Online Appendix

MONETARY POLICY AND FINANCIAL FRICTIONS IN A SMALL OPEN-ECONOMY MODEL FOR UGANDA

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1 Selected literature review

This section contains the literature review that is related to the present study, where we initially consider studies that apply structural macroeconomic models to low income countries (LICs) that may be found within Sub-Saharan Africa (SSA).Thereafter, we discuss the relevant literature that has considered the inclusion of financial frictions in structural macroeconomic models.

1.1 Structural macroeconomic models for LICs in SSA

The literature on the application of the structural macroeconomic models for LICs in SSA is not particularly extensive. This literature shrinks further when we focus our attention on studies that involve monetary policy investigations.

Among the existing studies, Peiris & Saxegaard (2007) were one of the first to estimate a dynamic structural general equilibrium (DSGE) model for the purposes of monetary policy analysis in LICs, using data for the Mozambique economy. To describe the conduct of monetary policy, they include a response function that allows for the monetary policy authority to influence the supply of money, as a result of foreign exchange and government bond transactions. In addition, they also recognised that there is a role for credit frictions that are faced by firms and suggest that the central bank should focus on maintaining the internal value of the currency (rather than the external value), when seeking to stabilise aspects that affect the real economic variables. However, contrary to the model that has been developed in this paper, they do not explicitly model financial frictions as a mechanism that could influence monetary policy.[1]

In a paper that focuses on the application of fiscal policy, Berg *et al.* (2010*a*), make use of a multi-sector calibrated DSGE model to investigate the impact of aid on selected macroeconomic variables. This model is applied to data from the Ugandan economy to evaluate the implications of different policy responses that follow an inflow of aid. Some of the LICs features that are captured in this model include, varying degrees of public investment efficiency, realistic monetary and fiscal policy rules and a household sector that comprises of dynamic optimization and rule-of-thumb agents. Their results provide a mixed

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[1]Peiris & Saxegaard (2007) utilise a pegged exchange rate regime for Mozambique, while the model in this paper makes use of a flexible exchange rate mechanism to ensure that it is consistent with the current Ugandan exchange rate policy.

outlook. For instance, they find a temporary demand increase and a real exchange rate appreciation results in an increase in public capital spending and aid absorption. In addition, they also find that real gross domestic product (GDP) increases over the medium term, when there is high public capital spending. Conversely, they find that high levels of public capital spending with partial absorption has the ability to reduce exchange rate appreciation pressures, and also decrease real GDP growth over the medium term (as it crowds out the private sector spending). Unlike their model which is designed for fiscal policy analysis, the model in this paper is used for an investigation into the conduct of monetary policy. Another important feature of the Berg *et al.* (2010*a*) paper is that they introduce heterogeneity using optimizing and non-optimizing households, where only the optimizing households have access to financial services. This is contrary to what has been proposed in this paper, where we assume that households have access to financial services and only differ in their marginal utility of consumption. In addition, unlike the model in their paper, which is fully calibrated, the model parameters in this paper are mostly estimated with the aid of Bayesian techniques, that combine prior information and observed data.

A second paper by Berg *et al.* (2010*b*) employs Bayesian techniques to estimate the parameters in a new-Keynesian DSGE model for monetary policy analysis in three LICs (Ghana, Tanzania and Uganda). They account for the differences in monetary policy frameworks in the three countries by assuming monetary aggregate rules for Tanzania and Uganda, and an interest rate rule for Ghana that was under an IT regime. Contrary to the assumption of a monetary aggregate rule, the model in this paper incorporates details of the new monetary policy regime that has recently been introduced in Uganda, where the Bank of Uganda (BOU) follows a nominal interest rate rule that may be modelled according to the general framework of Taylor (1993). They also do not allow for the inclusion of financial frictions in their model (through heterogeneity in the household sector).

To consider the role of constraints on the availability of foreign exchange in LICs, Senbeta (2011) extends the open-economy DSGE literature to LICs, where foreign exchange availability constraints are introduced as an additional friction in the model to capture the conditions faced by domestic firms.[2] Foreign exchange is introduced into the model with the aid of uncovered interest rate parity (UIP) and complete risk-sharing conditions.The results from this study suggest that the introduction of foreign exchange constraints increases the variability in the selected macroeconomic variables, following domestic and external shocks. In addition, the impulse responses are theoretically consistent and match stylised facts, as they suggest that foreign exchange availability plays an important role in the macroeconomic performance of LICs.

In a recent paper, Baldini *et al.* (2015) make use of a DSGE model to analyse the impact of the global financial crisis (GFC) and monetary policy in the Zambian economy. They included a banking sector in their model, which is used to assess the role of monetary policy in the transmission of the financial crisis. Their results suggest that the model broadly matches the path of most of the variables considered. Specifically, they suggest that shocks to the terms of trade, external risk-premium and changes in the bank's appetite for risk, help to explain the evolution of the macroeconomic data in Zambia during the crisis. While this model captures important LICs features, such as the use of monetary aggregate targets for monetary policy formulation, and the dominant role of banks in the financial system; they do not incorporate explicit financial frictions or heterogeneity in the household sector.

1.2 Financial frictions in structural macroeconomic models

Financial sector frictions were initially introduced into the models that are described in Kiyotaki *et al.* (1997) and Bernanke *et al.* (1999). In the first of these papers, Kiyotaki *et al.*

[2]The model is calibrated but not to any specific LIC.

(1997) introduces financial sector frictions by including collateral constraints. This framework assumes that output in the economy is produced by two sectors, whereby one sector is assumed to be more productive than the other. This heterogeneity gives rise to a dual role for durable assets where one form of collateral may be used for borrowing purpose and another for production purpose. Financial sector frictions then result from the differences in the collateral usage by the two sectors. The second approach for incorporating financial frictions, which is followed by Bernanke *et al.* (1999), makes use of the financial accelerator mechanism. This framework assumes that there is a degree of information asymmetry between lenders and entrepreneurs, which results in financial markets inefficiencies. This allows for an increase in credit premiums when the degree of leverage rises. As a result, the supply of credit in the market gets distorted and this amplifies business cycle fluctuations. As noted in Curdia & Woodford (2009), an important aspect of both of these approaches is that they focus on the demand side of credit, while omitting factors that may affect the supply of credit (which was one of the main causes of the GFC).

Most of the post-GFC literature that has incorporated financial sector frictions into structural macroeconomic models may be categorised into one of the following two groups. The first incorporates studies that support the view that the standard Taylor rule should include an interest rate spread (Taylor, 2009; McCulley & Toloui, 2008). According to this view, the intercept term in the Taylor rule should be adjusted downwards by the magnitude of the observed increases in spreads, in a way that would allow for a one-for-one relationship. The second strand of literature suggest that the Taylor rule should be modified to include a measure of credit (Christiano *et al.*, 2010).

Curdia & Woodford (2009) consider the potential role of these two modifications. They introduce features of heterogeneity to separate the participation of agents in the various financial markets, and suggest that an adjustment to the spread marginally improves upon the results provided by the standard Taylor rule, but are less robust when considering adjustments in credit volumes. Furthermore, Curdia & Woodford (2010) extend the new-Keynesian model for the monetary policy transmission mechanism to allow for a spread between the interest rate that is available to savers and borrowers. They suggest that the inclusion of a positive average spread in the model does not substantially alter the effect of policies (relative to the baseline model). It is worth noting that both of these studies are applied to the data of a developed economy and also assume a closed-economy setting. In addition, they make use of calibrated parameter estimates.

Gray *et al.* (2011) use data from the Chilean economy to extend a monetary policy model that is influenced by financial sector vulnerability, after incorporating a distance-to-default (DTD) measure to capture the credit risks in the banking sector. The results from this model suggest that by including this measure in the central banks reaction function the level of volatility in both inflation and output would be reduced.

Steinbach *et al.* (2014), extend the Curdia & Woodford (2010) model and apply it to the South African economy. Unlike the Curdia & Woodford (2010) model which was calibrated to the United States economy, their model parameters are estimated with the aid of Bayesian techniques. In their model, they investigate the benefits of the optimal response to rising credit spreads in a small open-economy that is subjected to a financial disturbance. They find that the optimal reaction coefficient that minimises the central banks loss function is less than unity. When compared to the closed-economy case, they find that the optimal reaction to a change in inflation declines by about 0.2 percentage points. They attribute this to the effect of the exchange rate on the evolution of inflation.[3]

Another novel approach for the introduction of financial sector frictions into a model for African economies is provided in Babilla (2014). They make use of a small-open econ-

[3]The model in this paper is in many ways similar to that of Steinbach *et al.* (2014), however, the small-open economy features in this particular paper are somewhat different.

omy DSGE model to explore the bank lending channel of the monetary policy transmission mechanism in the West African Monetary Union (WAEMU). This characterization of the financial system comprises of an oligopolistic banking sector, and a central bank that follows a fixed exchange rate regime. Similar to some of the findings for advanced and emerging economies, the authors suggest that the financial sector frictions improve upon the model performance when looking to explain the behaviour of real macroeconomic variables. Furthermore, they find that the bank lending channel ensures that the monetary policy transmission in WAEMU is more effective as it strengthens the monetary policy effects on real economic variables.[4]

Then lastly, Ezezew (2015) applies the financial accelerator mechanism of Bernanke *et al.* (1999) to a new-Keynesian DSGE model with a banking sector that is calibrated to the Ethiopian economy. Some of the LIC specific features that the author captures include, the existence of a relatively high investment adjustment cost, a strong fiscal dominance, and underdeveloped financial and/or capital markets in which monetary policy is conducted by targeting monetary aggregates. The results of the impulse response functions that follow a monetary policy shock suggest that credit market imperfections amplify the propagation of monetary policy shocks in Ethiopia. In addition, a comparison of the results from monetary growth and interest rate rules, suggests that the former generates higher volatility in output and inflation. Therefore, this setup is somewhat different to our study, where monetary policy is conducted from the perspective of an inflation-targeting central bank that makes use of an explicit interest rate rule.

2 Data

A summary of the observed variables, data transformations and data sources has been included below. In addition, we also include a summary table for the calibrated parameters, which are discussed in the paper.

Variables	Series	Source
Uganda		
$\triangle ln\,(y_t)$	Domestic real GDP	UBOS
$\triangle ln\,(s_t)$	Terms of trade	BOU
$\triangle ln\,(q_t)$	Nominal exchange rage	BOU
R_t	Domestic policy rate	BOU
π_t	Inflation rate	UBOS
R_t^b	Lending rate	BOU
χ_t	Non-performing loans to total loans	BOU
Foreign economy		
$\triangle ln\,(y_t^*)$	Foreign real GDP	OECD
R_t^*	Foreign policy rate	OECD and IMF
π_t^*	Foreign inflation rate	OECD and IMF

Table 1: Observable variables and data source

[4]The model in Babilla (2014) assumes a fixed exchange rate regime and homogeneous households, which is contrary to what is applied in this paper.

Parameter	Description	Value
β	Discount factor	0.9951
Λ_L	Labour disutility constant	7.5
σ_L	Inverse elasticity of labour supply	2.5
η	Elasticity of substitution between home and imported goods	1.5
α	Import share in the domestic economy	0.29
Heterogeneous households		
π_b	Share of borrowers	0.5
Ω	probability of draw for type change	0.975
σ_s^{-1}	Constant elasticity of savers	1.667
σ_b^{-1}	Constant elasticity of borrowers	3.333
Financial intermediaries		
ω	Steady state gross spread	$1.110^{1/4}$
η_χ	Elasticity of NPL	1.0
χ	Steady state of NPL	0.05
ρ_χ	NPL persistence	0.8

Table 2: Calibrated parameters

3 Log-linearised model

1. Law of one price gap

$$\psi_{F,t} = q_t - (1-\alpha)\, s_t$$

2. Terms of trade

$$s_t - s_{t-1} = \pi_{F,t} - \pi_{H,t}$$

3. Change in the nominal exchange rate

$$\triangle e_t = q_t - q_{t-1} + \pi_t - \pi_t^*$$

4. Uncovered interest rate parity condition

$$E_t q_{t+1} - q_t = (R_t - E_t \pi_{t+1}) - \left(R_t^* - E_t \pi_{t+1}^*\right) + \phi_{uip} a_t + \varepsilon_t^{rp}$$

5. Flow budget constraint

$$c_t + a_t = \beta^{-1} a_{t-1} - \alpha\,(s_t + \psi_{F,t}) + y_t$$

6. Domestic price inflation

$$\pi_{H,t} = \delta_H \pi_{H,t-1} + \theta_H^{-1}\,(1-\theta_H)\,(1-\beta\theta_H)\, mc_t + \beta E_t\,(\pi_{H,t+1} - \delta_H \pi_{H,t})$$

7. Firms marginal cost

$$mc_t = \frac{\sigma}{1-h}\,(c_t - h c_{t-1}) + \varphi y_t + \alpha s_t - (1+\varphi)\, z_t$$

8. Import price inflation

$$\pi_{F,t} = \delta_F \pi_{F,t-1} + \theta_F^{-1} (1-\theta_F)(1-\beta\theta_F)\psi_{F,t} + \beta E_t (\pi_{F,t+1} - \delta_F \pi_{F,t}) + \varepsilon_t^{cp}$$

where, $\varepsilon_{c,p}$ is the cost-push shock that evolves as an AR(1) process.

9. Domestic CPI inflation

$$\pi_t = (1-\alpha)\pi_{H,t} + \alpha \pi_{F,t}$$

10. Consumption Euler Equation

$$c_t^\tau = \frac{1}{1+h_\tau} E_t \left(c_{t+1}^\tau\right) + \frac{h_\tau}{1+h_\tau} c_{t-1}^\tau - \frac{1-h_\tau}{\sigma_\tau (1+h_\tau)} \left(R_t - E_t \pi_{t+1} - \varepsilon_t^c\right)$$

where ε^c is the exogenous demand shock, whose natural logarithm evolves as an AR(1) process, and $\tau \epsilon [b, s]$.

11. Goods market clearing

$$(1-\alpha) c_t = y_t - \alpha\eta (2-\alpha) s_t - \alpha\eta\psi_t - \alpha y_t^*$$

12. Borrowing

$$l_t = \lambda_r (R_{t-1} - \pi_t) + \lambda_y y_t + \lambda_\Omega \Omega + \lambda_\omega \omega + \lambda_b (l_{t-1} + \omega_{t-1})$$

$$+\lambda_\xi \left[\pi_b (1-\pi_b) \eta_t^c - s_\Omega \bar{\sigma}^{-1} (g_t + \chi_t)\right]$$

13. Lending rate:

$$R_t^b = R_t + \omega_t$$

14. Lending spread

$$\omega_t = \omega^{-1} \left[(1+\eta_\chi) \chi l_t^{\eta_\chi}\right] (\chi + \eta_\chi l_t)$$

15. Non-performing loans

$$\chi_t = \rho_\chi \chi_{t-1} - \theta_\chi y_t + \eta_t^\chi$$

16. Monetary policy rule

$$R_t = \rho_R R_{t-1} + (1-\rho_R) [\rho_\pi \pi_t + \rho_y y_t + \rho_e e_t + \rho_\omega \omega] + \varepsilon_t^R$$

17. Government spending

$$g_t = \rho_g g_{t-1} + \eta_t^g$$

18. Foreign Output

$$y_t^* = \rho_{y^*} y_{t-1}^* + \eta_t^{y^*}$$

19. Foreign Inflation

$$\pi_t^* + \rho_{\pi^*}\pi_{t-1}^* + \eta_t^{\pi^*}$$

20. Foreign Interest Rate

$$R^* = \rho_{R^*}R_{t-1}^* + \eta_t^{R*}$$

21. Risk premium shock

$$\varepsilon_t^{rp} = \rho_{\varepsilon_t^{rp}}\varepsilon_{t-1}^{rp} + \eta_t^{rp}$$

22. Cost-push shock

$$\varepsilon_t^{cp} = \rho_{\varepsilon_t^{cp}}\varepsilon_{t-1}^{cp} + \eta_t^{cp}$$

23. Preference shock

$$\varepsilon_t^{c} = \rho_{\varepsilon_t^{c}}\varepsilon_{t-1}^{c} + \eta_t^{c}$$

24. Technology shock

$$z_t = \rho_{z_t}z_{t-1} + \eta_t^{z}$$

25. Interest rate spread shock

$$\varepsilon_t^{\chi} = \rho_{\varepsilon_t^{\chi}}\varepsilon_{t-1}^{\chi} + \eta_t^{\chi}$$

4 Additional results

4.1 Posterior parameter distributions

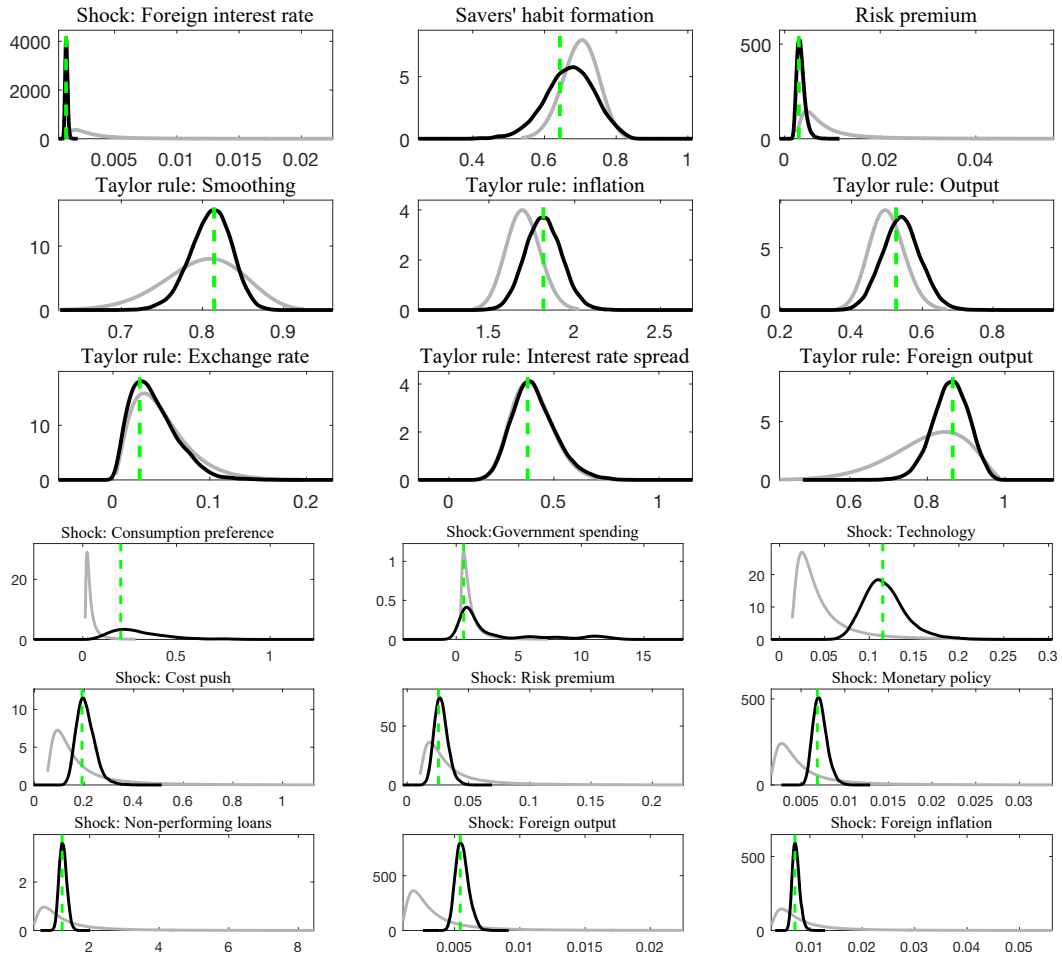


Figure 1: Prior and posterior density plots

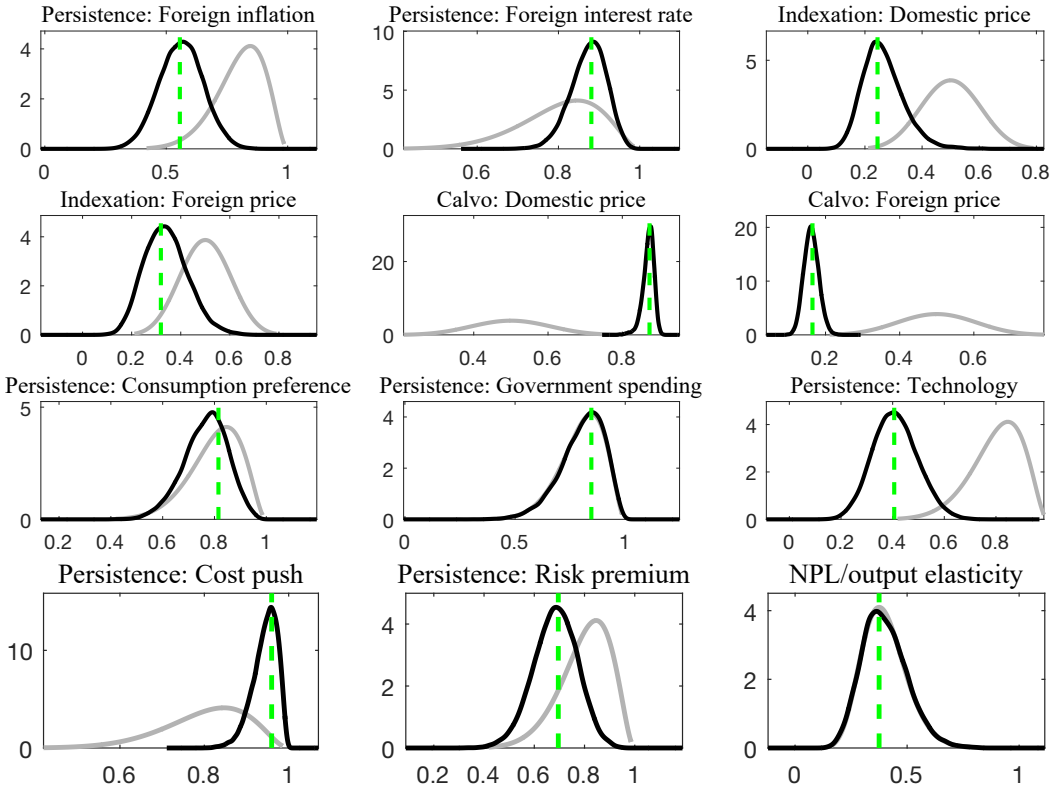


Figure 2: Prior and posterior density plots

4.2 Parameter estimation diagnostics

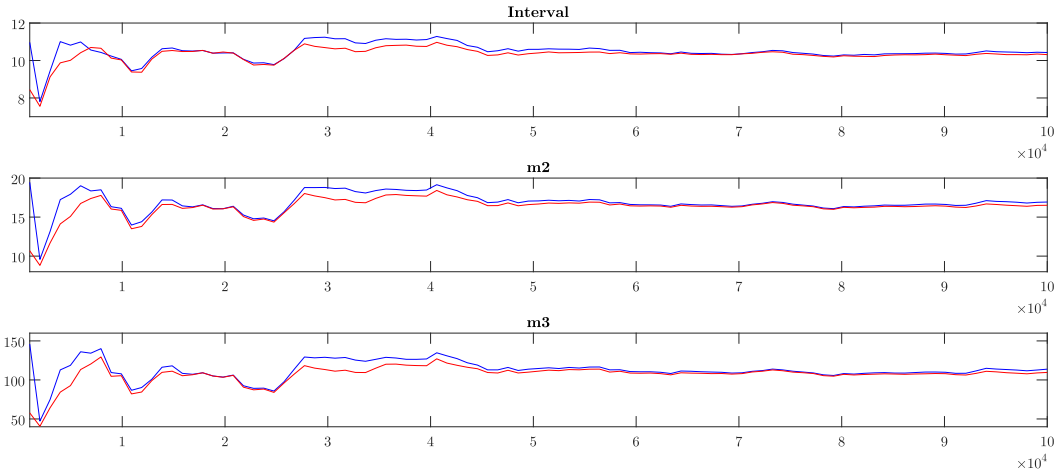
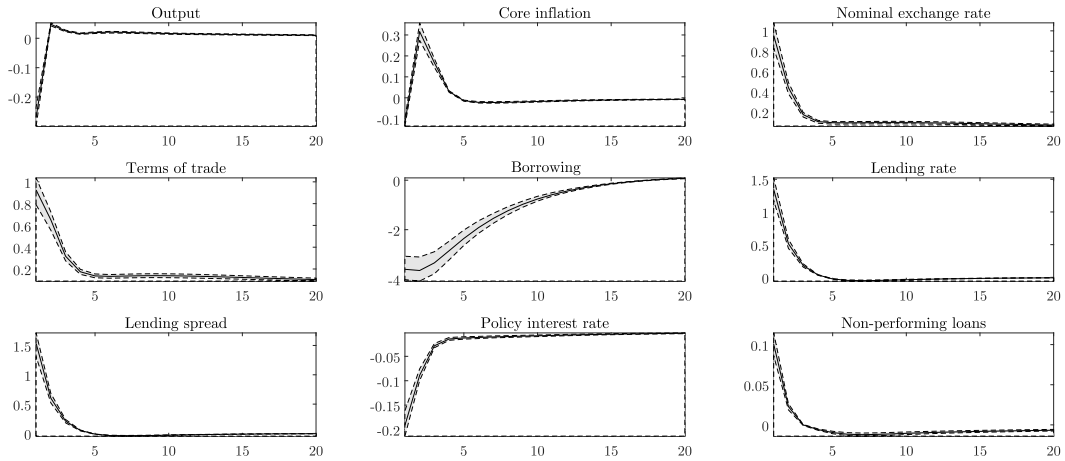


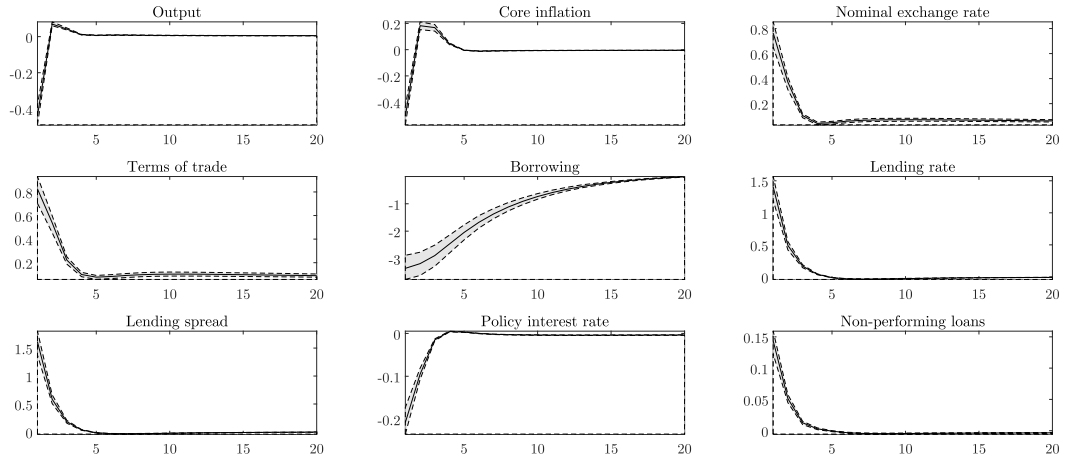
Figure 3: MCMC multivariate diagnostics

4.3 Bayesian impulse response functions

The separate Bayesian impulse response functions for the positive innovation to non-performing loans due to the widening of the lending spread are include below, in Figure 4.



(a) Including Financial Frictions

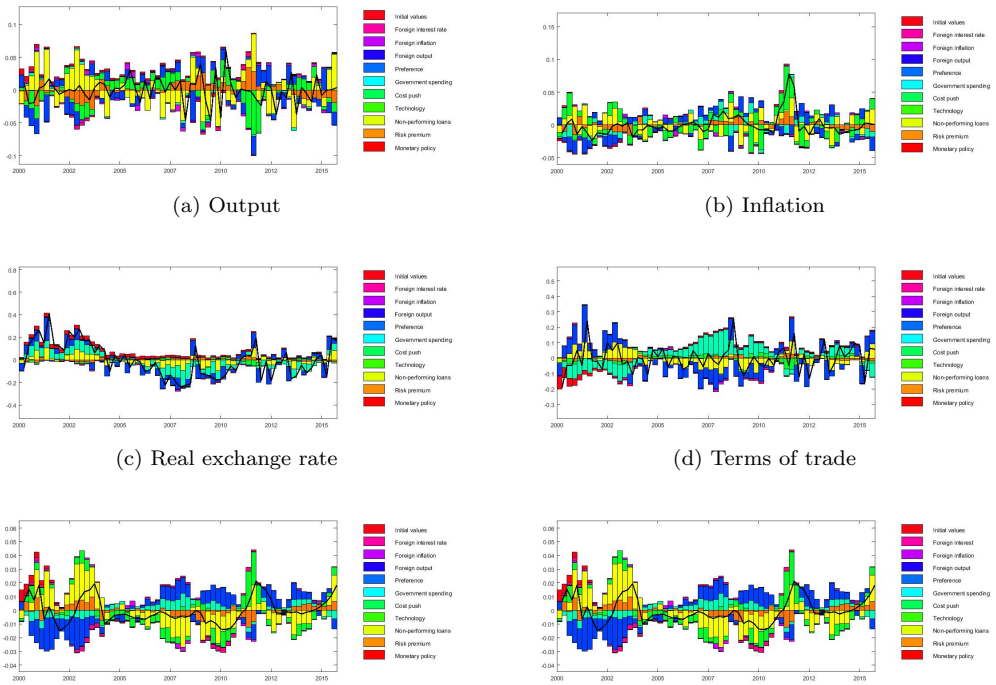


(b) Excluding Financial Frictions

Figure 4: Bayesian impulse response of a monetary policy shock

4.4 Historical decompositions

Figure 5 contains the historical decompositions for measures of output, inflation, real exchange rate, terms of trade, policy rate and lending rate.



(a) Output

(b) Inflation

(c) Real exchange rate

(d) Terms of trade

(e) Policy rate

(f) Lending rate

Figure 5: Historical decompositions

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