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Monetary and Fiscal Policy in Times of Crises: A New Keynesian Perspective in Continuous Time

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Abstract

To analyse the interdependence between monetary and fiscal policy during a financial crisis, we develop an open-economy DSGE model with monetary and fiscal policy as well as financial markets in a continuous-time framework based on stochastic differential equations. Monetary policy is modelled using both a standard and a modified Taylor rule and fiscal policy is modelled as either expansionary or austere. In addition, we differentiate between open economies and monetary union members. We find evidence that the modified Taylor rule notably reduces the likelihood that the financial market crisis affects the real economy. But if we assume that households are averse with respect to outstanding government debt, we find that a combination of expansionary monetary policy and austere fiscal policy provides better stabilisation of both domestic and foreign economies in terms of both output and inflation. In the case of a monetary union, we find that stabilisation of output in the country where the financial shock originates is no longer as easy and, in terms of prices, there is now deflation in the country where the crisis originated and a positive inflation rate in the other country.

JEL Classification Numbers: C63, E44, E47, E52, E62, F41

Keyords: New Keynesian Models, Financial Crisis, Dynamic Stochastic General Equilibrium Models, Continuous Time Model, Fiscal Policy, Monetary Policy

1 Introduction

Advances in globalisation, economic integration, and information technology have had, and continue to have, a profound effect on national economies. First, modern economies are characterised by unprecedented levels of openness with respect to trade and international capital flows. Although this has the benefit of resulting in an efficient allocation of resources, it also makes national economies more vulnerable to shocks originating in other countries. Second, market news, as well as economic policy news, happens more quickly and more frequently than ever before and economic activity is nearly continuous (Bergstrom and Nowman 2007). For example, the share of high-frequency trading grew from less than 10% in the early 2000s to more than 40 – 50% today (Curdia and Woodford 2008). Third, many advanced economies are characterised by a high degree of integration between their financial and real sectors. The interdependency between financial market stability and macroeconomic stability is clearly illustrated by the recent financial crisis. Fourth, following right on the heels of the financial crisis, the European debt crisis makes clear that a monetary union with a common monetary policy but national fiscal policies generates new economic interdependencies and highlights the linkages between monetary and fiscal policies. Given that there has not been a debt crisis outside the European Monetary Union, the question arises as to whether transformation of financial market shocks within a monetary union is different from what occurs in open economies that continue to have autonomy over their interest and exchange rates Finally, the use of stabilisation policy, for instance, to contain an economic crisis, generates spillovers to other countries, a fact often ignored in the economic literature.

Discrete-time frameworks are frequently used in theoretical macroecononomic analyses. However, Yu (2013) provides strong reasons for why continuous-time models should be preferred, as the economy is evolving continuously although time is only measured in discrete steps' (Bartlett 1946). Especially in models containing financial markets, a continuous time perspective may lead to a better approximation of the actual dynamics of economic behaviour. Another important advantage of continuous-time models is that they provide a convenient mathematical framework that allows researchers to price financial assets in an analytically tractable way. Moreover, continuous-time models allow treating stock and flow variables separately, which has the added advantage of making it possible to conduct a mathematical stability analysis (Thygesen 1997), which is often ignored in discrete-time macroeconomic models. Therefore, we rely on previous analyses of Brunnermeier and Sannikov (2012) and Hayo and Niehof (2013a, 2014) and build continuous-time models that allow for greater volatility in financial markets and a thorough modelling of the term structure of interest rates.

In the extant literature on the influence of the financial sector on the macroeconomy, most studies use techniques from either finance (Bianchi, Pantanella, and Pianese 2013) or macroeconomics (Aït-Sahalia, Cacho-Diaz, and Laeven 2010; Bekaert, Hoerova, and Lo Duca 2013; El-Khatib, Hajji, and Al-Refai 2013; Gertler and Karadi 2011; Gertler, Kiyotaki, and Queralto 2012) but a fully-fledged combination of the two approaches has not yet been undertaken. Brunnermeier and Sannikov (2012) provides a detailed literature overview of the latter research strand. In contrast, we synthesise both approaches by combining a macroeconomic dynamic stochastic general equilibrium model (DSGE) with a stochastic volatility model.[1] Our goal is a better understanding of the effects of financial market shocks on the real economy under different types of stabilisation policy. Hence, we analyse combinations of fiscal and monetary policy reactions to domestic and foreign financial market shocks. We develop a New Keynesian DSGE model of two open economies based on stochastic differential equations. Within this framework, we can analyse spillover effects between financial markets as well as contagion from financial markets to the real economy, both within and across economies. We then study various stabilisation policy scenarios. These include (1) a standard open-economy Taylor rule that focuses on stabilising output, inflation, and the exchange rate; (2) a modified Taylor rule that additionally takes into account financial market stabilisation; (3) an expansionary expenditure-based fiscal policy; and (4) an austere fiscal policy. In addition, we differentiate between market participants who are neutral with respect to high government debt and those who are debt averse.

We argue that academic research can aid policymakers by analysing the extent to which financial markets should be taken into consideration when designing stabilisation policy. In our approach, we explore the consequences of taking seriously the interaction between financial markets, stabilisation policy, and the real economy in a two-country, open-economy framework based on a fully dynamic theoretical model.

Our paper makes several contributions to the literature. First, we combine and extend the models of Smets and Wouters (2002) and Bekaert, Cho, and Moreno (2010) and compute a New Keynesian model with fiscal and monetary policy, including a financial market sector. Derivation of the monetary policy rule is in line with Ball (1998); specifically, we employ the nominal interest rate and the exchange rate as monetary policy targets in an open economy. Moreover, we follow Bekaert, Cho, and Moreno (2010) and Brunnermeier and Sannikov (2012) and model a financial market sector, which allows for the consistent inclusion of financial markets in the policy rule. Faia and Monacelli (2007) provide empirical

[1] Stochastic volatility models are a class of models in which the variance of a stochastic process is itself randomly distributed. They are widely used in finance. A famous representative of these models is the Heston model, which is used to describe asset evolution and which overcomes the shortcomings of the standard Black Scholes model

evidence that financial market variables in the Taylor rule have a significant impact on actual decision-making processes. In a similar vein, Belke and Klose (2010) estimate Taylor rules for the European Central Bank (ECB) and the Federal Reserve (Fed) and include asset prices as additional monetary policy targets. For our fiscal rules, we distinguish between an expansionary expenditure policy and fiscal austerity, which, to some extent, reflects current discussion in Europe, where southern European countries as well as France favour the former, and Germany and the United Kingdom prefer the latter.

In that financial markets are characterised by a substantial degree of simultaneity, our second contribution is to incorporate several interdependent financial markets in our model, i.e., markets for bonds and stocks. Empirical evidence for financial market simultaneity is presented by Bjornland and Leitemo (2009), Rigobon (2003), and Rigobon and Sack (2003)[2]. In light of this work, we include both markets in the modified monetary policy rule, which implies a stronger monetary policy response in the event of a general financial market crisis than would be the case if only one financial market showed crisis symptoms.Moreover, we study scenarios assuming either that households, who also act as financial market participants in our model, do not care about the number of bonds issued by the government or have a negative reaction to debt.

As our third contribution, we combine finance research with macroeconomic theory by employing a continuous-time framework as introduced by Hayo and Niehof (2013a). This allows the use of advanced techniques from the finance literature, such as jump-diffusion processes, to model financial markets. Technically, we transform the New Keynesian model into stochastic differential equations and compute solutions by using advanced numerical algorithms. We believe that forging this link between methods from economics, finance, and mathematics is a unique and valuable contribution.

The remainder of the paper is structured as follows. Section 2 derives the theoretical model. Section 3 shows how the model is shifted to a continuous-time framework. Section 4 containts the model calibration. Section 5 studies the effects of financial market turmoil using dynamic simulations. Section 6 concludes.

2 The Model

To study the effects of financial crisis under different types of stabilisation policy, we employ the extended New Keynesian short-term model developed by (among others) Ball (1998) and Clarida, Gali, and Gertler (1999, 2000, 2002). To account for globalisation, we extend the analysis to a two-country, open-economy world. Fiscal policy is modelled by debt-financed changes in government expenditure;

[2] A theoretical discussion is provided by Hildebrand (2006).

monetary policy by changes in the nominal interest rate. As our chief interest is short-term reactions in times of crises, we neglect tax effects and concentrate on government expenditure. However, we account for the financing side of expenditure policy by including the impact of higher public debt on the bond-pricing equation. Our model combines many features from the models of Ball (1998), Lindé, Nessén, and Söderström (2009), and Smets and Wouters (2002, 2007).

2.1 The Demand Side

Domestic households consume bundles of both domestic and imported goods. All goods have a a domestic and foreign currency price index P_t^d and P_t^f respectively. For the sake of simplicity, we assume perfect pass-through (in contrast to Lindé, Nessén, and Söderström (2009)); that is, domestic and foreign prices coincide. and argue that domestic and foreign prices coincide. This implies that the the exchange rate S_t is the ratio between domestic and foreign aggregate price levels

$$S_t = \frac{P_t^f}{P_t^d}. \tag{1}$$

Households

Households are assumed to exist in perpetuity and they consume Dixit-Stiglitz bundles of domestic and imported goods C_t^d and C_t^m (Dixit and Stiglitz 1977). The bundles of domestic and imported goods are defined by

$$C_t^d = \left[\int_0^1 \left(C_t^d(i)\right)^{\frac{\eta_d^c-1}{\eta_d^c}} di\right]^{\frac{\eta_d^c}{\eta_d^c-1}} \tag{2}$$

$$C_t^f = \left[\int_0^1 \left(C_t^f(i)\right)^{\frac{\eta_f^c-1}{\eta_f^c}} di\right]^{\frac{\eta_f^c}{\eta_f^c-1}} \tag{3}$$

where η_d and η_f are the elasticities of substitution across goods, assumed to be greater than one to ensure that firm i's mark-ups are positive in the steady state. In total, domestic and imported goods form a composite index such that

$$C_t = \left[(1-\omega_f)^{\frac{1}{\eta_c}}(C_t^d)^{\frac{\eta_c-1}{\eta_c}} + \omega_f^{\frac{\eta_c-1}{\eta_c}} S_t(C_t^f)^{\frac{\eta_c-1}{\eta_c}}\right]^{\frac{\eta_c}{\eta_c-1}} \tag{4}$$

where ω_f is the share of imports in consumption, and η_c is the elasticity of substitution across the two categories of goods. Accordingly, the aggregate consumer price index (CPI) is given by

$$P_t = \left[(1-\omega_f)(P_t^d)^{1-\eta_c} + \omega_f (P_t^f)^{1-\eta_c}\right]^{\frac{1}{1-\eta}} \tag{5}$$

Similarly, households invest either domestically or abroad. The share of exported investments of the domestic country is denoted by ω_{f_2} and the nominal exchange rate by $S_t(.)$. Therefore

$$I_t^d = \left[\int_0^1 \left(I_t^d(i)\right)^{\frac{\eta_d^i - 1}{\eta_d^i}} di\right]^{\frac{\eta_d^i}{\eta_d^i - 1}} \tag{6}$$

$$I_t^f = \left[\int_0^1 \left(I_t^f(i)\right)^{\frac{\eta_f^i - 1}{\eta_f^i}} di\right]^{\frac{\eta_f^i}{\eta_f^i - 1}} \tag{7}$$

$$I_t = \left[(1-\omega_{f_2})(I_t^d) + \omega_{f_2} S_t(I_t^f)\right] \tag{8}$$

Households decide on today's consumption by taking into account past aggregate consumption. Household j's utility depends positively on the fraction of its own consumption C_t^j in proportion to lagged aggregate consumption C_t and negatively on labour N_t^j. Furthermore, a household can purchase government securities $V_{t,t+m}$. In total, household j maximises its utility by choosing the optimal combination of consumption and labour supply.

$$u(C_t^j, N_t^j) = \left[\frac{(C_t^j - hC_{t-1}^j)^{1-\sigma}}{1-\sigma} - \frac{\epsilon_L}{1+\sigma_L}(N_t^j)^{1+\sigma_L}\right] \tag{9}$$

where $0 \leq h \leq 1$ is the component of habit formation as proposed in Abel (1990) and Fuhrer (2000), and $\sigma > 0$ is related to the intertemporal elasticity of substitution. Wages are set subsequently. The household's objective is to maximise expected discounted life-time utility

$$\max E_t \sum_{k=0}^{\infty} \beta^k u(C_{t+k}^j, N_{t+k}^j) \tag{10}$$

subject to the following budget constraint

$$\frac{W_t^i}{P_t}N_t^j + R_t^k Z_t^j K_{t-1}^j - a(Z_t^j)K_{t-1}^j - \frac{B_t^j R_t^{-1} - B_{t-1}^j}{P_t} - \frac{(V_t^E Equ_t^i - V_{t-1}^E Equ_{t-1}^i)}{P_t}$$
$$-\frac{S_t(B_t^j)^*(R_t^*)^{-1} - S_t(B_{t-1}^j)^*}{\Phi_2(S_t, B_t, P_t)P_t} - C_t - I_t^j - A_t^j - T_t + \frac{Div_t}{P_t}Equ_{t-1}^j$$
$$-\frac{(S_t(V_t^E)^*(Equ_t^j)^* - S_t(V_{t-1}^E)^*(Equ_{t-1}^j)^*)}{\Phi_2(S_t, V_t, P_t)P_t} - \sum_{j=0}^{J}\left(\frac{V_{t,t+m}^B}{P_t}B_{t,j}^j - \frac{V_{t-1,t+m-1}^B}{P_t}B_{t-1,t+m}^j\right)$$
$$-\sum_{j=0}^{J}\left(S_t\frac{(V_{t,t+m}^B)^*}{\Phi_2(S_t, V_t, P_t)P_t}(B_{t,t+m}^j)^* - S_t\frac{(V_{t,t+m-1}^B)^*}{\Phi_2(S_t, V_t, P_t)P_t}(B_{t-1,t+m}^j)^*\right)$$
$$+\frac{S_t Div_t^*}{P_t}(\Phi_2(S_t, Equ_t^j, P_t)Equ_{t-1}^j)^* = 0 \qquad (11)$$

where R_t is the domestic interest rate, R_t^f is the foreign interest rate, B_t and B_t^f are holdings of nominal bonds, X_t^j is the household's share of aggregate real profits in the domestic economy, $Equi_t$ are firm's equities and T_t are lump-sum taxes. $A_t \equiv \frac{S_t B_t^f}{P_t}$ is the net foreign asset position of the domestic economy. As in Benigno (2009), the term $\Phi_2(.)$ captures the costs for domestic households of participating in international financial markets. These costs are assumed to follow $\Phi_2(W_t) = e^{-\phi W_t}$ where $\phi > 0$. Thus, if the domestic economy is a net borrower, domestic households are charged a premium on the foreign interest rate.

Total income evolves as

$$Y_t^j = (W_t^j N_t^j + A_t^j) + (R^k Z_t^j K_{t-1}^j - \Psi(Z_t^j)K_{t-1}^j) + Div_t^j$$

where $W_t^j N_t^j + A_t^j$ is labour income plus securities, $r^k z_t^j K_{t-1}^j - \Psi(Z_t^j)K_{t-1}^j$ is the return on capital minus costs and Div_t^j are dividends. We assume $\Psi(1) = 0$ reflects the situation that the capital utilisation rate Z_t is one in the steady state.

Consumption

The maximisation problem described previously yields the consumption Euler equation (where λ_t is the Lagrangian parameter)

$$E_t\left[\beta\frac{\lambda_{t+1}}{\lambda_t}\left(h\frac{(C_{t+1}^j - hC_t^j)^{-\sigma}}{(C_t^j - hC_{t-1}^j)^{-\sigma}}\right)\frac{(1+R_t)P_t}{P_{t+1}}\right] = 1 \qquad (12)$$

Furthermore, this implies the uncovered interest rate parity (UIP) condition

$$1 = E_t \frac{S_{t+1}}{S_t} \Phi_2(W_t) \tag{13}$$

In the case where the domestic economy is a net borrower, $\Phi_2(W_t)$ implies that the domestic interest rate is higher than the foreign interest rate. Therefore, movements in an economy's asset position imply changes in the exchange rate.

Domestic and imported goods are allocated optimally

$$C_t^d = (1-\omega_x) \left[\frac{P_t^d}{P_t} \right]^{-\eta_c} C_t$$
$$C_t^f = S_t \omega_f \left[\frac{P_t^f}{P_t} \right]^{-\eta_c} C_t$$

Households own the capital stock, which they lend to producers of (intermediate) goods at a rental rate R_t^k. Households can either raise additional capital I_t or change the utilisation rate of existing capital Z_t. As households are restricted by their intertemporal budget constraint, both actions are costly in terms of forgone consumption. Furthermore, households choose investment, and utilisation rates so as to maximise their intertemporal objective function, subject to the intertemporal budget constraint and the capital accumulation equation, which is given by

$$K_t = K_{t-1}(1-\delta) + \left(1 - V\left(\frac{I_t}{I_{t-1}}\right)\right) I_t \tag{14}$$

where δ is the depreciation rate, and $V(.)$ is an adjustment cost function. We assume that V is zero in the steady state and that the first derivative is zero around the steady state too, so that the adjustment costs only depend on the second-order derivative: $V'(1) = V(1) = 0$ and $V''(1) > 0$

To specifically differentiate between real capital and financial assets, we exclude a firm's value, denoted in assets, from our definition of capital and incorporate the assets into a separate financial sector (see below). However, these assets are part of the aggregate demand.

2.2 The Supply Side

Firms

Both domestic and foreign firms are subject to monopolistic competition. However, imported goods are traded in a different market than domestic products and are imported by domestic firms. The final good is produced using the following production function

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}} \tag{15}$$

Firms profits are immediately paid out as dividends

$$\frac{Equ^j_{t-1} Div^i_t}{P_t} = \frac{P^i_t}{P_t} Y^j_t - \frac{W_t}{P_t} N^i_t - R^k_t \tilde{K}^i_t \tag{16}$$

The intermediate good is produced under monopolistic competition using the Cobb-Douglas production function

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

Prices are set according to the Calvo pricing mechanism (Calvo 1983). A fraction θ of firms exhibit 'rule of thumb' price-setting behaviour, which is modelled as

$$P_t(i) = P_{t-1}(i). \tag{17}$$

The other fraction of the firms $1 - \theta$ optimise their prices in consideration of their discounted profits

$$E_t \sum_{l=0}^{\infty} \beta^l \theta^l v_{t+l} (P_{t+l}(i) Y_{t+l}(i) - W_{t+l} N_{t+l}(i) - R^k_{t+l} K_{t+l}(i)) \tag{18}$$

where v_t is the multiplier of the household budget constraint in the Lagrangian representation. Firms maximise their profits subject to Calvo pricing, their production technology, and the demand for good $Y_t(j)$

$$Y_t(j) = \left(\frac{P_t}{P_t(j)} \right)^{\epsilon} Y_t \tag{19}$$

2.3 Wage Setting

Each household sells his labour due to the production function

$$N_t = \left(\int_0^1 \left(N^j_t \right)^{\frac{1}{\gamma_n}} \right)^{\gamma_n} \tag{20}$$

where γ_n is the wage mark-up and $1 \leq \gamma_n < \infty$. Similarly to the firm's problem households face a random probability $1-\theta_h$ of changing nominal wage. The j^{th} household reoptimised wage is $\overline{W_t^j}$, whereas the unchanged wage is given by $W_{t+1}^j = W_t^j \pi_t^{\iota_h} \pi^{1-\iota_h} \mu_z$, where μ_z is the technological growth rate $\frac{z_{t+1}}{z_t}$. Households then maximise their optimal wage subject to the demand for labour and the budget constraint.

$$N_{t+s}^i = \left(\frac{\overline{W_t^i} \prod_{l=1}^{s} \left(\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h} \mu_z \right)}{W_{t+s}} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_{t+s} \tag{21}$$

Wages therefore evolve as

$$W_t = \left[\theta_h \left(W_{t-1} \pi_{t-1}^{\iota_h} \pi^{1-\iota_h} \mu_z \right) \right)^{\frac{1}{1-\gamma_n}} + (1-\theta_h) \overline{W_t}^{\frac{1}{1-\gamma_n}} \right]^{1-\gamma_n} \tag{22}$$

2.4 The Exchange Rate and the Uncovered Interest Rate Parity

In line with Ball (1998), Lindé, Nessén, and Söderström (2009) and Batini and Nelson (2000), the exchange rate is a function of the nominal interest rate and inflation. The uncovered interest rate (UIP) condition states that

$$\frac{1+R_t}{1+R_t^f} = E_t \left[\frac{S_{t+1}}{S_t} \right] \Phi_2(W_t) \tag{23}$$

To explicitly analyse exchange rate bubbles, we follow Batini and Nelson (ibid.) and add another shock variable φ to reflect the potential burst of a bubble. A detailed description of the computation, length and values of the additional variable is provided by Batini and Nelson (ibid.).

$$\frac{1+R_t}{1+R_t^f} = E_t \left[\frac{S_{t+1}}{S_t} \right] \Phi_2(W_t) \varphi_t \tag{24}$$

Tobin's Q is given by $Q_t^i = \frac{\varphi_t^i}{\lambda_t^i}$ in

$$Q_t^i = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \left(R_t^k Z_t^i - a(Z_t^i) \right) + Q_{t+1}^i (1-\delta) \right) \tag{25}$$

2.5 Financial Sector

There are various ways of integrating financial variables into macroeconomic models. Gertler, Kiyotaki, and Queralto (2012) apply a micro-based model and incorporate a banking sector and financial frictions. However, we are focussing on asset market spillovers to the real economy and are thus less interested in analysing financial intermediaries. Brunnermeier and Sannikov (2012) construct a macroeconomic model with an emphasis on variations in risk preferences and the degree of information across households and financial experts. However, since the authors do not model real economic effects, their framework is not well-suited to our focus on financial and macroeconomic spillovers under different stabilisation policies. Instead, we extend the NK framework of Paoli, Scott, and Weeken (2010) by defining different term structures and rigidities and moving the analysis to an open-economy setting. We also follow Bekaert, Cho, and Moreno (2010) and Paoli, Scott, and Weeken (2010) and model financial market returns first in discrete time and then switch to continuous time. In the absence of frictions, the model exhibits the well-known equity and term premia puzzle. As demonstrated by Campbell and Cochrane (1999) in the context of endowment economies, consumption habits can be used to solve this puzzle. By switching off capital adjustment costs, we confirm the results of Boldrin, Christiano, and Fisher (2001) that, in a production economy, consumption habits by themselves do not suffice to remove the puzzles. In fact, consumer-investors can adjust their capital stock and alter production plans.

The presence of state-contingent claims implies that we can price all financial assets in the economy based on no-arbitrage arguments. Hence, the price of a zero-coupon bond is given by the first-order conditions (FOCs). We follow Binsbergen et al. (2012) and Paoli, Scott, and Weeken (2010) and model the term structure recursively. The one-period nominal bonds deriving the standard relationship are given by

$$\frac{1}{R_t} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \varphi_t^B \tag{26}$$

$$\frac{1}{R_t^*} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \frac{S_{t+1}}{S_t} \right] \varphi_t^{B^*} \tag{27}$$

where φ_t^B is a shock to a one-period nominal bond and λ_t is the Lagrangian from the household's FOCs

$$\lambda_t = \epsilon_t^U (C_t^i - hCt - 1^i)^{-\sigma_c} - \beta h E_t[\epsilon_{t+1}^U (C_{t+1}^i - hC_t^i)^{-\sigma_c}]$$

A real zero-coupon bond returns one unit of consumption at maturity. For $m = 1$ it is

$$-\lambda_t \frac{V^B_{t,1}}{P_t} = E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,0}}{P_{t+1}} \right] \varphi^V_t \tag{28}$$

$$\Leftrightarrow V^B_{t,1} = E_t \left[-\beta V_{t+1,0} \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right]]\varphi^V_t \tag{29}$$

$V_{t+1,1}$ is the price of a bond of original maturity $m = 2$ with one period left. Assuming no arbitrage, this price equals the price of a $j = 1$ bond issued next period. Bond prices can thus be defined recursively (using $SDF_t = \beta \frac{\lambda_{t+1}}{\lambda_t}$)

$$V^B_{t,t+m} = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} V^B_{t+1,t+m-1} \frac{P_t}{P_{t+1}} \right]]\varphi^V_t \tag{30}$$

$$= E_t(SDF_{t+1}\pi_{t+1}V^B_{t+1,t+m-1})]\varphi^V_t \tag{31}$$

Assuming $V_{t,1} = 1$ in terms of one unit of consumption, we apply recursion and obtain

$$V^B_{t,t+m} = E_t((SDF_{t+1}\pi_{t+1})^m) \tag{32}$$

Real yields are then given by

$$R^B_{t+1,t+m} = (V^B_{t,t+m})^{-\frac{1}{m}} \tag{33}$$

Similarly, it is

$$V^B_{t,t+m}{}^* = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} (V^B_{t+1,t+m-1})^* \frac{P_t}{P_{t+1}} \right]]\varphi^{V*}_t \tag{34}$$

$$R^B_{t+1,t+m}{}^* = ((V^B_{t,t+m})^*)^{-\frac{1}{m}} \tag{35}$$

Regarding the assets, we derive

$$1 = E_t \left[-\beta \frac{P_t}{P_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} \frac{V^E_t + Div_{t+1}}{V^E_t} \right]$$

with real return

$$R^E_{t+1} = \frac{V^E_t + Div_t}{V^E_t} \frac{P_t}{P_{t+1}}$$

Andreasen (2012), Andreasen (2010), and Wu (2006) show that this specification is equivalent to standard finance models, such as Dai and Singleton (2000), Duffie and Kan (1996), and Duffie, Pan, and Singleton (2000).

2.6 Fiscal and Monetary Policy Authorities

We take a look at different types of stabilisation policies. Regarding fiscal policy, the tax rule is derived from the government's budget constraint (Kirsanova and Wren-Lewis 2012; Schmitt-Grohé and Uribe 2007). Each period, the government collects tax revenues T_t and issues m-period nominal bonds $V^B_{t,t+m}$ to finance its interest payments and expenditure including government consumption G_t. The fiscal authority has two objectives: output stabilisation and debt stabilisation. We follow Çebi (2012), Favero and Monacelli (2005), Kirsanova and Wren-Lewis (2012), and Muscatelli, Tirelli, and Trecroci (2004) and employ a smoothed fiscal government spending rule based on the evolution of debt

$$G_t = G_{t-1}^{\varsigma_G}(Y_{t-1}^{\varsigma_Y} V_{t,t+m}^{\varsigma_b} \epsilon_t^G)^{1-\varsigma_G} \tag{36}$$

$$T_t = T_{t-1}^{\varsigma_T}(Y_{t-1}^{\varsigma_{Y_T}} V_{t,t+m}^{\varsigma_{b_T}} \epsilon_t^T)^{1-\varsigma_T} \tag{37}$$

where ς_G and ς_T are the degree of fiscal smoothing, and ς_Y, ς_{Y_T}, ς_b, ς_{b_z} specify the government's reaction to last period's income and bonds. ϵ_t^G and ϵ_t^T are hocks that cause actual government expenditure and revenue, respectively, to deviate from the plans. Different degrees of fiscal smoothing lead to different changes in the responsiveness of spending and tax with respect to debt income, which can be interpreted as an output gap. For example, an increase in the degree of fiscal smoothing results in a declining sensitivity of government spending and tax to income and debt. Both fiscal rules are ad-hoc rules and reflect our assumption that governments have no borrowing constraints in the short run. This is in line with Leith and Von Thadden (2008), who develop a tractable NK model where government debt is not subject to a budget constraint.

For the monetary policy rule, we follow Ball (1998), Justiniano, Primiceri, and Tambalotti (2010), Leitemo and Soderstrom (2005), Lubik and Schorfheide (2007), Lubik and Smets (2005), Smets and Wouters (2007), Svensson (2000), and Taylor (1993) and employ an open-economy Taylor rule taking into account output, inflation, and the exchange rate. In an extension of this standard Taylor rule, we construct a second monetary policy reaction function that also takes into account financial market developments.

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R_t}\right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi_{t-1}}\right)^{\psi_p i} \left(\frac{S_t}{S_{t-1}}\right)^{\psi_S} \left(\frac{R^E_t}{R^E_{t-1}}\right)^{\psi_E}\right]^{1-\rho_{E^*}} \eta_{mp,t} \tag{38}$$

represents the financial sector, which is comprised of bond and stock markets, and $\eta_{mp,t}$ is a monetary policy shock.

$$log\eta_{mp,t} = \rho_{mp,t} \; \log(\eta_{mp,t-1}) + \epsilon_{mp,t} \tag{39}$$

where $\epsilon_{mp,t}$ is $i.i.d.$ $N(0, \sigma^2_{mp})$. Thus, our modified Taylor rule accounts for domestic and foreign output, the exchange rate, inflation, and the financial market. The rule facilitates an analysis of spillover effects between financial markets and monetary policy as well as between foreign and domestic policy. Moreover, by including the financial sector, which consists of various markets, we account for a direct relationship between monetary policy and financial markets. Rigobon (2003) and Rigobon and Sack (2003) show empirically that including this aspect is useful.

2.7 Market Clearing

In the specific analysis of financial markets, we treat equities and bonds as financial instruments and assign them to a new sector, the financial market. A shortcoming of this way of modelling a financial sector is that it does not directly contribute to the economy's value-added as it only addresses allocational aspects. However, as is common in the finance literature, we model financial instruments stochastically. For simplicity reasons, we focus on the allocational purpose of financial markets. However, in principle, the introduction of a banking sector or entrepreneurs would easily allow for an extension of the financial sector's role in the economy.

In our simple framework, markets clear as

$$Y_t = C^d_t + C^f_t + I^d_t + I^f_t + FM^d_t + FM^f_t + a(Z_t)K_{t-1} + G_t \tag{40}$$

where FM_t is the financial sector.

2.8 The Special Case of a Monetary Union

As we are also interested in analysing the case of a monetary union, we model a monetary union characterised by a constant exchange rate and the same interest rate resulting from the common monetary policy rule. As we assume a perfect pass-through, the terms of trade equal the exchange rate, which is one, and this implies that purchasing power parity holds. To reflect the supranational central bank's position, we use the average rate of inflation and the average output gap of both economies in the Taylor rule. A full model derivation is provided by Fahr and Smets (2010).

3 Continuous-Time Framework

Setting up the model equations for equities and bonds requires linearisation at least up to the second order. Andreasen (2012) even propose a third order to capture the time-varying effects of the term structure. But standard linearisation would yield risk-neutral market participants, leading to similar prices for all assets. To overcome this dilemma, we follow Paoli, Scott, and Weeken (2010) and Wu (2006) by assuming $ln(SDF_{t+1}\frac{P_t}{P_{t+1}}) = \alpha_0 + \alpha_1 s_t + \alpha_2 \epsilon_{t+1}$, where s_t are the state variables.

However, even this degree of linearisation does not result in realistic modelling of the underlying financial instruments. In Hayo and Niehof (2013a), we propose solving the nonlinear DSGE model by switching to continuous time. We transform the difference equations discussed so far, such as the consumption equation, into a system of continuous-time equations. This transformation permits a more sophisticated inclusion of financial instruments without loss of information due to approximation. Moreover, we can model asset prices as jump-diffusion processes, which reflect market volatility much more realistically than do methods used in similar research. The specification of the financial sector reflects our assumption of simultaneously interacting stock and bond markets. Following Heston (1993), we model the stock market as a stochastic volatility model. This is an extension of Black and Scholes (1973) and takes into account a non-lognormal distribution of asset returns, leverage effect, and mean-reverting volatility, while remaining analytically tractable. To reflect highly interacting markets, we include the foreign stock markets, bond prices, exchange rates, output, and interest rates in the drift term. For example, including the output gap in the stock market is in line with Cooper and Priestley (2009) and Vivian and Wohar (2013); a general approach to incorporating macroeconomic factors in stock returns is developed by Pesaran and Timmermann (1995).

In line with Bayer, Ellickson, and Ellickson (2010), house prices are modelled as stochastic differential equations taking into account local risk, national risk, and idiosyncratic risk. This allows modelling house prices in an asset pricing environment. As before, we account for macroeconomic variables in the drift term. Consistent with the empirical findings of Adams and Füss (2010), Agnello and Schuknecht (2011), Capozza et al. (2002), and Hirata et al. (2012), we include the real interest rate, the output gap, and the derived asset from the stock market in the drift term to account for interconnectedness. To analyse call and put prices, we apply the extended Black-Scholes formula as in Kou (2002).

$$
\begin{aligned}
dS &= (S_t((r-\lambda\mu) + \rho_b b_t + \rho_b^* b_t^* + \rho_s^* S_t^* + \rho_i i_t + \rho_y y_t + \rho_e e_t + \rho_p i\pi_t)dt \\
&\quad + \sqrt{V_t}dW_S(t) + \sum_{i=1}^{dN_t} J(Q_i) && (41) \\
dV_t &= \kappa(\theta - V_t)dt + \sigma\sqrt{V_t}dW_V(t) \\
db_t &= (\gamma_b b_t + \gamma_S S_t + \gamma_s^* S_t^* + \gamma_b^* h_t^* + \gamma_y y_t - \gamma_i(i_t - \pi_t))dt \\
&\quad + \sigma_1 dW_b^1(t) + \sigma_2 dW_b^2(t) + \sigma_3 dW_b^3(t) && (42)
\end{aligned}
$$

where $J(Q)$ is the Poisson jump-amplitude, Q is an underlying Poisson amplitude mark process ($Q = \ln(J(Q)+1)$), and $N(t)$ is the standard Poisson jump counting process with jump density λ and $E(dN(t)) = \lambda dt = Var(dN(t))$. dW_s and dW_v denote Brownian motions. β is the long-term mean level.

Furthermore, the above model can be written as

$$dK_t = (I_t - \delta K_t)dt + \left(1 + V\left(\frac{dI_t}{I_t dt}\right)\right)dI_t \tag{43}$$

$$dY_t = dC_t + dI_t + dFM_t + dG_t + a(dZ_t)K_t dt \tag{44}$$

$$hdC = \frac{1}{\beta}\frac{\Gamma dt}{d\Gamma}\frac{dP^C}{((1+r)P)dt}\frac{/C - h\dot{C})dt}{hCdt} \tag{45}$$

Using calculus, each difference equation can be transformed in a similar way. Further details about the derivation of the model can be found in Hayo and Niehof (2013b).

We analyse the model's stability with Lyapunov techniques (Khasminskii 2012). We apply the following Lyapunov function

$$V(x) = \|x\|_2^2 = \left(\sqrt{\sum |x_i|^2}\right)^2 \tag{46}$$

where $\|\|_2$ denotes the Euclidean norm. Since the zero solution is only locally stable, there is no global stable rest point only parameter-dependent partial solutions. However, all sets of applied parameters provide stable zero-solutions in the Lyapunov sense.

4 Model Calibration

We calibrate the parameters of our system of equations using values from the literature. We use parameters similar to those employed in theoretical and empirical analyses by Fernández-Villaverde (2010), Justiniano, Primiceri, and Tambalotti (2010), and Smets and Wouters (2007). For the monetary and fiscal policy parameters we use parameters similar to those of Adolfson et al. (2011) and Lindé (2005). Regarding the financial market, we use previously estimated parameters from Hayo and Niehof (2013a, 2014). Table 1 in the Appendix lists the various parameters and their corresponding values.

The calibration of the household and firm side is standard. Elasticities of substitution regarding investments and consumption (η_d^c, η_d^i, η_f^c, η_f^i) vary between 1.30 and 1.50, whereas the general elasticity of substitution between domestic and foreign consumption is 2.00, reflecting a bias toward domestic products (Fernández-Villaverde 2010). The share of imports in consumption is 0.75. The household's utility function is similarly to the one employed by Smets and Wouters (2007). The elasticity for substitution of consumption σ is 1.20, the elasticity of substitution for labour σ_l is 1.25. On the supply side, we assume standard Calvo-pricing parameters as in Smets and Wouters (ibid.). The Calvo parameters for prices θ and wages θ_h are 0.75 and 0.66, respectively.

We use monetary and fiscal policy parameters similar to those ofAdolfson et al. (2011) and Lindé (2005). The inflation parameter ψ_π is 1.20, reflecting our assumption that central bank's chief goal isinflation stability. Government expenditures mainly depend on the output gap ($\varphi_y = 0.80$). Parameters reflecting our assumption of international interaction are taken from empirical results in Hayo and Niehof (2014). For example, the weight of financial markets in the monetary policy reaction function is estimated to be 0.30. For the financial market parameters in the bond and stock market equations, we rely on Hayo and Niehof (ibid.). For example, the stock markets is strongly affected by previous realisations (0.80) and weakly affected by foreign stock markets (0.10). Further details are given in the cited literature.

To derive the dynamic adjustment, we take the mean of 1,000,000 simulations with 0.01 time steps. We use a normalised Euler-Maruyama scheme to simulate the trajectories of the stochastic differential equations. We normalise our time frame to one, interpreting it as five years in the economy.

5 Simulation Results

We differentiate between the 16 cases: open economy vs. monetary union, standard vs. modified Taylor rule, spending-oriented vs. austere fiscal policy, and neutral vs. debt- averse market participants. We compare these cases based on impulse responses (see Figures 1 to 3) and their respective minima and maxima (see Tables 2 and 3). Given the similarity of the models, it is not surprising that impulse response functions more or less coincide. Therefore, we show only selected cases in the form of detailed graphs. As the transmission mechanisms are similar, we believe that the combination of descriptive statistics and graphical means is the most economical way to convey the key results.

Our benchmark case is a two country open-economy setting, with a modified Taylor rule, spending-oriented fiscal policy, and debt-neutral financial market participants. The impulse responses in Figure 1 showcase the transmission of a stock market crash in the domestic country A (black lines). In the simulation, before the shock occurs, stock markets in both country A and the foreign country B (dashed lines) are on an upward trend. Although A's stock market tanks after the shock, B's stock market continues to rise in the same period. This is due to modelling the stock market equation as an autoregressive process and the assumption of there being a relatively small correlation between these financial markets. However, one period later, B's stock market goes down rapidly as well. After a short period of recovery, A's stock market deteriorates as a consequence of the declining macroeconomic conditions and this development is mirrored by B's stock market. After the recession is over, both stock markets move back to the baseline.

On the real side of the economy, the stock market crash leads to a liquidity shortage for A's firms. As the stock market reflects firms' net worth, the crash caused country A's firms to lose competitiveness. Therefore, output in A starts decreasing only three periods after the crash. Consumption and investment show a very similar development.

Under the modified Taylor rule, monetary policy in A reacts to the financial market shock as well as the developing recession by substantially lowering the interest rate. As investment in B becomes more attractive, capital outflows from A cause a depreciation of its currency. This improves competitiveness in B and helps it to avoid an output contraction similar to that experienced by. Otherwise, the economic adjustment in both countries is very similar.

To stabilise the economy, a fiscal policy of increasing government expenditures is implemented. As taxes decrease due to the recession, there will be a fiscal budget deficit. In spite of declining output, the combined influence of monetary and fiscal stimulus leads to inflation. The results regarding the financial markets spillover suggest that due to the fiscal deficit, as well as the interdependence of financial markets, domestic and foreign bond markets are affected by the crisis. The decrease in government bond prices, which corresponds to an increase in government bond yields, creates higher borrowing conditions for both countries.

We now analyse differences between the benchmark case and what happens if we vary important model assumptions. First, we compare our extended model with the model in Hayo and Niehof (2013a). Simulations with the standard Taylor rule show (see Tables 2 and 3) that the modified monetary policy rule outperforms the standard Taylor rule after a stock market crisis in terms of reducing the size of the recession. However, if the standard Taylor rule is applied, monetary policy is less expansionary, the recession causes deflation, and the exchange rate remains almost unchanged.

Second, we compare the spending-oriented fiscal policy with an austere policy (see Figure 2 and Tables 2 and 3). In the latter case, the increase in government expenditures is mainly financed by a tax increase, but due to the assumed smooth fiscal policy adjustment, some bonds still have to be issued. Thus, during A's recession, taxes do not go down but start increasing due to the government's attempt to limit the fiscal deficit. As country B's recession is less intense, taxes in that country do not need to be raised as aggressively as they are in A. The consequence of an austere fiscal policy is a deepening of the recession, which is in line with the typical result of Keynesian stabilisation policy. However, in addition, our model shows that for stabilising the inflation rate, the austere policy is superior in both countries, a result not commonly derived in models characterised by Ricardian equivalence.

Third, we now assume that households are risk averse with respect to debt (see Tables 2 and 3) and, therefore, react negatively to the number of issued government bonds issued. Thus, although the spending-oriented fiscal policy works as before, it does not result in the desired outcome. This is because, following the increase in government bonds, households substantially reduce their consumption expenditure. This additional drop in consumption more than overcompensates the positive impulse coming from fiscal policy. Thus, if households react negatively to the resulting fiscal deficit, the outcome of austere policy in terms of stabilising the output gap during the recession dominates the spending-oriented policy. This result is similar to that derived from models exhibiting Ricardian equivalence, but, as outlined above, the adjustment mechanism here is different.

Fourth, we look at the case of a monetary union, again focussing on a spending-based fiscal policy and a modified Taylor rule as well as risk-neutral households. The results of the simulations are shown in Figures 3 and Table 3. Note that we shut down the exchange rate channel and that the interest rate is roughly the average of A's and B's interest rates in the open-economy case. The consideration of B in the Taylor rule implies that after the stock market crash in A, and the ensuing recession, the monetary policy reaction is not as strong as in the two-country case. At the same time, B benefits from the shared monetary policy. Due to cheap borrowing conditions and fewer recessionary pressures, investments in

B increase in spite of the financial crisis. The consequence of this asymmetric development is not only a much lighter recession in B, but also a difference in terms of domestic inflation. Therefore, in a monetary union, a stock market crisis creates notable spillover effects from national financial markets to other countries. Comparing these results with the case of a monetary union with an austerity-oriented fiscal policy shows that the austere policy is less successful in terms of output stabilisation. However, as in the two-country example, introducing risk-averse households overturns this finding, as output in both countries as well as inflation in B fluctuate less.

6 Conclusion

In this paper, we study the interaction of monetary and fiscal policy after a financial market crisis in a two-country, open-economy setting as well as in a monetary union setting. Technically, we extend the well-known, open-economy New Keynesian model of Clarida, Gali, and Gertler (1999), Lindé, Nessén, and Söderström (2009), and Smets and Wouters (2002, 2007) and Lubik and Schorfheide (2007) in two important ways. First, we include a well-developed financial sector and, second, we apply stochastic differential equations and conduct the analysis in a continuous-time framework. The continuous-time approach allows us to employ classic research from the field of finance and model the financial sector by including the markets for foreign exchange, stocks, and bonds. We therefore combine macroeconomic research with advanced methods for capturing financial market processes developed in the finance literature (Merton (1973) and Black and Scholes (1973)). To guarantee stability we employ Lyapunov techniques (Khasminskii 2012). Thus, in our analysis, we combine DSGE macroeconomic analysis, classic finance research, and standard mathematical procedures.

Our main research question concerns the interaction of different types of fiscal and monetary policy after a financial market crash and how this interaction affects other important macroeconomic variables, particularly output and inflation. We undertake this analysis by looking at various combinations of stabilisation policies and economic environment, that is, independent but globalised economies versus a monetary union. Monetary policy either follows a standard open-economy Taylor rule or a modified rule that includes financial market variables in the central bank reaction function. We also distinguish between a passive or 'austere' fiscal policy, which is primarily concerned with balancing the intertemporal budget constraint, and a spending-based fiscal policy, that is, one that includes bond-financed, expansionary government expenditure.

After a financial market crash in one country, its economy heads toward a recession. This forces policymakers to lower interest rates and engage in higher government spending. We find evidence that a co-ordinated adoption of fiscal and monetary policy is very effective in lessening the effects of a financial crisis in terms of output. Stabilisation is particularly powerful if the central bank directly reacts to the financial crisis by including a financial market indicator in its Taylor rule. However, such action comes at the cost of increasing the inflation rate in the country where the financial crisis occurred. This positive impact of a debt-financed fiscal expenditure policy is conditional on the assumption that households do not care about the number of bonds issued by the government. If we assume that households are averse to outstanding government debt, the situation changes dramatically. Now we find that a combination of expansionary monetary policy and austere fiscal policy is more appropriate for stabilising both domestic and foreign economies in terms of both output and inflation.

Extending our setup to the case of a monetary union adds another interesting asymmetry and shows significant spillover from a financial crisis in one country to other members of the monetary union. In this case, we find that stabilisation of output in the country where the financial shock originates is no longer as easy as now monetary policy takes into account the other country, the output of which is much less affected, and a depreciation of the domestic currency is no longer possible. Moreover, in terms of inflation, there is now a clear asymmetry, with deflation in the country where the crisis originated and a higher inflation rate in the other country.

Our study has some interesting policy implications. First, by directly reacting to financial market shocks, a central bank can mitigate the resulting crisis in the real economy. This would support arguments for extending the Taylor rule to encompass financial market indicators. Second, co-ordinating monetary and debt-financed expenditure policy to combat a recession following a financial crisis is a powerful way of stabilising the economy. Thus, we find support for the Keynesian approach to stabilisation. Third, this result, however, is highly dependent on the assumption that households do not worry about the number of outstanding government bonds in the economy. As the recent debt crisis in Europe suggested, this is not necessarily the case. Fourth, the alternative would be to constrain fiscal policy to take into account the government budget constraint, often termed 'fiscal austerity'. This type of policy has been severely criticised based on the argument that it would be detrimental to economic recovery. Our results show that, in general, this criticism is not valid. If households are debt averse, it may be that an austere fiscal policy is superior to a spending-oriented fiscal policy in terms of output and inflation stabilisation. Finally, applying our model to the case of a monetary union shows that policymakers should be even more wary with respect to financial crisis spillovers than in standard open economies. Not only are financial market shocks in one country easily transmitted to other members of the monetary union, monetary policy stabilisation will be much less effective for the country where the crisis started. Moreover, the central bank will find itself in the difficult position that there are diverging price developments within the currency area. In the country where the crisis erupted, a deflationary development is likely, whereas in the other countries, inflation is likely to be observed. This may put even more pressure on the currency area's monetary policy committee and may exacerbate a possible tendency of national representatives to vote in their own country's best interest when it comes to interest rate changes (Hayo and Méon 2013).

References

Abel, Andrew B (1990). "Asset Prices under Habit Formation and Catching up with the Joneses". In: *The American Economic Review* 80(2), pp. 38–42.

Adams, Zeno and Roland Füss (2010). "Macroeconomic Determinants of International Housing Markets". In: *Journal of Housing Economics* 19(1), pp. 38–50.

Adolfson, Malin et al. (2011). "Optimal Monetary Policy in an Operational Medium-Sized DSGE Model". In: *Journal of Money, Credit and Banking* 43(7), pp. 1287–1331.

Agnello, Luca and Ludger Schuknecht (2011). "Booms and Busts in Housing Markets: Determinants and Implications". In: *Journal of Housing Economics* 20(3), pp. 171–190.

Aït-Sahalia, Yacine, Julio Cacho-Diaz, and Roger JA Laeven (2010). "Modeling Financial Contagion using Mutually Exciting Jump Processes". In: *National Bureau of Economic Research Working Paper Series* w15850.

Andreasen, Martin M (2012). "On the Effects of Rare Disasters and Uncertainty Shocks for Risk Premia in Non-Linear DSGE Models". In: *Review of Economic Dynamics* 15(3), pp. 295–316.

Andreasen, Martin Møller (2010). "How to Maximize the Likelihood Function for a DSGE Model". In: *Computational Economics* 35(2), pp. 127–154.

Ball, Laurence (1998). "Policy Rules for Open Economies". In: *National Bureau of Economic Research Working Paper Series* 6760.

Bartlett, Maurice S (1946). "On the Theoretical Specification and Sampling Properties of Autocorrelated Time-Series". In: *Supplement to the Journal of the Royal Statistical Society*, pp. 27–41.

Batini, Nicoletta and Edward Nelson (2000). "When the Bubble Bursts: Monetary Policy Rules and Foreign Exchange Market Behavior". In: *Bank of England, London.*

Bayer, Patrick, Bryan Ellickson, and Paul B Ellickson (2010). "Dynamic Asset Pricing in a System of Local Housing Markets". In: *The American Economic Review* 100(2), pp. 368–372.

Bekaert, Geert, Seonghoon Cho, and Antonio Moreno (2010). "New Keynesian Macroeconomics and the Term Structure". In: *Journal of Money, Credit and Banking* 42(1), pp. 33–62.

Bekaert, Geert, Marie Hoerova, and Marco Lo Duca (2013). "Risk, Uncertainty and Monetary Policy". In: *Journal of Monetary Economics* 60(7), pp. 771–788.

Belke, Ansgar and Jens Klose (2010). "(How) Do the ECB and the Fed React to Financial Market Uncertainty?" In: *Ruhr Economic Papers* 166.

Benigno, Pierpaolo (2009). “Price Stability with Imperfect Financial Integration”. In: *Journal of Money, Credit and Banking* 41(1), pp. 121–149.

Bergstrom, Albert Rex and Khalid Ben Nowman (2007). *A Continuous Time Econometric Model of the United Kingdom with Stochastic Trends*. Cambridge University Press.

Bianchi, Sergio, Alexandre Pantanella, and Augusto Pianese (2013). “Modeling Stock Prices by Multifractional Brownian Motion: An Improved Estimation of the Pointwise Regularity”. In: *Quantitative Finance* 13(8), pp. 1317–1330.

Binsbergen, Jules H. van et al. (2012). “The Term Structure of Interest Rates in a DSGE Model with Recursive Preferences”. In: *Journal of Monetary Economics* 59(7), pp. 634 –648.

Bjornland, Hilde and Kai Leitemo (2009). “Identifiying the Interdependence Between US Monetary Policy and the Stock Market”. In: *Journal of Monetary Economics* 56(2), pp. 275–282.

Black, Fischer and Myron Scholes (1973). “The Pricing of Options and Corporate Liabilities”. In: *The Journal of Political Eeconomy* 81(3), pp. 637–654.

Boldrin, Michele, Lawrence Christiano, and Jonas Fisher (2001). “Habit Persistence, Asset Returns, and the Business Cycle”. In: *American Economic Review* 91(1), pp. 149–166.

Brunnermeier, Markus and Yuliy Sannikov (2012). “A Macroeconomic Model with a Financial Sector”. In: *National Bank of Belgium Working Paper* 236.

Calvo, Guillermo (1983). “Staggered Prices in a Utility-Maximizing Framework”. In: *Journal of Monetary Economics* 12(3), pp. 383–398.

Campbell, John and John Cochrane (1999). “By Force of Habit: A Consumption-Based Explanation of Aggregate Stock Market Behavior”. In: *The Journal of Political Economy* 107(2), pp. 205–251.

Capozza, Dennis R et al. (2002). “Determinants of Real House Price Dynamics”. In: *National Bureau of Economic Research Working Paper Series* w9262.

Çebi, Cem (2012). “The Interaction between Monetary and Fiscal Policies in Turkey: An Estimated New Keynesian DSGE model”. In: *Economic Modelling* 29(4), pp. 1258–1267.

Clarida, Richard, Jordi Gali, and Mark Gertler (1999). “The Science of Monetary Policy: An New Keynesian Perspective”. In: *Journal of Economic Literature* 37(4), pp. 1661–1707.

– (2000). “Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory”. In: *The Quarterly Journal of Economics* 115 (1), pp. 147–180.

– (2002). “A Simple Framework of Monetary Policy Analysis”. In: *Journal of Monetary Economics* 49(5), pp. 879–904.

Cooper, Ilan and Richard Priestley (2009). “Time-Varying Risk Premiums and the Output Gap”. In: *Review of Financial Studies* 22(7), pp. 2801–2833.

Curdia, Vasco and Michael Woodford (2008). “Credit Frictions and Optimal Monetary Policy”. In: *BIS Working Paper Series* 278.

Dai, Qiang and Kenneth Singleton (2000). “Specification Analysis of Affine Term Structure Models”. In: *The Journal of Finance* 55(5), pp. 1943–1978.

Dixit, Avinash and Joseph Stiglitz (1977). “Monopolistic Competition and Optimum Product Diversity”. In: *The American Economic Review* 67(3), pp. 297–308.

Duffie, Darrell and Rui Kan (1996). “A Yield-Factor Model of Interest Rates”. In: *Mathematical Finance* 6(4), pp. 379–406.

Duffie, Darrell, Jun Pan, and Kenneth Singleton (2000). “Transform Analysis and Asset Pricing for Affine Jump-Diffusions”. In: *Econometrica* 68(6), pp. 1343–1376.

El-Khatib, Youssef, Mohamed Ali Hajji, and Mohammed Al-Refai (2013). “Options Pricing in Jump Diffusion Markets during Financial Crisis”. In: *Applied Mathematics & Information Sciences* 7(6), pp. 2319–2326.

Fahr, Stephan and Frank Smets (2010). “Downward Wage Rigidities and Optimal Monetary Policy in a Monetary Union”. In: *The Scandinavian Journal of Economics* 112(4), pp. 812–840.

Faia, Ester and Tommaso Monacelli (2007). “Optimal Interest Rate Rules, Asset Prices, and Credit Frictions”. In: *Journal of Economic Dynamics and Control* 31(10), pp. 3228–3254.

Favero, Carlo and Tommaso Monacelli (2005). “Fiscal Policy Rules and Regime (In)Stability: Evidence from the US”. In: *IGIER – Università Bocconi–Working Paper Series* 282.

Fernández-Villaverde, Jesús (2010). “The Econometrics of DSGE Models”. In: *SERIEs* 1(1-2), pp. 3–49.

Fuhrer, Jeffrey (2000). “Habit Formation in Consumption and its Implications for Monetary-Policy Models”. In: *American Economic Review*, pp. 367–390.

Gertler, Mark and Peter Karadi (2011). “A Model of Unconventional Monetary Policy”. In: *Journal of Monetary Economics* 58(1), pp. 17–34.

Gertler, Mark, Nobuhiro Kiyotaki, and Albert Queralto (2012). “Financial Crises, Bank Risk Exposure and Government Financial Policy”. In: *Journal of Monetary Economics* 59, pp. 17–34.

Hayo, Bernd and Pierre-Guillaume Méon (2013). “Behind Closed Doors: Revealing the ECB’s Decision Rule”. In: *Journal of International Money and Finance* 37, pp. 135–160.

Hayo, Bernd and Britta Niehof (2013a). “Spillovers in a New Keynesian Continuous Time Framework with Financial Markets”. In: *MAGKS Working Paper Series* 12.

Hayo, Bernd and Britta Niehof (2013b). "Spillovers in a New Keynesian Continuous Time Framework with Financial Markets". In: *MAGKS Working Paper Series* 12.

– (2014). "Analysis of Monetary Policy Responses After Financial Market Crises in a Continuous Time New Keynesian Model". In: *MAGKS Working Paper Series* 21.

Heston, Steven (1993). "A Closed Form Solution for Options with Stochastic Volatiliy with Applications to Bond and Currency Options". In: *The Review of Financial Studies* 6(2), pp. 327–343.

Hildebrand, Phillip (2006). "Monetary Policy and Financial Markets". In: *Financial Markets and Portfolio Management* 20(1), pp. 7–18.

Hirata, Hideaki et al. (2012). "Global House Price Fluctuations: Synchronization and Determinants". In:

Justiniano, Alejandro, Giorgio E. Primiceri, and Andrea Tambalotti (2010). "Investment Shocks and Business Cycles". In: *Journal of Monetary Economics* 57(2), pp. 132–145.

Khasminskii, Rafail (2012). *Stochastic Stability of Differential Equations.* Ed. by Boris Rozovskii and Peter W. Glynn. Springer.

Kirsanova, Tatiana and Simon Wren-Lewis (2012). "Optimal Fiscal Feedback on Debt in an Economy with Nominal Rigidities". In: *The Economic Journal* 122(559), pp. 238–264.

Kou, Steven (2002). "A Jump-Diffusion Model for Option Pricing". In: *Management science* 48(8), pp. 1086–1101.

Leitemo, Kai and Ulf Soderstrom (2005). "Simple Monetary Policy Rules and Exchange Rate Uncertainty". In: *Journal of International Money and Finance* 24(3), pp. 481–507.

Leith, Campbell and Leopold Von Thadden (2008). "Monetary and Fiscal Policy Interactions in a New Keynesian Model with Capital Accumulation and Non-Ricardian Calvo Consumers". In: *Journal of Economic Theory* 140(1), pp. 279–313.

Lindé, Jesper (2005). "Estimating New-Keynesian Phillips Curves: A Full Information Maximum Likelihood Approach". In: *Journal of Monetary Economics* 52(6), pp. 1135–1149.

Lindé, Jesper, Marianne Nessén, and Ulf Söderström (2009). "Monetary Policy in an Estimated Open-Economy Model with Imperfect Pass-Through". In: *International Journal of Finance and Economics* 14(4), pp. 301–333.

Lubik, Thomas and Frank Schorfheide (2007). "Do Central Banks Respond to Exchange Rate Movements? A Structural Investigation". In: *Journal of Monetary Economics* 54(4), pp. 1069–1087.

Lubik, Thomas and Frank Smets (2005). "A Bayesian Look at New Open Economy Macroeconomics". In: *National Bureau of Economic Research Macroeconomics Annual* 20.

Merton, Robert (1973). “Theory of Rational Option Pricing”. In: *Bell Journal of Economics and Management Science* 4(1), pp. 141–183.

Muscatelli, V Anton, Patrizio Tirelli, and Carmine Trecroci (2004). “Fiscal and Monetary Policy Interactions: Empirical Evidence and Optimal Policy Using a Structural New-Keynesian Model”. In: *Journal of Macroeconomics* 26(2), pp. 257–280.

Paoli, Bianca De, Alasdair Scott, and Olaf Weeken (2010). “Asset Pricing Implications of a New Keynesian Model”. In: *Journal of Economic Dynamics and Control* 34(10), pp. 2056 –2073.

Pesaran, Hashem and Allan Timmermann (1995). “Predictability of Stock Returns: Robustness and Economic Significance”. In: *The Journal of Finance* 50(4), pp. 1201–1228.

Rigobon, Roberto (2003). “Identification through Heteroskedasticity”. In: *The Review of Economics and Statistics* 85(4), pp. 777–792.

Rigobon, Roberto and Brian Sack (2003). “Measuring the Reacton of Monetary Policy to the Stock Market”. In: *The Quarterly Journal of Economics* 118(2), pp. 639–669.

Schmitt-Grohé, Stephanie and Martin Uribe (2007). “Optimal Simple And Implementable Monetary and Fiscal Rules”. In: *Journal of Monetary Economics* 54(6), pp. 1702–1725.

Smets, Frank and Rafael Wouters (2002). “Openness, Imperfect Exchange Rate Pass–Through and Monetary Policy”. In: *Journal of Monetary Economics* 49(5), pp. 947–981.

– (2007). “Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach”. In: *The American Economic Review* 97(3), pp. 586–606.

Svensson, Lars (2000). “Open–Economy Inflation Targeting”. In: *Journal of International Economics* 50(1), pp. 155–183.

Taylor, John (1993). “Discretion versus Policy Rules in Practice”. In: *Carnegie–Rochester Conference Series on Public Policy* 39(1), pp. 195–214.

Thygesen, Uffe Hogsbro (1997). “A Survey of Lyapunov Techniques for Stochastic Differential Equations”. In: *Technical Report/ Dept. Math. Modeling, Tech. Uni. Denmark* 18.

Vivian, Andrew and Mark Wohar (2013). “The Output Gap and Stock Returns: Do Cyclical Fluctuations Predict Portfolio Returns?” In: *International Review of Financial Analysis* 26(1), pp. 40–50.

Wu, Tao (2006). “Macro Factors and the Affine Term Structure of Interest Rates”. In: *Journal of Money, Credit and Banking* 38(7), pp. 847–1875.

Yu, Jun (2013). “Econometric Analysis of Continuous Time Models: A Survey of Peter Phillips’ Work and Some New Results”. In: *Econometric Theory* 30(4), pp. 737–774.

7 Figures and Tables

Figure 1: **Spending-oriented Fiscal Policy, Modified Taylor Rule**

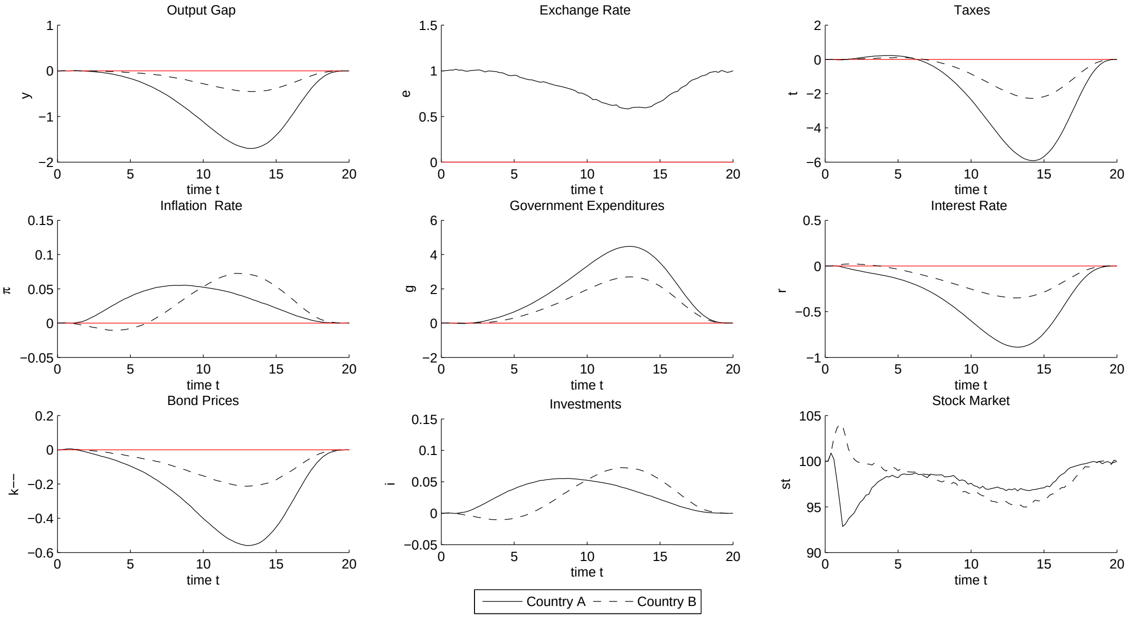

Figure 2: **Austere Fiscal Policy, Modified Taylor Rule**

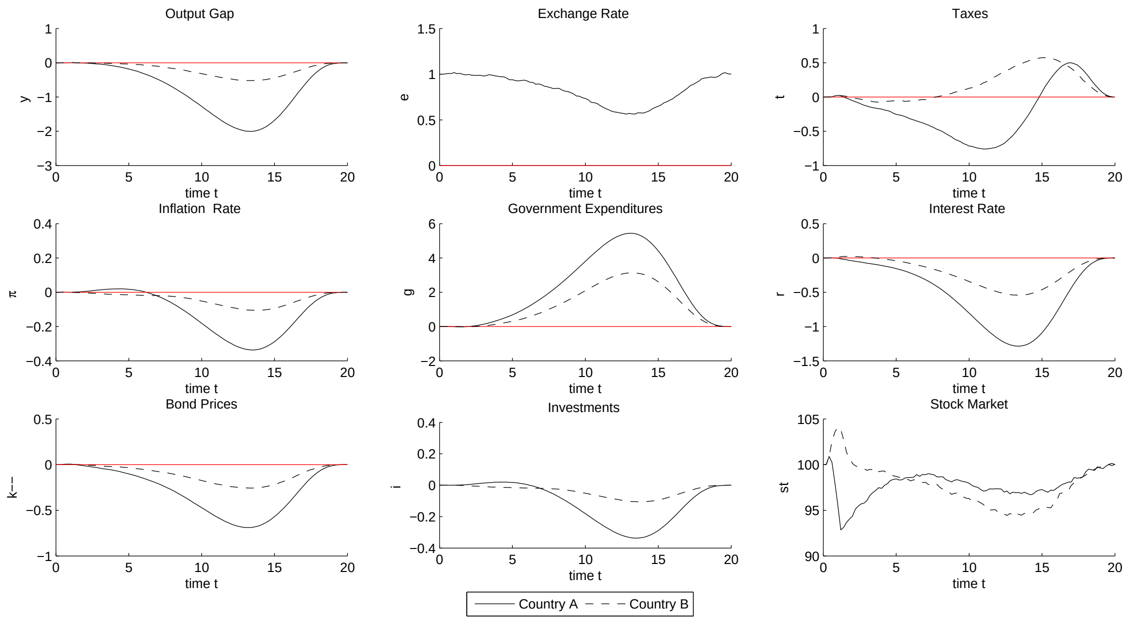

Figure 3: **Monetary Union, Spending-oriented Fiscal Policy, Modified Taylor Rule**

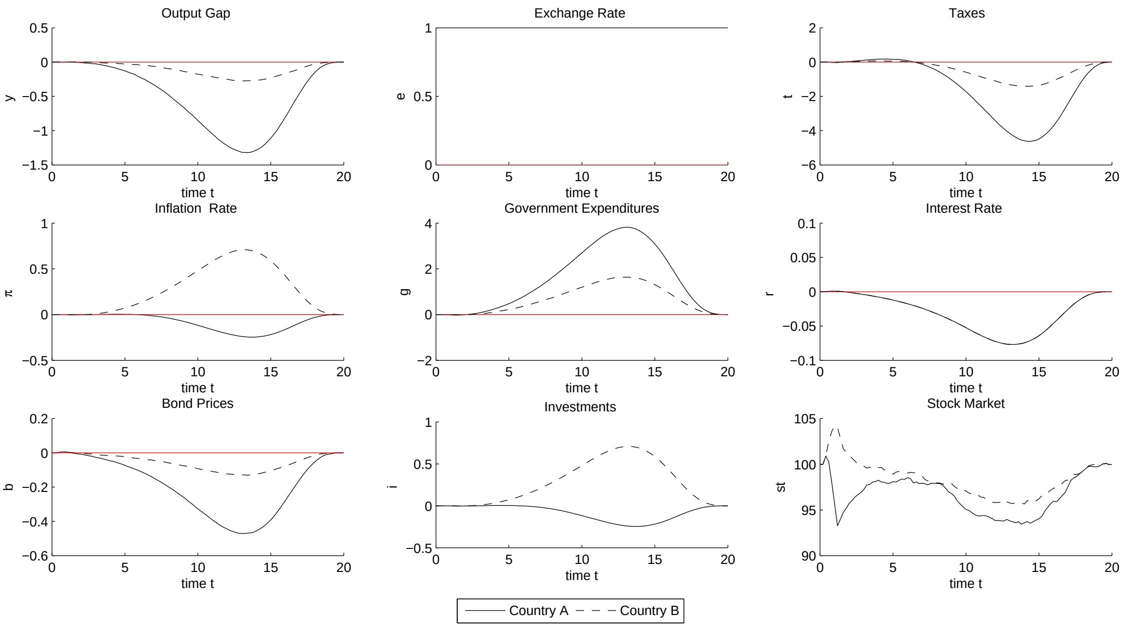

Table 1: Parameters

variable	parameter	variable	parameter	variable	parameter	variable	parameter
η_d^c	1.50	ω_x	0.75	ρ_{E*}	0.20	ρ_{r^*}	0.10
η_f^c	1.30	ω_{x2}	0.65	ς_g	0.20	ρ_y	0.80
η_d^i	1.50	τ	0.20	ς_y	0.80	ρ_{fx}	0.50
η_f^i	1.30	θ	0.75	ς_b	0.10	$\rho_p i$	0.25
η^c	2.00	ι	0.60	ς_{tt}	0.10	γ_h	0.80
ω_f	0.75	π	1.02	ς_{yt}	0.95	γ_s	0.30
ω_{f2}	0.65	ϵ	0.55	ς_{bt}	0.10	γ_{h^*}	0.90
β	0.99	α	0.25	ρ_h	0.20	γ_{s^*}	0.90
σ	1.20	ρ_R	0.75	ρ_s	0.80	γ_r	0.90
σ_l	1.25	$\psi_p i$	1.20	ρ_{h^*}	0.10	γ_y	0.50
h	0.97	ψ_S	0.30	ρ_{s^*}	0.10		
δ	0.30	ψ_E	0.10	ρ_r	0.95		

Table 2: Extreme Values - Open-Economy Simulations

open-economy				y	i	π	c	bo	l	r	st	e	g	t
Classic Taylorrule	risk-neutral	spending	Min_A	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	1.02	6.53	0.24
			Min_B	0.00	0.01	0.00	0.00	0.00	0.03	0.00	104.20	0.00	3.79	0.10
			Max_A	-2.08	-0.04	-0.28	-1.87	-0.84	-0.06	-0.04	91.27	0.95	-0.02	-6.86
			Max_B	-0.57	-0.03	-0.08	-0.53	-0.32	-0.01	-0.01	90.84	0.00	-0.01	-2.74
		austere	Min_A	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	1.02	6.98	0.81
			Min_B	0.00	0.01	0.00	0.00	0.00	0.03	0.00	104.20	0.00	4.06	0.79
			Max_A	-2.19	-0.05	-0.30	-1.98	-0.89	-0.07	-0.05	90.49	0.92	-0.02	-0.87
			Max_B	-0.57	-0.02	-0.08	-0.54	-0.34	-0.01	-0.01	89.87	0.00	-0.01	-0.07
	risk-averse	spending	Min_A	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	1.02	7.92	0.24
			Min_B	0.00	0.02	0.00	0.00	0.00	0.03	0.00	104.20	0.00	4.59	0.09
			Max_A	-2.49	-0.06	-0.34	-2.23	-1.04	-0.07	-0.05	89.28	0.91	-0.02	-7.90
			Max_B	-0.64	-0.02	-0.09	-0.59	-0.40	-0.01	-0.01	88.84	0.00	-0.01	-3.10
		austere	Min_A	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	1.04	7.71	0.92
			Min_B	0.00	0.01	0.00	0.00	0.00	0.03	0.00	104.20	0.00	4.45	0.86
			Max_A	-2.36	-0.04	-0.32	-2.13	-1.00	-0.06	-0.05	90.18	0.91	-0.02	-0.96
			Max_B	-0.61	-0.03	-0.09	-0.57	-0.39	-0.02	-0.01	88.98	0.00	-0.01	-0.07
Extended Taylorrule	risk-neutral	spending	Min_A	0.00	0.00	0.16	0.01	0.01	0.01	0.00	100.90	1.02	4.48	0.22
			Min_B	0.00	0.00	0.21	0.00	0.00	0.04	0.00	104.20	0.00	2.60	0.09
			Max_A	-1.70	-0.43	0.00	-1.50	-0.56	-0.04	-0.11	93.26	0.36	-0.02	-5.80
			Max_B	-0.36	-0.08	0.00	-0.32	-0.20	0.00	-0.06	93.53	0.00	-0.01	-2.11
		austere	Min_A	0.00	0.00	0.18	0.01	0.01	0.01	0.00	100.90	1.03	4.92	0.00
			Min_B	0.00	0.00	0.22	0.00	0.00	0.04	0.00	104.20	0.00	2.85	0.01
			Max_A	-1.81	-0.45	0.00	-1.61	-0.61	-0.04	-0.12	92.57	0.33	-0.02	-2.30
			Max_B	-0.37	-0.09	0.00	-0.33	-0.22	0.00	-0.06	92.93	0.00	-0.01	-0.37
	risk-averse	spending	Min_A	0.00	0.00	0.17	0.01	0.01	0.01	0.00	100.90	1.03	5.03	0.21
			Min_B	0.00	0.00	0.22	0.00	0.00	0.04	0.00	104.20	0.00	2.87	0.09
			Max_A	-1.83	-0.43	0.00	-1.61	-0.64	-0.04	-0.12	93.26	0.35	-0.02	-6.04
			Max_B	-0.38	-0.08	0.00	-0.33	-0.23	0.00	-0.06	92.94	0.00	-0.01	-2.17
		austere	Min_A	0.00	0.00	0.16	0.01	0.01	0.01	0.00	100.90	1.03	4.79	0.46
			Min_B	0.00	0.00	0.21	0.00	0.00	0.04	0.00	104.20	0.00	2.77	0.58
			Max_A	-1.75	-0.44	0.00	-1.54	-0.61	-0.05	-0.12	93.26	0.34	-0.02	-0.68
			Max_B	-0.33	-0.07	0.00	-0.29	-0.22	0.00	-0.06	93.06	0.00	-0.01	-0.06

Table 3: Extreme Values - Monetary Union Model

monetary-union				y	i	pi	c	bo	l	r	st	e	g	t
Classic Taylorrule	risk-neutral	spending	Min_A	0.00	0.01	0.00	0.01	0.01	0.01	0.00	100.90	-	6.24	0.21
			Min_B	0.00	0.02	0.00	0.00	0.00	0.03	0.00	104.20	-	3.47	0.09
			Max_A	-1.98	-0.03	-0.34	-1.79	-0.80	-0.06	-0.03	91.00	-	-0.02	-6.51
			Max_B	-0.53	-0.03	-0.01	-0.48	-0.30	-0.01	-0.03	91.76	-	-0.01	-2.50
		austere	Min_A	0.00	0.01	0.00	0.01	0.01	0.01	0.00	100.90	-	6.95	0.81
			Min_B	0.00	0.02	0.00	0.00	0.00	0.03	0.00	104.20	-	3.88	0.75
			Max_A	-2.16	-0.03	-0.37	-1.95	-0.89	-0.07	-0.03	89.73	-	-0.02	-0.84
			Max_B	-0.56	-0.03	-0.01	-0.52	-0.33	-0.01	-0.03	90.78	-	-0.01	-0.07
	risk-averse	spending	Min_A	0.00	0.01	0.00	0.01	0.01	0.01	0.00	100.90	-	6.95	0.84
			Min_B	0.00	0.02	0.00	0.00	0.00	0.03	0.00	104.20	-	3.80	0.73
			Max_A	-2.13	-0.03	-0.36	-1.92	-0.90	-0.07	-0.03	89.83	-	-0.02	-0.86
			Max_B	-0.54	-0.03	-0.01	-0.50	-0.33	-0.01	-0.03	90.67	-	-0.01	-0.06
		austere	Min_A	0.00	0.01	0.00	0.01	0.01	0.01	0.00	100.90	-	6.43	0.20
			Min_B	0.00	0.02	0.00	0.00	0.00	0.03	0.00	104.20	-	3.58	0.09
			Max_A	-2.00	-0.03	-0.33	-1.80	-0.84	-0.06	-0.03	91.49	-	-0.02	-6.34
			Max_B	-0.52	-0.03	-0.01	-0.47	-0.31	-0.01	-0.03	91.30	-	-0.01	-2.46
Extended Taylorrule	risk-neutral	spending	Min_A	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	-	5.06	0.56
			Min_B	0.00	0.00	0.21	0.00	0.00	0.04	0.00	104.20	-	2.60	0.48
			Max_A	-1.62	-0.13	-0.07	-1.46	-0.63	-0.04	-0.06	92.03	-	-0.02	-0.60
			Max_B	-0.44	-0.11	0.00	-0.38	-0.22	0.00	-0.06	93.49	-	-0.01	-0.07
		austere	Min_A	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	-	5.20	0.19
			Min_B	0.00	0.00	0.21	0.00	0.00	0.04	0.00	104.20	-	2.79	0.09
			Max_A	-1.68	-0.13	-0.08	-1.51	-0.65	-0.04	-0.07	92.22	-	-0.02	-5.81
			Max_B	-0.46	-0.12	0.00	-0.40	-0.23	0.00	-0.07	93.13	-	-0.01	-2.21
	risk-averse	spending	Min_A	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	-	6.40	0.74
			Min_B	0.00	0.00	0.25	0.00	0.00	0.04	0.00	104.20	-	3.25	0.61
			Max_A	-1.98	-0.14	-0.09	-1.77	-0.81	-0.04	-0.08	90.40	-	-0.02	-0.75
			Max_B	-0.51	-0.13	0.00	-0.44	-0.28	0.00	-0.08	91.76	-	-0.01	-0.06
		austere	Min_A	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	-	5.97	0.21
			Min_B	0.00	0.00	0.23	0.00	0.00	0.04	0.00	104.20	-	3.10	0.09
			Max_A	-1.89	-0.13	-0.09	-1.69	-0.76	-0.04	-0.07	90.91	-	-0.02	-6.30
			Max_B	-0.50	-0.12	0.00	-0.43	-0.27	0.00	-0.07	91.96	-	-0.01	-2.30