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Abstract

To analyse the interdependence between monetary policy and financial markets in the context of the recent financial crisis, we use stochastic differential equations to develop a dynamic, stochastic general equilibrium New Keynesian model of two open economies. Our focus is on how stock and housing market bubbles are transmitted to and affect the domestic real economy and the consequent contagious effects on foreign markets. We simulate adjustment paths for the economies under two monetary policy rules: a standard open-economy Taylor rule and a modified Taylor rule that takes into account stabilisation of financial markets as a monetary policy objective. The results suggest a clear trade-off for monetary policymakers: under the modified rule, a severe economic recession can be avoided after a financial crisis but only at the price of a strong hike in inflation during the crisis and much more volatile inflation patterns during normal times, compared to under the standard Taylor rule. Using Bayesian estimation techniques, we calibrate the model to the cases of the United States and Canada and find that the resulting economic adjustment paths are similar to the ones we obtained from the extended Taylor rule theoretical model.

JEL Classification Numbers: C02, C63, E44, E47, E52, F41

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1 Introduction

Many OECD countries are still recovering from the worst financial and economic crisis since the Great Depression. One important lesson learned from this experience is that stable financial markets are a precondition to macroeconomic stability. Indeed, the crisis was a forceful reminder that there are important linkages not only between different domestic financial markets but also between international financial markets, meaning that shocks originating in one financial market in one country can spillover to other financial markets in the same country as well as to financial markets in other countries. In North America and Europe, there has been unprecedented use of monetary policy to stabilise financial markets and the real economy. However, stabilisation policy itself generates spillovers to other countries, a fact often ignored.

Indeed, continuing to act as though there really is such a thing as purely national policy making in a globalised world could facilitate the spread of a crisis to other countries, with foreseeable and unfortunate results, if history is any guide. We believe a better understanding of the influence of financial market spillovers, as well as of foreign monetary policy, is crucial to appropriate national monetary policy. Thus, it is important to learn more about the consequences of policymaker reactions to financial turmoil and how these vary based on the degree of importance policymakers attach to domestic and foreign financial markets.

Although the recent financial crisis resulted in the development of macroeconomic models that have helped us understand what happened, given direction on how to clean up the mess, and provided suggestions for avoiding another crisis, most of these studies either use techniques from finance 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). A detailed literature overview is provided by Brunnermeier and Sannikov (2012). In this paper, we build a bridge between macroeconomics and finance intended to achieve better understanding of the effects of financial markets on real markets. We study spillover effects between financial markets, as well as from financial markets to the real economy, both within one economy and across economies, and we analyse the economic consequences of different monetary policy responses. We develop a fully dynamic stochastic general equilibrium New Keynesian (NK) model of two open economies based on stochastic differential equations. In our simulation analysis, we compare a standard open-economy Taylor rule that focuses on stabilising output, inflation, and the exchange rate to a modified Taylor rule that additionally takes account of financial market stabilisation.

We argue that academic research can aid central banks by analysing the extent to which financial markets should be taken into consideration when formulating monetary policy. We thus explore the consequences of treating seriously the interaction between financial markets, monetary policy, and the real economy in a globalised world by developing a fully dynamic theoretical modelling framework. We are particularly interested in the relationship between financial markets, financial crises, and monetary policy, which can be characterised by a substantial degree of simultaneity.

Given our open-economy setting, we need to include the foreign exchange market in addition to stock and bond markets. Clarida, Gali, and Gertler (2002) incorporate the exchange rate in a NK two-country model in which domestic and foreign households have the same preferences. Under quite restrictive assumptions, they find that purchasing power parity (PPP) holds and that the consumption real exchange rate is constant. Gali and Monacelli (2005) expand on this approach by applying Calvo sticky pricing and analysing the policy effects of either a Taylor rule or an exchange rate peg. Engels (2009), in turn, extend this open-economy model by incorporating local currency pricing and allowing for differences in domestic and foreign household preferences. Including the exchange rate in the monetary policy analysis takes into account a large and important financial market and the exchange rate itself could also be viewed as a policy objective. For example, Leitemo and Soderstrom (2005) include exchange rate uncertainty in a NK model and analyse different monetary policy rules. They find evidence that an interest rate reaction function in the form of a Taylor rule incorporating the exchange rate works particularly well. Similarly, Wang and Wu (2012) report that in their analysis of a group of exchange rate models for 10 OECD countries, the Taylor rule performs best empirically as a monetary policy rule. Taylor (2001) discusses the role of the exchange rate in monetary policy rules. Based on these empirical and theoretical findings, we model the policy reaction function as a Taylor rule.

Our theoretical approach is somewhat similar to that of Asada et al. (2006) and Chen et al. (2006a,b). These authors transform the Keynesian AS-AD model into a disequilibrium model with a wage-price spiral and include two Phillips curves, one targeting wages and the other targeting prices. The model is transformed into five differential equations-explaining real wages, real money balances, investment climate, labour intensity, and inflationary climate-and its dynamics are analysed extensively. Malikane and Semmler (2008b) extend this framework by including the exchange rate; Malikane and Semmler (2008a) consider asset prices. However, none of these studies includes two financial markets and the exchange rate, particularly not in a framework controlling for the simultaneity between monetary policy and financial markets. Thus, our paper makes several contributions to the literature. First, we follow Ball (1998) and derive the Taylor rule within the model by employing the nominal interest rate and the exchange rate as monetary policy targets. Moreover, we follow Bekaert, Cho, and Moreno (2010) and Brunnermeier and Sannikov (2012) and model a financial market sector, which allows consistent inclusion of financial markets in the policy rule. Faia and Monacelli (2007) provide empirical evidence that including financial market variables in the Taylor rule has 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. We account for simultaneity between monetary policy and financial markets by incorporating several financial markets (i.e., foreign exchange, bond, and stock markets). The issue of simultaneity is empirically analysed by Bjornland and Leitemo (2009), Rigobon (2003), and Rigobon and Sack (2003). A theoretical discussion is provided by Hildebrand (2006).

Second, following Hayo and Niehof (2013), we combine finance research with macroeconomic theory by employing a continuous-time framework. This allows us to use advanced techniques from the finance literature, such as jump-diffusion processes, to model financial markets. Technically, we transform the NK model into stochastic differential equations and compute solutions by means of advanced numerical algorithms. We use stochastic differential equations to tackle the issue of the nonlinear model. We thus avoid the need for third-order perturbation methods, as well as simplify model estimation. Yu (2013) states that continuous-time models should be very appealing to both economists and financial specialists because 'the economy does not cease to exist in between observations' (Bartlett 1946). On aggregate levels, economic decision-making almost always involves many agents and is typically conducted during the course of a month. As a result, continuous-time models may provide a good approximation of the actual dynamics of economic behaviour. Another important advantage of continuous-time models is that they provide a convenient mathematical framework for the development of financial economic theory, enabling simple and often analytically tractable ways to price financial assets. Continuous-time models can treat stock and flow variables separately and can be subjected to rigorous mathematical analysis(Thygesen 1997).

Third, to discover whether our theoretical analysis captures important aspects of real-world economies, we study the interaction between the United States and Canada. We estimate model parameters using Bayesian estimation techniques and compare the simulated adjustment paths to those from our model based on a priori calibration. The remainder of the paper is structured as follows. Section 2 derives the theoretical model. Section 3 briefly sketches the advantages of continuous-time modelling. In Section 4, we study the effects of financial market turmoil using dynamic simulations based on a calibrated version of the theoretical model and employing empirically estimated parameters. Section 5 concludes.

2 Derivation of the Theoretical Model

2.1 Placing the Model in the Literature

Our open-economy model begins with the typical New Keynesian (NK) approach of **romera**; Blinder (1997), Clarida, Gali, and Gertler (1999), and Woodford (1999) and, in line with Clarida, Gali, and Gertler (2002), it incorporates the exchange rate. We also adopt the extensions of Gali and Monacelli (2005) and Engels (2009) that introduce Calvo pricing. Following Leitemo and Soderstrom (2005), we include exchange rate uncertainty in our NK model and analyse different monetary policy rules. Bekaert, Cho, and Moreno (2010), Paoli, Scott, and Weeken (2010), and Wu (2006) discuss including a financial market sector in an extended NK model. Brunnermeier and Sannikov (2012) also attempts to include an advanced financial market, albeit not in a NK model. Other research concentrates on monetary policy transmission channels. For example, Curdia and Woodford (2008, 2010) and Woodford (2010), include the credit channel in their NK models, while Christiano, Motto, and Rostagno (2010) and Gertler and Kiyotaki (2010) model a banking sector as a financial intermediary.

The switch from discrete to continuous time is in line with papers by Asada et al. (2006), Chen et al. (2006a,b), and Malikane and Semmler (2008a,b), but no previous NK approach has taken this step. As argued in Hayo and Niehof (2013), using a continuous-time framework makes it possible to consistently include state-of-the-art finance approaches in an open-economy NK macroeconomic framework, which is, to the best of our knowledge, a unique modelling approach. Thus, our core model is based on the New Keynesian model proposed by Smets and Wouters (2002, 2007). In addition, we follow Bekaert, Cho, and Moreno (2010) and incorporate a financial sector, represented by various markets, so as to analyse domestic and international financial spillover effects. We work within a continuous-time framework, in line with Asada et al. (2006) and Chen et al. (2006a,b). Hayo and Niehof (2013) show that continuous-time models yield more realistic dynamic adjustment patterns compared to discrete-time models in otherwise similarly specified models. Here, we extend the closed-economy model in Hayo and Niehof (ibid.) to a two-country open-economy setting with different Taylor rules-a standard open-economy rule and a modified open-economy rule that takes financial market developments into account.

2.2 Households

The representative household operates as a consumer with access to domestic and foreign goods. We assume that the economy is inhabited by a continuum of consumers $i \in [0,1]$. First, we consider a consumption index, such as that of Dixit and Stiglitz (1977), C_t (P_t) which consists of domestic goods $c_t^{d,j}$, produced by firm j, and foreign goods $c_t^{f,j}$, produced by a foreign firm j. η_d^c and η_f^x are the domestic and foreign demand elasticities, respectively. Similarly, we define a production price index P_t, using $p_t^{d,j}$ and $p_t^{f,j}$.

Intermediate goods from abroad can be imported and turned into either final consumption goods or final investment goods. Both are modelled in accordance with Dixit and Stiglitz (ibid.)

$$C_t^{d,f} = \left(\int_0^1 \left((C_t^j)^{d,f} \right)^{\frac{1}{\mu_t^{cm}}} dj \right)^{\mu_t^{cm}} \tag{1}$$

We start by deriving the optimal consumption choice. The consumption index for all goods j is defined following Dixit and Stiglitz (ibid.)

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

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

where C_t^d is domestic consumption and C_t^f are imported consumption goods. η_d^c, η_f^c are the domestic elasticities of consumption for domestically and foreign produced goods, respectively.

Solving this equation by forming a Langrangian and deriving the first-order conditions

(FOCs) reveals the typical characteristic of a Dixit-Stiglitz consumption index, namely

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

where ω_f is the share of imports in consumption, and η_c is the elasticity of substitution between domestic and foreign goods.

In a similar manner, we define an investment index

$$I_t^d = \left(\int_0^1 \left((I_t^j)^d\right)^{\frac{1}{\mu_t^i}} dj\right)^{\mu_t^i} \tag{5}$$

$$I_t^f = \left(\int_0^1 \left((I_t^j)^f\right)^{\frac{1}{\mu_t^i}} dj\right)^{\mu_t^i} \tag{6}$$

and

$$I_t = \left[\omega_i^{\frac{1}{\eta_i}} (I_t^d)^{\frac{\eta_i - 1}{\eta_i}} + (1-\omega_i)^{\frac{1}{\eta_i}} (I_t^f)^{\frac{\eta_i - 1}{\eta^i}}\right]^{\frac{\eta_i}{\eta_i - 1}} \tag{7}$$

Foreign demand for domestic consumption and investment goods is given by

$$C_t^x = \left(\frac{P_t^x}{P_t^*}\right)^{-\eta_m} C_t^* \qquad\qquad I_t^x = \left(\frac{P_t^x}{P_t^*}\right)^{-\eta_m} I_t^* \tag{8}$$

where C_t^*, I_t^*, P_t^* denote foreign aggregate consumption, investment and price level respectively. Accordingly, the aggregate price index is given by

$$P_t = \left[\omega (P_t^d)^{1-\eta_c} + (1-\omega)(P_t^f)^{1-\eta_c}\right]^{\frac{1}{1-\eta_c}} \tag{9}$$

with associated prices

$$P_t^d = \left[\int_0^1 \left(P_t^{d,j}\right)^{1-\eta_d^c} dj\right]^{\frac{1}{1-\eta_d^c}} \tag{10}$$

$$P_t^f = S_t \left[\int_0^1 \left(P_t^{f,j}\right)^{1-\eta_f^c} dj\right]^{\frac{1}{1-\eta_f^c}} \tag{11}$$

where S_t is the nominal exchange rate.

Consumption is maximised subject to $\int_0^1 (P_t^{d,j} C_t^{d,j} + P_t^{f,j} C_t^{f,j}) dj = Z_t$, where Z_t is expenditure.

Optimisation yields

$$C_t^{d,j} = \left(\frac{P_t^{d,j}}{P_t^d} \right)^{-\eta_d^c} C_t^d \tag{12}$$

$$C_t^{f,j} = \left(\frac{P_t^{f,j}}{P_t^f} \right)^{-\eta_f^c} C_t^f \tag{13}$$

which can be transformed to

$$C_t^d = \omega_f \left(\frac{P_t^d}{P_t} \right)^{-\eta_c} C_t \tag{14}$$

$$C_t^f = (1 - \omega_f) \left(\frac{P_t^f}{P_t} \right)^{-\eta_c} C_t \tag{15}$$

Export firms face

$$X_t = \left(\int_0^1 \left((X_t^j)^m \right)^{\frac{1}{\mu_t^x}} dj \right)^{\mu_t^x} \tag{16}$$

where X is the export sector (as in Justiniano, Primiceri, and Tambalotti (2010)), with time-varying mark-up mu_t^x.

Our discrete time model is based on Smets and Wouters (2002, 2007). We extend it following Paoli, Scott, and Weeken (2010) by including various types of assets in the household's budget constraint. We assume that there is a continuum of infinitely-lived households i.

Each household provides a different type of labour. Households seek to maximise the discounted sum of expected utilities with regard to consumption C_t, labour N_t and money M_t subject to a period-by-period budget constraint. Using a constant relative risk aversion utility function (CRRA), the representative household's lifetime utility can be written as

$$E_0 \sum_{t=0}^{\infty} \beta^t u_t^i \left(C_t^i, N_t^i, \frac{M_t^i}{P_t} \right) \tag{17}$$

where β is the discount factor. Specifically, it is

$$u_t^i = \epsilon_t^U \left(\frac{1}{1-\sigma_c} (C_t^i - hC_{t-1}^i)^{1-\sigma_c} + \frac{\epsilon_t^M}{1-\sigma_m} \left(\frac{M_t^i}{P_t} \right)^{1-\sigma_m} - \frac{\epsilon_t^L}{1+\sigma_l} \left(N_t^i \right)^{1+\sigma_l} \right) \tag{18}$$

where h represents an external habit formation, ϵ_t^U is a general shock to preferences, ϵ_t^L, and

ϵ_t^M are specific shocks to labour and money and σ_c, σ_m and σ_l are elasticities of consumption, money and labour. Households maximise their utility due to the intertemporal budget constraint

$$\begin{aligned}
&\frac{W_t^i}{P_t}N_t^i + R_t^k Z_t^i K_{t-1}^i - a(Z_t^i)K_{t-1}^i - \frac{(M_t^i - M_{t-1}^i)}{P_t} \\
&-\frac{B_t^i R_t^{-1} - B_{t-1}^i}{P_t} - \frac{S_t(B_t^i)^*(R_t^*)^{-1} - S_t(B_{t-1}^i)^*}{P_t} \\
&-\sum_{j=0}^{J}\left(\frac{V_{t,t+m}^B}{P_t}B_{t,j}^i - \frac{V_{t-1,t+m-1}^B}{P_t}B_{t-1,t+m}^i\right) \\
&-\sum_{j=0}^{J}\left(S_t\frac{(V_{t,t+m}^B)^*}{P_t}(B_{t,t+m}^i)^* - S_t\frac{(V_{t,t+m-1}^B)^*}{P_t}(B_{t-1,t+m}^i)^*\right) \\
&-\frac{(V_t^E Equ_t^i - V_{t-1}^E Equ_{t-1}^i)}{P_t} + \frac{Div_t}{P_t}Equ_{t-1}^i \\
&-\frac{(S_t(V_t^E)^*(Equ_t^i)^* - S_t(V_{t-1}^E)^*(Equ_{t-1}^i)^*)}{P_t} \\
&+\frac{S_t Div_t^*}{P_t}(Equ_{t-1}^i)^* - C_t - I_t^i - A_t^i - T_t = 0
\end{aligned} \tag{19}$$

where T are lump-sum taxes, W_t is the nominal wage rate, Div_t are dividends, and $(R_t^k Z_t^i - a(Z_t^i))K_{t-1}^i$ is the return on the real capital stock minus capital utilisation costs. Furthermore, B_t^i and $B_t^{*,i}$ denote domestic and foreign one-period bonds, and $B_{t,j}^n$ denotes a m-period bond with $V_{t,t+m}^B$ as its price. S_t is the exchange rate, Equ_t^i is a share in an equity index with value V_t^E, and A_t^i are stage-contingent claims, and I_t^i are investments in capital.

Furthermore, the formation of the capital stock evolves as

$$K_t^i = (1-\delta)K_{t-1}^i + \left(1 - V\left(\frac{I_t^i}{I_{t-1}^i}\right)\right)I_t^i \tag{20}$$

where δ is the depreciation rate and investment adjustment cost function $V(.)$ as in Smets and Wouters (2007).

2.3 Domestic Firms

2.3.1 Domestic Firms

Final goods are derived under monopolistic competition using a CES function

$$Y_t = \left(\int_0^1 (Y_t^j)^{\frac{1}{\mu_t^d}} dj \right)^{\mu_t^d} \tag{21}$$

where Y_t^j is the input of the intermediate good and μ_t^d is a price elasticity. Final goods producers minimise their costs subject to the production function

$$\max \left(P_t Y_t - \int_0^1 P_t^j Y_t^j \right) \tag{22}$$

2.4 Intermediate Firms

The intermediate goods Y_t^j are produced using a Cobb-Douglas production function

$$Y_t^j = z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha} (N_t^j)^{1-\alpha} \tag{23}$$

where Φ_t is the total factor productivity, ϵ_t^F is a technology shock, $\tilde{K}_t$ are capital services (ZK_{t-1}), z_t is a technology shock to both domestic and foreign economies, and N_t is labour input. Firm profits are immediately paid out as dividends

$$\frac{Equ_{t-1}^j Div_t^j}{P_t} = \frac{P_t^j}{P_t} Y_t^j - \frac{W_t}{P_t} N_t^j - R_t^k \tilde{K}_t^j \tag{24}$$

Nominal profits for firm j are therefore given by

$$\frac{Equ_t^i Div_t^i}{P_t} \pi_t^j = \left(\frac{P_t^j}{P_t} - MC_t \right) Y_t^j = \left(\frac{P_t^j}{P_t} - MC_t \right) \left(\frac{P_t}{P_t^j} \right)^{\frac{-\mu_t^d}{\mu_t^d - 1}} Y_t \tag{25}$$

The pricing kernel is derived from the FOCs of the households

$$\frac{\lambda_t}{P_t} = \beta E_t \left(\frac{(1+R_t)\lambda_{t+1}}{P_{t+1}} \right) \tag{26}$$

This gives the pricing kernel for the discount rate $\frac{1}{1+R_t}$.

Each period, a fraction of the firms $(1-\theta)$ are able to adjust prices, while the remainder follow a rule of thumb. We denote $\pi_t = \frac{P_t}{P_{t-1}}$ and π is the steady state inflation. The optimisation problem of the price-adjusting firm is:

$$E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(\frac{\overline{P_t^j}}{P_{t+s}} \prod_{l=1}^{s} (\pi_{t+l-1}^{\iota} \pi^{1-\iota}) - MC_{t+s} \right) Y_{t+s}^j \tag{27}$$

$$s.t. \left(\frac{\overline{P_t^j} \prod_{l=1}^{s} (\pi_{t+l-1}^{\iota} \pi^{1-\iota})}{P_{t+s}} \right)^{-\frac{\mu_{t+s}^d}{\mu_{t+s}^d - 1}} Y_{t+s} = Y_{t+s}^j \tag{28}$$

For the sake of simplification, we define $-\frac{\mu_{t+s}^d}{\mu_{t+s}^d - 1} = \delta$ We obtain

$$P_t = \left[\theta \left(P_{t-1} \pi_{t-1}^{\iota} \pi^{1-\iota} \right)^{\frac{1}{1-\mu_t^d}} + (1-\theta) \overline{P_t}^{\frac{1}{1-\mu_t^d}} \right]^{1-\mu_t^d} \tag{29}$$

2.5 Wage Setting

Each household sells its labour based on the Stiglitz labour bundling function

$$N_t = \left(\int_0^1 \left(N_t^i \right)^{\frac{1}{\gamma_n}} \right)^{\gamma_n} \tag{30}$$

where γ_n is the wage elasticity and $1 \leq \gamma_n < \infty$. Demand for labour is given by

$$N_t^i = \left(\frac{W_t^i}{W_t} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_t \tag{31}$$

Households experience a changing wage with random probability $1 - \theta_h$. The i^{th} household's reoptimised wage is $\overline{W_t^i}$, whereas the unchanged wage is given by $W_{t+1}^i = W_t^i \pi_t^{\iota_h} \pi^{1-\iota_h} \mu_z$, where μ_z is the steady state 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. Hence, wages evolve as

$$W_t = \left[\theta_h \left(W_{t-1} \pi_{t-1}^{\iota_h} \pi^{1-\iota_h} \mu_z) \right)^{\frac{1}{1-\gamma_n}} + (1-\theta_h) \overline{W_t}^{\frac{1}{1-\gamma_n}} \right]^{1-\gamma_n} \tag{32}$$

2.6 The Financial Sector

We follow Bekaert, Cho, and Moreno (2010) and Paoli, Scott, and Weeken (2010) and model bond and asset yields first in discrete time and then in to continuous time. Gertler, Kiyotaki, and Queralto (2012) apply a micro-based model and incorporate a banking sector and financial frictions. However, we focus on spillovers from the asset markets to the real economy and we are less interested in analysing intermediaries. Brunnermeier and Sannikov (2012) construct a macroeconomic model with an emphasis on variations in risk preferences and extent of information across households and financial experts. However, since the authors do not model real economic effects, their framework is not appropriate for our focus on financial and macroeconomic spillovers under different monetary policy rules. Therefore, we extend the NK framework by Paoli, Scott, and Weeken (2010) by defining different term structures and rigidities and moving the analysis to an open-economy setting.

When there are no frictions, the model exhibits the classic equity and term premia puzzle. As demonstrated by Campbell and Cochrane (1999) in the context of endowment economies, the puzzle can be solved via use of consumption habits. 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 are not sufficient. In other words, we need to ensure that households do not merely dislike consumption volatility, they have to be prevented from doing something about it; capital adjustment costs are one modelling device that can achieve this. The presence of state contingent claims implies that we can price all financial assets in the economy based on no-arbitrage arguments.

The presence of state contingent claims implies that we can price all financial assets in the economy based on no-arbitrage arguments.

We follow Binsbergen et al. (2012) and Paoli, Scott, and Weeken (2010) and model the term structure recursively. The following equation describes the classic relationship based on one-period nominal bonds

$$\frac{1}{R_t} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \tag{33}$$

$$\frac{1}{R_t^*} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \frac{S_{t+1}}{S_t} \right] \tag{34}$$

The uncovered interest rate parity condition (UIP) condition is given by the households FOCs

$$\frac{1}{R_t} = \frac{1}{R_t^*} E_t \left[\frac{S_{t+1}}{S_t} \right] \tag{35}$$

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

$$q_t^i = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \left(R_t^k Z_t^i - a(Z_t^i) \right) + q_{t+1}^i (1-\delta) \right) \tag{36}$$

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

$$-\lambda_t \frac{V_{t,1}^B}{P_t} = E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,0}}{P_{t+1}} \right] \tag{37}$$

$$\Leftrightarrow V_{t,1}^B = E_t \left[-\beta V_{t+1,0} \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \tag{38}$$

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

$$V_{t,t+m}^B = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} V_{t+1,t+m-1}^B \frac{P_t}{P_{t+1}} \right] \tag{39}$$

$$= E_t (SDF_{t+1} \pi_{t+1} V_{t+1,t+m-1}^B) \tag{40}$$

Assuming the price of a one–period bond to equal one ($V_{1,t} = 1$) in terms of one unit of consumption, we apply recursion and obtain

$$V_{t,t+m}^B = E_t ((SDF_{t+1} \pi_{t+1})^j) \tag{41}$$

Real yields are then given by

$$R_{t+1,t+m}^B = (V_{t,t+m}^B)^{-\frac{1}{j}} \tag{42}$$

The price of a one-period bond can also be written as

$$(V_{t,t+m}^B)^* = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} (V_{t+1,t+m-1}^B)^* \frac{P_t}{P_{t+1}} \right] \tag{43}$$

$$(R_{t+1,t+m}^B)^* = ((V_{t,t+m}^B)^*)^{-\frac{1}{j}} \tag{44}$$

Regarding the assets, we derive

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

with real return

$$R_{t+1}^E = \frac{V_t^E + Div_t}{V_t^E} \frac{P_t}{P_{t+1}}$$

is based on nonlinear but cointegrated relations. Thus, the model reconciles the non-stationary behaviour of consumption from the macroeconomics literature with the assumption of stationary interest rates in the finance literaturee[1]. Therefore, approximation would lead to a great loss of information.

2.7 The Monetary Policy Reaction Function

Since we want to compare two different types of monetary policy reaction, our simulations are based on two different Taylor rules. First, in line with 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), we employ a standard open-economy Taylor rule. Second, we modify this standard Taylor rule by accounting for central bank reaction to financial market developments. The modified Taylor rule takes the following form

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R_t} \right)^{\rho_R} \left[\left(\frac{\pi_t \pi}{\pi_{t-1}} \right)^{\psi_p i} \left(\frac{\pi_t^f \pi^f}{\pi_{t-1}^f} \right)^{\psi_{\pi f}} \left(\frac{Y_t}{Y_{t-1}} \right)^{\psi_Y} \left(\frac{S_t}{S_{t-1}} \right)^{\psi_S} \left(\frac{R_t^E}{R_{t-1}^E} \right)^{\psi_E} \right]^{1-\rho_{E*}} \eta_{mp,t} \quad (45)$$

where R^E represents the entire financial market, including bonds and stocks and $\eta_{mp,t}$ is a monetary policy shock.

$$log(\eta_{mp,t}) = \rho_{mp,t} \ \log(\eta_{mp,t-1}) + \epsilon_{mp,t} \quad (46)$$

where $\epsilon_{mp,t}$ is $i.i.d.\ N(0, \sigma_{mp}^2)$

Thus, our modified Taylor rule accounts for domestic and foreign output, the exchange rate,

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[1] Andreasen (2012), Andreasen (2010), and Wu (2006) show that this equals standard finance models such as Dai and Singleton (2000), Duffie and Kan (1996), and Duffie, Pan, and Singleton (2000)

inflation and the financial market. The rule facilitates analysing the 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; Rigobon and Sack 2003).

In contrast to our detailed modelling of monetary policy, government spending is solely dependent on cash balances and lump-sum taxes.

2.8 Market Clearing

To specifically analyse financial markets, we treat equities and bonds as financial instruments and assign them to a new sector, the financial market. A shortcoming of this sector is that it has no real purpose other than an allocative one. However, since our aim is to build a bridge between finance and macroeconomic research, we model financial instruments stochastically and hence this solely allocative purpose is appropriate for our purposes. Thus, market clearing is given by

$$Y_t = C_t^d + C_t^f + I_t^d + I_t^f + FM^d + FM^f + a(Z_t)K_{t-1} + G_t \tag{47}$$

where FM is the financial market sector.

3 The Continuous-Time Framework

To analyse discrete-time models, equities and bonds need to be linearised at least up to the second order; indeed, Andreasen (2012) even propose a third order so as to capture the time-varying effects of the term structure. However, linearisation would yield risk-neutral market participants, implying similar prices for all assets and making it difficult to study various financial markets Paoli, Scott, and Weeken (2010) and Wu (2006).

Hayo and Niehof (2013) propose another way of solving the nonlinear DSGE model, namely, by switching to continuous time. Hence, we turn a system of difference equations into a system of continuous-time equations. This has the added advantage of being able to include financial instruments in a more sophisticated way without losing information due to approximation. Our specification of the financial sector reflects our assumption of a simultaneously interacting stock market and house price index. Following Heston (1993), we model the stock market as a stochastic volatility model. This approach is an extension of Black and Scholes (1973) and takes account of the specific distribution of asset returns, leverage effects, and mean-reverting volatility, while remaining analytically tractable. To meet the assumption of highly interacting markets, we include the foreign stock market, house prices, exchange rates, output, and interest rates in the drift term of the stochastic differential equation. Shocks are included as Brownian motions. Including the output gap in the stock market follows 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 empirical findings by 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). Turning to our continuous-time approach, the stochastic differential equations regarding the financial market can be expressed as:

$$\begin{aligned} dS &= (S_t((r-\lambda\mu) + \rho_b b_t + \rho_b^* b_t^* + \rho_s^* S_t^* + \rho_i i_t + \rho_y y_t + \rho_e e_t + \rho_p i\pi_t)dt \\ &\quad + \sqrt{V_t} dW_S(t) + \sum_{i=1}^{dN_t} J(Q_i) \qquad (48) \\ dV_t &= \kappa(\theta - V_t)dt + \sigma\sqrt{V_t} dW_V(t) \\ dhb_t &= (\gamma_h h_t + \gamma_S S_t + \gamma_s^* S_t^* + \gamma_h^* h_t^* + \gamma_y y_t - \gamma_i(i_t - \pi_t))dt \\ &\quad + \sigma_1 dW_h^1(t) + \sigma_2 dW_h^2(t) + \sigma_3 dW_h^3(t) \qquad (49) \end{aligned}$$

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.

For example, we can then write the discrete model as

$$dK_t = (I_t - \delta K_t)dt + \left(1 + V\left(\frac{dI_t}{I_t dt}\right)\right) dI_t \tag{50}$$

$$dY_t = dC_t + dI_t + dFM_t + dG_t + a(dZ_t)K_t dt \tag{51}$$

Using some calculus, each difference equation can be transformed similarly into a differential equation (**hayo2013**).

4 Studying the Reaction of Monetary Policy After a Financial Market Crash

4.1 Simulating Economies

To analyse the contagious effects of financial crises for highly connected domestic and foreign real economies, we study the impulse responses following financial market turmoil in the form of a stock market and housing market crash. The second column of Table 1 contains the parameter values for our simulation analysis. 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 (Fernández-Villaverde 2010). The household's utility function is similar 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. We use monetary policy parameters similar to those of Adolfson et al. (2011) and Lindé (2005). The monetary policy parameter reflects our assumption that monetary policy has multiple goals. Further details can be found in the cited literature. We compare the ensuing adjustment process based on the two types of Taylor rules outlined above: the standard Taylor rule and the modified Taylor rule that takes financial markets into account. By comparing the advantages and disadvantages of both policy rules, we will shed light on the question of whether central banks should directly respond to financial market developments.

We commence the analysis by simulating a stock market crisis. Technically, we take the mean of 100,000 simulations with 0.01 time steps, which we interpret as 20 quarters. We use a normalised Euler-Maruyama scheme to simulate the trajectories of the stochastic differential equations.

Figure 1 shows the impulse-response functions after a contractionary monetary policy shock under the modified Taylor Rule in the domestic economy. The adjustment found under the standard Taylor rule is similar to that found in the extant literature. In the figures, the black lines represent the domestic economy; the dashed lines show how the spillovers affect the foreign economy. Both economies are the same size and have the same parameters. As expected, the contractionary policy causes a decrease in the inflation rate. However, due to a worsening of investment conditions, output drops too, which then causes monetary policy to change path and decrease the interest rate again. Thus, we find that our model can replicate important aspects of a business cycle.

Figures 2 to 5 display the impulse responses after a stock market shock originating in the domestic economy. We differentiate between a minor upset and a major stock market crash. Reactions to both events have a similar pattern, but are notably different in terms of magnitude. In the case of the minor stock market upset (see Figure 2), output drops by less than 1 percentage point. Yet, the modified Taylor rule triggers an immediate interest rate drop, which leads to a booming real economy and a notable increase in the inflation rate. Thus, under the modified rule we observe a notable spillover from minor financial market movements to the real economy. In contrast, the original Taylor rule reacts negligibly and financial markets are left to recover more or less on their own. Thus, under a standard Taylor rule, small movements in financial markets have very little effect on the real economy.

In case of a severe crisis, under the standard Taylor rule, after the domestic stock market crash, output and consumption begin to decline. Moreover, financial markets are positively connected and thus the drop in the domestic stock market causes a decline in the domestic house price index. Thus, the stock market crisis turns into a general financial market crisis, which brings about a decline in output. Reacting to the recession, the central bank starts lowering the interest rate, which triggers a depreciation of the exchange rate and helps with the recovery of the domestic economy. The domestic stock market shock and the following recession spill over to the foreign economy, causing a negative stock market development and a real economic downturn. The appreciating foreign exchange rate hinders the recovery of foreign output and forces the foreign central bank to lower the interest rate by more than seems necessary given the relatively mild recession. This rather loose foreign monetary policy causes a notable increase in the foreign inflation rate. Thus, we find that in the standard Taylor rule case, there are symmetric spillovers in real and financial variables, but asymmetric spillovers in the case of the inflation rate.

Looking now at the modified Taylor rule case, Figure 4, reveals some noteworthy differences from the standard Taylor rule case. First, and perhaps not surprisingly, monetary policy reacts even more quickly and much more forcefully. As a consequence, the domestic recession is not as deep as in the case of the standard Taylor rule. Second, domestic financial markets recover more quickly. Third, given the extremely expansionary monetary policy, inflation starts rising. Again, we find the domestic situation spilling over to the foreign country. However, this time the adjustment is basically mirroring the domestic country's development.

Tables 2 and 3 compare adjustment following the crisis under the two different Taylor rules, which basically boils down to a trade-off. On the one hand, the output gap declines less when monetary policy directly reacts to financial market variables. On the other hand, the interest rate decreases twice as much under the modified rule, with the consequence of domestic inflation.

Next, we analyse a crash in the house price index, which, in our framework, represents a country's real estate market. Under a standard Taylor rule, a housing market crash causes a major economic downturn in the real economy, as housing is not just a financial instrument but also a sector of the real economy (see Figure 6). Under the standard Taylor rule, declining GDP leads monetary policymakers to lower the interest rate. After some time, real and financial variables recover toward the steady state. This development also occurs in the foreign economy, except that the appreciating exchange rate causes the foreign central bank to lower interest rates by more than is warranted by the rather mild recession, resulting in inflation. Under the modified Taylor rule (Figure 7), stabilisation of the output gap is achieved somewhat more quickly, but the attempt to stabilise financial markets leads to a strong decline in domestic interest rates, resulting in inflation. Thus, after some time, there is a surge in the inflation rate of both countries. In regard to domestic and international financial market spillovers, the domestic housing market crisis causes foreign house prices to decline, as well as domestic and foreign stock prices, thus illustrating the interconnectedness of financial markets, both within as well as across borders.

Tables 2 and 3 show the differences between the standard and modified Taylor rule. The smaller decline in the output gap and the greater increase in the inflation rate under the modified rule is clearly demonstrated.

4.2 Employing Empirically Estimated Parameters

To ensure that our theoretical simulations are compatible with empirical evidence, we estimate model parameters using data from Canada and the United States. Reflecting our use of continuous-time equations, we rely on stochastic estimation (approximate Bayesian computation; see Beaumont, Zhang, and Balding (2002)).

Two inputs are crucial to obtaining plausible results via Marcov Chain Monte Carlo (MCMC) estimations: the choice of priors and the choice of initial values. Our choice of prior distributions for NK models is similar to that of Smets and Wouters (2002, 2007), Negro et al. (2007) or Lindé (2005).

We follow Kimmel (2007), Wright (2008) or Jones (2003) and choose normal distributions for our financial variables. The financial parameters take the natural conjugate g-prior specification so that each prior for a financial parameter is $N(0, \sigma^2(X_i' X_i)^{-1})$, conditional on σ^2. To account for quarterly data in macroeconomic variables, we select a tighter distribution and apply the standard normal distribution.

Data are obtained from the Bureau of Economic Analysis, the Federal Reserve Bank of St. Louis, the US Bureau of Labor Statistics, Statistics Canada, Datastream, and the OECD database. We employ quarterly data from 1981:Q1 to 2013:Q4. The output gap is based on the transitory component after applying the HP filter to logged quarterly GDP. The monetary policy interest rate is the short-term money market rate. The inflation series is constructed as $400(CPI_t/CPI_{t-1} - 1)$.

For the financial variables, we employ the major stock index in the United States, S&P, and that of Canada, TSX. We also include the housing market in both countries, represented by changes in the house price.

Columns 5 to 8 in Table 1 show that the posteriors are comparatively close to our calibrated parameters, suggesting that our choice of parameters for the simulation analyses is consistent with real-world data. Comparing the impulse-response functions given our estimated parameters, we observe a similar dynamic adjustment as described above (results available on request). This further supports our hypothesis of a strong linkage between monetary policy and financial markets and the importance of international spillovers.

We find spillover effects from monetary policy conducted by the United States, but only very small effects from policy initiated by the Bank of Canada. Moreover, US monetary policy appears to have a larger effect on Canada than does its own monetary policy. This finding is consistent with empirical evidence reported by Hayo and Neuenkirch (2012) on how monetary policy communication impacts financial markets in the two countries. We find no evidence that the Taylor rules of either central bank incorporate financial market variables. In line with our theoretical analysis, this might have amplified the effects of the crisis but avoided increasing inflation.

5 Conclusions

In this paper, we extend Smets and Wouters (2007) well-known open-economy New Keynesian model 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. This allows us to employ classic research from the field of finance and model the financial sector by means of the housing and stock markets. Given our two-country framework, we model the financial sector both in the domestic and in the foreign economy, thereby taking into account international economic interdependence over and above any linkages through the exchange rate. Applying stochastic differential equations allows us to rely on established research in finance, for instance, that of Merton (1973). In particular, we specify the financial markets as jump-diffusion processes and use the Black-Scholes equations Black and Scholes (1973) for call prices. Furthermore, we employ Lyapunov techniques Khasminskii (2012) to analyse the stability of the solutions and steady-state properties. We thus combine New Keynesian macroeconomic analysis, classic finance research, and standard mathematical procedures used for studying differential equations.

Our main research question concerns the effects of different monetary policy reactions and how variations in these affect the transmission of financial crises to real markets. Specifically, we compare a standard open-economy Taylor rule with a modified Taylor rule that directly takes financial market developments into account. In our simulation analysis based on theoretically derived impulse-response functions we find for both cases that a financial crisis, no matter whether it starts on the stock market or in the housing market, has negative spillovers to the domestic real economy. In addition, there are spillovers to the other country, both in terms of its financial markets as well as real economic variables. Given that we model the housing market as a sector of the real economy, the magnitude of the recession following a housing market crash is much larger than that which follows a stock market crash.

We also find notable differences in adjustment patterns depending on which type of Taylor rule is being applied. First, we discover that under a standard Taylor rule, the development of foreign variables mirrors that of domestic variables, but fluctuations are less pronounced. There is one exception, though, which is the inflation rate. The inflation rate remains roughly constant in the domestic economy, where the crisis originated, but it increases in the foreign country. This is because in the standard open-economy Taylor rule, the exchange rate is in the objective function of the central bank. Due to an appreciation of the foreign currency against the domestic currency, the foreign central bank lowers the interest rate by more than would be strictly necessary to stabilise the drop in the output gap and the resulting extremely expansionary monetary policy causes inflation. In the modified Taylor rule that contains financial market variables, we find again that there will be inflation in the domestic economy, as now monetary policy rates are decreased not only to counter the recession but also to stabilise financial markets.

Second, we find that the modified Taylor rule leads to a faster adjustment of both the domestic and foreign economy after a financial market crisis, as monetary policy reacts more quickly and more decisively compared to what occurs under the standard Taylor rule. Thus, we find that choosing a monetary policy rule involves a trade-off. If, on the one hand, policymakers put more weight on a quick stabilisation of both financial markets and real variables, they should adopt the modified Taylor rule. If, on the other hand, policymakers are concerned about inflation, they may be well advised to operate under the standard Taylor rule. To see whether our theoretical models have any implications for the real world, we use data from the United States and Canada to estimate the model parameters. Applying approximate Bayesian estimation techniques, we find that the estimated parameters are quite similar to our theoretical priors. However, most likely due to difference in size of the two countries' economies, we find strong spillovers from the United States to the Canada, but only very weak spillovers in the other direction. We find no evidence that the Taylor rules of either central bank incorporate financial market variables, which could explain why there has not been higher inflation, even in the face of extensive use of monetary policy in the period after the crisis and continuing to the present.

Our study has some interesting policy implications. Taking financial markets directly into account in the Taylor rule mitigates the severity of economic recessions in the aftermath of financial crises. However, the price could be a higher inflation rate and more volatility of other variables. While this may be a small price to pay in the case of a severe crisis, during normal times, the typical up and down movements of financial markets will be transmitted to, and magnified in, other economic variables. Given the rarity of major crises in advanced economies, this suggests that perhaps monetary policy should not include financial variables in its reaction function, but should have an emergency plan for quickly replacing rule-based monetary policy with discretion-based policy in the event of a major financial crisis. Regarding the international dimensions, we find evidence that it is not only financial and real shocks that spill over to other countries, but also monetary policy actions. Thus, monetary policy in one country can substantially affect financial markets in other countries, even to the extent of triggering booms and busts. The impact and size of the effect depends on, first, the linkage between the markets and, second, the structure of the markets. Policymakers, particularly those of very open and well-integrated countries, should consider that spillovers from their countries could have international effects that (depending on the degree of interaction) might be even larger than the intended effect on their own economy.

References

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.

Allsopp, Christopher and David Vines (2000). "The Assessment: Macroeconomic Policy". In: *Oxford Review of Economic Policy* 16(4), pp. 1–32.

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.

Asada, Toichiro et al. (2006). “Keynesian Dynamics and the Wage–Price Spiral: A Baseline Disequilibrium Model”. In: *Journal of Macroeconomics* 28(1), pp. 90–130.

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.

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.

Beaumont, Mark A, Wenyang Zhang, and David J Balding (2002). “Approximate Bayesian Computation in Population Genetics”. In: *Genetics* 162(4), pp. 2025–2035.

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.

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).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*, pp. 637–654.

Blanchard, Olivier (2007). “Real Wage Rigidities and the New Keynesian Model”. In: *Journal of Money, Credit and Banking* 39(1), pp. 35–65.

– (2008). “The State of Macro”. In: *National Bureau of Economic Research Working Paper Series* 14259.

Blinder, Alan (1997). “Is There A Core of Practical Macroeconomics That We Should All Believe?” In: *The American Economic Review* 87(2), pp. 240–243.

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.

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.

Chen, Pu et al. (2006a). “Keynesian Disequilibrium Dynamics: Convergence, Roads to Instability and the Emergence of Complex Business Fluctuations”. In: *Working Paper Series of the School of Finance and Economics* 146.

Chen, Pu et al. (2006b). “Keynesian Macrodynamics and the Philipps Curve. An Estimated Baseline Macromodel for the U.S. Economy”. In: *Quantitative Finance Research Centre Research Paper* 147.

Christiano, Lawrence, Roberto Motto, and Massimo Rostagno (2010). “Financial Factors in Economic Fluctuations”. In: *ECB Working Paper* 1192.

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.

– (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.

– (2010). “Credit Spreads and Monetary Policy”. In: *Journal of Money, Credit and Banking* 42(s1), pp. 3–35.

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.

Engels, Charles (2009). "Currency Misalignments and Optimal Monetary Policy: A Reexamination". In: *National Bureau of Economic Research Working Paper Series* w14829.

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.

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

Gali, Jordi and Tommaso Monacelli (2005). "Monetary Policy and Exchange Rate Volatility in a Small Open Economy". In: *Review of Economic Studies* 72(3), pp. 707–734.

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

Gertler, Mark and Nobuhiro Kiyotaki (2010). "Financial Intermediation and Credit Policy in Business Cycle Analysis". In: *Handbook of Monetary Economics* 3, pp. 547–599.

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 Matthias Neuenkirch (2012). "Domestic or U.S. News: What Drives Canadian Financial Markets?" In: *Economic Inquiry* 50(3), pp. 690–706.

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

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:

Jones, Christopher (2003). "The Dynamics of Stochastic Volatility: Evidence from Underlying and Options Markets". In: *Journal of Econometrics* 116(1), pp. 181–224.

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

Kass, Robert E and Adrian E Raftery (1995). "Bayes Factors". In: *Journal of the American Statistical Association* 90(430), pp. 773–795.

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

Kimmel, Robert (2007). "Maximum Likelihood Estimation of Stochastic Volatility Models". In: *Journal of Financial Economics* 83(2), pp. 413–452.

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

Leamer, Edward E (1985). "Sensitivity Analyses Would Help". In: *The American Economic Review* 75(3), pp. 308–313.

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.

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

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.

Malikane, Christopher and Willi Semmler (2008a). "Asset Prices, Output and Monetary Policy in a Small Open Economy". In: *Metronomica* 59(4), pp. 666–686.

– (2008b). "The Role of Exchange Rate in Monetary Policy Rules: Evidence from a Dynamic Keynesian Model". In: *Working Paper Series of the New School – Comparative Empirical Macroeconomics*.

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

Negro, Marco del et al. (2007). "On the Fit of New Keynesian Models". In: *Journal of Business and Economic Statistics* 25(2), pp. 123–143.

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.

Picchini, Umberto (2013). “Inference for SDE models via approximate Bayesian computation”. In: *Journal of Computational and Graphical Statistics* just-accepted.

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.

Romer, David (2000). “Keynesian Macroeconomics without the LM Curve”. In: *Journal of Economic Perspectives* 14(2), pp. 149–169.

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.

– (2001). “The Role of Exchange Rate in Monetary–Policy Rules”. In: *American Economic Review* 91(2), pp. 263–267.

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.

Wang, Jian and Jason Wu (2012). “The Taylor Rule and Forecast Intervals for Exchange Rates”. In: *Journal of Money, Credit and Banking* 44(1), pp. 103–144.

Woodford, Michael (1999). “Optimal Monetary Policy Inertia”. In: *National Bureau of Economic Research Working Paper Series* 7261.

Woodford, Michael (2010). “Financial Intermediation and Macroeconomic Analysis”. In: *The Journal of Economic Perspectives* 24(4), pp. 24–44.

Wright, Jonathan H. (2008). “Bayesian Model Averaging and Exchange Rate Forecasts”. In: *Journal of Econometrics* 146(2), pp. 329 –341.

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.*

Zellner, Arnold and Franz C Palm (2004). “Time Series Analysis and Simultaneous Equation Econometric Models”. In: *The Structural Econometric Time Series Analysis Approach*, 243ff.

6 Technical Appendix

Households

The household operates as a consumer with access to domestic and foreign goods. We assume that the economy is inhabited by a continuum of consumers $i \in [0,1]$. First, we consider a consumption index, such as that of Dixit and Stiglitz (1977), C_t (P_t), which consists of domestic goods $c_t^{d,j}$ produced by firm j and foreign goods $c_t^{f,j}$ produced by a foreign firm j. η_d^c and η_f^x are the demand elasticities. Similarly, we define a production index P_t, using $p_t^{d,j}$ and $p_t^{f,j}$.

Intermediate goods from abroad can be imported and turned into either final consumption goods or final investment goods. Both are modelled following Dixit and Stiglitz (ibid.)

$$C_t^m = \left(\int_0^1 \left((C_t^j)^m\right)^{\frac{1}{\mu_t^{cm}}} dj \right)^{\mu_t^{cm}} \tag{52}$$

We start by finding the optimal consumption bundle. The consumption index for all goods j is defined, again following Dixit and Stiglitz (ibid.) as

$$C_t^d = \left[\int_0^1 \left(C_t^{d,j}\right)^{\frac{\eta_d^c - 1}{\eta_d^c}} dj \right]^{\frac{\eta_d^c}{\eta_d^c - 1}} \tag{53}$$

$$C_t^f = \left[\int_0^1 \left(C_t^{f,j}\right)^{\frac{\eta_f^c - 1}{\eta_f^c}} dj \right]^{\frac{\eta_f^c}{\eta_f^c - 1}} \tag{54}$$

where C_t^d is domestic consumption and C_t^f are imported consumption goods. η_d^c, and η_f^c are the elasticities of consumption for domestic and foreign goods, respectively.

Solving this equation by forming a Langrangian and deriving the first order conditions (FOC) reveals the typical characteristic of a Dixit-Stiglitz consumption index, namely

$$C_t = \left[\omega_f \frac{1}{\eta_c} (C_t^d)^{\frac{\eta_c - 1}{\eta_c}} + (1-\omega_f)^{\frac{1}{\eta_c}} (C_t^f)^{\frac{\eta_c - 1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c - 1}} \tag{55}$$

where ω_f is the share of imports in consumption, and η_c is the elasticity of substitution across the two categories of goods.

In a similar manner, we define an investment index

$$I_t^d = \left(\int_0^1 \left((I_t^j)^d \right)^{\frac{1}{\mu_t^i}} dj \right)^{\mu_t^i} \tag{56}$$

$$I_t^f = \left(\int_0^1 \left((I_t^j)^f \right)^{\frac{1}{\mu_t^i}} dj \right)^{\mu_t^i} \tag{57}$$

and

$$I_t = \left[\omega_i^{\frac{1}{\eta_i}} \left(I_t^d\right)^{\frac{\eta_i - 1}{\eta_i}} + (1-\omega_i)^{\frac{1}{\eta_i}} \left(I_t^f\right)^{\frac{\eta_i - 1}{\eta^i}} \right]^{\frac{\eta_i}{\eta_i - 1}} \tag{58}$$

Foreign demand for domestic consumption and investment goods equals

$$C_t^x = \left(\frac{P_t^x}{P_t^*} \right)^{-\eta_m} C_t^* \qquad\qquad I_t^x = \left(\frac{P_t^x}{P_t^*} \right)^{-\eta_{m_2}} I_t^* \tag{59}$$

where C_t^*, I_t^*, P_t^* denote foreign consumption, investment and price level, respectively. Accordingly, the aggregate price index is given by

$$P_t = \left[\omega (P_t^d)^{1-\eta_c} + (1-\omega)(P_t^f)^{1-\eta_c} \right]^{\frac{1}{1-\eta_c}} \tag{60}$$

with associated prices

$$P_t^d = \left[\int_0^1 \left(P_t^{d,j} \right)^{1-\eta_d^c} dj \right]^{\frac{1}{1-\eta_d^c}} \tag{61}$$

$$P_t^f = S_t \left[\int_0^1 \left(P_t^{f,j} \right)^{1-\eta_f^c} dj \right]^{\frac{1}{1-\eta_f^c}} \tag{62}$$

where S_t is the nominal exchange rate.

Consumption is maximised subject to $\int_0^1 (P_t^{d,j} C_t^{d,j} + P_t^{f,j} C_t^{f,j}) dj = Z_t$, where Z_t are expenditures. Optimisation yields

$$C_t^{d,j} = \left(\frac{P_t^{d,j}}{P_t^d} \right)^{-\eta_d^c} C_t^d \tag{63}$$

$$C_t^{f,j} = \left(\frac{P_t^{f,j}}{P_t^f} \right)^{-\eta_f^c} C_t^f \tag{64}$$

This can be transformed into

$$C_t^d = \omega_f \left(\frac{P_t^d}{P_t}\right)^{-\eta_c} C_t \tag{65}$$

$$C_t^f = (1-\omega_f) \left(\frac{P_t^f}{P_t}\right)^{-\eta_c} C_t \tag{66}$$

On the other hand, export firms face

$$X_t = \left(\int_0^1 \left((X_t^j)^m\right)^{\frac{1}{\mu_t^x}} dj\right)^{\mu_t^x} \tag{67}$$

The price setting problems of importing and exporting firms are completely analogous to those of domestic firms. Demand for the differentiated goods is modelled as in Adolfson et al. (2011). Each household provides a different type of labour. Households seek to maximise the discounted sum of expected utilities with regard to consumption C_t, labour N_t and money M_t subject to a period-by-period budget constraint. Using a constant relative risk aversion utility function (CRRA), the representative household's lifetime utility can be written as

$$E_0 \sum_{t=0}^{\infty} \beta^t u_t^i \left(C_t^i, N_t^i, \frac{M_t^i}{P_t}\right) \tag{68}$$

where β is the discount factor. Specifically, it is

$$u_t^i = \epsilon_t^U \left(\frac{1}{1-\sigma_c}(C_t^i - hC_{t-1}^i)^{1-\sigma_c} + \frac{\epsilon_t^M}{1-\sigma_m}\left(\frac{M_t^i}{P_t}\right)^{1-\sigma_m} - \frac{\epsilon_t^L}{1+\sigma_l}\left(N_t^i\right)^{1+\sigma_l}\right) \tag{69}$$

where h represents external habit formation, ϵ_t^U is a general shock to preferences, ϵ_t^L, and ϵ_t^M are specific shocks to labour and money, and σ_c, σ_m, and σ_l are the elasticities of consumption, money and labour. Households maximise their utility based on the intertemporal budget constraint

$$
\begin{aligned}
&\frac{W_t^i}{P_t}N_t^i + R_t^k Z_t^i K_{t-1}^i - a(Z_t^i)K_{t-1}^i - \frac{(M_t^i - M_{t-1}^i)}{P_t} \\
&-\frac{B_t^i R_t^{-1} - B_{t-1}^i}{P_t} - \frac{S_t (B_t^i)^* (R_t^*)^{-1} - S_t (B_{t-1}^i)^*}{P_t} \\
&-\sum_{j=0}^{J}\left(\frac{V_{t,t+m}^B}{P_t}B_{t,j}^i - \frac{V_{t-1,t+m-1}^B}{P_t}B_{t-1,t+m}^i\right) \\
&-\sum_{j=0}^{J}\left(S_t\frac{(V_{t,t+m}^B)^*}{P_t}(B_{t,t+m}^i)^* - S_t\frac{(V_{t,t+m-1}^B)^*}{P_t}(B_{t-1,t+m}^i)^*\right) \\
&-\frac{(V_t^E Equ_t^i - V_{t-1}^E Equ_{t-1}^i)}{P_t} + \frac{Div_t}{P_t}Equ_{t-1}^i \\
&-\frac{(S_t (V_t^E)^* (Equ_t^i)^* - S_t (V_{t-1}^E)^* (Equ_{t-1}^i)^*)}{P_t} \\
&+\frac{S_t Div_t^*}{P_t}(Equ_{t-1}^i)^* - C_t - I_t^i - A_t^i - T_t = 0
\end{aligned}
\tag{70}
$$

Furthermore, households accumulate capital in the following form:

$$
K_t^i = (1-\delta)K_{t-1}^i + \left(1 - V\left(\frac{I_t^i}{I_{t-1}^i}\right)\right)I_t^i \tag{71}
$$

where δ is the depreciation rate and $V(.)$ is as in Smets and Wouters (2002).

We obtain the first order conditions

$$C_t^i: \quad \epsilon_t^U (C_t^i - h_t C_{t-1}^i)^{-\sigma_c} - \beta h E_t\left[\epsilon_{t+1}^U (C_{t+1}^i - h C_t^i)^{-\sigma_c}\right] - \lambda_t = 0 \tag{72}$$

$$N_t^i: \quad \epsilon_t^U \epsilon_t^L \left(N_t^i\right)^{\sigma_L} - \lambda_t \frac{W_t^i}{P_t} = 0 \tag{73}$$

$$\frac{M_t^i}{P_t}: \quad \epsilon_t^U \epsilon_t^M \left(\frac{M_t^i}{P_t}\right)^{-\sigma_m} - \lambda_t + \beta E_t\left[\lambda_{t+1}\frac{P_t}{P_{t+1}}\right] = 0 \tag{74}$$

$$B_t^i: \quad -\frac{\lambda_t}{R_t P_t} + \beta E_t\left[\frac{\lambda_{t+1}}{P_{t+1}}\right] = 0 \tag{75}$$

$$B_t^{*,i}: \quad -\frac{S_t \lambda_t}{R_t^* P_t} + \beta E_t\left[\frac{S_{t+1}\lambda_{t+1}}{P_{t+1}}\right] = 0 \tag{76}$$

$$Z_t^i: \quad R_t^k - a'(Z_t^i) = 0 \tag{77}$$

$$K_t^i: \quad \beta E_t\left[\lambda_{t+1}(R_t^k Z_t^i - a(Z_t^i))\right] - \varphi_t + \beta E_t\left[\varphi_{t+1}(1-\delta)\right] = 0 \tag{78}$$

$$I_t^i: \quad -\lambda_t + \varphi_t\left(1 - V\left(\frac{I_t^i}{I_{t-1}^i}\right)\right) - \varphi_t\left(\frac{I_t^i}{I_{t-1}^i} V'\left(\frac{I_t^i}{I_{t-1}^i}\right)\right) + \beta E_t\left(\varphi_{t+1}\left(\frac{I_{t+1}^i}{I_t^i}\right)^2 V'\left(\frac{I_{t+1}^i}{I_t^i}\right)\right) = 0 \tag{79}$$

$$Equ_t^i: \quad -\frac{\lambda_t V_t^E}{P_t} + \beta\left(E_t\left(\lambda_{t+1}\frac{V_t^E + Div_{t+1}^i}{P_{t+1}}\right)\right) = 0 \tag{80}$$

$$(Equ_t^i)^*: \quad -\frac{S_t \lambda_t (V_t^E)^*}{P_t} + \beta\left(E_t\left(\lambda_{t+1}\frac{S_{t+1}(V_t^E)^* + (S_{t+1}Div_{t+1})^*}{P_{t+1}}\right)\right) = 0 \tag{81}$$

$$B_{t,t+m}^i: \quad -\lambda_t \frac{V_{t,t+m}^B}{P_t} + E_t\left[\beta\lambda_{t+1}\frac{V_{t+1,t+m-1}^B}{P_{t+1}}\right] = 0 \tag{82}$$

$$(B_{t,t+m}^i)^*: \quad -\lambda_t \frac{(S_t V_{t,t+m}^B)^*}{P_t} + E_t\left[\beta\lambda_{t+1}\frac{(S_{t+1}V_{t+1,t+m-1}^B)^*}{P_{t+1}}\right] = 0 \tag{83}$$

Following Fernández-Villaverde (2010) we assume capital adjustment costs $a(.)$ to be like

$$a(u) := \gamma_1(u-1) + \gamma_2(u-1)^2$$

The investment adjustment cost function is

$$S\left(\frac{x_t}{x_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{x_t}{x_{t-1}} - \Lambda_x\right)^2$$

where $x_t = I_t^i$ and Λ_x is the growth rate of investment.

Firms

Domestic Firms

Final goods are derived under monopolistic competition using a CES function

$$Y_t = \left(\int_0^1 (Y_t^j)^{\frac{1}{\mu_t^d}} dj\right)^{\mu_t^d} dj \tag{84}$$

where Y_t^j is the input of the intermediate good and μ_t^d is a price mark-up. Final good producers minimise their costs subject to the production function

$$\max\left(P_t Y_t - \int_0^1 P_t^j Y_t^j\right) dj \tag{85}$$

The first order conditions are given by

$$0 = -P_t^j + P_t \mu_t^d \left(\int_0^1 (Y_t^j)^{\frac{1}{\mu_t^d}} dj\right)^{\mu_t^d - 1} \left(\frac{1}{\mu_t^d}(Y_t^j)^{\frac{1-\mu_t^d}{\mu_t^d}}\right) \tag{86}$$

$$\Leftrightarrow 0 = -P_t^j + P_t \left(\left(\int_0^1 (Y_t^j)^{\frac{1}{\mu_t^d}} dj\right)^{\mu_t^d}\right)^{\frac{\mu_t^d - 1}{\mu_t^d}} (Y_t^j)^{\frac{1-\mu_t^d}{\mu_t^d}} \tag{87}$$

$$\Leftrightarrow \frac{P_t^j}{P_t} = Y_t^{\frac{\mu_t^d - 1}{\mu_t^d}} (Y_t^j)^{-\frac{\mu_t^d - 1}{\mu_t^d}} \tag{88}$$

$$\Leftrightarrow Y_t^j = \left(\frac{P_t}{P_t^j}\right)^{\frac{\mu_t^d}{\mu_t^d - 1}} Y_t \tag{89}$$

Integrating Equation (**??**) into Equation (22) we obtain

$$Y_t = \left(\int_0^1 \left(\left(\frac{P_t}{P_t^j} \right)^{\frac{\mu_t^d}{\mu_t^d - 1}} Y_t \right)^{\frac{1}{\mu_t^d}} dj \right)^{\mu_t^d} \tag{90}$$

$$\Leftrightarrow Y_t = \left(\int_0^1 \left(\frac{P_t}{P_t^j} \right)^{\frac{1}{\mu_t^d - 1}} Y_t^{\frac{1}{\mu_t^d}} dj \right)^{\mu_t^d} \tag{91}$$

$$\Leftrightarrow Y_t = Y_t \left(\int_0^1 \left(\frac{P_t}{P_t^j} \right)^{\frac{1}{\mu_t^d}} \right)^{\mu_t^d} \tag{92}$$

$$\Leftrightarrow 1 = P_t^{\frac{\mu_t^d}{\mu_t^d - 1}} \left(\int_0^1 \left(P_t^j \right)^{-\frac{1}{\mu_t^d - 1}} dj \right)^{\mu_t^d} \tag{93}$$

$$\Leftrightarrow P_t^{-\frac{\mu_t^d}{\mu_t^d - 1}} = \left(\int_0^1 \left(P_t^j \right)^{\frac{1}{1 - \mu_t^d}} dj \right)^{\mu_t^d} \tag{94}$$

$$\Leftrightarrow P_t = \left(\int_0^1 \left(P_t^j \right)^{\frac{1}{1 - \mu_t^d}} dj \right)^{1 - \mu_t^d} \tag{95}$$

Intermediate Firms

The intermediate good Y_t^j is produced using a Cobb-Douglas production function

$$Y_t^j = z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^\alpha (N_t^j)^{1-\alpha} \tag{96}$$

where Φ_t is total factor productivity, ϵ_t^F is a technology shock, $\tilde{K}_t$ are capital services, z_t is a technology shock to the domestic and foreign economies, and, N_t is labour input. Firm profits are immediately paid out as dividends

$$\frac{Equ_{t-1}^j Div_t^j}{P_t} = \frac{P_t^j}{P_t} Y_t^j - \frac{W_t}{P_t} N_t^j - R_t^k \tilde{K}_t^j \tag{97}$$

Firms minimise their costs with respect to the production technology

$$\tilde{K}_t^j: \qquad R_t^k - \Gamma_t \alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha-1} (N_t^j)^{1-\alpha} \tag{98}$$

$$\Leftrightarrow \frac{R_t^k}{\alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha-1} (N_t^j)^{1-\alpha}} = \Gamma_t \tag{99}$$

$$N_t^j: \qquad \frac{W_t}{P_t} - \Gamma(1-\alpha) z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha} (N_t^j)^{-\alpha} = 0 \tag{100}$$

$$\Leftrightarrow \frac{W_t}{P_t(1-\alpha) z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha} (N_t^j)^{-\alpha}} = \Gamma_t \tag{101}$$

with Γ_t marginal costs. This implies

$$\frac{R_t^k}{\alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha-1} (N_t^j)^{1-\alpha}} = \frac{W_t}{P_t(1-\alpha) z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha} (N_t^j)^{-\alpha}} \tag{102}$$

$$\Leftrightarrow \frac{R_t^k}{W_t} = \frac{\alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha-1} (N_t^j)^{1-\alpha}}{P_t(1-\alpha) z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha} (N_t^j)^{-\alpha}} \tag{103}$$

$$\Leftrightarrow \frac{W_t}{R_t^k} = \frac{P_t(1-\alpha)\tilde{K}_t^j}{\alpha N_t^j} \tag{104}$$

$$\Leftrightarrow \tilde{K}_t^j = \frac{\alpha}{1-\alpha} \frac{W_t}{P_t R_t^k} N_t^j \tag{105}$$

We interpret the Lagrangian parameters as marginal costs

$$\frac{R_t^k}{\alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t (\frac{\alpha}{1-\alpha} \frac{W_t}{P_t R_t^k} N_t^j)^{\alpha-1} (N_t^j)^{1-\alpha}} = MC_t \tag{106}$$

$$\Leftrightarrow \frac{(R_t^k)^{\alpha} \left(\frac{W_t}{P_t}\right)^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha} z_t^{1-\alpha} \epsilon_t^F \Phi_t} = MC_t \tag{107}$$

Nominal profits for firm j are therefore given by

$$\pi_t^j = \left(\frac{P_t^j}{P_t} - MC_t\right) Y_t^j = \left(\frac{P_t^j}{P_t} - MC_t\right) \left(\frac{P_t}{P_t^j}\right)^{\frac{-\mu_t^d}{\mu_t^d - 1}} Y_t \tag{108}$$

The pricing kernel is derived from the FOCs of the households

$$\frac{\lambda_t}{P_t} = \beta E_t\left(\frac{(1+R_t)\lambda_{t+1}}{P_{t+1}}\right) \tag{109}$$

$$\Leftrightarrow \beta E_t(1+R_t) = E_t\frac{P_{t+1}}{\lambda_{t+1}}\frac{\lambda_t}{P_t} \tag{110}$$

This gives the pricing kernel for the discount rate $\frac{1}{1+R_t}$.

Each period a fraction of firms $(1-\theta)$ is able to adjust prices, the remaining fraction follows a rule of thumb. We denote $\pi_t = \frac{P_t}{P_{t-1}}$ and π is the steady state inflation.

$$E_t\sum_{s=0}^{\infty}(\beta\theta)^s\frac{\lambda_{t+s}}{\lambda_t}\left(\frac{\overline{P_t^j}}{P_{t+s}}\prod_{l=1}^{s}(\pi_{t+l-1}^{\iota}\pi^{1-\iota}) - MC_{t+s}\right)Y_{t+s}^j \tag{111}$$

$$s.t.\left(\frac{\overline{P_t^j}\prod_{l=1}^{s}(\pi_{t+l-1}^{\iota}\pi^{1-\iota})}{P_{t+s}}\right)^{-\frac{\mu_{t+s}^d}{\mu_{t+s}^d-1}} Y_{t+s} = Y_{t+s}^j \tag{112}$$

We define $-\frac{\mu_{t+s}^d}{\mu_{t+s}^d-1} = \mu_z$. The FOC is

$$E_t\sum_{s=0}^{\infty}(\beta\theta)^s\frac{\lambda_{t+s}}{\lambda_t}\left(\left(\frac{1}{P_{t+s}}\overline{P_t^j}\prod_{l=1}^{s}(\pi_{t+l-1}^{\iota}\pi^{1-\iota})\right)^{\mu_z+1}\frac{Y_{t+s}}{P_{t+s}^{\mu_z}} - MC_{t+s}\left(\overline{P_t^j}\prod_{l=1}^{s}(\pi_{t+l-1}^{\iota}\pi^{1-\iota})\right)^{\mu_z}\frac{Y_{t+s}}{P_{t+s}^{\mu_z}}\right) \tag{113}$$

Furthermore,

$$\begin{aligned} E_t\sum_{s=0}^{\infty}(\beta\theta)^s\frac{\lambda_{t+s}}{\lambda_t}\left(\left(\frac{1}{P_{t+s}}\right)\overline{P_t^j}^{\mu_z}(\mu_z+1)\left(\prod_{l=1}^{s}(\pi_{t+l-1}^{\iota}\pi^{1-\iota})\right)^{\mu_z+1}\frac{Y_{t+s}}{P_{t+s}^{\mu_z}}\right) \\ -E_t\sum_{s=0}^{\infty}(\beta\theta)^s\frac{\lambda_{t+s}}{\lambda_t}\left(MC_{t+s}\mu_z\overline{P_t^j}^{\mu_z a-1}\left(\prod_{l=1}^{s}(\pi_{t+l-1}^{\iota}\pi^{1-\iota})\right)^{\mu_z}\frac{Y_{t+s}}{P_{t+s}^{\mu_z}}\right) = 0 \end{aligned} \tag{114}$$

$$\begin{aligned} E_t\sum_{s=0}^{\infty}(\beta\theta)^s\frac{\lambda_{t+s}}{\lambda_t}\left(\left(\overline{P_t^j}^*\right)^{\mu_z}\left(\prod_{l=1}^{s}\frac{1}{\pi_{t+l}}\right)^{1+\mu_z}(1+\mu_z)\left(\prod_{l=1}^{s}(\pi_{t+l-1}^{\iota}\pi^{1-\iota})\right)^{\mu_z+1}Y_{t+s}\right) \\ -E_t\sum_{s=0}^{\infty}(\beta\theta)^s\frac{\lambda_{t+s}}{\lambda_t}\left(\mu_z MC_{t+s}\left(\overline{P_t^j}^*\right)^{\mu_z-1}\left(\prod_{l=1}^{s}\frac{1}{\pi_{t+l}}\right)^{\mu_z}\left(\prod_{l=1}^{s}(\pi_{t+l-1}^{\iota}\pi^{1-\iota})\right)^{\mu_z}Y_{t+s}\right) = 0 \end{aligned} \tag{115}$$

We obtain

$$
\begin{aligned}
P_t &= \left[\theta\left(P_{t-1}\pi_{t-1}^{\iota}\pi^{1-\iota}\right)^{\frac{1}{1-\mu_t^d}} + (1-\theta)\overline{P_t}^{\frac{1}{1-\mu_t^d}}\right]^{1-\mu_t^d} \\
\Leftrightarrow 1 &= \left[\theta\left(\pi_{t-1}\pi_{t-1}^{\iota}\pi^{1-\iota}\right)^{\frac{1}{1-\mu_t^d}} + (1-\theta)(\overline{P_t}^{*})^{\frac{1}{1-\mu_t^d}}\right]^{1-\mu_t^d}
\end{aligned} \tag{116}
$$

Wage Setting

Each household sells his labour based on the production function

$$
N_t = \left(\int_0^1 \left(N_t^i\right)^{\frac{1}{\gamma_n}}\right)^{\gamma_n} \tag{117}
$$

where γ_n is the wage mark-up and $1 \leq \gamma_n < \infty$. The demand for labour is given by

$$
N_t^i = \left(\frac{W_t^i}{W_t}\right)^{\frac{\gamma_n}{1-\gamma_n}} N_t \tag{118}
$$

Households face a random probability $1-\theta_h$ of changing nominal wage. The i^{th} household's reoptimised wage is $\overline{W_t^i}$, whereas the unchanged wage is given by $W_{t+1}^i = W_t^i \pi_t^{\iota_h}\pi^{1-\iota_h}\mu_z$, 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.

$$
N_{t+s}^i = \left(\frac{\overline{W_t^i}\prod_{l=1}^{s}\left(\pi_{t+l-1}^{\iota_h}\pi^{1-\iota_h}\mu_z\right)}{W_{t+s}}\right)^{\frac{\gamma_n}{1-\gamma_n}} N_{t+s} \tag{119}
$$

The Langrangian function is

$$
\begin{aligned}
&E_t\sum_{s=0}^{\infty}(\beta\theta_h)^s\left(-\frac{\epsilon_{t+s}^L}{1+\sigma_l}\left(N_{t+s}^i\right)^{1+\sigma_l} + \lambda_{t+s}\left(\frac{\overline{W_t^i}\prod_{l=1}^{s}\left(\pi_{t+l-1}^{\iota_h}\pi^{1-\iota_h}\mu_z\right)}{P_{t+s}}N_{t+s}\right)\right) \\
&\quad + E_t\sum_{s=0}^{\infty}(\beta\theta_h)^s\left(\lambda_{t+s}^b\left(N_t^i - \left(\frac{\overline{W_t^i}\prod_{l=1}^{s}\left(\pi_{t+l-1}^{\iota_h}\pi^{1-\iota_h}\mu_z\right)}{W_{t+s}}\right)^{\frac{\gamma_n}{1-\gamma_n}} N_{t+s}\right)\right)
\end{aligned} \tag{120}
$$

FOCs

$$\overline{W_t^i}: \quad E_t \sum_{s=0}^{\infty} (\beta\theta_h)^s \left(\lambda_{t+s} \frac{\prod_{l=1}^{s} \left(\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h} \mu_z\right)}{P_{t+s}} N_{t+s} \right)$$

$$-E_t \sum_{s=0}^{\infty} (\beta\theta_h)^s \left(\epsilon_{t+s}^L (\left(\frac{\overline{W_t^i} \prod_{l=1}^{s} \left(\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h} \mu_z\right)}{W_{t+s}} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_{t+s})^{\sigma_l+1} \frac{\gamma_n}{1-\gamma_n} \frac{1}{\overline{W_t^i}} \right) \quad (121)$$

Wages therefore evolve as

$$W_t = \left[\theta_h \left(W_{t-1} \pi_{t-1}^{\iota_h} \pi^{1-\iota_h} \mu_z \right)^{\frac{1}{1-\gamma_n}} + (1-\theta_h) \overline{W_t}^{\frac{1}{1-\gamma_n}} \right]^{1-\gamma_n} \quad (122)$$

The Financial Sector

We follow Binsbergen et al. (2012) and Paoli, Scott, and Weeken (2010) and model the term structure recursively. Using one-period nominal bonds, we derive the classic relationship

$$\frac{1}{R_t} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \quad (123)$$

$$\frac{1}{R_t^*} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \frac{S_{t+1}}{S_t} \right] \quad (124)$$

Remember that

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

The UIP condition is similarly given by the households' FOCs

$$\frac{1}{R_t} = \frac{1}{R_t^*} E_t \left[\frac{S_{t+1}}{S_t} \right] \quad (125)$$

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

$$q_t^i = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \left(R_t^k Z_t^i - a(Z_t^i) \right) + q_{t+1}^i (1-\delta) \right) \quad (126)$$

More generally, the FOCs are given as

$$\tag{127}$$

$$Equ_t^i: \quad -\frac{\lambda_t V_t^E}{P_t} + \beta\left(E\left(\lambda_{t+1}\frac{V_t^E + Div_{t+1}^i}{P_{t+1}}\right)\right) = 0 \tag{128}$$

$$(Equ_t^i)^*: \quad -\frac{S_t\lambda_t(V_t^E)^*}{P_t} + \beta\left(E\left(\lambda_{t+1}\frac{S_{t+1}(V_t^E)^* + (S_{t+1}Div_{t+1})^*}{P_{t+1}}\right)\right) = 0 \tag{129}$$

$$B_{t,t+m}^i: \quad -\lambda_t\frac{V_{t,t+m}^B}{P_t} + E_t\left[\beta\lambda_{t+1}\frac{V_{t+1,t+m-1}^B}{P_{t+1}}\right] = 0 \tag{130}$$

$$(B_{t,t+m}^i)^*: \quad -\lambda_t\frac{(S_tV_{t,t+m}^B)^*}{P_t} + E_t\left[\beta\lambda_{t+1}\frac{(S_{t+1}V_{t+1,t+m-1}^B)^*}{P_{t+1}}\right] = 0 \tag{131}$$

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

$$-\lambda_t\frac{V_{t,1}^B}{P_t} = E_t\left[\beta\lambda_{t+1}\frac{V_{t+1,0}}{P_{t+1}}\right] \tag{132}$$

$$\Leftrightarrow V_{t,1}^B = E_t\left[-\beta V_{t+1,0}\frac{\lambda_{t+1}}{\lambda_t}\frac{P_t}{P_{t+1}}\right] \tag{133}$$

For $m = 2$ it is

$$-\lambda_t\frac{V_{t,2}^B}{P_t} = E_t\left[\beta\lambda_{t+1}\frac{V_{t+1,1}}{P_{t+1}}\right] \tag{134}$$

$$\Leftrightarrow V_{t,2}^B = E_t\left[-\beta V_{t+1,1}\frac{\lambda_{t+1}}{\lambda_t}\frac{P_t}{P_{t+1}}\right] \tag{135}$$

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

$$V_{t,t+m}^B = E_t\left[-\beta\frac{\lambda_{t+1}}{\lambda_t}V_{t+1,t+m-1}^B\frac{P_t}{P_{t+1}}\right] \tag{136}$$

$$= E_t(SDF_{t+1}\pi_{t+1}V_{t+1,t+m-1}^B) \tag{137}$$

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

$$V_{t,t+m}^B = E_t((SDF_{t+1}\pi_{t+1})^j) \tag{138}$$

Real yields are then given by

$$R^B_{t+1,t+m} = (V^B_{t,t+m})^{-\frac{1}{j}} \tag{139}$$

Similarly the following equation holds

$$(V^B_{t,t+m})^* = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} (V^B_{t+1,t+m-1})^* \frac{P_t}{P_{t+1}} \right] \tag{140}$$

$$(R^B_{t+1,t+m})^* = ((V^B_{t,t+m})^*)^{-\frac{1}{j}} \tag{141}$$

Regarding the financial variables 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

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

7 Figures and Tables

Figure 1: **Monetary Policy Shock - Modified Monetary Policy**

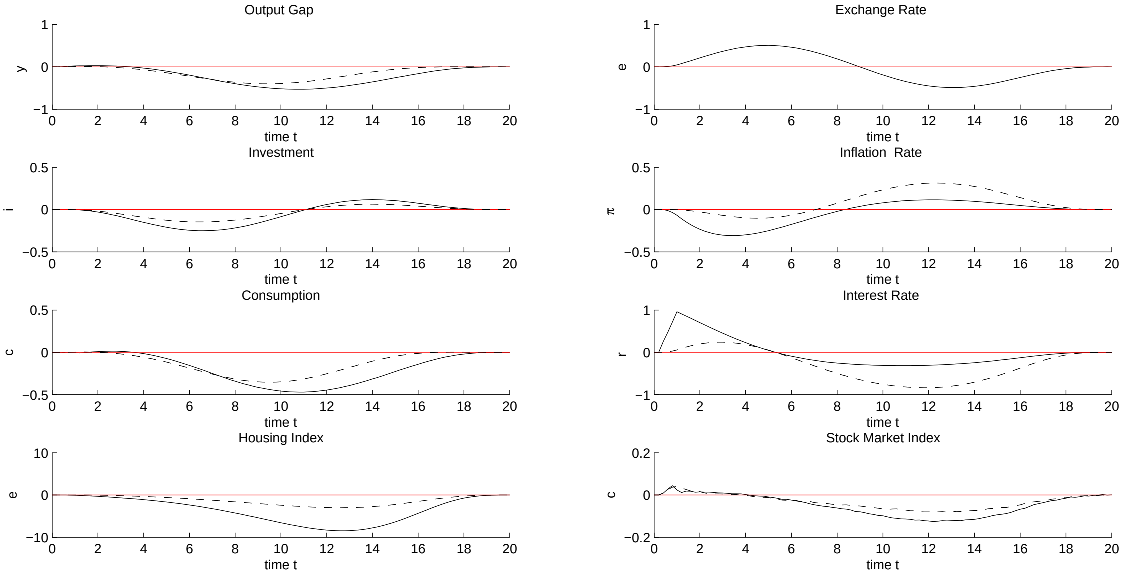

Figure 2: **Minor Stock Market Crisis - Modified Monetary Policy**

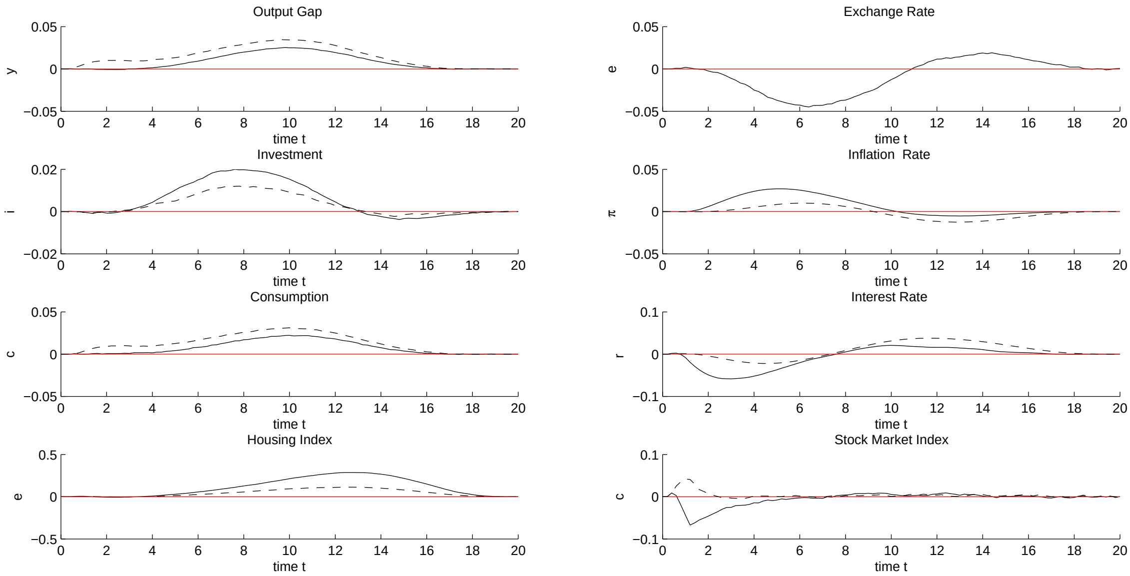

Figure 3: **Minor Stock Market Crisis - Standard Monetary Policy**

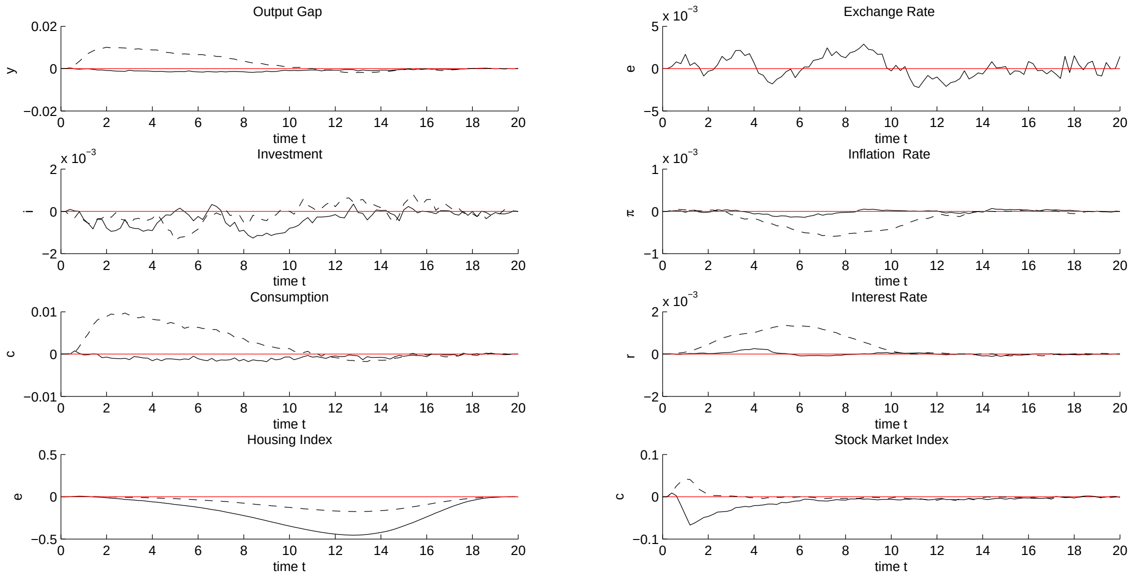

Figure 4: **Stock Market Crisis - Modified Monetary Policy**

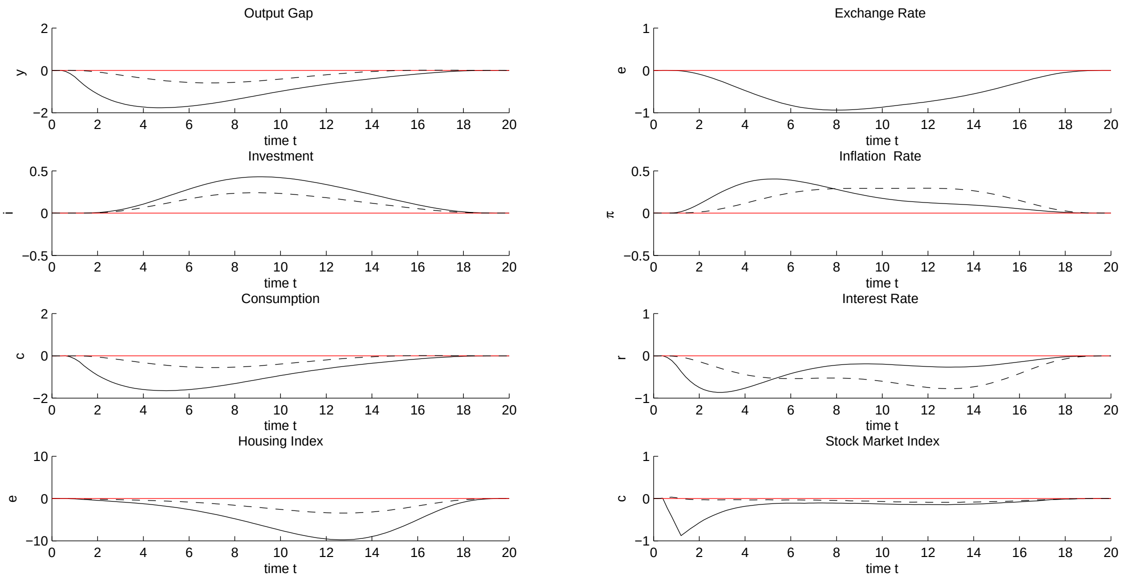

Figure 5: **Stock Market Crisis - Standard Monetary Policy**

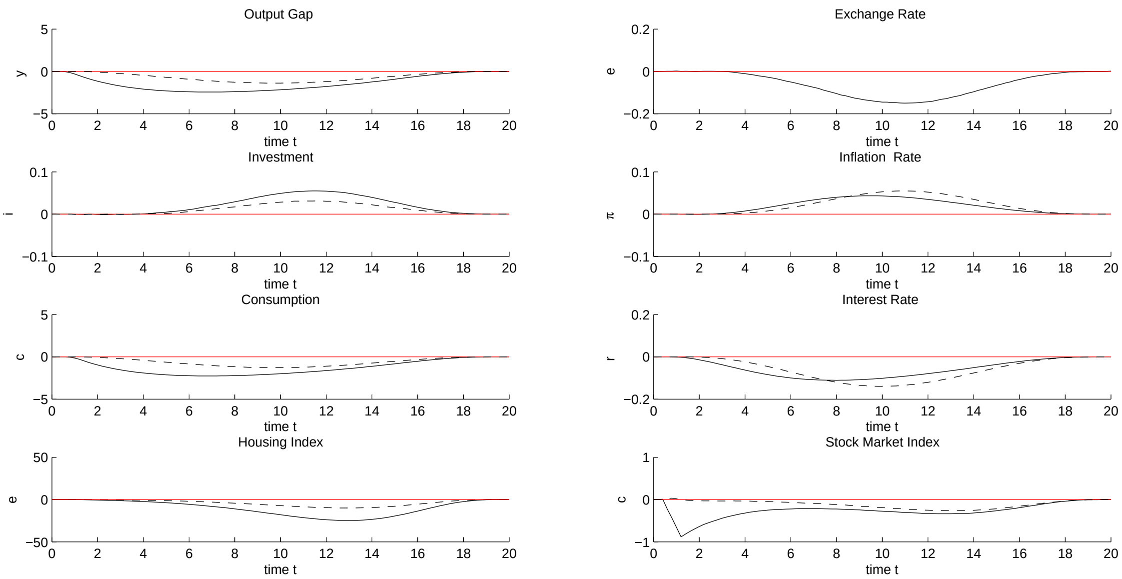

Figure 6: **Housing Market Crisis - Modified Monetary Policy**

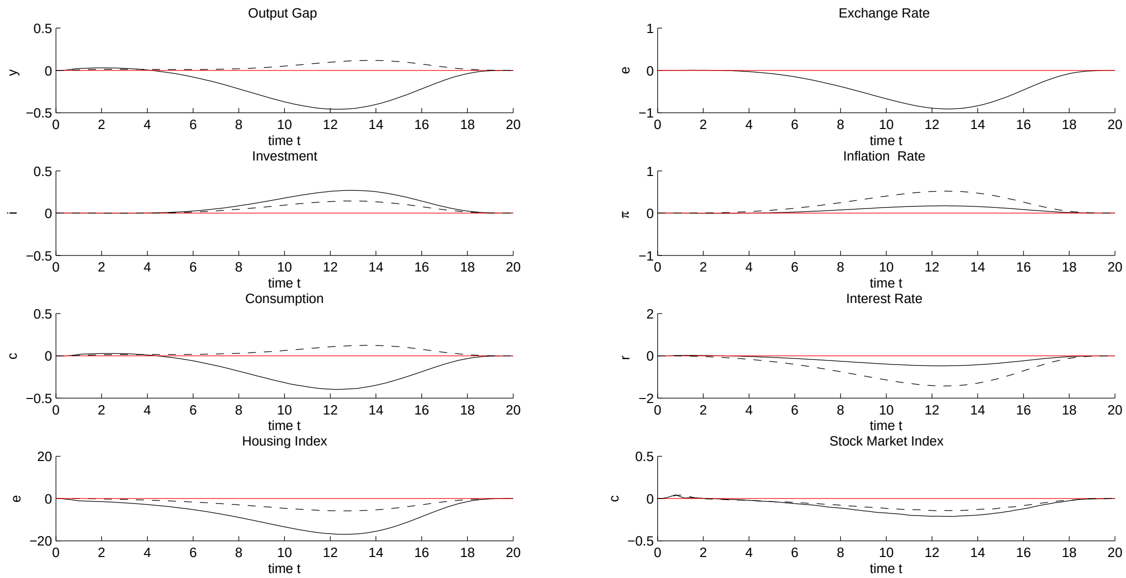

Figure 7: **Housing Market Crisis - Standard Monetary Policy**

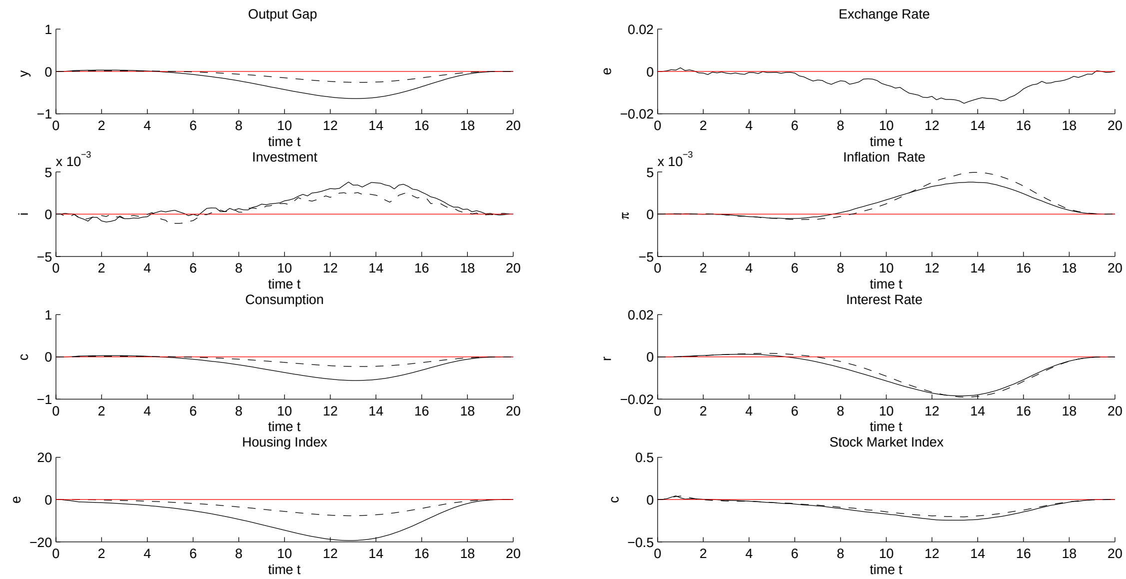

Table 1: Priors and Posteriors

			Prior		Post. USA		Post. Can	
Variable	Parameter	Dist	Mean	Std	Mean	Std	Mean	Std
μ_t^{cm}	5.00	-	-	-	-	-	-	-
η_d^c	1.50	-	-	-	-	-	-	-
η_f^c	1.30	-	-	-	-	-	-	-
η^c	2.00	-	-	-	-	-	-	-
ω_f	0.75	-	-	-	-	-	-	-
μ_t^i	1.50	-	-	-	-	-	-	-
η_i	2.00	-	-	-	-	-	-	-
η_m	0.20	-	-	-	-	-	-	-
ω_i	0.80	-	-	-	-	-	-	-
μ_t^x	3.00	-	-	-	-	-	-	-
ω	0.75	-	-	-	-	-	-	-
β	0.99	Gamma	1.00	0.20	1.19	0.12	1.14	0.20
σ_c	1.20	Normal	1.50	0.50	1.24	0.11	1.23	0.50
σ_l	1.25	Normal	2.00	0.75	2.85	0.69	2.83	0.19
σ_m	1.00	Normal	1.50	0.50	1.31	0.87	1.44	0.48
h	0.97	Beta	0.70	0.10	0.72	0.36	0.71	0.20
δ	0.30	Beta	0.50	0.15	0.28	0.16	0.26	0.35
μ_t^d	0.30	Beta	0.50	0.15	0.32	0.00	0.33	0.22
α	0.20	Normal	0.30	0.10	0.24	0.00	0.24	0.56
θ	0.75	Beta	0.50	0.15	0.77	0.12	0.78	0.68
ι	0.60	-	-	-	-	-	-	-
π	1.02	Gamma	1.50	0.20	0.71	0.52	0.69	0.73
γ_n	0.50	Beta	0.50	0.15	0.44	0.00	0.39	0.32
ι_l	0.60	-	-	-	-	-	-	-
θ_h	0.68	Beta	0.50	0.15	0.79	0.61	0.78	0.48
ρ_R	0.75	Beta	0.75	0.10	0.83	0.47	0.81	1.16
$\psi_p i$	1.20	Normal	1.50	0.25	1.46	1.19	1.79	1.51
ψ_Y	0.30	Normal	0.50	0.25	0.09	0.90	0.22	0.31
ψ_h	0.10	Normal	0.50	0.25	0.25	0.31	0.23	0.22

ψ_{h^*}	0.25	Normal	0.50	0.25	0.09	0.50	0.13	0.14
ψ_s	0.10	Normal	0.50	0.25	0.24	0.60	0.23	0.27
ψ_{s^*}	0.05	Normal	0.50	0.25	0.04	0.15	0.15	0.37
ψ_{fx}	0.20	Normal	0.50	0.25	0.25	0.30	0.35	0.22
ρ_h	0.20	Normal	0.00	1.00	0.25	0.67	0.53	0.51
ρ_s	0.80	Normal	0.00	1.00	0.97	0.31	0.67	0.51
ρ_{h^*}	0.10	Normal	0.00	1.00	0.25	0.90	0.31	0.32
ρ_{s^*}	0.10	Normal	0.00	1.00	0.63	0.53	0.31	0.62
ρ_r	0.95	Normal	0.00	1.00	1.75	0.30	1.37	0.34
ρ_{r^*}	0.10	Normal	0.00	5.00	0.04	0.04	0.09	1.82
ρ_y	0.80	Normal	0.00	1.00	0.72	0.45	0.92	0.47
ρ_{fx}	0.50	Normal	0.00	1.00	0.46	0.02	0.93	2.14
$\rho_p i$	0.25	Normal	0.00	1.00	0.89	0.19	0.98	0.91
γ_h	0.80	Normal	0.00	1.00	2.37	2.01	1.34	0.22
γ_s	0.30	Normal	0.00	1.00	1.53	0.26	0.28	0.91
γ_{h^*}	0.90	Normal	0.00	1.00	1.07	2.61	0.58	1.68
γ_{s^*}	0.90	Normal	0.00	1.00	1.04	0.37	0.61	0.31
γ_r	0.90	Normal	0.00	1.00	0.99	0.79	0.85	0.99
γ_y	0.50	Normal	0.00	1.00	0.69	0.85	0.74	0.08

Table 2: Extreme Values of the Simulated NK model: Maximum

Max	Modified Taylor Rule				Original Taylor Rule			
shocks:	mon. pol.	stock	bond	minor stock	mon. pol.	stock	bond	minor stock
y	0.000	0.002	0.028	0.025	0.000	0.002	0.028	0.000
y^*	0.000	0.009	0.012	0.035	0.000	0.002	0.012	0.010
S	0.537	0.001	0.003	0.019	0.396	0.002	0.004	0.003
I	0.115	0.430	0.541	0.020	0.097	0.055	0.025	0.000
I^*	0.389	0.241	0.301	0.012	0.056	0.031	0.015	0.001
π	0.000	0.404	0.598	0.027	0.000	0.043	0.032	0.000
π^*	0.536	0.295	0.747	0.010	0.000	0.055	0.029	0.000
C	0.000	0.003	0.026	0.022	0.000	0.003	0.027	0.001
C^*	0.000	0.012	0.013	0.031	0.000	0.002	0.011	0.010
R	0.942	0.002	0.021	0.021	0.940	0.000	0.001	0.000
R^*	0.235	0.000	0.000	0.038	0.000	0.000	0.001	0.001
B	0.001	0.001	0.000	0.286	0.001	0.001	0.000	0.006
B^*	0.006	0.001	0.001	0.113	0.008	0.001	0.001	0.003
N	0.083	0.009	0.041	0.009	0.044	0.009	0.041	0.009
N^*	0.082	0.032	0.040	0.042	0.081	0.032	0.040	0.042

Table 3: Extreme Values of the Simulated NK Model: Minimum

Min	Modified Taylor Rule				Original Taylor Rule			
shocks:	mon. pol.	stock	bond	minor stock	mon. pol.	stock	bond	minor stock
y	-3.786	-1.766	-2.989	-0.001	-4.227	-2.439	-5.506	-0.002
y^*	-0.917	-0.592	-0.440	0.000	-1.230	-1.384	-1.515	-0.002
S	-1.231	-0.939	-1.722	-0.045	-0.001	-0.150	-0.089	-0.002
I	-0.087	0.000	-0.002	-0.004	-0.105	-0.001	-0.001	-0.001
I^*	-0.274	0.000	-0.001	-0.002	-0.255	-0.001	-0.002	-0.001
π	-0.783	0.000	-0.004	-0.005	-1.578	-0.001	0.000	0.000
π^*	-0.236	0.000	0.000	-0.012	-0.386	0.000	0.000	-0.001
C	-3.341	-1.648	-2.609	0.000	-3.864	-2.263	-4.780	-0.002
C^*	-0.770	-0.555	-0.374	0.000	-1.151	-1.275	-1.352	-0.002
R	-2.213	-0.865	-1.615	-0.059	-0.867	-0.111	-0.155	0.000
R^*	0-2.077	-0.777	-2.080	-0.022	-0.506	-0.139	-0.110	0.000
B	-13.622	-9.763	-20.878	-0.007	-16.467	-24.783	-29.687	-0.455
B^*	-4.485	-3.442	-7.212	-0.003	-6.176	-9.991	-11.533	-0.176
N	-0.747	-0.877	-1.116	-0.067	-0.761	-0.883	-2.198	-0.067
N^*	-1.204	-0.090	-0.197	-0.004	-1.698	-0.265	-0.372	-0.008

Table 4: Selected Extreme Values of Estimated NK Model

	Minimum							
	Taylor Modified				Taylor Original			
	Pre-Crisis		After Crisis		Pre-Crisis		After Crisis	
	US	CA	US	CA	US	CA	US	CA
y	-0.195	-0.212	-0.207	-0.232	-0.194	-0.214	-0.202	-0.230
π	-0.002	-0.042	-0.009	-0.048	-0.011	-0.039	-0.009	-0.035
e	-0.013	0.000	-0.009	0.000	-0.018	0.000	-0.023	0.000
h	-0.055	-0.166	-0.069	-0.181	-0.061	-0.169	-0.060	-0.187
s	98.137	96.219	98.256	96.274	98.232	96.268	98.023	96.164
i	-0.261	-0.260	-0.280	-0.268	-0.262	-0.258	-0.264	-0.262

	Maximum							
	Taylor Modified				Taylor Original			
	Pre-Crisis		After Crisis		Pre-Crisis		After Crisis	
	US	CA	US	CA	US	CA	US	CA
y	0.004	0.000	0.002	0.000	0.000	0.000	0.001	0.000
π	0.007	0.003	0.003	0.001	0.002	0.001	0.000	0.002
e	0.003	0.000	0.004	0.000	0.001	0.000	0.000	0.000
h	0.004	0.021	0.002	0.031	0.002	0.025	0.002	0.019
s	100.006	100.000	100.044	100.000	100.038	100.000	100.042	100.000
i	0.023	0.000	0.027	0.000	0.028	0.000	0.032	0.000