the United States.

This paper focuses precisely on bank lending and on whether monetary policy responded and should respond to credit exuberance. First, it provides Bayesian estimates of a DSGE model in which frictions in the bank-loan market arise due to the presence of lending relationships, and monetary policy is set according to a credit-growth-augmented Taylor-type rule. The model is otherwise standard and exhibits the real and nominal frictions commonly found in the mainstream literature. Then, the paper provides also a normative analysis via the computation of optimised simple interest-rate rules. We deem this strategy to be appropriate as (i) Bayesian estimation is suitable to empirically assess whether a leaning-against-the-wind policy can be detected in standard US macroeconomic data and to estimate the shocks, which we find to be key determinants of optimal policy, and (ii) optimised simple rules unveil whether the credit-growth-augmented Taylor-type rule is welfare-optimal.

Lending relationships (LR) provide an appealing determinant of the bank spread, i.e. the difference between the loan rate and the deposit rate, and prove empirically important. Among other studies using US data, Aliaga-Diaz and Olivero (2010, 2011) provide substantial evidence of LR, the average duration of which is 11 years according to Petersen and Rajan (1994). This is in

agreement with the findings of Santos and Winton (2008) who show that during recessions banks raise the bank spread more for bank-dependent borrowers than for those with access to public bond markets. Among the studies analysing LR in the DSGE arena, Aliaga-Diaz and Olivero (2010) introduce this friction into an otherwise standard Real Business Cycle model where counter-cyclical bank spreads play a financial accelerator role in the propagation mechanism of technology shocks. Aksoy et al. (2013) show that LR is a feature of financial intermediation relevant for monetary policy making in a New Keynesian (NK) model with staggered prices and cost channels. Melina and Villa (2014) build a medium-scale DSGE model with a banking sector exploiting LR to study the implications that fiscal policy has on loan market conditions. In order to tractably introduce LR into a DSGE model, these studies assume that firms form habits at the level of each variety of loans. In other words they form deep habits in banking analogously to how consumers form deep habits in consumption in the model of Ravn et al. (2006).

The paper provides an estimate of the parameter representing the interest-rate response to nominal credit growth within the monetary policy rule. This turns out to be statistically positive and economically important. A constrained version of the model featuring a standard Taylor-type rule, in which the interest rate exhibits inertia and responds to inflation and output, leads to a significantly lower marginal data density. In other words, estimates point to an evidence that during the Great Moderation monetary policy leaned against the wind blowing from the loan market and that this had a partial stabilisation role towards credit exuberance.

Is this the welfare-optimal policy? To answer this question, we perform a welfare comparison of alternative interest-rate rules: first, a standard optimised simple Taylor-type rule; second, an optimised simple rule featuring also a response to nominal credit growth or other financial variables; third, the estimated credit-growth-augmented interest-rate rule. In designing the optimised simple rules, we impose an approximate zero-lower-bound constraint in a way similar to Levine et al. (2008). We find that optimal monetary policy features a muted response to output and to any financial variable in the model. While the former result is in line with the findings of Schmitt-Grohe and Uribe (2007) in a model with perfect credit markets, the latter is a novel contribution. The explanation of such a finding lies in the fact that supply shocks – technology, price and wage mark-up – turn out to be the main drivers of output, lending and inflation fluctuations in the estimated model. Since these shocks imply a trade-off between inflation and output stabilisation, there is no “divine coincidence” (Blanchard and Galí, 2007). Given the pro-cyclical behaviour of lending in the model, a monetary policy that responds also to financial variables should respond more aggressively to inflation. As a result, it turns out to be optimal for monetary policy to respond exclusively to inflation.

The remainder of the paper is structured as follows. Section 2 presents the DSGE model. Section 3 outlines the estimation strategy, discusses empirical results and investigates the dynamic properties of the estimated model via impulse responses and variance decomposition analysis. Section 4 examines the welfare implications of alternative interest-rate policies. Finally, Section

5 concludes. The appendix complements the paper by providing (a) the full set of the DSGE model equilibrium conditions; (b) the derivation of the deterministic steady state; (c) details on the construction of the dataset; (d) additional estimation results; and (e) robustness exercises highlighting that the sources of business cycle fluctuations are crucial for the optimal policy results.

## 2 Model

The model is a NK model with standard frictions *à la* Smets and Wouters (2007) augmented with a banking sector that exploit lending relationships. While this section outlines the optimisation problem of each agent in the model, equilibrium conditions evaluated at the symmetric equilibrium and the deterministic steady state are reported in Appendices A and B.

### 2.1 Households

Households are infinitely-lived and solve an inter-temporal utility maximisation problem. The economy is populated by a continuum of households indexed by  $j \in (0, 1)$ . Each household's preferences are represented by the following inter-temporal utility function:

$$U_t^j = E_t \sum_{s=0}^{\infty} e_{t+s}^B \beta^{t+s} \frac{\left[ (X_{t+s}^j)^\phi (1 - H_{t+s}^j)^{1-\phi} \right]^{1-\sigma_c}}{1 - \sigma_c}, \quad (1)$$

where  $\beta \in (0, 1)$  is the discount factor,  $e_t^B$  is a preference shock,  $X_t^j$  is habit-adjusted consumption,  $H_t^j$  is labor supply in terms of hours worked,  $\sigma_c$  is the relative risk aversion parameter and  $\phi$  is a preference parameter affecting labor supply. Total time available to households is normalised to unity, thus  $1 - H_t^j$  represents leisure time. As in Fuhrer (2000),  $X_t^j$  is given by

$$X_t^j = C_t^j - \theta S_{t-1}, \quad (2)$$

$$S_t = \rho S_{t-1} + (1 - \rho) C_t, \quad (3)$$

where  $C_t^j$  is the level of consumption,  $S_t$  is the stock of external habit formation,  $\theta \in (0, 1)$  is the degree of habit formation, and  $\rho \in (0, 1)$  is the persistence of the stock of habit.

Each household  $j$  is a monopolistic provider of a differentiated labor service and supplies labor  $H_t^j$  to satisfy demand,

$$H_t^j = \left( \frac{w_t^j}{w_t} \right)^{-e_t^W \eta^W} H_t, \quad (4)$$

where  $w_t^j$  is the real wage charged by household  $j$ ,  $w_t$  is the average real wage in the economy,  $\eta^W$  is the intra-temporal elasticity of substitution across labor services,  $e_t^W$  is a wage mark-up shock, and  $H_t$  is average demand of labor services by firms. Similarly to Zubairy (2014), the households'

budget constraint also includes a Rotemberg quadratic cost of adjusting the nominal wage,  $W_t^j$ , which is zero at the steady state. This cost is proportional to the average real value of labor services as in Furlanetto (2011),  $\frac{\xi^W}{2} \left( \frac{W_t^j}{W_{t-1}^j} - \bar{\Pi} \right)^2 w_t H_t = \frac{\xi^W}{2} \left( \frac{w_t^j}{w_{t-1}^j} \Pi_t - \bar{\Pi} \right)^2 w_t H_t$ , where  $\xi^W$  is the wage adjustment cost parameter,  $\Pi_t = P_t/P_{t-1}$  is the gross inflation rate of price index  $P_t$ , and  $\bar{\Pi}$  is the steady state value of inflation.

The representative household enters period  $t$  with  $D_t^j$  units of real deposits in the bank. During period  $t$ , the household chooses to consume  $C_t^j$ ; supplies  $H_t^j$  hours of work; receive real wage  $w_t$ , firms' profits  $\int_0^1 \Pi_{it} di$ , banks' profits  $\int_0^1 \Pi_{bt} db$ , bears the wage adjustment cost, pays lump-sum taxes  $T_t$ , and allocates savings in deposits at the bank,  $D_{t+1}^j$ , that pay the net interest rate  $R_{t+1}^D$  between  $t$  and  $t+1$ . Therefore, the budget constraint reads as

$$C_t^j + D_{t+1}^j + \frac{\xi^W}{2} \left( \frac{w_t^j}{w_{t-1}^j} \Pi_t - \bar{\Pi} \right)^2 w_t H_t \leq w_t^j H_t^j + (1 + R_t^D) D_t^j + \int_0^1 \Pi_{it} di + \int_0^1 \Pi_{bt} db - T_t. \quad (5)$$

Each household maximises inter-temporal utility (1) with respect to  $C_t^j$ ,  $D_{t+1}^j$ ,  $w_t^j$  subject to (2), (3), (4) and (5).

## 2.2 Entrepreneurs

Entrepreneurs are distributed over a unit interval and indexed by  $e \in (0, 1)$ . They borrow from banks to produce a differentiated output,  $Y_t^e$  sold in a imperfectly competitive market at price  $P_t^e$ . Entrepreneurs solve two optimisation problems: an intra-temporal problem, giving rise to lending relationships, in which they decide the composition of their loan demand; and an inter-temporal problem in which they maximise the flow of discounted profits by choosing the quantity of factors for production and the price level.

Entrepreneurs minimise their borrowing costs by choosing their demand for each variety of loans and exhibit deep habits in lending.<sup>1</sup> This feature is present also in the models by Aliaga-Diaz and Olivero (2010), Aksoy et al. (2013), and Melina and Villa (2014) and represents a reduced form way to incorporate the effects of informational asymmetries on borrowers' creditworthiness that lead to lending relationships into a DSGE model. Although the deep habits framework is not a formal setup of asymmetric information, it produces the same effects in the symmetric equilibrium

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<sup>1</sup>An other important component of firm's debt in the US is non-banking finance. This paper focuses on bank-to-firm relationships, hence it abstracts from the issuance of corporate bonds. For a model featuring also corporate bonds see e.g. De Fiore and Uhlig (2011).



(as shown by Aksoy et al., 2013, Appendix). The optimisation problem consists in the following:

$$\min_{L_{bt}^e} \int_0^1 (1 + R_{bt}^L) L_{bt}^e db, \quad (6)$$

$$s.t. \left[ \int_0^1 (L_{bt}^e - \theta^L S_{bt-1}^L)^{1-\frac{1}{\eta^L}} db \right]^{1/(1-\frac{1}{\eta^L})} = (X_t^L)^e, \quad (7)$$

$$S_{bt}^L = \varrho^L S_{bt-1}^L + (1 - \varrho^L) L_{bt}, \quad (8)$$

where  $R_{bt}^L$  is the net lending rate,  $L_{bt}^e$  is the demand by firm  $e$  for loans issued by bank  $b$ ,  $\theta^L$  is the degree of habit in lending,  $S_{bt}^L$  is the stock of (external) habit in lending,  $\eta^L$  is the elasticity of substitution across varieties of loans,  $(X_t^L)^e$  is the demand for loans by firm  $e$  augmented by lending relationships and  $\varrho^L$  is the persistence of lending relationships. Equation (6) represents overall lending expenditure, equation (7) imposes deep habits in lending, and (8) imposes persistence in the stock of habit.

Entrepreneur  $e$  faces also an inter-temporal problem by solving which she chooses employment  $H_t^e$ , capital  $K_{t+1}^e$ , investment  $I_t^e$ , capital utilisation,  $U_t^e$ , and the price level,  $P_t^e$  to maximise the expected discounted value of its lifetime profits. Recalling that in this economy firms are owned by households, the stochastic discount factor of the former,  $\Lambda_{t,t+1}$ , is given by the inter-temporal marginal rate of substitution of the latter. The inter-temporal optimisation problem is summarised by the following:

$$\max_{H_t^e, K_{t+1}^e, I_t^e, U_t^e, P_t^e} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left\{ \begin{aligned} & \frac{P_{t+s}^e}{P_{t+s}} Y_{t+s} - W_{t+s} H_{t+s}^e - I_{t+s}^e \\ & - \Psi(U_{t+s}^e) K_{t+s}^e - \frac{\xi}{2} \left( \frac{P_{t+s}^e}{P_{t+s-1}^e} - \bar{\Pi} \right)^2 Y_{t+s} \\ & + (X_{t+s}^L)^e - \int_0^1 (1 + R_{bt+s-1}^L) L_{bt+s-1}^e db + \Xi_{t+s}^e \end{aligned} \right\}, \quad (9)$$

$$s.t. K_{t+1}^e = I_t^e \left[ 1 - S \left( \frac{I_t^e}{I_{t-1}^e} \right) \right] e_t^I + (1 - \delta) K_t^e, \quad (10)$$

$$\int_0^1 L_{bt}^e db \geq I_t^e \quad (11)$$

$$Y_t^e = \left( \frac{P_t^e}{P_t} \right)^{-e_t^P \eta} Y_t = F(e_t^A, U_t^e, K_t^e, H_t^e) \quad (12)$$

Equation (9) is the sum of discounted profits expressed in terms of net cash flows, in which  $W_t H_t^e$  is the wage bill;  $I_t^e$  is the expenditure in investment goods; using capital at rate  $U_t^e$  entails a cost of  $\Psi(U_t^e) K_t^e$ , where  $\Psi(U_t) = \gamma_1 (U_t - 1) + \frac{\gamma_2}{2} (U_t - 1)^2$ ;  $\frac{\xi}{2} \left( \frac{P_{t+s}^e}{P_{t+s-1}^e} - \bar{\Pi} \right)^2 Y_{t+s}$  is a Rotemberg

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<sup>2</sup>We normalise the steady-state utilisation rate to unity,  $u = 1$ . It follows that  $\Psi(u) = 0$ ,  $\Psi'(u) = \gamma_1$ ,  $\Psi''(u) = \gamma_2$  and the elasticity of the utilization rate to changes in the marginal utilization cost is  $\frac{\Psi'(u)}{\Psi''(u)u} = \frac{\gamma_1}{\gamma_2} \equiv \sigma_u \equiv \frac{1-\eta_u}{\eta_u}$ . Following Smets and Wouters (2007) we estimate  $\eta_u \in [0, 1]$ .

convex cost of adjusting prices;  $\Xi_t^e \equiv \theta^L \int_0^1 \frac{1+R_{bt}^L}{1+R_t^L} S_{bt-1}^L db$  such that  $(X_t^L)^e + \Xi_t^e = \int_0^1 L_{bt}^e db = L_t^e$ , i.e. the amount of loans that flow into the entrepreneur's balance sheet, while  $\int_0^1 (1+R_{bt}^L) L_{bt}^e db$  represents what they repay to banks. Equation (10) is a standard law of motion of capital, which depreciates at rate  $\delta$ , and investment is subject to adjustment costs, where  $S(1) = S'(1) = 0$  and  $S''(1) > 0$ . In particular, following Smets and Wouters (2007), we assume that investment adjustment costs are quadratic:  $S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\psi}{2} \left(\frac{I_t}{I_{t-1}} - 1\right)^2$ ,  $\psi > 0$ , where  $\psi$  represents the elasticity of the marginal investment adjustment cost to changes in investment. The term  $e_t^I$  represents a shock to the investment-specific technology process. Constraint (11) makes it necessary for firms to borrow from banks in order to finance investment expenditure, i.e. it represents a *financing constraint* needed for external credit to play a role in the model. Without the imposition of this constraint, firms would always find it optimal to satisfy their financing needs via internal funds. Thus constraint (11) holds with equality in equilibrium. Lastly, expression (12) equates the firm-specific Dixit-Stiglitz demand with intra-temporal elasticity of substitution  $\eta$  and subject to price mark-up shock  $e_t^P$ , with firm's production, which we assume to obey to a Cobb-Douglas technology,  $F(e_t^A, U_t, K_t, H_t) = e_t^A (H_t)^\alpha (U_t K_t)^{1-\alpha}$ , with  $\alpha$  being the labor share of income and  $e_t^A$  being a total factor productivity shock.

## 2.3 Banks

Each bank  $b$  chooses its demand for deposits,  $D_{bt+1}$ , and the loan rate,  $R_{bt+1}^L$ , to maximise the expected discounted value of its lifetime profits. Banks are owned by households as well; therefore, their stochastic discount factor,  $\Lambda_{t,t+1}$ , is given by the inter-temporal marginal rate of substitution of the households. The optimisation problem is summarised by the following:

$$\max_{D_{bt+1}, R_{bt+1}^L} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \{D_{bt+s+1} - L_{bt+s+1} + (1 + R_{bt+s}^L) L_{bt+s} - (1 + R_{t+s}^D) D_{bt+s}\}, \quad (13)$$

$$s.t. \ L_{bt} = D_{bt}, \quad (14)$$

$$L_{bt} = \left(\frac{1 + R_{bt}^L}{1 + R_t^L}\right)^{-\eta^L} X_t^L + \theta^L S_{bt-1}^L. \quad (15)$$

Equation (13) represents the cash flow of the bank in each period, given by the difference between deposits and loans and the difference between earnings on assets, priced at the net rate  $R_{bt}^L$ , and interest payments on liabilities. Equation (14) represents the bank's balance sheet, where loans on the asset side are equal to deposits on the liabilities side. Equation (15) represents the bank-specific demand for loans.

## 2.4 Central bank

A central bank conducts monetary policy by following a Taylor-type rule,

$$\log \left( \frac{R_t^n}{\bar{R}^n} \right) = \rho_r \log \left( \frac{R_{t-1}^n}{\bar{R}^n} \right) + (1 - \rho_r) \left[ \rho_\pi \log \left( \frac{\Pi_t}{\bar{\Pi}} \right) + \rho_y \log \left( \frac{Y_t}{\bar{Y}} \right) + \rho_s \log \left( \frac{L_t}{L_{t-1}} \Pi_t \right) \right] + e_t^R, \quad (16)$$

where  $R_t^n$  is the gross nominal interest rate, and  $\rho_r$ ,  $\rho_\pi$ ,  $\rho_y$ , and  $\rho_s$  are policy parameters referring to interest-rate smoothing, the responsiveness of the nominal interest rate to inflation deviations, to output, and to nominal credit growth (as e.g. Christiano et al., 2010b,a, among others), respectively, while  $e_t^R$  is a monetary policy shock. We include output in deviation from steady state instead of the output gap so that the central bank responds only to observable variables (see e.g. Faia and Monacelli, 2007; Schmitt-Grohe and Uribe, 2007). A Fisher equation links the net real deposit rate  $R_{t+1}^D$  to the gross nominal interest rate,  $1 + R_{t+1}^D = E_t \left[ \frac{R_t^n}{\Pi_{t+1}} \right]$ . Alternative monetary policy rules are employed in Appendix E.

## 2.5 Equilibrium

The government is assumed to run a balanced budget, i.e.  $T_t = e_t^G$ , where  $e_t^G$  is government spending. In the symmetric equilibrium all markets clear.

The model is closed by the resource constraint,

$$Y_t = C_t + I_t + e_t^G + \frac{\xi}{2} (\Pi_t - \bar{\Pi})^2 Y_t + \frac{\xi^W}{2} (\Pi_t^W - \bar{\Pi})^2 w_t H_t + \Psi(U_t) K_t, \quad (17)$$

a set of AR(1) processes,

$$\log \left( \frac{e_t^\varkappa}{\bar{e}^\varkappa} \right) = \rho_\varkappa \log \left( \frac{e_{t-1}^\varkappa}{\bar{e}^\varkappa} \right) + \epsilon_t^\varkappa, \quad (18)$$

where  $\varkappa = \{A, B, G, I, R, P, W\}$ ,  $\bar{e}^\varkappa$  are steady-state values,  $\rho_\varkappa$  are auto-regressive parameters, and  $\epsilon_t^\varkappa$  are mean zero, i.i.d. random shocks with standard deviations  $\sigma_\varkappa$ .

## 3 Estimation

This section reports the results of the Bayesian estimation. Subsection 3.1 discusses the data and the estimation strategy. Subsection 3.2 presents parameter estimates and a marginal likelihood comparison confirming the leaning-against-the-wind policy from an empirical viewpoint. Subsection 3.3 discusses estimated impulse responses of key macroeconomic and financial variables to the structural shocks of the model and disentangles the stabilisation properties of a credit-growth-augmented Taylor rule. Finally, Subsection 3.4 presents the analysis of the variance decomposition to assess the importance of the exogenous structural shocks.

### 3.1 Data and estimation strategy

The model is estimated with Bayesian methods (see An and Schorfheide, 2007; Smets and Wouters, 2007, among others). The Kalman filter is used to evaluate the likelihood function of the observable variables. The likelihood function and the prior distribution of the parameters are combined to calculate the posterior distributions. The posterior Kernel is then simulated numerically using the Metropolis-Hasting algorithm with two chains of 150,000 draws each. This Markov Chain Monte Carlo method generates draws from the posterior density and updates the candidate parameter after each draw.

The model is estimated for the US over the Great Moderation period, 1984Q1–2008Q2, using a deliberately standard set of macroeconomic variables. In particular, we use the following observable seven variables: GDP, consumption, investment, wage, hours worked, GDP deflator inflation and the federal funds rate.<sup>3</sup> Although observations on all variables are available at least from 1955 onwards, we focus on the above-mentioned period because it is characterised by a single monetary policy regime. Extending the sample period to include the Great Recession may yield biased estimates due to the nonlinearities induced by the fact that the nominal interest rate in the US reached the zero lower bound (on this see e.g. Galí et al., 2011). The number of variables in the data coincides with the number of shocks in the model. The following set of measurement equations show the link between the observables in the dataset and the endogenous variables of the DSGE model:

$$\begin{bmatrix} \Delta Y_t^o \\ \Delta C_t^o \\ \Delta I_t^o \\ \Delta W_t^o \\ H_t^o \\ \pi_t^o \\ r_t^{n,o} \end{bmatrix} = \begin{bmatrix} \gamma \\ \gamma \\ \gamma \\ \gamma \\ \bar{h} \\ \bar{\pi} \\ \bar{r}^n \end{bmatrix} + \begin{bmatrix} \hat{Y}_t - \hat{Y}_{t-1} \\ \hat{C}_t - \hat{C}_{t-1} \\ \hat{I}_t - \hat{I}_{t-1} \\ \hat{W}_t - \hat{W}_{t-1} \\ \hat{H}_t \\ \hat{\Pi}_t \\ \hat{R}_t^n \end{bmatrix} \quad (19)$$

where variables on the left-hand side are the observables,  $\gamma$  is the common quarterly trend growth rate of GDP, consumption, investment and wages;  $\bar{h}$  is average hours worked;  $\bar{\pi}$  is the average quarterly inflation rate; and  $\bar{r}^n$  is the average quarterly nominal interest rate. A hat over a variable indicates the log-deviation from its own steady state.

Our general estimation and calibration strategy follows the standard procedure proposed by Smets and Wouters (2007). Table 1 shows the calibration of the parameters which could not be identified in the dataset and/or are related to steady-state values of the variables. The time period in the model corresponds to one quarter in the data. The discount factor,  $\beta$ , is equal to the conventional value of 0.99, implying an annual steady-state real interest rate of 4%. The capital depreciation rate,  $\delta$ , is equal to 0.025, amounting to an annual depreciation of 10%. As

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<sup>3</sup>See Appendix C for a detailed discussion of data sources, definitions and transformations.

Parameter		Value
Discount factor	$\beta$	0.99
Capital depreciation rate	$\delta$	0.025
Production function parameter	$\alpha$	0.67
Elasticity of substitution in goods	$\eta$	6
Elasticity of substitution in labor	$\eta^W$	11
Elasticity of substitution in banking	$\eta^L$	set to target $R^L - R^D = 0.0076$
Preference parameter	$\phi$	set to target $H = 0.33$
Government share of output	$\frac{G}{Y}$	0.19

Table 1: Calibrated parameters

standard, the labor share of income,  $\alpha$ , is equal to 0.67. The elasticity of substitution across different varieties,  $\eta$ , is equal to 6 in order to target a steady state gross mark-up equal to 1.20. The elasticity of substitution in the banking sector,  $\eta^L$ , is set in order to match a spread between the bank prime loan rate and the 3-month Treasury bill rate of 304 basis points per year – given the estimated value of lending relationship parameter  $\theta^L$  – consistently with US data during the Great Moderation. The elasticity of substitution in the labor market,  $\eta^W$  is set equal to 11 as in Del Negro et al. (2011), implying a steady state gross mark-up of 1.10. The preference parameter,  $\phi$ , is set to target steady state hours of work equal to 0.33. The government-output ratio is calibrated at 0.19, in line with the data.

The remaining parameters governing the dynamics of the model are estimated using Bayesian techniques.<sup>4</sup> The locations of the prior means correspond to a large extent to those in previous studies on the US economy, e.g. Smets and Wouters (2007). We use the Inverse Gamma (IG) distribution for the standard deviation of the shocks and we set a loose prior with 2 degrees of freedom. We use the Beta distribution for all parameters bounded between 0 and 1. For the unbounded parameters we use the Normal distribution. In addition, we set the prior means of the constants in the measurement equations equal to average values in the dataset. There are a few non-standard structural parameters. As regards the parameters measuring lending relationships we choose prior means close to the values estimated by Aliaga-Diaz and Olivero (2010), equal to 0.70 for  $\theta^L$  and to 0.80 for  $\rho^L$ , and we set a standard deviation of 0.125 for both. The prior distribution of the parameter measuring the response of the nominal interest rate to nominal credit growth,  $\rho_s$ , is on purpose loose. In fact, as shown in Figure 1, a prior mean of zero and a standard deviation of 0.30 enable the prior distribution to encompass a broad range of values around zero. This allows us to be agnostic on whether monetary policy leaned against the wind or not during the Great Moderation. Table 2 summarises the prior distributions chosen to estimate the deep structural parameters and the shock processes.

<sup>4</sup>Version 4.3.3 of the Dynare toolbox for Matlab is used for the estimation.

Parameter		Distrib.	Prior Mean	Std/df	Posterior Mean
<i>Structural</i>					
Relative risk aversion	$\sigma_c$	Normal	1.50	0.10	1.54 [1.37;1.70]
Habits in consumption	$\theta$	Beta	0.70	0.10	0.63 [0.53;0.72]
Habit persist. in consumption	$\rho$	Beta	0.70	0.10	0.62 [0.49;0.76]
Deep habits in banking	$\theta^L$	Beta	0.70	0.125	0.73 [0.54;0.99]
Habit persist. in banking	$\varrho^L$	Beta	0.80	0.125	0.79 [0.62; 0.97]
Price stickiness	$\xi$	Normal	30.0	5.00	43.75 [36.79;50.59]
Wage stickiness	$\xi^W$	Normal	100.0	10.00	95.84 [78.28;114.30]
Invest. adjust. costs	$\psi$	Normal	4.00	1.50	4.65 [2.37;6.89]
Capital utilisation	$\eta_u$	Beta	0.50	0.15	0.86 [0.77;0.95]
Inflation -Taylor rule	$\rho_\pi$	Normal	1.50	0.20	2.01 [1.73;2.32]
Output -Taylor rule	$\rho_y$	Beta	0.10	0.05	0.02 [0.00;0.04]
Credit growth-Taylor rule	$\rho_s$	Normal	0.00	0.30	0.30 [0.18;0.41]
Interest rate smoothing	$\rho_r$	Beta	0.80	0.10	0.86 [0.83;0.89]
<i>Averages</i>					
Trend growth rate	$\gamma$	Normal	0.44	0.10	0.43 [0.38;0.48]
Inflation rate	$\bar{\pi}$	Gamma	0.63	0.10	0.66 [0.58;0.75]
Interest rate	$\bar{r}^n$	Gamma	1.31	0.10	1.30 [1.17;1.41]
Hours of work	$\bar{h}$	Normal	0.00	0.10	-0.01 [-0.17;0.15]
<i>Shocks</i>					
TFP	$\rho_A$	Beta	0.50	0.20	0.95 [0.90;1.00]
	$\sigma_A$	IG	0.10	2.0	0.46 [0.41;0.52]
Government spending	$\rho_G$	Beta	0.50	0.20	0.96 [0.94;0.99]
	$\sigma_G$	IG	0.10	2.0	2.25 [1.96;2.52]
Interest rate	$\sigma_R$	IG	0.10	2.0	0.13 [0.11;0.15]
Investment-specific	$\rho_I$	Beta	0.50	0.20	0.68 [0.55;0.80]
	$\sigma_I$	IG	0.10	2.0	3.40 [1.60;5.04]
Preference	$\rho_B$	Beta	0.50	0.20	0.80 [0.70;0.90]
	$\sigma_B$	IG	0.10	2.0	1.47 [1.12;1.82]
Price mark-up	$\rho_P$	Beta	0.50	0.20	0.89 [0.82;0.98]
	$\sigma_P$	IG	0.10	2.0	1.37 [1.16;1.60]
Wage mark-up	$\rho_W$	Beta	0.50	0.20	0.79 [0.69;0.89]
	$\sigma_W$	IG	0.10	2.0	4.81 [3.49;6.13]
Log-likelihood					-539.818

Table 2: Prior and posterior distributions of estimated parameters

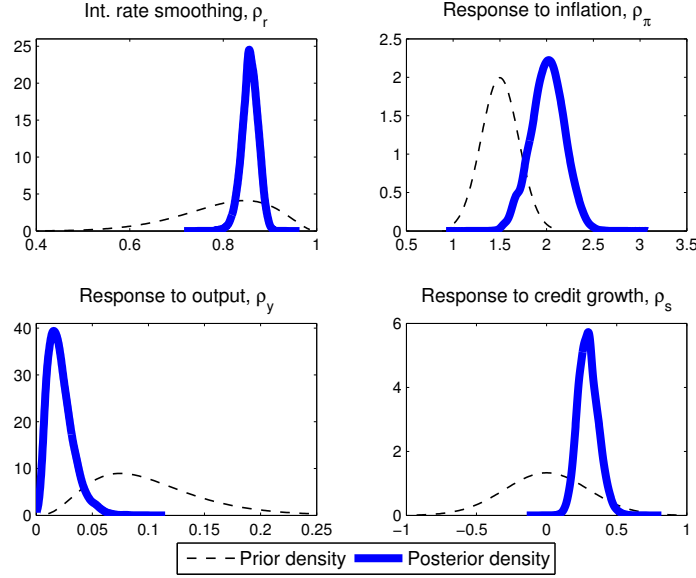


Figure 1: Prior and posterior probability densities of the Taylor rule parameters

### 3.2 Estimation results

Table 2 reports the posterior mean with 95% probability intervals in square brackets and the log-likelihood of the model. There is evidence of both habit in consumption and habit persistence, with statistically positive parameter values, the mean of which equals 0.63 and 0.62 respectively. The degree of deep habits in banking is equal to 0.73 with a persistence of 0.79. The point estimate of the degree of deep habits in banking is very close to the one found via single-equation GMM estimation by Aliaga-Diaz and Olivero (2010).

The degree of price stickiness implies that firms adjust prices almost every three quarters and a half, while the estimate of the Rotemberg parameter for wage stickiness is higher, in line with Zubairy (2014). TFP and government spending are more persistent than the other shocks.

As regards the Taylor rule parameters, in line with many other studies, estimates capture nominal interest rate inertia and that, during the Great Moderation, monetary policy was more aggressive on inflation than on the output gap, with posterior estimates of the latter parameter in the range  $[0.00, 0.04]$ . A novel result is that the monetary authority is found to respond to nominal credit growth with a point estimate for coefficient  $\rho_s$  of 0.30 and a confidence interval of  $[0.18, 0.41]$ .

Figure 1 shows the prior and posterior densities of the Taylor rule parameters, which are well identified by the data. This is particularly important for  $\rho_s$ , i.e. the responsiveness of the nominal interest rate to credit growth, which exhibits a posterior distribution entirely located around positive values, with the probability density tightly gathered around the posterior mean, despite the loose prior.

This last result is confirmed also by a log-likelihood race between the baseline model and a

	Baseline	$\rho_s = 0$
Log-likelihood	-539.818	-550.132
Bayes factor		$3.01 \times 10^4$
Kass-Raftery statistics		20.63

Table 3: Model comparison

restricted model featuring a standard Taylor rule, i.e. with  $\rho_s = 0$ . The last two rows of Table 3 report the Bayes factor (BF) and the statistics by Kass and Raftery (1995) (KR).<sup>5</sup> According to Jeffreys (1998), a BF of 3 – 10 provides “slight” evidence in favour of model  $i$  relative to model  $j$ ; a BF in the range [10 – 100] provides “strong to very strong” evidence; and a BF greater than 100 provides “decisive evidence”. Hence, here we find “decisive evidence” in favour of a model featuring a credit-growth-augmented Taylor rule over a standard one. The KR statistics is computed as twice the log of the BF. A KR statistics of around 21 also points to “very strong” evidence in favour of the unconstrained baseline model versus the restricted model featuring a standard Taylor rule, the full estimation of which is reported in Appendix D.<sup>6</sup> In other words, these results point to evidence that, during the Great Moderation, monetary policy leaned against the wind blowing from the loan market. So far the literature has focused more on the response of monetary policy to asset prices. For instance, on the empirical side, Castelnuovo and Nisticò (2010) argue that a model where the monetary authority has an active concern towards stock-market fluctuations is supported by US data. Our results complement the findings of Christiano et al. (2010b), whose estimates identify a significant degree of “leaning against credit exuberance” in the euro area monetary policy framework for the period 1985Q1-2008Q2.

### 3.3 Dynamic properties of the estimated model

In this section we disentangle the effects of the estimated leaning-against-the-wind policy versus a standard Taylor rule via the analysis of the responses of key macroeconomic variables to all seven structural shocks in the model. In Figure 2 we report impulse responses to shocks of size one percent that determine a fall in real output. The solid line represents responses within the estimated model featuring the credit-growth augmented Taylor rule, whereas the dashed line represents responses of a counterfactual model with  $\rho_s = 0$ .

<sup>5</sup>Let  $m_i$  be a given model, with  $m_i \in M$ , and  $L(Y|m_i)$  be the marginal data density of model  $i$  for the common dataset  $Y$ , then the BF between model  $i$  and model  $j$  is computed as:

$$BF_{i/j} = \frac{L(Y|m_i)}{L(Y|m_j)} = \frac{\exp(LL(Y|m_i))}{\exp(LL(Y|m_j))}$$

where  $LL$  stands for log-likelihood.

<sup>6</sup>Values of the KR statistics above 10 can be considered “very strong” evidence in favour of model  $i$  relative to model  $j$ ; between 6 and 10 represent “strong” evidence; between 2 and 6 “positive” evidence; while values below 2 are “not worth more than a bare mention”.



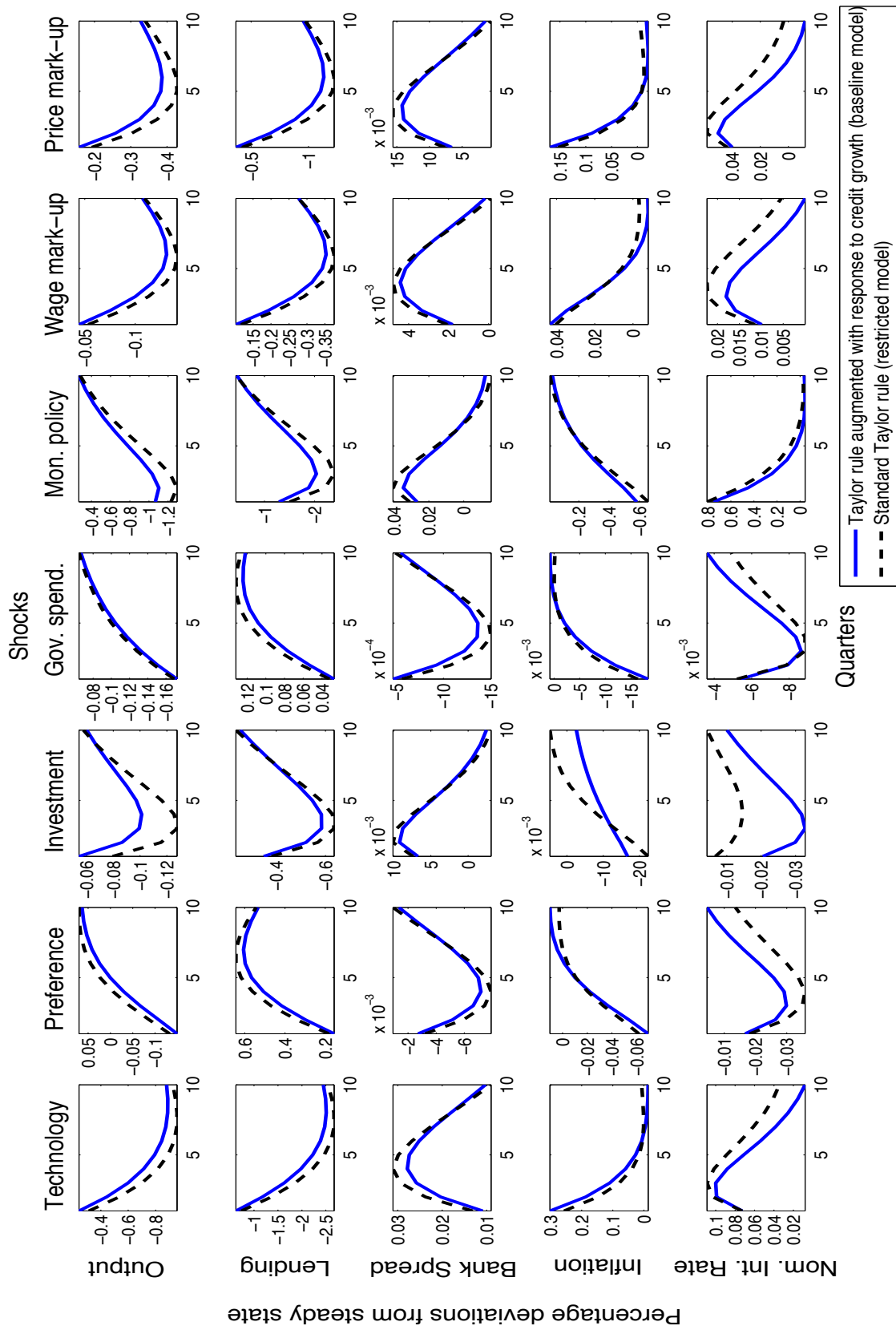


Figure 2: Impulse responses of selected variables to structural shocks of size 1 percent in the estimated model featuring a Taylor rule augmented with a response to credit growth and with a restricted model with a standard Taylor rule

In particular, the model features four aggregate demand shocks (preference, investment-specific, government spending, monetary policy), in which output and inflation move in the same direction, and three aggregate supply shocks (technology, wage mark-up and price mark-up), in which output and inflation move in opposite directions.

A number of noteworthy results emerge from the inspection of Figure 2. First, while the sign of impulse responses is preserved across the two Taylor rule specifications, the severity of the economic downturn generated by each shock varies. Second, with the exception of the preference and government spending shocks, lending positively comoves with real output and the bank spread exhibits a counter-cyclical behaviour. This is a feature of lending relationships: in the simulated contractions future profits are expected to be low (indeed real output persistently remains below steady state), hence banks find it optimal to exploit current lending relationships by charging higher bank spreads and enhancing current profits.

As far as the contractionary preference shock is concerned, this generates a shorter-lived output contraction and an overshooting. The explanation is in the fact that such a shock determines a fall of future marginal utility of consumption relative to the current one, and this leads to a fall in consumption and an increase in savings. The subsequent greater availability of financial funds makes banks willing to supply more loans, which in turn boost future economic activity and profits. The latter are anticipated by banks, which find it optimal to charge a lower spread and lock in new customers into bank-firm lending relationships. Similar arguments apply to the contractionary government spending shock, which crowds in private investment.

In the presence of a credit-growth-augmented Taylor rule, the central bank partially counteracts fluctuations of lending. In the model, lending has real effects because it is instrumental for the acquisition of capital. Therefore, for those shocks in response to which lending exhibits a pro-cyclical behaviour, the contraction of output is more severe in the absence of a credit-growth-augmented Taylor rule. On the contrary, for the preference shock and (to a lower extent) the government spending shock – which yields a counter-cyclical lending response – such a Taylor rule leads to a relatively more severe output contraction. The presence of lending relationships consistently generates responses of the bank spread of opposite sign relative to those of lending. Thus, the general lesson to be learned is that leaning against the wind has a stabilising effect on output for those shocks that imply a pro-cyclical response of lending and counter-cyclical response of the bank spread.

### 3.4 Variance decomposition

Movements in output, lending, bank spread and inflation are now decomposed into parts caused by each shock at different time horizons, based on the mean of the model’s posterior distribution. Table 4 reports both the conditional and the unconditional variance decomposition.

While, on impact, demand shocks play a dominant role in affecting output dynamics, in the

Horizon		Structural shocks						
		TFP	Gov. spending	Mon. policy	Preference	Invest. specific	Price mark-up	Wage mark-up
Output	1	3.45	42.16	5.44	13.51	9.63	13.14	12.68
	4	9.46	16.80	2.87	3.36	14.04	24.60	28.87
	8	13.60	9.38	1.55	1.52	11.11	27.05	35.79
	20	21.54	6.72	0.91	1.56	8.55	27.46	33.27
	40	26.25	6.47	0.81	1.58	8.11	26.50	30.29
	uncon.	27.45	6.42	0.79	1.57	8.01	26.09	29.66
Lending	1	3.95	0.18	1.36	2.52	68.09	12.26	11.63
	4	7.03	0.37	0.88	4.66	49.29	18.04	19.74
	8	10.49	0.59	0.53	6.59	35.10	21.75	24.96
	20	17.24	1.00	0.35	7.66	25.36	24.09	24.30
	40	18.81	1.11	0.35	7.46	25.05	23.52	23.70
	uncon.	18.71	1.10	0.34	7.48	25.13	23.56	23.67
Bank spread	1	3.44	0.15	1.65	2.16	71.39	11.13	10.08
	4	7.00	0.37	0.96	4.65	49.32	18.01	19.69
	8	10.02	0.57	0.70	6.33	37.69	20.69	23.99
	20	8.95	0.52	0.72	6.35	38.64	19.50	25.32
	40	9.81	0.55	0.66	6.76	36.31	20.40	25.50
	uncon.	9.94	0.56	0.66	6.75	36.26	20.38	25.45
Inflation	1	14.02	1.22	4.16	7.48	2.34	39.16	31.61
	4	12.76	1.17	5.97	8.70	3.73	30.40	37.27
	8	12.39	1.14	6.36	8.56	4.39	30.27	36.89
	20	11.91	1.09	6.10	8.70	4.32	30.02	37.87
	40	11.91	1.09	6.07	8.69	4.48	29.95	37.81
	uncon.	12.00	1.10	6.05	8.68	4.54	29.91	37.71

Table 4: Variance decomposition

longer term the TFP shock together with the other two supply shocks – wage and price mark-up – are its main drivers. These three shocks account for about 30% of output fluctuations on impact, more than 60% at a one-year horizon and more than 80% at a five-year horizon, with demand shocks having a minor effect. The role of government and monetary policy shocks decay over time. These results are in line with Smets and Wouters (2007).

The unconditional variance decomposition of lending shows that the three supply shocks accounts for almost 65% of variation in lending. However, differently from output dynamics, the investment-specific technology shock plays a stronger role: on impact it dominates – explaining 68% of lending fluctuations – and in the longer term it accounts for about 25% of the variation in lending. This results is not surprising as this shocks affects the investment Euler equation and lending is used to finance purchases of capital goods.

Results on the variance decomposition of the bank spread show that, on impact, the investment-specific technology shock is the most important exogenous source of its variation. Price and wage mark-up shocks also play an important role. The model features a tight (negative) relationship

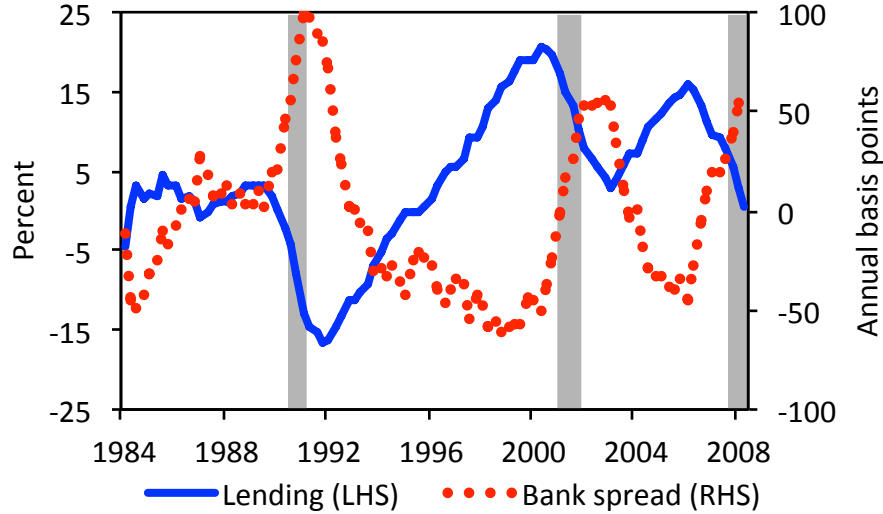


Figure 3: Model-implied cyclical deviations of lending and bank spread (shaded areas indicate NBER recessions)

between the bank spread and lending. Hence, those shocks playing a key role in explaining the dynamics of lending are likely to play a similar role in accounting for the variation of the bank spread. On this point it is important to stress that the shocks that are dominant sources of movements in lending and the bank spread imply a pro-cyclical response of the former and a counter-cyclical response of the latter (as reported in Section 3.3). The series of these two variables implied by the model, as a result of the shocks hitting the US economy during the Great Moderation, are depicted in Figure 3. The model predicts a pronounced fall of lending and a rapid surge of the bank spread during recessions. In addition, the model captures the low lending rates and the build-up of non-financial business sector debt of the late 1990s, and the sudden collapse in the early 2000s concurrent with the burst of the dot-com bubble.

Price and wage mark-up shocks are also the dominant factors behind both short-run and medium-run movements in inflation.

## 4 Optimised simple monetary policy rules

The analysis so far has brought a general equilibrium model with banking frictions to the data and has provided evidence that US monetary policy leaned against the wind blowing from the market for loans during the Great Moderation. This had a partial stabilisation role towards credit exuberance. In this section we pose a normative question: should the monetary policy rate react to developments in the loan market? To answer this question we rely on the literature on optimal monetary policy whereby optimised simple interest-rate feedback rules responding to promptly observable macroeconomic indicators are able to closely mimic the Ramsey rule (Schmitt-Grohe and Uribe, 2007; Levine et al., 2008).

To accomplish this task we rewrite the Taylor-type interest-rate feedback rule (16) as

$$\log \left( \frac{R_t^n}{\bar{R}^n} \right) = \rho_r \log \left( \frac{R_{t-1}^n}{\bar{R}^n} \right) + \alpha_\pi \log \left( \frac{\Pi_t}{\bar{\Pi}} \right) + \alpha_y \log \left( \frac{Y_t}{\bar{Y}} \right) + \alpha_s \log \left( \frac{L_t}{L_{t-1}} \Pi_t \right), \quad (20)$$

where  $\alpha_\pi \equiv (1 - \rho_r)\rho_\pi$ ,  $\alpha_y \equiv (1 - \rho_r)\rho_y$  and  $\alpha_s \equiv (1 - \rho_r)\rho_s$ . This re-parametrization allows for the possibility of integral rules with a unitary persistence parameter ( $\rho_r = 1$ ). Then we numerically search for those feedback coefficients in (20) to maximise the present value of life-time utility, which reads

$$\Omega_t = E_t \left[ (1 - \beta) \sum_{s=0}^{\infty} \beta^s U(X_{t+s}, 1 - H_{t+s}) \right], \quad (21)$$

given the equilibrium conditions of the model. Assuming no growth in the steady state, we follow Levine et al. (2008) and rewrite equation (21) in recursive form as

$$\Omega_t = (1 - \beta)U(X_t, 1 - H_t) + \beta E_t[\Omega_{t+1}]. \quad (22)$$

Given the numerous frictions in our model, this optimisation problem does not collapse to the minimisation of an *ad-hoc* loss function. In addition, while more stylised models allow for a first-order approximation to the equilibrium conditions to be sufficient to accurately approximate welfare up to a second order, the presence of the frictions in our model requires taking a second-order approximation both of the mean of  $\Omega_t$  and of the model's equilibrium conditions around the deterministic steady state. Given that it is now established in the literature that the Ramsey solution to NK models sets  $\Pi = 1$  in the steady state (see e.g. Schmitt-Grohe and Uribe, 2004; Levine et al., 2008), we take the approximation around a zero-inflation steady state.

Given that we approximate the solution to the equilibrium using perturbation methods and these do not easily allow incorporating non-negativity constraints, in similar fashion to Levine et al. (2008), we approximate the zero lower bound (ZLB) constraint on the nominal interest rate by penalising large deviations of the mean gross rate,  $\bar{R}^n$ , from its steady state. This is achieved by replacing our objective function (21) with modified welfare,

$$\Omega_t^* = E_t \left\{ (1 - \beta) \sum_{s=0}^{\infty} \beta^s \left[ U(X_{t+s}, 1 - H_{t+s}) - w_r (R_{t+s}^n - \bar{R}^n)^2 \right] \right\}, \quad (23)$$

where term  $w_r (R_t^n - \bar{R}^n)^2$  represents a penalty for deviations of  $R_t^n$  from its steady state. Hence, the imposition of the approximate ZLB constraint translates into setting an arbitrarily low per-period probability of hitting the ZLB,  $Pr(ZLB) \equiv Pr(R_t^n < 1)$ , and appropriately choosing the weight  $w_r$ , raising which the variance of  $R_t^n$ ,  $\sigma_r^2$ , lowers accordingly.

The use of  $\Omega_t^*$  is confined to the design of optimised rules that hit the ZLB only very infrequently. However, we make all welfare comparisons among competing rules using the original

$w_r$	$\sigma_r$	$Pr(ZLB)$	$\rho_r$	$\alpha_\pi$	$\alpha_y$	$\alpha_s$	$\Omega$	$\omega$
<i>Optimised standard Taylor-type rules</i>								
0.0	1.09	0.176	0.518	3.000	0.000	–	-2.5863	0.00
5.0	0.58	0.042	0.918	1.046	0.002	–	-2.5864	-0.04
10.0	0.46	0.014	1.000	0.718	0.002	–	-2.5865	-0.08
15.0	0.41	0.006	1.000	0.586	0.000	–	-2.5866	-0.12
20.0	0.37	0.003	1.000	0.496	0.000	–	-2.5866	-0.12
<i>Optimised augmented Taylor-type rule</i>								
16.5	0.39	0.005	1.000	0.555	0.000	0.000	-2.5866	-0.12
20.0	0.37	0.003	1.000	0.496	0.000	0.000	-2.5866	-0.12
<i>Estimated Taylor-type rule</i>								
–	0.39	0.005	0.857	0.287	0.003	0.042	-2.5875	-0.48

Table 5: Optimised monetary policy rules

welfare definition  $\Omega$ . Welfare comparisons can be interpreted in terms of a consumption equivalent calculation. For a particular equilibrium we compute the increase in the single-period utility, given by a permanent 1% increase in consumption,

$$\varpi \equiv (1 - \beta)^{-1} [U(1.01X, 1 - H) - U(X, 1 - H)]. \quad (24)$$

Then a consumption equivalent welfare change between two inter-temporal welfare outcomes  $\Omega_1$  and  $\Omega_2$  is defined as  $\omega \equiv 100 \times \frac{\Omega_1 - \Omega_2}{\varpi}$ , which represents the compensation in terms of permanent percent change in consumption that the representative agent should receive to be as well off under regime 2 as under regime 1.

Table 5 first shows the results arising from the computation of optimised standard Taylor-type rules in which the nominal interest rate features inertia and reacts to inflation and output ( $\alpha_s = 0$ ). Increasing the penalty parameter  $w_r$  delivers a smaller and smaller variability of the nominal interest rate, which translates into a lower and lower per-period probability of hitting the ZLB. Assuming that the gross nominal interest rate is normally distributed, in the table  $Pr(ZLB) = \Phi(z_0)$  is computed as the cumulated density function (CDF) of the standard normal distribution evaluated at  $z_0 \equiv -\frac{100(R_n - 1)}{\sigma_r}$ . In the absence of the ZLB constraint we impose an upper bound of 3 on the feedback coefficient to inflation  $\alpha_\pi$ . Leaving this coefficient unconstrained would imply an implausibly high responsiveness, with immaterial welfare gains. Irrespective of the value of  $w_r$ , we replicate the result on “the importance of not responding to output” of Schmitt-Grohe and Uribe (2007). A higher penalty  $w_r$  delivers a lower optimal  $\alpha_\pi$ . In the table we compute

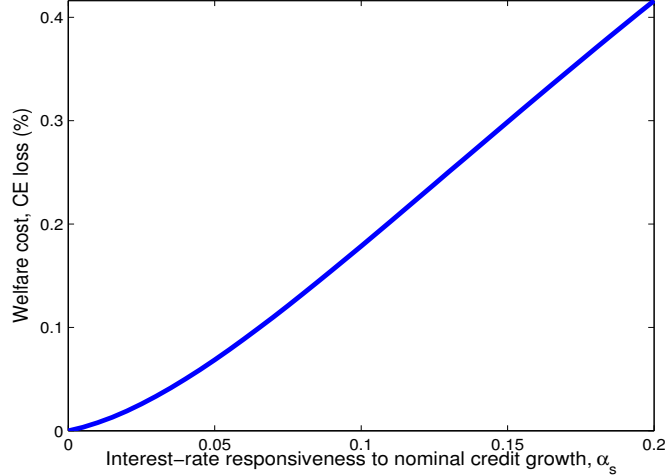


Figure 4: Welfare cost associated to leaning against the wind

the consumption equivalent welfare loss  $\omega$  relative to the standard Taylor-type rule with  $w_r = 0$  (first row). Under this monetary policy rule the ZLB is reached approximately every five quarters, hence it is clearly not implementable. With  $w_r = 20$  the probability of hitting the ZLB is 0.003, i.e. approximately once every 75 years and the welfare loss is equivalent to a permanent loss in consumption of 0.12%.

We then move to optimised rules in which the interest rate reacts also to nominal credit growth,  $(L_t/L_{t-1})\Pi_t$ , as in Christiano et al. (2010b,a) and Ozkan and Unsal (2013), among others, while keeping  $Pr(ZLB) = 0.003$ . We find a zero optimal responsiveness to nominal credit growth and that the welfare loss remains unaltered relative to the case of the standard Taylor-type rule. Appendix E checks the robustness of the results to interest rate rules reacting to alternative financial variables, such as lending and the bank spread, similarly to Curdia and Woodford (2010) and Aksoy et al. (2013).

The estimated monetary policy rule implies  $Pr(ZLB) = 0.005$ , i.e. that the nominal interest rate hits the ZLB once every 49 years and implies a consumption-equivalent welfare loss of  $(0.48 - 0.12)\% = 0.36\%$ , relative to the optimised rule with the same  $Pr(ZLB)$ , obtained setting  $w_r = 16.5$ .

To check the extent to which the welfare loss suffered from employing the empirical rule is due to the presence of the responsiveness to nominal credit growth, in Figure 4, we isolate its effect on welfare by keeping  $\rho_r$ ,  $\alpha_\pi$  and  $\alpha_y$  fixed at their optimal values and by changing  $\alpha_s$  in the interval  $[0, 0.2]$ . The estimated value of  $\alpha_s = 0.042$  implies a small consumption-equivalent loss of around 0.05%. In addition, this exercise unveils also a positive relationship whereby that the economy suffers a more-than-double welfare loss if  $\alpha_s$  doubles.

In a nutshell these results show that it is not optimal, and is actually detrimental, for monetary policy to lean against windy bank lending. This finding can be rationalised by noticing that supply

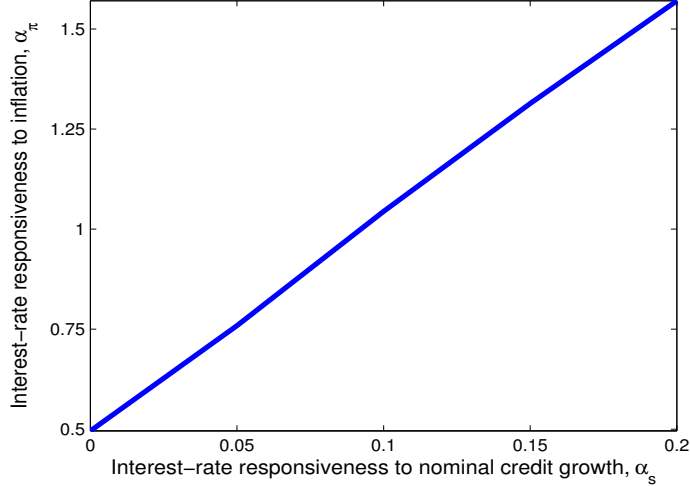


Figure 5: Optimal responsiveness of inflation for given degrees of leaning against the wind

shocks (technology, price mark-up and wage mark-up) explain the largest share of business cycle fluctuations of lending and inflation. Indeed, Section 3.4 shows that the three supply shocks together explain around 66% and 80% of the unconditional variance of lending and inflation, respectively. A, say, contractionary shock of such a kind causes lending to decrease and inflation to rise. A monetary policy that leans against windy bank lending is more accommodative towards inflation in an attempt to boost lending (as shown in Section 3.3). But this turns out not to be optimal. In fact, in Figure 5, we show that, if we fix  $\alpha_r = 1$ ,  $\alpha_y = 0$ , we let  $\alpha_s$  vary in the interval  $[0, 0.2]$ , and we optimise over  $\alpha_\pi$ , the optimal value of this last coefficient monotonically increases when  $\alpha_s$  increases, while welfare (not shown) attains virtually the same level for any combination of the two parameter values. In other words, if monetary policy is forced to react more to a(n) tightening (expansion) of lending growth, it is optimal for it to react more also to the increase (decrease) in inflation. As the two objectives are conflicting, there is no “divine coincidence” in this case and the nominal interest rate achieves a better outcome if it only stabilises inflation. This result is in line with Faia and Monacelli (2007), who find that the presence of only one policy instrument – the nominal interest rate – cannot simultaneously neutralise both financial frictions and price stickiness and that a strong anti-inflationary stance always leads to the highest level of welfare.

To show the importance of the source of business cycle fluctuations on the optimality of monetary policy responses, in Figure 6, again, we keep  $\rho_r$ ,  $\alpha_\pi$  and  $\alpha_y$  fixed at their optimal values and change  $\alpha_s$ , after artificially switching off wage mark-up shocks, being these the most prominent shocks in the unconditional variance decomposition of inflation. This exercise is important as (i) it shows that, in the absence of such shocks, it would be indeed optimal to lean against windy bank lending, with an optimal  $\alpha_s$  around 0.06; and (ii) it allows reconciling our results with the literature. In fact, Aksoy et al. (2013), in a similar but simpler calibrated model with no wage



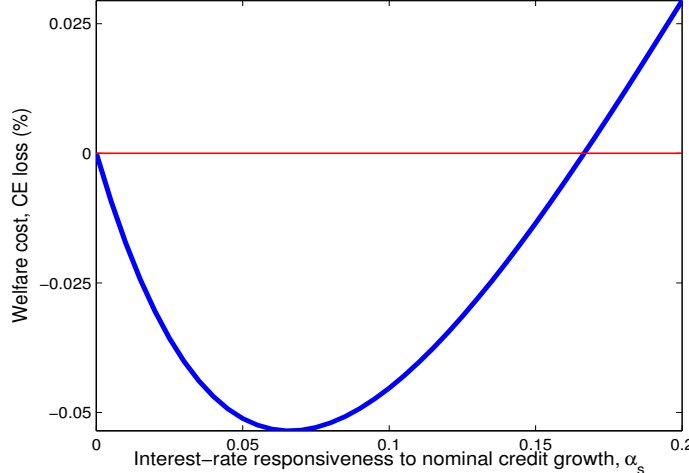


Figure 6: Welfare cost associated to leaning against the wind in the absence of wage mark-up shocks

mark-up shocks, find leaning against the wind to be optimal. Moreover, Curdia and Woodford (2010) and Nisticò (2012) show that the optimality of a leaning-against-the-wind-type of monetary policy is very sensitive to the source of business cycle fluctuations. We deem our research strategy to be desirable as we first bring an almost canonical model (augmented with banking) to the data; estimate a set of standard shocks; and on the estimation results we base optimal policy computations. Appendix E investigates also the robustness of the results to scenarios characterised by higher volatility of business cycle fluctuations. In particular we increase the volatility of shocks in order to match the levels of output growth volatility observed during the Great Recession or higher. If the increased volatility is due to a proportional increase in all shocks, results remain unchanged. We find some room for leaning against the wind if the increase in volatility is entirely due to the investment-specific shock, in response to which lending and inflation positively co-move.

## 5 Concluding remarks

In recent times credit booms and busts have dramatically affected business cycle fluctuations. This has called for a deeper understanding of credit market conditions and the potential role of central banks in ensuring financial stability. This paper examines whether monetary policy has reacted and whether it should indeed react to bank lending growth in the US economy.

We first estimate a DSGE model in which banking frictions arise due to the presence of lending relationships and monetary policy is set according to a credit-growth-augmented Taylor-type rule. The empirical results provide evidence that during the Great Moderation monetary policy leaned against the wind blowing from the loans market.

We then compare the welfare implications of estimated and optimised interest-rate rules. Results unveil that the estimated responsiveness of monetary policy to credit growth delivers a small welfare loss, but the higher such a responsiveness the higher is the detriment to welfare. Therefore, the main lesson that can be learned from the analysis is that the monetary policy rate should not respond to credit exuberance more than it did in the past. If anything, it should not respond at all. Such a finding can be rationalised by noticing that supply shocks are the main drivers of output, lending and inflation fluctuations in the estimated model and that these shocks imply a trade-off between inflation and output stabilisation. Given the pro-cyclical behaviour of lending, it turns out to be optimal for monetary policy to respond only to inflation. On this aspect, the paper highlights that the optimality of a leaning-against-the-wind policy is sensitive to the sources of business cycle fluctuations.

The findings of this paper agree with the recent tendency in central banking to move towards macroprudential instruments as tools to promote financial stability. Indeed, a bolder research effort is necessary to identify effective instruments and design rules that achieve the goal of reducing systemic risk without conflicting with the objective of inflation stabilisation.

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# Appendix

## A Symmetric equilibrium

Production function and marginal products:

$$Y_t = e_t^A H_t^\alpha (U_t K_t)^{1-\alpha} \quad (\text{A.1})$$

$$F_{K,t} = \frac{(1-\alpha)}{\mu_t} \frac{Y_t}{U_t K_t} \quad (\text{A.2})$$

$$F_{H,t} = \frac{\alpha}{\mu_t} \frac{Y_t}{H_t} \quad (\text{A.3})$$

Utility function, marginal utilities, Euler equation, and wage setting:

$$U(X_t, 1 - H_t) = \frac{\left[ (X_t)^\phi (1 - H_t)^{1-\phi} \right]^{1-\sigma_c}}{1 - \sigma_c} \quad (\text{A.4})$$

$$U_{X_t} = \phi (1 - H_t)^{1-\phi} \left[ X_t^\phi (1 - H_t)^{1-\phi} \right]^{-\sigma_c} X_t^{\phi-1} \quad (\text{A.5})$$

$$U_{H_t} = - (1 - \phi) (1 - H_t)^{-\phi} X_t^\phi \left[ X_t^\phi (1 - H_t)^{1-\phi} \right]^{-\sigma_c} \quad (\text{A.6})$$

$$X_t = C_t - \theta S_{t-1} \quad (\text{A.7})$$

$$S_t = \rho S_{t-1} + (1 - \rho) C_t \quad (\text{A.8})$$

$$e_t^B U_{X_t} = \beta E_t \left[ e_{t+1}^B U_{X_{t+1}^c} (1 + R_{t+1}^D) \right] \quad (\text{A.9})$$

$$(1 - e_t^W \eta^W) + \frac{e_t^W \eta^W}{\mu_t^W} - \xi^W (\Pi_t^W - \bar{\Pi}) \Pi_t^W + \xi^W E_t \left[ \Lambda_{t,t+1} (\Pi_{t+1}^W - \bar{\Pi}) \Pi_t^W \frac{W_{t+1} H_{t+1}}{W_t H_t} \right] = 0 \quad (\text{A.10})$$

$$\mu_t^W = \frac{W_t}{-\frac{U_{H,t}}{U_{X_t}}} \quad (\text{A.11})$$

Investment demand, labor demand, and price setting:

$$K_{t+1} = (1 - \delta) K_t + I_t \left[ 1 - S \left( \frac{I_t}{I_{t-1}} \right) \right] e_t^I \quad (\text{A.12})$$

$$S \left( \frac{I_t}{I_{t-1}} \right) = \frac{\psi}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 \quad (\text{A.13})$$

$$S' \left( \frac{I_t}{I_{t-1}} \right) = \psi \left( \frac{I_t}{I_{t-1}} - 1 \right) \quad (\text{A.14})$$

$$Q_t = E_t \Lambda_{t,t+1} \left[ U_{t+1} F_{K,t+1} - \Psi_{t+1} + Q_{t+1} (1 - \delta) \right] \quad (\text{A.15})$$

$$E_t [\Lambda_{t,t+1}(1 + R_t^L)] = e_t^I Q_t \left[ 1 - S \left( \frac{I_t}{I_{t-1}} \right) - S' \left( \frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right] + E_t \Lambda_{t,t+1} \left[ e_{t+1}^I Q_{t+1} S' \left( \frac{I_{t+1}}{I_t} \right) \left( \frac{I_{t+1}}{I_t} \right)^2 \right] \quad (\text{A.16})$$

$$\Psi_t = \gamma_1 (U_t - 1) + \frac{\gamma_2}{2} (U_t - 1)^2 \quad (\text{A.17})$$

$$\Psi_t' = \gamma_1 + \gamma_2 (U_t - 1) \quad (\text{A.18})$$

$$\Psi_t' = F_{K,t} \quad (\text{A.19})$$

$$\Lambda_{t,t+1} = \beta E_t \left[ \frac{\lambda_{t+1}}{\lambda_t} \right] \quad (\text{A.20})$$

$$F_{H,t} = W_t \quad (\text{A.21})$$

$$1 - e_t^P \eta + e_t^P \eta MC_t - \xi (\Pi_t - \bar{\Pi}) \Pi_t + \xi E_t \left[ \Lambda_{t,t+1} (\Pi_{t+1} - \bar{\Pi}) \Pi_{t+1} \frac{Y_{t+1}}{Y_t} \right] = 0 \quad (\text{A.22})$$

$$\mu_t = 1/MC \quad (\text{A.23})$$

### Demand and supply for loans

$$L_t = I_t \quad (\text{A.24})$$

$$L_t = X_t^L + \theta^L S_{t-1}^L \quad (\text{A.25})$$

$$S_t^L = \varrho^L S_{t-1}^L + (1 - \varrho^L) L_t \quad (\text{A.26})$$

$$L_t = D_t \quad (\text{A.27})$$

$$\nu_t = E_t \Lambda_{t,t+1} [(R_{t+1}^L - R_{t+1}^D) + \nu_{t+1} \theta^L (1 - \varrho^L)] \quad (\text{A.28})$$

$$E_t [\Lambda_{t,t+1} L_{t+1}] = \nu_t \eta^L E_t [X_{t+1}^L] \quad (\text{A.29})$$

$$\text{spread}_t = (1 + R_t^L) / (1 + R_t^D) \quad (\text{A.30})$$

### Resource constraint:

$$Y_t = C_t + I_t + G_t + \frac{\xi}{2} (\Pi_t - 1)^2 Y_t + \frac{\xi^W}{2} (\Pi_t^W - \bar{\Pi})^2 W_t H_t + \Psi_t K_t \quad (\text{A.31})$$

### Taylor rule and Fisher equation:

$$\log \left( \frac{R_t^n}{\bar{R}^n} \right) = \rho_r \log \left( \frac{R_{t-1}^n}{\bar{R}^n} \right) + (1 - \rho_r) \left[ \rho_\pi \log \left( \frac{\Pi_t}{\bar{\Pi}} \right) + \rho_y \log \left( \frac{Y_t}{\bar{Y}} \right) + \rho_s \log \left( \frac{L_t}{L_{t-1}} \Pi_t \right) \right] + e_t^R \quad (\text{A.32})$$

$$R_{t+1}^D = E_t \left[ \frac{R_t^n}{\Pi_{t+1}} \right] \quad (\text{A.33})$$

Exogenous processes:

$$\log \left( \frac{e_t^\varkappa}{\bar{e}^\varkappa} \right) = \rho_\varkappa \log \left( \frac{e_{t-1}^\varkappa}{\bar{e}^\varkappa} \right) + \epsilon_t^\varkappa, \quad \varkappa = \{A, B, G, I, R, P, W\} \quad (\text{A.34})$$

## B Steady state

$K$  and  $H$  solve equations (A.28) and (A.3), evaluated at the steady state, while the value of the remaining variables is found recursively by using the following relationships

$$\Pi = 1 \quad (\text{B.1})$$

$$\Pi^W = \Pi \quad (\text{B.2})$$

$$\Lambda = \beta \quad (\text{B.3})$$

$$U = 1 \quad (\text{B.4})$$

$$\mu^W = \frac{\tilde{\eta}}{\tilde{\eta} - 1} \quad (\text{B.5})$$

$$MC = \frac{\eta - 1}{\eta} \quad (\text{B.6})$$

$$\mu = 1/MC \quad (\text{B.7})$$

$$R^D = \frac{1}{\beta} - 1 \quad (\text{B.8})$$

$$I = \delta K \quad (\text{B.9})$$

$$Y = H^\alpha K^{1-\alpha} \quad (\text{B.10})$$

$$G = \frac{G}{Y} Y \quad (\text{B.11})$$

$$C = Y - I - G \quad (\text{B.12})$$

$$S = C \quad (\text{B.13})$$

$$X = (1 - \theta) C \quad (\text{B.14})$$

$$U = \frac{\left[ (X)^\phi (1 - H)^{1-\phi} \right]^{1-\sigma_c}}{1 - \sigma_c} \quad (\text{B.15})$$

$$U_X = \phi (1 - H)^{1-\phi} \left[ X^\phi (1 - H)^{1-\phi} \right]^{-\sigma_c} X^{\phi-1} \quad (\text{B.16})$$

$$U_H = - (1 - \phi) (1 - H)^{-\phi} X^\phi \left[ X^\phi (1 - H)^{1-\phi} \right]^{-\sigma_c} \quad (\text{B.17})$$

$$W = \mu^W (-U_H/U_X) \quad (\text{B.18})$$



$$L = I \quad (\text{B.19})$$

$$S^L = L \quad (\text{B.20})$$

$$X^L = (1 - \theta^L)L \quad (\text{B.21})$$

$$D = L \quad (\text{B.22})$$

$$F_K = \frac{(1 - \alpha) Y}{\mu} \frac{Y}{K} \quad (\text{B.23})$$

$$R = \frac{\beta F_K}{\beta (1 - \beta (1 - \delta))} - 1 \quad (\text{B.24})$$

$$\nu = \Lambda L (1 + R^L) / (\eta^L X^L) \quad (\text{B.25})$$

$$\text{spread} = (1 + R^L) / (1 + R^D) \quad (\text{B.26})$$

$$F_H = W \quad (\text{B.27})$$

$$Q = \Lambda (1 + R^L) \quad (\text{B.28})$$

$$\Psi = 0 \quad (\text{B.29})$$

$$\gamma_1 = F_K \quad (\text{B.30})$$

$$\Psi' = \gamma_1 \quad (\text{B.31})$$

$$\gamma_2 = \frac{\gamma_1}{\sigma_u} \quad (\text{B.32})$$

$$S = 0 \quad (\text{B.33})$$

$$S' = 0 \quad (\text{B.34})$$

## C Data sources and transformations

This section discusses the sources of the seven observables used in the estimation and their transformation. GDP, GDP deflator inflation, the federal funds rate, civilian population (CNP160V) and civilian employment (CE160V) are downloaded from the ALFRED database of the Federal Reserve Bank of St. Louis. Private consumption expenditures and fixed private investment are extracted from the NIPA Table 1.1.5 of the Bureau of Economic Analysis. Average weekly hours worked (PRS85006023) and compensation per hour (PRS85006103) are downloaded from the Bureau of Labor Statistics.

Data are transformed as in Smets and Wouters (2007). In particular, GDP, consumption and investment are transformed in real per-capita terms by dividing their nominal values by the GDP deflator and the civilian population. Real wages are computed by dividing compensation per hour by the GDP deflator. As shown in the measurement equations in Section (3.1), the observable variables of GDP, consumption, investment and wages are expressed in first differences. Hours worked are multiplied by civilian employment, expressed in per capita terms and demeaned. The inflation rate is computed as a quarter-on-quarter difference of the log of the GDP deflator. The federal funds rate is expressed in quarterly terms and the remaining variables are expressed as 100 times their logarithm. All series are seasonally adjusted by their sources.

## D Posterior estimates of the model featuring a standard Taylor rule

Parameter			Prior		Posterior Mean
		Distrib.	Mean	Std/df	
<i>Structural</i>					
Relative risk aversion	$\sigma_c$	Normal	1.50	0.10	1.53 [1.36;1.69]
Habits in consumption	$\theta$	Beta	0.70	0.10	0.69 [0.60;0.78]
Habit persist. in consumption	$\rho$	Beta	0.50	0.10	0.63 [0.51;0.75]
Deep habits in banking	$\theta^L$	Beta	0.70	0.125	0.72 [0.53;0.94]
Habit persist. in banking	$\varrho^L$	Beta	0.70	0.125	0.82 [0.65;0.98]
Price stickiness	$\xi$	Normal	30.0	5.00	41.79 [35.30;48.51]
Wage stickiness	$\xi^W$	Normal	100.0	10.00	80.22 [59.68;100.27]
Investment adjust. costs	$\psi$	Normal	4.00	1.50	4.45 [2.88;6.01]
Capital utilisation	$\eta_u$	Beta	0.50	0.10	0.86 [0.77;0.95]
Inflation -Taylor rule	$\rho_\pi$	Normal	1.50	0.20	2.08 [1.83;2.34]
Output -Taylor rule	$\rho_y$	Beta	0.10	0.05	0.01 [0.00;0.02]
Interest rate smoothing	$\rho_r$	Beta	0.80	0.10	0.83 [0.80;0.86]
<i>Averages</i>					
Trend growth rate	$\gamma$	Normal	0.44	0.10	0.41 [0.35;0.47]
Inflation rate	$\bar{\pi}$	Gamma	0.63	0.10	0.65 [0.56;0.75]
Interest rate	$\bar{r}^n$	Gamma	1.31	0.10	1.29 [1.15;1.42]
Hours of work	$\bar{h}$	Normal	0.00	0.10	-0.01 [-0.17;0.16]
<i>Shocks</i>					
TFP	$\rho_A$	Beta	0.50	0.20	0.96 [0.92;0.99]
	$\sigma_A$	IG	0.10	2.0	0.46 [0.41;0.51]
Government spending	$\rho_G$	Beta	0.50	0.20	0.97 [0.94;0.99]
	$\sigma_G$	IG	0.10	2.0	2.24 [1.97;2.49]
Interest rate	$\sigma_R$	IG	0.10	2.0	0.15 [0.13;0.17]
Investment-specific	$\rho_I$	Beta	0.50	0.20	0.80 [0.70;0.89]
	$\sigma_I$	IG	0.10	2.0	2.54 [1.65;3.46]
Preference	$\rho_B$	Beta	0.50	0.20	0.79 [0.70;0.89]
	$\sigma_B$	IG	0.10	2.0	1.64 [1.24;2.03]
Price mark-up	$\rho_P$	Beta	0.50	0.20	0.96 [0.94;0.99]
	$\sigma_P$	IG	0.10	2.0	1.38 [1.20;1.56]
Wage mark-up	$\rho_W$	Beta	0.50	0.20	0.91 [0.84;0.98]
	$\sigma_W$	IG	0.10	2.0	3.64 [2.88;4.43]
Log-likelihood					-550.132

Table D.1: Prior and posterior distributions of the estimated parameters of the NK model featuring a standard Taylor rule

$\mathcal{S}_t$	$w_r$	$\sigma_r$	$Pr(ZLB)$	$\rho_r$	$\alpha_\pi$	$\alpha_y$	$\alpha_s$	$\Omega$	$\omega$
<i>Optimised standard Taylor-type rules</i>									
–	20.0	0.37	0.003	1.000	0.496	0.000	–	-2.5866	-0.12
<i>Optimised augmented Taylor-type rule</i>									
$L_t/L_{t-1}$	20.0	0.37	0.003	1.000	0.496	0.000	0.000	-2.587	-0.12
$L_t/L$	20.0	0.37	0.003	1.000	0.496	0.000	0.000	-2.5866	-0.12
$\text{spread}_t/\text{spread}$	20.0	0.37	0.003	1.000	0.496	0.000	0.000	-2.5866	-0.12

Table E.1: Optimised alternative augmented monetary policy rules

## E Robustness exercises for optimal policy

This section illustrates a series of modifications in the DSGE model in order to (i) investigate the robustness of the results to a Taylor-type rules augmented with financial variables different from nominal credit growth and (ii) analyse the effects of a higher volatility of structural shocks on optimal policy.

We can write the Taylor rule as

$$\log\left(\frac{R_t^n}{\bar{R}^n}\right) = \rho_r \log\left(\frac{R_{t-1}^n}{\bar{R}^n}\right) + \alpha_\pi \log\left(\frac{\Pi_t}{\bar{\Pi}}\right) + \alpha_y \log\left(\frac{Y_t}{\bar{Y}}\right) + \alpha_s \log(\mathcal{S}_t), \quad (\text{E.1})$$

where  $\mathcal{S}_t$  is a financial variable the monetary policy rate may react to. In particular, we consider (i) real credit growth,  $L_t/L_{t-1}$ ; (ii) the percent deviation of lending from its steady state ( $L_t/L$ ); and (iii) the bank spread,  $\text{spread}_t/\text{spread} \equiv (1+R_t^L)/(1+R_t^D)/(1+R^L)/(1+R^D)$ , similarly to Curdia and Woodford (2010) and Aksoy et al. (2013).

Table E.1 shows that the optimal response to all financial variables is always zero. The optimal  $\rho_r$ ,  $\alpha_\pi$  and  $\alpha_y$  are identical to the ones under the standard Taylor-type rule for the same  $Pr(ZLB) = 0.003$ ; hence, the welfare loss,  $\omega$ , is unaltered. This exercise unveils that monetary policy should not respond to any financial variable considered.

The shocks used for the computation of optimised simple rules are those estimated using data of the Great Moderation, characterised by low volatility of business cycle fluctuations. Therefore it seems appropriate to check whether the main results hold in more turbulent periods characterised by higher volatilities. The Great Recession witnessed a double standard deviation of real output growth compared to the average level observed during the Great Moderation.

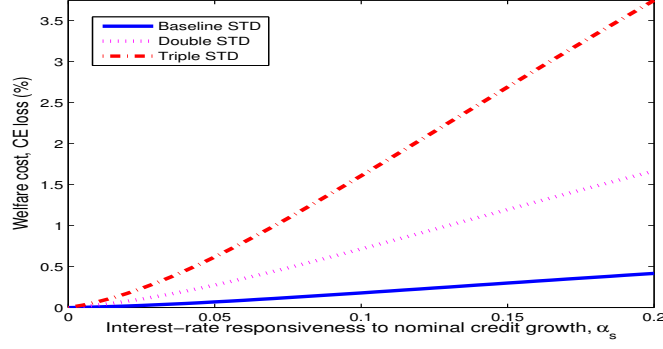


Figure E.1: Welfare cost associated to leaning against the wind for proportional increases in the volatilities of all shocks (STD = standard deviation of real output growth).

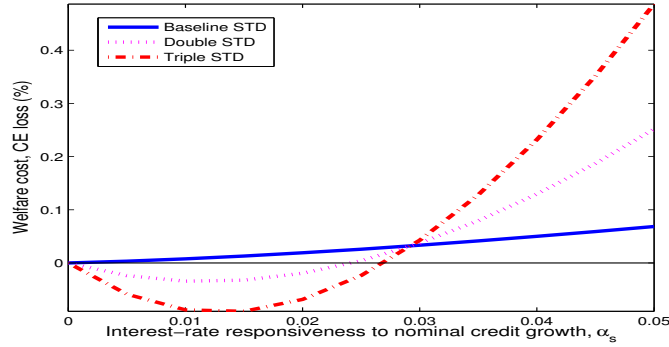


Figure E.2: Welfare cost associated to leaning against the wind for larger volatilities of the investment-specific technology shock (STD = standard deviation of real output growth).

Figure E.1 presents a counterfactual experiment in which we proportionally change the volatilities of all the structural shocks to match a standard deviation of output double and triple compared to the baseline estimated model – by keeping  $\rho_r$ ,  $\alpha_\pi$  and  $\alpha_y$  fixed at their optimal values and by changing  $\alpha_s$  in the interval  $[0; 0.2]$ . The higher the standard deviation, the stronger is the trade-off between inflation and financial stabilisation. Hence the welfare loss is greater under the most volatile scenario and it monotonically increases for a more aggressive responsiveness to nominal credit growth.

In order to highlight the importance of supply versus demand shocks in the design of optimal policy, we then artificially calibrate only the volatility of the investment-specific technology shock to match the higher standard deviation of output, keeping the volatilities of the other shocks at their estimated values shown in Table 2. This exogenous disturbance is a demand shock, in which output, lending and inflation move into the same direction. Figure E.2 shows that it would be indeed optimal to lean against windy bank lending, with an optimal  $\alpha_s$  around 0.015 in the higher volatility scenarios. This result confirms that the source of business cycle fluctuations is crucial for the optimality of the leaning-against-the-wind policy.