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Financial Factors and Monetary Policy: Determinacy and Learnability of Equilibrium

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Abstract

This paper contributes to the debate whether central banks should respond to asset prices, credit spreads and other financial factors in setting monetary policy, by evaluating determinacy and expectational stability of equilibria under various monetary policy rules. With adaptive learning, beliefs constitute an additional set of state variables, which may require more than a response to inflation, that has traditionally been argued in the literature as sufficient to achieve central bank objectives under rational expectations. Furthermore, financial frictions are introduced by extending the determinacy and adaptive learning methodology embodied in Bullard and Mitra (2002) and Bullard and Mitra (2007), beyond the New Keynesian modelling framework by incorporating a Financial Accelerator (Bernanke, Gertler and Gilchrist 1999). A key result is that monetary policy rules responding to lagged asset prices and credit volume have less desirable determinacy and learnability characteristics than responding to current asset prices and credit spreads. This conclusion dovetails with recent research such as Gilchrist and Zakrajsek (2011) and Gilchrist and Zakrajsek (2012), who show that signals derived from credit spreads contain information which help explain business cycle fluctuations and demonstrate that a credit spread augmented monetary policy rule dampens cycle variability. Another result is that the conclusions in both Bullard and Mitra (2002) and Bullard and Mitra (2007) are robust to a New Keynesian model with financial frictions.

Keywords

DSGE, financial frictions, learning, determinacy, e-stability, expectations, asset prices, credit spreads, financial factors, monetary policy, Taylor rule

JEL Classification

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This paper contributes to the debate whether central banks should respond to asset prices, credit spreads and other financial factors in setting monetary policy, by evaluating determinacy and expectational stability of equilibria under various monetary policy rules. With adaptive learning, beliefs constitute an additional set of state variables, which may require more than a response to inflation, that has traditionally been argued in the literature as sufficient to achieve central bank objectives under rational expectations. Furthermore, financial frictions are introduced by extending the determinacy and adaptive learning methodology embodied in Bullard and Mitra (2002) and Bullard and Mitra (2007), beyond the New Keynesian modelling framework by incorporating a Financial Accelerator (Bernanke, Gertler and Gilchrist 1999). A key result is that monetary policy rules responding to lagged asset prices and credit volume have less desirable determinacy and learnability characteristics than responding to current asset prices and credit spreads. This conclusion dovetails with recent research such as Gilchrist and Zakrajsek (2011) and Gilchrist and Zakrajsek (2012), who show that signals derived from credit spreads contain information which help explain business cycle fluctuations and demonstrate that a credit spread augmented monetary policy rule dampens cycle variability. Another result is that the conclusions in both Bullard and Mitra (2002) and Bullard and Mitra (2007) are robust to a New Keynesian model with financial frictions.

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1 Introduction

1.1 Overview

Events such as the Global Financial Crisis (GFC) in 2007-2009, the LTCM and Asian crises of 1997-1998, the bursting of the Japanese property bubble in 1989 and the “Lost Decade” that ensued, together with the stock market crash of 1929 and the “Great Depression” that followed, have inspired research into the links between financial variables and the real economy. Recent empirical studies such as Christiano, Motto and Rostagno (2010b) and Gilchrist and Zakrajsek (2012) demonstrate the important role that financial factors play in explaining business cycle fluctuations. If these conclusions are accepted, should monetary policy rules, determined by central banks to set the policy interest rate, respond to financial factors?

Traditional literature, such as Bernanke and Gertler (1999), answer this question negatively, since in the presence of shocks, a response to inflation is as sufficient response to all relevant state variables to achieve the objectives of the monetary authority. In other words, financial factor effects are captured by inflation, under rational expectations. This motivates an experiment with a small departure from rational expectations, namely considering the same question where expectations are generated using adaptive learning. Under learning, beliefs constitute an additional set of state variables, which may require more than a response to inflation, to achieve the objectives of central banks.

This paper evaluates monetary policy rule response to financial factors according to two desirable criteria, closely following the approach of Bullard and Mitra (2002). The first criterion is determinacy of Rational Expectations Equilibria (REE) and the second, under adaptive learning, is the expectational stability (e-stability) of equilibria. A determinate or unique REE is desirable under a given policy rule since with indeterminacy it is difficult to predict future system dynamics. Also, if a central bank follows a rule that induces indeterminacy, as Bullard and Mitra (2002) argue, the system may be unexpectedly volatile as the agents are unable to coordinate on a particular equilibrium among the many that exist. Bullard and Mitra (2002) also propose that economists only advocate policy rules that imply learnable REE, which is governed by e-stability for a broad class of models, including the model presented herein. If agents can learn the REE under a given monetary policy rule then private agents can coordinate on the targeted equilibrium by the central bank, as the

learning dynamics converge with those under rational expectations. Under learning, agents are assumed initially not to have rational expectations but act like econometricians and update their forecasts using a stochastic recursive algorithm such as least squares Evans and Honkapohja (2001). The forecasts introduce an expanded set of state variables that may be relevant in considering the merit of policy response to financial factors, as argued above.

The model chosen for determinacy and e-stability analysis here is Bernanke et al. (1999) (hereinafter BGG). BGG is a New Keynesian, Dynamic Stochastic General Equilibrium (DSGE) model with an embedded financial friction, which arises from the inclusion of a financial intermediary. An optimal financial contract featuring information asymmetry between borrowers and the financial intermediary also appears in this framework. Consequently, the model has three endogenous financial factors: asset prices, financial leverage and credit spreads (external finance premium), which are included explicitly in monetary policy rules. BGG also features a Financial Accelerator, which is shock propagation mechanism that is not a regular feature of a New Keynesian DSGE model. The Financial Accelerator arises from the financial friction and whose persistent dynamics influence the determinacy and e-stability results herein.

1.2 Related Literature

Paper	Labor Models		Capital Models	
	Determinacy	e-stability	Determinacy	e-stability
Bullard and Mitra (2002, 2007)	X	X		
Carlstrom and Fuerst (2005)			X	
Duffy and Xiao (2011)	X	X	X	X
Dupor (2001)			X	

Table 1: Determinacy and Learnability of Monetary Policy Rules in New Keynesian Models

A summary of the general literature devoted to studying determinacy and learnability of monetary policy rules is provided in the Table 1. The seminal work in this literature is Bullard and Mitra (2002), which explores determinacy and e-stability of a simple two equation model under different policy rule assumptions finds that the *Taylor Principle* implies a determinate and e-stable equilibrium. Bullard and Mitra (2007) is an extension which examines policy

rules, that exhibit policy inertia. It is shown that range of determinacy and e-stability increases with the degree of policy inertia in the policy rule.

The *Taylor Principle* described above, using the notation in this paper, is given by the following expression, which corresponds to Woodford (2003)[Chapter 4]:

$$\phi_{\pi} + \frac{1 - \beta}{\kappa} \phi_y > 1. \quad (1)$$

Both papers are labor only models so the natural extension was to include capital to assess the impact on the determinacy and e-stability results. Dupor (2001) took up this question first and found that the *Taylor Principle* does not necessarily lead to a determinate outcome when capital is included in a continuous time model.

Carlstrom and Fuerst (2005) entered the frame and conducted the study in discrete time and found that the *Taylor Principle* can imply a determinate outcome if inflation is included in the HMT rule as current data. However, if the forward expectations rule is used, then the *Taylor Principle* implies indeterminacy.

The recent paper by Duffy and Xiao (2011) provides a comprehensive treatment for both determinacy and e-stability under various policy rules. They consider the New Keynesian models in the labor only case as well as capital in two forms: an economy-wide rental market and firm specific capital. In the labor only model the *Taylor Principle* implies determinacy and e-stability. In the economy wide rental market case for capital, the *Taylor Principle* implies determinacy and e-stability in the current data rule. However, the *Taylor Principle* implies indeterminacy in the other rules such as the forward and contemporaneous expectations cases. In the firm specific capital case, the *Taylor Principle* does not hold as being determinate and e-stable in any rules studied.

It should be noted that Duffy and Xiao (2011) distinguish between the *Taylor Principle* in (1) and the *Simple Taylor Principle* in (2). In models with no capital, an expression for (1) can be derived but once capital is introduced, it is not possible to obtain an analytical expression. Duffy and Xiao (2011) use

$$\phi_{\pi} > 1 \quad (2)$$

as a proxy for the *Taylor Principle* in bigger models, including capital. This simplification is also made by the author for the modelling work in the present paper based on the more complex Bernanke et al. (1999) model.

In Table 2, there is a summary of the literature devoted to determinacy and learnability of equilibria in the presence of financial factors in monetary policy rules. This leads to the literature most relevant to the research question raised and the methodology herein. Table 2 shows the emphasis so far has been on asset prices and not credit factors.

In Bullard and Schaling (2002), the question is whether a HMT rule should respond to equity prices. A small dynamic macroeconomic model Woodford (1999) with no financial frictions is used for this purpose. Determinacy results are contrasted between a rule that includes a response to current equity prices and one that does not. The conclusion is that including a response to equity prices can introduce indeterminacy, not previously present.

Carlstrom and Fuerst (2007) argues there is an inherent risk of indeterminacy or sun spot equilibria (explosive outcomes) if a policy rule responds to equity prices. Equity prices represent forecasts of future firm profitability. Assuming the model has sticky prices then the main distortion is marginal cost. Profitability is negatively related to production costs. As marginal costs fall, the price mark up rises, representing monopoly power. Determinacy is more likely if the nominal interest rate adjusts in the same direction of the distortion. That is, a central bank would raise rates in the face of higher marginal costs. However, if the central bank raises rates as a response to higher asset prices, it is responding negatively to marginal cost, thus increasing the chance of indeterminacy. Carlstrom and Fuerst (2007) argue that Cecchetti, Genberg and Wadhvani (2002) may inadvertently introduce non-fundamental asset price movements via the introduction of indeterminacy or sunspot equilibria if they respond to asset prices in their model, designed to avoid asset bubbles.

Singh, Stone and Suda (2015) use BGG as a framework to study the impact on equilibrium determinacy of including lagged asset prices in a current data monetary policy rule. The main conclusion is that the determinate parameter set expands with the strength of response to asset prices, thus inducing macroeconomic stability. This result is contrary to Carlstrom and Fuerst (2007) and Bullard and Schaling (2002).

Kanik (2012) employs a modified¹ version of Iacoviello (2005) as the workhorse model

¹The main modification is the removal of capital and capital accumulation

to research the impact of including housing price response in a policy rule on equilibrium determinacy and learnability. The housing price augmented policy rules analysed are the current data, lagged data and forward expectations rules used in Bullard and Mitra (2002), together with some treatment of policy inertia in the spirit of Bullard and Mitra (2007). The main result is that responding to asset prices in the current data rule does not improve the determinate and e-stable parameter set. This is consistent with Carlstrom and Fuerst (2007) and Bullard and Schaling (2002) and differs from Singh et al. (2015). Responding to asset prices in the lagged data rule and forward expectations rule improves the determinate and e-stable set but only if the central bank can respond to current asset prices.

Paper	Asset Prices		Credit Volume		Credit Spreads	
	Determinacy	e-stability	Determinacy	e-stability	Determinacy	e-stability
Bullard and Schaling (2002)	X					
Carlstrom and Fuerst (2007)	X					
Kanik (2012)	X	X				
Singh, Stone and Suda (2015)	X					
This Paper	X	X	X	X	X	X

Table 2: Determinacy and Learnability of Financial Factors in Monetary Policy Rules

1.3 Objectives and Positioning

To follow are the main objectives and an outline of where this paper fits in the literature. There is a recent discernible shift in emphasis towards the credit markets in the literature, such as Christiano, Ilut, Motto and Rostagno (2010a), Curdia and Woodford (2010), Gilchrist and Zakrajsek (2011) and Gilchrist and Zakrajsek (2012) and Taylor (2008). However, to the author's knowledge, there has been no published literature on determinacy and learnability of monetary policy rules when there is a response to credit volume, credit spreads or other credit market financial factors. As illustrated the table above, this paper seeks to fill that gap, together with making its own assessment of the merit of responding to asset prices. The author is motivated by the notion that adaptive learning introduces an additional set of state variables that may require a monetary policy response to financial factors, in addition to inflation. Another objective is to assess whether the results in the seminal papers Bullard and Mitra (2002) and Bullard and Mitra (2007) are robust to a New Keynesian model with

financial frictions.

1.4 Main Results

Firstly, the Henderson-McKibbin-Taylor (hereinafter HMT) style monetary rules in Bullard and Mitra (2002) are applied directly to BGG. The objective is to assess how robust the results of Bullard and Mitra (2002), a model with no capital, are to BGG, which includes capital, nominal rigidities and financial frictions.

The *Simple Taylor Principle* result in Bullard and Mitra (2002) is upheld in BGG with the exception of the forward expectations rule but the latter result is consistent with models with capital such as Duffy and Xiao (2011).²

The remaining results in Bullard and Mitra (2002) are similar with those derived from BGG. These include the result that determinacy implies e-stability in the current data rule and the contemporaneous data rule. Also, the determinate and e-stable parameter sets in both of these cases are identical, a result common to Bullard and Mitra (2002) and the analysis herein. Both sets of results show a large explosive region in the lagged data case. There is one discrepancy in results in the lagged data rule but this is due to a difference in timing convention, which if synchronized, leads to the same result. Hence, on the whole, the results in Bullard and Mitra (2002) are robust to the BGG modelling framework.

Next, the approach of Bullard and Mitra (2007) is extended to BGG. The key result from Bullard and Mitra (2007) is the inclusion of policy inertia in a monetary policy rule improves the determinate and e-stable set in the parameter space. This result is robust to an application to BGG. Additionally, absent from the Bullard and Mitra (2007) analysis was the current data rule, which was computed and shown to be robust to BGG here, which constitutes a new result.

The results related to the main research question pertain to policy rules which include financial factors. When including a response to lagged asset prices, the result across all policy rules studied, is a decrease in the e-stable portion of the parameter space. It is shown through sensitivity analysis that financial frictions, are behind this result. However, when the policy rule responds to current asset prices, the determinate and e-stable parameter set expands,

²The abbreviation of the *Taylor Principle* by the *Simple Taylor Principle*, employed by Duffy and Xiao (2011), as explained in (1) and (2)

which is more desirable for the policy maker. It is shown that the timing of response to asset prices affects the learning agents updating of forecasts of the external finance premium. A response to lagged asset prices leads to an updating of the external finance premium that is self-fulfilling, which opposes the stabilization effects of an inflation response. However, a response to current asset prices provides additional stabilization, which assists agents to learn the REE.

The rationale for including financial leverage as a policy response factor is that it is a proxy for responding to the volume of credit in the economy. The results are not encouraging. Across the policy rules, responding to credit volumes significantly increases the indeterminate region and thus reduces the determinate and e-stable parameter set. A policy response to credit volume should thus be avoided .

The results for including credit spreads in monetary policy rules are more promising. There is a neutral to modest improvement in the determinate and e-stable region in the parameter space, when the various specifications of policy rule are examined. The intuition relates to the consistency of the effect on stabilization from responding to credit spreads alongside a response to inflation, which slightly improves agents ability to learn the equilibrium under rational expectations. The credit spread results are particularly encouraging given they dovetail well with the recent literature, such as Gilchrist and Zakrajsek (2011) and Gilchrist and Zakrajsek (2012), which demonstrate the importance of credit spreads in explaining business cycle fluctuations and espouse a credit spread augmented HMT rule, which according to their studies, dampen business cycle variability.

1.5 Organization

To follow in Section 2 is a presentation of a fully specified version of the BGG model that is analysed throughout the paper. This is followed in Section 3 by an outline of the methodology used for determinacy and e-stability analysis. The results and findings are then presented in Section 4 and discussed, followed by some concluding remarks in Section 5.

2 Model

2.1 BGG Overview

BGG is a New Keynesian DSGE model with an embedded partial equilibrium, optimal financial contract, arising from an information asymmetry, which leads to the Financial Accelerator mechanism. The agents are households, retailers and entrepreneurs with a framework that includes a government sector, a monetary authority and a financial intermediary (FI). The households and retailers are infinitely lived but the entrepreneurs have finite lives, with a probability of γ surviving to the next period.

Households save in this economy and keep deposits with the FI, which lends to the entrepreneurs. The entrepreneurs and the FI operate in competitive markets. The nominal rigidities in the model come from the retail sector, which operates in monopolistic competition. The entrepreneurs sell their output to the retailers in the wholesale market, who differentiate the products costlessly and mark up the price to sell in the retail market.

The optimal financial contract is based on a costly state verification problem Townsend (1979) where there is asymmetric information between borrowers (entrepreneurs) and lenders (the FI). The financial friction arises from the information advantage the entrepreneurs have over the FI with regards to their own performance (productivity outcomes). This leads to two distinct interest rates, the risk free, R_t and the return to capital, R_t^k and motivates the external finance premium ($s = \frac{E_t R_{t+1}^k}{R_t}$), which is interpreted throughout this paper as a corporate credit spread.

Consider the following equation (derived from the contracting problem in the next subsection) which illustrates this concept, where Q_t is the price of capital and N_t is net worth:

$$E_t R_{t+1} = s \left(\frac{N_{t+1}}{Q_t K_{t+1}} \right) R_t. \quad (3)$$

Equation (3) and $s'(\frac{N_{t+1}}{Q_t K_{t+1}}) < 0$ shows that under the model assumption of $Q_t K_{t+1} < N_t$ or the entrepreneur is not fully financed, then the equilibrium return to capital equals the marginal cost of external finance. Credit spreads are thus positively affected by financial leverage ($\frac{Q_t K_{t+1}}{N_t}$) and by macroeconomic shocks that influence leverage of entrepreneurs.

A macroeconomic shock, a negative productivity shock for example, reduces the demand

for capital, thus lowering the price for capital, lowering net worth and increasing financial leverage, which expands the external finance premium or credit spread. The widening credit spread is an adverse feedback loop, which restricts the amount of capital that can be purchased, which lowers the price of capital and so on. The persistent nature of shocks in this context is referred to as the Financial Accelerator.

2.2 Optimal Financial Contract

The financial contract is based on a partial equilibrium, costly state verification problem. Since this is a static problem time subscripts are dropped for the time being. Entrepreneurs seek to fund their investments in capital from borrowings from the FI. The return on capital is subject to an idiosyncratic productivity shock, $\omega \in [0, \infty)$, where $E(\omega) = 1$ and is only observable by the entrepreneur.

It is assumed that both the entrepreneur and the FI do not know ω prior to the investment decision. In order to observe ω , the FI must pay a fixed auditing cost, $\mu \in (0, 1)$, which is a fraction of the entrepreneur's total return on capital. Profits per unit of capital equal ωR^k . So the monitoring cost is $\mu \omega R^k QK$, where R^k is aggregate return to capital, Q is the price of capital and K is capital. The amount the entrepreneur borrows (B) to fund capital investment is $B = QK - N$, where N is net worth.

Since it is too costly for the FI to monitor every contract there is a productivity level $\bar{\omega}$ specified by the optimal contract such that for $\omega \geq \bar{\omega}$ the FI does not monitor. In this case, the FI is paid $\bar{\omega} R^k QK$ and the entrepreneur retains the residual equity $(\omega - \bar{\omega}) R^k QK$. If $\omega < \bar{\omega}$, the entrepreneur defaults, receives nothing and exits the economy. The FI pays the monitoring costs and receives the balance net of costs, $(1 - \mu) \omega R^k QK$. Since there is a continuum of entrepreneurs on $[0, 1]$ and the FI has contracts with each of them, the loan risk is perfectly diversifiable.

The probability of default or business failure rate is given by a continuous cdf, which is given the following log-normal functional form, where $\ln(\omega) \sim N(-\frac{1}{2}\sigma^2, \sigma^2)$,³

$$F(\bar{\omega}) = Pr[\omega < \bar{\omega}] = \Phi\left[\frac{\ln(\bar{\omega}) + \frac{1}{2}\sigma^2}{\sigma}\right]. \quad (4)$$

³Note that Φ denotes cdf and ϕ denotes pdf

Assuming the required rate of return on lending is R , where $R < R^k$ then in equilibrium the FI receives an expected return equal to the risk free return, R . This implies,

$$[\bar{\omega}Pr(\omega \geq \bar{\omega}) + (1 - \mu)E(\omega|\omega < \bar{\omega})Pr(\omega < \bar{\omega})]R^k QK = R(QK - N). \quad (5)$$

The share of gross profits between the entrepreneur and FI is determined by $\bar{\omega}$.⁴ Let $\Gamma(\bar{\omega}, \sigma)$ denote the FI's gross share of profits. Then following (4) is the expression,

$$\begin{aligned} \Gamma(\bar{\omega}, \sigma) &= \int_0^{\bar{\omega}} \omega f(\omega) d\omega + \bar{\omega} \int_{\bar{\omega}}^{\infty} f(\omega) d\omega \\ &= \Phi\left[\frac{\ln(\bar{\omega}) - \frac{1}{2}\sigma^2}{\sigma}\right] + [1 - \Phi\left(\frac{\ln(\bar{\omega}) + \frac{1}{2}\sigma^2}{\sigma}\right)]. \end{aligned} \quad (6)$$

The first component of $\Gamma(\bar{\omega}, \sigma)$ is $G(\bar{\omega}, \sigma)$, which is defined as

$$\begin{aligned} G(\bar{\omega}, \sigma) &= \int_0^{\bar{\omega}} \omega f(\omega) d\omega \\ &= \Phi\left[\frac{\ln(\bar{\omega}) - \frac{1}{2}\sigma^2}{\sigma}\right] \end{aligned} \quad (7)$$

, which is the expected gross share of profit going to the lender, where productivity realizations do not hit the $\bar{\omega}$ threshold or $\omega \in [0, \bar{\omega})$. Therefore, $\mu G(\bar{\omega}, \sigma)$ are the expected monitoring costs by the FI. It follows that the net share of profits going to the FI is $\Gamma(\bar{\omega}, \sigma) - \mu G(\bar{\omega}, \sigma)$ and the share going to the entrepreneur is $1 - \Gamma(\bar{\omega}, \sigma)$. Substituting the FI share of profits into (5) the FI participation constraint or zero profit condition is thus derived in

$$[\Gamma(\bar{\omega}, \sigma) - \mu G(\bar{\omega}, \sigma)]R^k QK = R(QK - N). \quad (8)$$

The optimal financial contracting problem is defined by entrepreneurs maximizing their expected share of profits subject to the FI zero profit condition, or

$$\max_{K, \bar{\omega}} E\{(1 - \Gamma(\bar{\omega}, \sigma))R^k QK\}$$

⁴This follows from an assumption of constant returns to scale

subject to:

$$[\Gamma(\bar{\omega}, \sigma) - \mu G(\bar{\omega}, \sigma)]\omega R^k QK = R(QK - N)$$

Let $k = \frac{QK}{N}$ and $s = \frac{R^k}{R}$, which is the external finance premium. Then the Lagrangian is given by

$$\mathcal{L} = (1 - \Gamma(\bar{\omega}, \sigma))sk + \lambda\{[\Gamma(\bar{\omega}, \sigma) - \mu G(\bar{\omega}, \sigma)]sk - (k - 1)\} \quad (9)$$

and therefore the first order conditions are:

$$\bar{\omega} : \lambda(\bar{\omega}, \sigma) = \frac{\Gamma_{\omega}}{\Gamma_{\omega} - \mu G_{\omega}}, \quad (10)$$

$$k : s = \frac{\lambda(\bar{\omega}, \sigma)}{1 - \Gamma(\bar{\omega}, \sigma) + \lambda(\bar{\omega}, \sigma)(\Gamma(\bar{\omega}, \sigma) - \mu G(\bar{\omega}, \sigma))}, \quad (11)$$

$$\lambda : s = \frac{k - 1}{k} \frac{1}{\Gamma(\bar{\omega}, \sigma) - \mu G(\bar{\omega}, \sigma)}. \quad (12)$$

Given some regularity assumptions Bernanke et al. (1999)[p.1383], there is an interior solution. Equation (11) is the key optimality condition for the credit contract, which is the wedge between the expected rate of return on capital and the FI risk free return requirement. From (12), it is clear that the term $\frac{1}{\Gamma(\bar{\omega}, \sigma) - \mu G(\bar{\omega}, \sigma)} > 0$. The term $\frac{k-1}{k} = 1 - \frac{1}{k}$, which is decreasing in $\frac{1}{k} = \frac{N}{QK}$. Since, $s = \frac{R^k}{R}$, then it follows that $R^k = s(\frac{N}{QK})R$, where $s'(\frac{N}{QK}) < 0$.

Returning now to the dynamic economy with uncertainty. There are three equations that characterize the contracting problem. The first is the FI zero profit condition:

$$(\Gamma(\omega_t, \sigma_{t-1}) - \mu G(\omega_t, \sigma_{t-1}))R_t^k Q_{t-1}K_t = R_t(Q_{t-1}K_t - N_t). \quad (13)$$

The second is the optimality condition for the credit contract,

$$\frac{E_t R_{t+1}^k}{R_t} = \frac{\lambda(\omega_t, \sigma_{t-1})}{(1 - \Gamma(\omega_t, \sigma_{t-1})) + \lambda(\omega_t, \sigma_{t-1})(\Gamma(\omega_t, \sigma_{t-1}) - \mu G(\omega_t, \sigma_{t-1}))} \quad (14)$$

Finally, to fully specify the optimal financial contract in this paper, an AR(1) process

for σ , the volatility of productivity cutoff is required, specified by

$$\sigma_t = \rho_\sigma \sigma_{t-1} + \epsilon_{\sigma t}. \quad (15)$$

The external finance premium, (efp_t) , is defined as

$$efp_t = \frac{E_t R_{t+1}}{R_t} \quad (16)$$

and financial leverage, (lv_t) , is given by

$$lv_t = \frac{Q_t K_t}{N_t} \quad (17)$$

The optimal financial contract also specifies the monitoring costs that are included in the economy-wide resource constraint, given which follows from substituting (7), or

$$\begin{aligned} Y_t &= C_t + C_t^e + I_t + \bar{G}_t + \mu \int_0^{\bar{\omega}} \omega f(\omega) d\omega \\ &= C_t + C_t^e + I_t + \bar{G}_t + \mu G(\bar{\omega}_t, \sigma_{t-1}) \end{aligned} \quad (18)$$

Note that I_t is investment expenditure, $\bar{G}_t$ is government expenditure, Y_t is output, C_t is consumption and C_t^e is entrepreneurial consumption.

The log-linearized system of first order and optimality conditions in the BGG framework are summarized in Appendix VII. This system is utilized in the determinacy and e-stability sections to follow.

3 Methodology - BGG Determinacy and e-stability

3.1 Equilibrium Determinacy in BGG

The Blanchard and Kahn (1980) state space representation is

$$\mathbf{B} \begin{bmatrix} \mathbf{x}_{t+1} \\ \mathbf{E}\mathbf{y}_{t+1} \end{bmatrix} = \mathbf{A} \begin{bmatrix} \mathbf{x}_t \\ \mathbf{y}_t \end{bmatrix} + \mathbf{G}\mathbf{v}_{t+1} \quad (19)$$

where, the vector $\mathbf{x}$ consists of predetermined variables and has dimension $n \times 1$. The vector $\mathbf{y}$ is a $m \times 1$ vector of non-predetermined variables so that the vector $[\mathbf{x}, \mathbf{y}]'$ is $(n + m) \times 1$. The vector $\mathbf{v}$ is a $(n_v \times 1)$ vector of shocks. Matrices $\mathbf{A}, \mathbf{B}$ are $(n + m) \times (n + m)$ and $\mathbf{G}$ is $(n + m) \times n_v$.

Using this state space, the BGG reduced system can be characterized as follows. There are $m = 9$ non predetermined variables and $n = 5$ predetermined variables. The vector of predetermined variables $\mathbf{x}_t = (a_{t-1}, g_{t-1}, q_{t-1}, k_{t-1}, n_{t-1})'$, non-predetermined variables $\mathbf{y}_t = (y_t, i_t, r_t, x_t, efp_t, lv_t, c_t, r_t^k, \pi_t)'$ and iid shocks $\mathbf{v}_t = (\epsilon_{at}, \epsilon_{gt})'$.

Note that this system is using the current data monetary policy rule or $r_t^n = \phi_\pi \pi_t + \phi_y y_t$, which includes no response to financial factors. The number of pre-determined and non-predetermined variables changes and on occasions the dimensionality of the system changes when new policy rules are introduced.

The system is determinant when there is a unique REE. The general condition to satisfy uniqueness (provided $\mathbf{A}$ is non-singular) is that the matrix $\mathbf{A}^{-1}\mathbf{B}$ has m eigenvalues within the unit circle. When the $\mathbf{A}$ matrix is singular there is an equivalent eigenvalue condition using the Generalized Schur Decomposition using the QZ algorithm, which modifies the Blanchard Kahn state space in the following way McCandless (2008)[pp.134-138].⁵

The matrices B and A in equation (19) are decomposed into matrices S, T, Q and Z , where

$$B = QTZ', \quad (20)$$

$$A = QSZ' \quad (21)$$

⁵The determinacy analysis in this paper employs the QZ algorithm throughout due to the frequency of singularity in at least part of the parameter space under particular monetary policy rules.

, $QQ' = Q'Q = I$, $ZZ' = Z'Z = I$, S and T are upper triangular matrices. Substituting (21) and (20) into (19), the Blanchard Kahn state space becomes

$$\mathbf{QTZ}' \begin{bmatrix} \mathbf{x}_{t+1} \\ \mathbf{E}\mathbf{y}_{t+1} \end{bmatrix} = \mathbf{QSZ}' \begin{bmatrix} \mathbf{x}_t \\ \mathbf{y}_t \end{bmatrix} + \mathbf{G}\mathbf{v}_{t+1} \quad (22)$$

Let s_{ii} and t_{ii} denote the diagonal elements of S and T , respectively. Then the appropriate eigenvalues of the system determinacy are $\lambda_{ii} = \frac{s_{ii}}{t_{ii}}$. Let λ_n denote the number of λ_{ii} that are stable or $|\lambda_{ii}| < 1$. The determinacy conditions are related to the number of stable system eigenvalues and the number of predetermined variables (n). If $\lambda_n = n$ the system is determinate. If $\lambda_n > n$ the system is indeterminate and if $\lambda_n < n$ the system is explosive.

3.2 Learnability and e-stability in BGG

Agents learn according to the adaptive learning methodology, following Evans and Honkapohja (2001). It is assumed that agents update their beliefs according to recursive least squares (RLS) learning. Attention is restricted to the minimal state variable solution (MSV), which is a unique stationary solution based on fundamental shocks. A more general class of solutions would include the irregular case, where solutions depend on sunspots. However, this is beyond the scope of the analysis in this paper.

The BGG model is based on time- t expectations and is consistent with the following structural form Evans and Honkapohja (2001)[pp.237-238]:

$$y_t = \beta E_t y_{t+1} + \delta y_{t-1} + \kappa \omega_t \quad (23)$$

$$\omega_t = \varphi \omega_{t-1} + e_t.$$

The Minimum State Variable (MSV) solution to this system has the form:

$$y_t = a + by_{t-1} + c\omega_t \quad (24)$$

Taking expectations on (24),

$$\begin{aligned}
E_t y_{t+1} &= E_t \{a + by_t + cw_{t+1}\} \\
&= a + by_t + c E_t w_{t+1} \\
&= a + by_t + c\varphi\omega_t
\end{aligned} \tag{25}$$

Substituting (25) and (24) into (23), yields

$$\begin{aligned}
y_t &= \beta[a + b(a + by_{t-1} + c\omega_t) + c\varphi\omega_t] + \delta y_{t-1} + \kappa\omega_t \\
&= (\beta a + \beta b a) + (\beta b^2 + \delta)y_{t-1} + (\beta b c + \beta c\varphi + \kappa)\omega_t
\end{aligned} \tag{26}$$

Using the method of undetermined coefficients, the MSV solution coefficients are equated with (26),

$$\begin{aligned}
a &= \beta a + \beta b a \\
b &= \beta b^2 + \delta \\
c &= \beta b c + \beta c\varphi + \kappa
\end{aligned}$$

Rearranging yields the three sets of matrix equations that the MSV solutions satisfy,

$$(I - \beta b - \beta)a = 0 \tag{27}$$

$$\beta b^2 - b + \delta = 0 \tag{28}$$

$$(I - \beta b)c - \beta c\varphi = \kappa \tag{29}$$

The Actual Law of Motion (ALM) is derived by substituting (24) into (23), or

$$\begin{aligned}
y_t &= \beta(a + by_t + c\varphi\omega_t) + \delta y_{t-1} + \kappa\omega_t \\
\Rightarrow y_t(I - \beta b) &= (\beta a) + \delta y_{t-1} + (\beta c\varphi + \kappa)\omega_t \\
\Rightarrow y_t &= (I - \beta b)^{-1}(\beta a) + (I - \beta b)^{-1}\delta y_{t-1} + (I - \beta b)^{-1}(\beta c\varphi + \kappa)\omega_t
\end{aligned} \tag{30}$$

The T-mapping from the PLM to the ALM is thus,

$$T(a, b, c) = ((I - \beta b)^{-1}(\beta a), (I - \beta b)^{-1}\delta, (I - \beta b)^{-1}(\beta c\varphi + \kappa)) \quad (31)$$

e-stability is given the ordinary differential equation system:

$$\frac{d}{d\tau}(a, b, c) = T(a, b, c) - (a, b, c) \quad (32)$$

The fixed point of (32), $(\bar{a}, \bar{b}, \bar{c})$ is the MSV solution. This solution is e-stable if the MSV fixed point of the differential equation system is locally asymptotically stable at that point. Following Proposition 10.3 of Evans and Honkapohja (2001, p.238), the MSV solution $(\bar{a}, \bar{b}, \bar{c})$ is e-stable if the eigenvalues of the Jacobian matrices $DT_a(\bar{a}, \bar{b})$, $DT_b(\bar{b})$ and $DT_c(\bar{b}, \bar{c})$, given by equations (33), (34) and (35) have real parts less than unity.⁶

$$DT_a(\bar{a}, \bar{b}) = (I - \beta \bar{b})^{-1}\beta \quad (33)$$

$$DT_b(\bar{b}) = [(I - \beta \bar{b})^{-1}\delta]' \otimes [(I - \beta \bar{b})^{-1}\beta] \quad (34)$$

$$DT_c(\bar{b}, \bar{c}) = \varphi' \otimes [(I - \beta \bar{b})^{-1}\beta] \quad (35)$$

The link between learnability and e-stability is now made. The Perceived Law of Motion (PLM) in real time learning is given by,

$$y_t = a_{t-1} + b_{t-1}y_{t-1} + c_{t-1}\omega_t \quad (36)$$

where the parameters a_t , b_t and c_t are updated using RLS. Let $\xi'_t = (a_t, b_t, c_t)$, $z'_t = (1, y'_{t-1}, \omega_t)$ and $\epsilon_t = y_t - \xi'_{t-1}z_{t-1}$. RLS can then be written as,

$$\xi_t = \xi_{t-1} + t^{-1}R_t^{-1}z_{t-1}\epsilon'_t \quad (37)$$

$$R_t = R_{t-1} + t^{-1}(z_{t-1}z'_{t-1} - R_{t-1}) \quad (38)$$

⁶However, since all variables in equation (21) for our system are included in y_t , there is no need to compute DT_c .

Given $y_t = T(\xi_t)'z_t$, beliefs are updated according to the RLS learning algorithm:

$$\xi_t = \xi_{t-1} + t^{-1}R_t^{-1}z_{t-1}z_{t-1}'(T(\xi_{t-1}) - \xi_{t-1}) \quad (39)$$

Consider a model in the form of (23) under RLS learning with a MSV solution $(\bar{a}, \bar{b}, \bar{c})$, for example, BGG. By Proposition 10.4 of Evans and Honkapohja (2001)[p.238], the learning algorithm converges locally to $(\bar{a}, \bar{b}, \bar{c})$ if the solution is e-stable. In other words, the learnability of a REE is governed by e-stability.

4 Results - BGG Determinacy and e-stability

This section begins with a discussion as to whether the determinacy and e-stability results in Bullard and Mitra (2002) and Bullard and Mitra (2007) are robust to the New Keynesian framework with financial frictions. Then the primary question of whether a central bank should respond to financial factors is addressed via a discussion of determinacy and e-stability results from including various financial factors in monetary policy rules.

4.1 Robustness of Bullard and Mitra (2002) - Monetary Policy Rules

Determinacy and e-stability are now examined under the four policy rules employed by Bullard and Mitra (2002), namely the current data rule, the lagged data rule, the forward expectations rule and the contemporaneous data rule, in the BGG modelling framework.

4.1.1 Current Data Rule: $r_t^n = \phi_\pi \pi_t + \phi_y y_t$

The first monetary policy rule examined is the current data rule in Figure 1, where the nominal interest rate is adjusted to current realizations of data in both the output gap and inflation. This rule provides a large region in the parameter space that is both determinate and e-stable, thus indicating a substantial opportunity set for agents to coordinate on a unique and learnable REE. It is clear that the *Simple Taylor Principle* (2) implies determinacy and e-stability. Numerically, using the Bullard and Mitra (2002) parameterization, the *Taylor Principle* in (1) is $\phi_\pi + 0.1168\phi_y > 1$, which corresponds to a ϕ_y intercept at 8.5, which is a

little higher than the 6.5 in BGG, while the ϕ_π intercept is the same as BGG at 1. Figure 1 is thus a numerical presentation of the long-run *Taylor Principle* in BGG. Also, in the parameter space in Figure 1, determinacy implies e-stability in the current data rule. The intuition is elucidated via an assumption of an exogenous rise in inflationary expectations. Under rational expectations, higher $E_t\pi_{t+1}$ raises both the nominal and real interest rate if the *Taylor Principle* is satisfied. This restrains aggregate demand via substitution effects and via the New Keynesian Phillips curve (50) reduces inflationary pressure. This results in a determinate rational expectations equilibrium, avoiding indeterminacy or self fulfilling fluctuations. Under learning, the updating of the private agents forecasts corresponds to the expectations dynamics under rational expectations so that the MSV solution or REE is e-stable or learned by the private agents. This is how a targeted equilibrium by a central bank, reflecting the *Taylor Principle*, can be coordinated upon by private agents. The consistency of these results with Bullard and Mitra (2002) and Duffy and Xiao (2011), shows they are robust to a model with financial frictions.

Figure 1: Determinacy and e-stability in the Current Data Rule

4.1.2 Lagged Data Rule: $r_t^n = \phi_\pi \pi_{t-1} + \phi_y y_{t-1}$

Figure 2: Determinacy and e-stability in the Lagged Data Rule

In the lagged data rule, again the *Taylor Principle* implies a determinate and e-stable equilibrium. However, there is a large portion of the parameter space where this policy rule induces an explosive outcome. When $\phi_\pi = 0$ then aggressive responses to the output gap of $\phi_y > 6.5$ imply explosive outcomes. Also, when there is response to inflation and output in the zone of approximately $\phi_\pi > 1$ and $\phi_y > 1.5$, there is also an explosive result. The indeterminate region in the parameter space (ϕ_π, ϕ_y) is approximately bounded by $(0, 0)$, $(0, 1.3)$, $(0.8, 1.3)$, $(1, 0)$. This leaves the determinacy region in two parts. The first, denoted by A, which is approximately bounded by $(0, 1.5)$, $(0.8, 1.5)$, $(0.6, 1.5)$ in the parameter space and the second, B is approximately bounded by $(1, 0)$, $(0.8, 1.5)$, $(5.1, 1.3)$, $(0, 5)$ in Figure 2.

The determinacy region is similar to both Bullard and Mitra (2002) and Duffy and Xiao (2011). However, determinacy implies e-stability as both regions A and B are e-stable. This is a new result. In Bullard and Mitra (2002) and Duffy and Xiao (2011), the equivalent of region A is e-unstable and region B is e-stable. This, however, does not mean that the determinacy

and e-stability results in BGG are inconsistent for the lagged policy rule. The Bullard and Mitra (2002) result is based on time $t - 1$ expectations whereas the BGG model and analysis herein is based on time- t expectations. Not shown here but when the determinacy and e-stability regions in Bullard and Mitra (2002) are re-computed by the author using time- t expectations, the result is that determinacy implies e-stability, which is analogous to both regions A and B being determinate and e-stable, as in Figure 2. Bullard and Mitra (2002) uses $t - 1$ timing so as to avoid the possible case where private agents' information sets are greater than the central bank's. The interpretation herein differs slightly, in that both private agents and the central bank can have the same information set but time- t expectations are preserved so as to: (a) maintain consistency with timing in the BGG model; and (b) give a monetary authority with forward expectations, the flexibility to respond to lagged data in the inflation and output gap, even if this is based on a subset of their information set.

4.1.3 Forward Expectations Rule: $r_t^n = \phi_\pi E_t \pi_{t+1} + \phi_y E_t y_{t+1}$

Consider next the forward expectations rule in Figure 3 and a close up view around unity in the inflation response, ϕ_π , in Figure 4 to investigate the *Taylor Principle*.

Figure 3: Determinacy and e-stability in the Forward Expectations Rule

Figure 4: Forward Expectations Rule and the Taylor Principle

In Figure 3, the forward expectations rule is shown to have a relatively small determinate and e-stable parameter set in comparison to the current data rule and lagged data rule. Also, the *Taylor Principle* does not imply determinacy or e-stability. However, as Figure 4 shows, there is a small region near unity in the response to inflation (ϕ_π) where there is determinacy and e-stability. This result differs from Bullard and Mitra (2002), where the *Taylor Principle* implies determinacy and e-stability. However, as Duffy and Xiao (2011) point out, it is the presence of investment adjustment costs with the inclusion of a rental market for capital (which is the nature of investment in BGG) that lead to indeterminacy for most of the inflation response parameter region beyond unity.

4.1.4 Contemporaneous Expectations Rule: $r_t^n = E_{t-1}\pi_t + E_{t-1}y_t$

Figure 5: Determinacy and e-stability in the Contemporaneous Expectations Rule

The results for the contemporaneous expectations rule are identical to the current data rule. That is, there is a large determinate and e-stable parameter set reflecting the *Taylor Principle*. This result is consistent with Bullard and Mitra (2002).⁷

⁷Given the similarity with the current data rule, this rule is not used in subsequent analysis in this paper

4.2 Robustness of Bullard and Mitra (2007) - Policy Inertia

4.2.1 Policy Inertia in the Current Data Rule: $r_t^n = \phi_\pi \pi_t + \phi_y y_t + \phi_r r_{t-1}^n$

Figure 6: Determinacy and e-stability in the Current Data Rule with Policy Inertia

In Bullard and Mitra (2007), it is shown that the inclusion of policy inertia or a lagged response to the policy interest rate, is successful in enhancing the determinate and e-stable parameter set in both the lagged data rule and the forward expectations rule in a model with no capital. Interest rate smoothing is a common feature of monetary policy rule setting and according to Bullard and Mitra (2007) and Sack (1998), policy inertia or interest rate smoothing in the U.S. post-War period has been approximately $\phi_r = 0.65$. In Figure 6 above, the results for the current data rule with inertia are displayed. From the base case of $\phi_r = 0$, there is a significant improvement in the determinate and e-stable parameter set as the smoothing parameter, ϕ_r , increases. This result adds further evidence of the merit of including inertia in policy rules, as Bullard and Mitra (2007) do not include the current

data rule in their study of policy inertia. However, Kanik (2012) find that in a model with capital and financial frictions (albeit of a different nature to BGG), the current data rule with policy inertia, does not improve the determinate and e-stable parameter set. Nevertheless, in Appendix V, the results in BGG show a monotonic increase in the determinate and e-stable parameter set for both the lagged policy rule and the forward expectations rule when the smoothing parameter, ϕ_r is increased.

The discussion thus far has been focused on the question of whether the results of Bullard and Mitra (2002) and Bullard and Mitra (2007) are robust to a larger scale New Keynesian model with financial frictions, which has been generally shown to be the case. Attention now turns to whether the inclusion of financial factors in policy rules affect the determinacy and e-stability of equilibria and whether such factors such as asset prices and credit market variables should be considered by policy makers in setting the policy interest rate.

4.3 Monetary Policy Response to Asset Prices

The inclusion of asset prices in the monetary policy rule is now considered, initially with a policy response to lagged and then current asset prices, where such timing is shown to have a significant effect on determinacy and e-stability outcomes. Parameter sensitivity analysis shows that financial frictions, in particular the strength of the financial accelerator, influences determinacy and e-stability of policy rules, which include asset price response. Some intuition is provided to explain the mechanism behind these results in terms of the BGG model, in the context of both rational expectations and learning dynamics.

4.3.1 Lagged Asset Prices in the Current Data Rule: $r_t^n = \phi_\pi \pi_t + \phi_y y_t + \phi_q q_{t-1}$

Figure 7: Determinacy and e-stability in the Current Data Rule with Lagged Asset Prices

Consider the the current data rule with lagged asset price response, where the asset price response parameter is ϕ_q in Figure 7. The base case of $\phi_q = 0$ is the same result as in Figure 1 or the current data rule with responses only to inflation and the output gap. The

first observation is that as ϕ_q is increased the *Taylor Principle* does not imply e-stability for $\phi_q > 1$. In fact for $\phi_q > 2.5$ an explosive region in the parameter space appears and expands as ϕ_q increases. It is apparent from $\phi_q > 1$ that the determinate but e-unstable region is enlarged.

The results for the lagged asset prices in the lagged data and forward expectations rules appear in Appendix VI. In the case of the forward expectations rule, the inclusion of a response to asset prices introduces indeterminacy into the parameter space monotonically with ϕ_q . For the lagged data rule, lagged asset prices response increases the chance of explosive outcomes. In all cases, the determinate and e-stable parameter set shrinks with policy rules that respond to lagged asset prices. These results differ from Singh et al. (2015) on determinacy but are consistent with Carlstrom and Fuerst (2007), Bullard and Schaling (2002) and Kanik (2012).

Figure 8: Lagged Asset Prices Response with No Financial Accelerator

It is desirable to isolate the mechanism behind the worsening e-stability and determinacy

outcome resulting from increasing the strength of response to lagged asset prices in the current data rule in Figure 7. To do this, the financial accelerator is deactivated by setting the parameter ν to zero in equation (45) so that the external finance premium is always zero or $E_t r_{t+1}^k - r_t = 0$. This parameter is the elasticity of the external finance premium to financial leverage and is the parameter that indicates the strength of the financial accelerator in BGG. Figure 8 displays the results of the current data rule without the financial accelerator and a comparison with Figure 7 shows that the results are indeed sensitive to the financial accelerator effect. With no financial accelerator, the *Taylor Principle* implies determinacy and e-stability for $\phi_q = 1$ and goes close to doing so for $\phi_q = 2.5$. Clearly, the determinate and e-stable parameter space is larger with no financial accelerator for each value of ϕ_q displayed in the figure.

Figure 9: Sensitivity Analysis - External Finance Premium Elasticity (ν)

In Figure 9, there is some further sensitivity analysis conducted with respect to the key financial friction parameter in BGG, ν . The case of a one to one asset price response or

$\phi_q = 1$ is examined but the value of ν is varied to show the sensitivity of the determinacy and e-stability results to the strength of the financial accelerator. The top left panel shows the case of no financial accelerator or $\nu = 0$. The top right shows a mild elasticity of the external finance premium to financial leverage or $\nu = 0.01$. The bottom left panel shows the base calibrated case of $\nu = 0.0411$ and the bottom right panel shows a higher elasticity with $\nu = 0.08$. It is demonstrative that as the parameter value ν increases or the strength of the financial accelerator is enhanced, the smaller the region for joint determinacy and e-stability in the parameter space for the current data policy rule responding proportionally ($\phi_q = 1$) to lagged asset prices.

Some intuition is warranted. Consider again the thought experiment where exogenously, inflation expectations ($E_t \pi_{t+1}$) increase and there is an increase in the previous period asset price (q_{t-1}). Suppose also that the *Taylor Principle* holds and the policy response is to current inflation, the current output and lagged asset prices. Under rational expectations, the higher inflationary expectations raise nominal and real interest rates, aggregate demand is suppressed and inflationary pressure is diminished via the New Keynesian Phillips curve (50). This stabilizing mechanism ensures a determinate REE, which is unaffected by the response to asset prices as shown in Figure 9, where determinacy is not affected by any increase in ν .

The dynamics under adaptive learning are now considered. The response to inflation in the policy rule under learning leads to a similar stabilizing outcome as under rational expectations but it is the response to asset prices in the policy rule that differs from rational expectations. This relates to how the response to lagged asset prices affects the return to capital r_t^k in the investment demand equation (42). In equation (42) the equilibrium condition for investment shows that r_t^k depends negatively on the previous period asset price q_{t-1} . Therefore, in the case where the policy rule is implying an increase in the nominal interest rate r_t^n in response to an increase in q_{t-1} , the current period data point for r_t^k falls. Under adaptive learning, beliefs update according to forecasts based on a stochastic recursive algorithm, in particular recursive least squares.⁸ There is thus a fall in the data point for r_t^k , which shifts $E_t^* r_{t+1}^k$ downward alongside an increase in r_t^n . Taken together, there is an unambiguous fall in the external finance premium under learning, $E_t^* r_{t+1}^k - r_t$. This stimulates output by increasing the demand for capital as the entrepreneurial productivity

⁸Let the operator E^* denote expectations under learning

threshold ($\bar{\omega}$) from the optimal financial contract is lowered. This stimulates inflationary pressure in the New Keynesian Phillips curve.

Consequently, the response to inflation and the response to lagged asset prices have opposite effects on inflationary pressure in response to an exogenous increase in inflationary expectations under learning. The degree of e-stability or the likelihood that agents can learn the rational expectations equilibrium for given (ϕ_π, ϕ_y) pairs depends on the net effect of these opposing dynamics. In Figure 7, the increase in the policy response to lagged asset prices, ϕ_q , shows that the net effect is an decrease in e-stability in the parameter space. Figure 8 shows that if the financial accelerator is shut down, the agents under learning will not anticipate a decline in the external finance premium and so will learn the REE as the policy response to inflation dominates. Finally, in Figure 9 it is clear that for a given policy response to lagged asset price ($\phi_q = 1$), while the *Taylor Principle* is upheld, the monotonic decrease in e-stability corresponds to the relative weight of the forces raising inflationary pressure via the increased strength of the financial accelerator in the face of rising inflationary expectations. Thus, agents find it more difficult to learn rational expectations equilibria.

4.3.2 Current Asset Prices in the Forward Expectations Rule:

$$r_t^n = \phi_\pi E_t \pi_{t+1} + \phi_y E_t y_{t+1} + \phi_q q_t$$

The determinacy and e-stability implications from policy rules responding to current asset prices are somewhat better than those where the response is to lagged asset prices. Consider the forward expectations rule in Figure 10. It is apparent that with increases in the asset price response parameter, ϕ_q , the determinate and e-stable parameter space increases, offering greater coordination opportunities for agents. In fact, for $\phi_q > 1$ the *Simple Taylor Principle* implies determinacy and e-stability, where it did not without a response to asset prices. In Appendix VII, it is clear that the lagged data rule induces a larger determinate and e-stable region as ϕ_q increases, while in the case of the current data rule, the policy response to asset prices does not increase the determinate and e-stable region but does not decrease it either.

Consider Figure 10 also for a discussion on the intuition of this result. As discussed earlier, the forward expectations rule with no asset price response does not have any condition where the *Taylor Principle* or *Simple Taylor Principle* implies determinacy or e-stability. It requires some response to output. However, for the Taylor (1993) calibration, adjusted for

Figure 10: Forward Expectations Rule with Current Asset Price Response

quarterly data, the recommended responses of $\phi_\pi = 1.5$ and $\phi_y = 0.125$ are sufficient to guarantee determinacy and e-stability with no response to asset prices.

Again an increase in exogenous inflationary expectations is contemplated, together with an increase in current asset prices (q_t) and a response to inflation where $\phi_\pi > 1$ and a response to current asset prices, ϕ_q . Under rational expectations a response of $\phi_\pi > 1$ raises the nominal and real interest rate, restrains demand via substitution effects and softens output via the New Keynesian Phillips curve to lighten inflationary pressure but not sufficiently to ward off self-fulfilling fluctuations and indeterminacy. However, if in addition to an inflation response there is a response to asset prices, the negative effect on investment softens output through this additional channel and thus reduces output sufficiently to lower inflationary expectations via the New Keynesian Phillips curve to stabilize inflation. This leads to determinacy, even for zero response to the output gap directly. Hence, in Figure 10, the second and third panels show that the *Simply Taylor Principle* implies determinacy.

Under learning, the intuition is analogous to the discussion regarding lagged asset prices. Unlike lagged asset prices, the return to capital, r_t^k depends positively on current asset prices q_t by equation (42). So, when the nominal interest rate rises in response to a rise in current asset prices, the return to capital rises. Via the updating of beliefs under recursive least squares, this leads to an upward shift in $E_t^* r_{t+1}^k$. For a given real interest rate, this raises the external finance premium. A rise in the external finance premium under learning suppresses output by reducing the demand for capital as the entrepreneurial productivity threshold ($\bar{\omega}$) from the optimal financial contract is raised. This softens inflationary pressure in the New Keynesian Phillips curve. This is important as it supports rather than opposes the inflation response in the monetary policy rule and is sufficiently stabilizing under learning for agents to learn the rational expectations equilibrium and leads to a greater likelihood of e-stability in the parameter space. Consequently, a response to current asset prices is preferred in monetary policy rules as it increases the determinant and e-stable range in the parameter space, as shown by Figure 10.

4.4 Monetary Policy Response to Credit Volume

The debate now turns to whether policy rules should respond to credit market factors, by evaluating determinacy and e-stability when credit factors are included. Credit volume is the

first of these considered.

In BGG, financial leverage or $\frac{Q_t K_t}{N_t}$ is a proxy for credit volume in the economy as it is a function of the amount of lending undertaken by FI's to fund entrepreneur's capital requirements. The results for responding to credit volume are not encouraging as they appear to introduce indeterminacy into the parameter space.

4.4.1 Credit Volume Response in the Lagged Data Rule

$$r_t^n = \phi_\pi \pi_{t-1} + \phi_y y_{t-1} + \phi_{lv} lv_t$$

Figure 11: Determinacy and e-stability in the Lagged Data Rule with Credit Volume

Consider Figure 11, which illustrates the determinacy and e-stability map for the lagged policy rule, which includes a response to credit volume, where financial leverage lv_t is the proxy and the response parameter is ϕ_{lv} . The base case is the lagged policy rule with a response only to lagged inflation and the lagged output gap. A one for one response to credit volume or $\phi_{lv} = 1$ leads to a significant increase in the explosive or non-fundamental

component of the parameter space and the *Taylor Principle* does not imply a determinate and e-stable REE but implies an explosive path.

As the response to credit volume increases, the determinate and e-stable parameter set decreases accordingly and for $\phi_{lv} = 2.5$, the *Simple Taylor Principle* implies indeterminacy. In the case of the current data rule and the forward expectations rule, the strength of response to credit volume induces indeterminacy, perhaps more quickly in the forward expectations rule. Since credit volume is a function of both current period asset prices and current period net worth, which is a function of lagged asset prices, the mechanism for introducing indeterminacy and explosiveness may be via the asset price (particularly lagged) channel. Given the undesirable determinacy and e-stability implications, responding to credit volume in monetary policy rules should be avoided.

4.5 Monetary Policy Response to Credit Spreads

The results to follow pertaining to credit spreads demonstrate a benign to moderately positive impact in the determinacy and e-stability parameter set, when included in policy rules.

4.5.1 Credit Spread Response in the Forward Expectations Rule:

$$r_t^n = \phi_\pi E_t \pi_{t+1} + \phi_y E_t y_{t+1} + \phi_{cs} efp_t$$

Consider Figure 12, which illustrates the parameter space when a credit spread response appears in the forward expectations rule. The response parameter is ϕ_{cs} , where unlike the response parameters that have followed, $\phi_{cs} \leq 0$. The central bank in this instance responds by lowering the nominal interest rate when the credit spread rises and raises the policy interest rate when credit spreads fall, if following a rule that includes a credit spread response. As can be seen in Figure 12, there is a modest shift upwards in the determinate and e-stable parameter set as the strength of response shifts from 0 to -4. In Appendix IX, a similar result is found in the lagged data rule and in the case of the current data rule there is no change in the determinate and e-stable parameter set.

The intuition regarding the results with respect to credit spreads is naturally found. Credit spreads tend to fall during expansions and rise during contractions. Consider again the case where there is an exogenous rise in inflationary expectations, which is most likely to occur in the event of falling credit spreads. Assume $\phi_\pi > 1$. An increase in the policy interest

Figure 12: Forward Expectations Rule with Credit Spread Response

rate in response to inflation raises the real interest rate and dampens inflationary pressure via substitution effects inhibiting demand via the New Keynesian Phillips curve. However, inflationary pressure is not diminished sufficiently to ward off self fulfilling fluctuations unless there is also a policy response to the output gap directly, irrespective of the response to credit spreads, under rational expectations. However, a response to credit spreads in addition to a response to inflation and the output gap involves raising the nominal interest rate when the external finance premium (credit spreads) falls, which dampens demand and lowers inflationary pressure further so as to increase the determinant space. The learning dynamics do not diverge from the dynamics under rational expectations, so that determinacy implies e-stability for this rule.

This result is encouraging since there is a growing body of evidence showing the benefits of credit spreads as an accurate predictor of economic activity, via what may be interpreted as a clean signal, together with showing that including credit spreads in monetary policy rules dampens business cycle fluctuations in the presence of shocks Gilchrist and Zakrajsek (2011), which have been arrived at using approaches orthogonal to those taken in this paper.

5 Conclusion

This paper explores both the robustness of the results in Bullard and Mitra (2002) and Bullard and Mitra (2007) to a model with financial frictions (BGG) and the merits of central banks responding to financial factors in monetary policy rules, via an analysis of determinacy and e-stability.

The Bullard and Mitra (2002) results are upheld in the current data rule and the contemporaneous expectations rule. That is, the *Simple Taylor Principle* as well as a numerically computed version of the *Taylor Principle*, imply determinacy and e-stability of equilibrium in the (ϕ_π, ϕ_y) parameter space. The result for the lagged rule differs and this is shown to be as a result of an inconsistency between the time $t - 1$ method used in Bullard and Mitra (2002) and the time-t convention used in the New Keynesian literature, including BGG. In Bullard and Mitra (2002), the *Simple Taylor Principle* implies determinacy but not e-stability. However, in BGG it is shown that determinacy implies e-stability, which is therefore a new result. Once the timing convention is made consistent, the author shows that the Bullard and Mitra

(2002) results are robust to the BGG framework, so that the *Simple Taylor Principle* implies determinacy and e-stability. The only difference is the forward expectations rule, where the introduction of capital via adjustment costs partially vitiates the Bullard and Mitra (2002) result that the *Taylor Principle* implies a determinate and e-stable equilibrium. In the case of Bullard and Mitra (2007), both the lagged data rule and forward expectations rule are shown to have monotonic increases in the determinate and e-stable parameter sets with corresponding increases in the degree of policy inertia. One rule that is not present in Bullard and Mitra (2007) is the current data rule, which is conducted by the author and shown to be consistent with the BGG framework. This is therefore also a new result. Hence, Bullard and Mitra (2002) and Bullard and Mitra (2007) are robust to BGG.

As for the primary research question addressed, namely, whether incorporating financial factors in monetary rules is warranted, by means of examining determinacy and e-stability, the results are mixed and have important policy implications. It is shown that a policy response to current asset prices is preferred to policy rules that respond to lagged asset prices. In credit markets, the conclusion is that responding to credit spreads is more desirable than a policy response to credit volumes or financial leverage.

The clearest conclusion from the inclusion of lagged asset prices in the monetary policy rule is that the *Simple Taylor Principle* and the numerically generated or heuristic *Taylor Principle* no longer guarantees e-stability, although determinacy is maintained for reasonable strength of response, say $\phi_q = 1$, with the current data rule. Under learning, agents forecasts of the external finance premium lead to self-fulfilling fluctuations and oppose the stabilizing effects of beliefs updated according to a policy response to inflation. Consequently, a monetary policy rule that responds to both inflation and lagged asset prices implies that agents are less likely to learn the MSV solution as the weight of response to lagged asset prices increases. Sensitivity analysis demonstrates the role that financial frictions play in this result. The financial accelerator, in particular the elasticity of the external finance premium with respect to financial leverage or ν , is central to this conclusion. When the financial accelerator is switched off ($\nu = 0$) the *Taylor Principle* implies a determinate, e-stable equilibrium, even with a response to lagged asset prices. However, as the strength of the financial accelerator increases or ν rises, the less likely it is that agents can learn the rational expectations equilibrium. Conversely, a policy response to current asset prices leads to learning agents updating

forecasts of the external finance premium that are in synch with the stabilizing effects of a response to inflation, which leads to greatly increased regions of determinacy and e-stability as learning dynamics more easily coincide with those of rational expectations.

In addition to asset prices, the other financial factors considered here are credit market factors in monetary policy rules. To the author's knowledge, this is the first examination of credit market factors in the determinacy and e-stability literature. Monetary policy rules that respond to credit spreads are more promising than those that are augmented with a credit volume or financial leverage policy response. There is a significant reduction in the determinate and e-stable parameter space as response to credit volume is introduced. Credit volume is a function of net worth, where there is an implicit policy response to lagged asset prices, which are shown here to have negative implications for policy. However, when a policy response to credit spreads is included there is a modest improvement in the determinate and e-stable parameter set. It is argued that the policy response to credit spreads alongside the inflation response, under rational expectations and learning are both stabilizing and help avoid self-fulfilling fluctuations. This result is particularly encouraging as it dovetails well with some recent literature such as Gilchrist and Zakrajsek (2011) and Gilchrist and Zakrajsek (2012), which show that credit spreads are important in explaining business fluctuations and that policy rules that augment credit spreads are beneficial for macro-stabilization.

The findings of this paper have clear recommendations for policy makers. First, the robustness of the Bullard and Mitra (2002) and Bullard and Mitra (2007) results to a medium scale New Keynesian model with financial frictions demonstrates the continued relevance and importance of the *Taylor Principle* and the merit of policy smoothing in monetary policy rules. Second, there is a case for responding to asset prices but the response must be as close to instantaneous as possible for the monetary authority. Finally, when considering financial sector stress in an economy, the degree of financial leverage and the associated volume of credit is not the appropriate measure to respond to when setting the policy interest rate. It is the pricing of credit, or the external finance premium, as measured by credit spreads that is a more promising as a policy response variable for central banks.

Appendix I - BGG Lagged Policy and Forward Expectations Results with Policy Inertia

Inertia in the Lagged Data Rule: $r_t^n = \phi_\pi \pi_{t-1} + \phi_y y_{t-1} + \phi_r r_{t-1}^n$

Figure 13: Determinacy and e-stability in the Lagged Data Rule with Policy Inertia

Inertia in the Forward Expectations Rule: $r_t^n = \phi_\pi E_t \pi_{t+1} + \phi_y E_t y_{t+1} + \phi_r r_{t-1}^n$

Figure 14: Determinacy and e-stability in the Forward Expectations Rule with Policy Inertia

Appendix II - Policy Rules with Lagged Asset Price Response

Lagged Asset Prices in the Lagged Data Rule: $r_t^n = \phi_\pi \pi_{t-1} + \phi_y y_{t-1} + \phi_q q_{t-1}$

Figure 15: Lagged Data Rule with Lagged Asset Prices

Lagged Asset Prices in Forward Expectations Rule: $r_t^n = \phi_\pi E_t \pi_{t+1} + \phi_y E_t y_{t+1} + \phi_q q_{t-1}$

Figure 16: Forward Expectations Rule with Lagged Asset Prices

Appendix III - Policy Rules with Current Asset Price Response

Current Asset Prices in the Current Data Rule: $r_t^n = \phi_\pi \pi_t + \phi_y y_t + \phi_q q_t$

Figure 17: Current Data Rule with Current Asset Price Response

Current Asset Prices in the Lagged Data Rule: $r_t^n = \phi_\pi \pi_{t-1} + \phi_y y_{t-1} + \phi_q q_t$

Figure 18: Lagged Data Rule with Current Asset Price Response

Appendix IV - Policy Rules with Credit Volume Response

Credit Volume in the Current Data Rule: $r_t^n = \phi_\pi E_t \pi_{t+1} + \phi_y E_t y_{t+1} + \phi_{lv} lv_t$

Figure 19: Current Data Rule with Credit Volume Response

5.0.1 Credit Volume in the Forward Expectations Rule: $r_t^n = \phi_\pi E_t \pi_{t+1} + \phi_y E_t y_{t+1} + \phi_{cs} efp_t$

Figure 20: Forward Expectations Rule with Credit Volume Response

Appendix V - Policy Rules with Credit Spread Response

5.0.1 Credit Spreads in the Current Data Rule: $r_t^n = \phi_\pi \pi_t + \phi_y y_t + \phi_{cs} efp_t$

Figure 21: Current Data Rule with Credit Spread Response

5.0.2 Credit Spreads in the Lagged Data Rule: $r_t^n = \phi_\pi \pi_{t-1} + \phi_y y_{t-1} + \phi_{cs} efp_t$

Figure 22: Lagged Data Rule with Credit Spread Response

Appendix VI - BGG System Parameterization Summary

Parameters				Variables and Great Ratios				Steady State Distributions			
μ	0.1172	σ	0.2713	R	1.0101	Y	0.7732	F	0.0075	G_σ	0.0925
γ	0.9796	β	0.9900	Q	1.0000	W	1.8094	G	0.0034	Γ_ω	0.9925
α	0.3500	η	3.0000	R^k	1.0151	V	3.1268	Γ	0.4979	Γ_σ	-0.0103
δ	0.0250	θ	0.7500	H	0.2500	N	3.0677	λ	1.0091	$G_{\omega\omega}$	1.3737
A	1.0000	κ	0.0858	$\bar{\omega}$	0.4982	$\bar{G}$	0.1546	F_ω	0.1532	$G_{\omega\sigma}$	1.5692
Ω	0.9900	ν	0.0411	K	6.1353	K/Y	7.9345	F_σ	0.2064	$\Gamma_{\omega\omega}$	-0.1532
ξ	3.4013	ρ_a	0.8500	X	1.1000	I/Y	0.1984	G_ω	0.0763	$\Gamma_{\omega\sigma}$	-0.2064
ϵ	0.9605	ρ_g	0.8500	π	0.0000	C/Y	0.5160				
ψ	0.2500	ρ_σ	0.8500	C	0.3990	C^e/Y	0.0824				
				C^e	0.0637	$\bar{G}/Y$	0.2000				
				I	0.1534	K/N	2.0000				

Table 3: Calibrated Parameters, Steady State Variables, Great Ratios and Distributions

Table 3 is a summary of all calibrated parameters, variables and distributions in the BGG system.

Appendix VII - BGG Log-linearized System

The following equations characterize the BGG system, which augments the New Keynesian DSGE model with the optimal financial contract, described in this section.

Aggregate Demand

Economy-wide Resource Constraint

$$y_t = \frac{C}{Y}c_t + \frac{I}{Y}i_t + \frac{\bar{G}}{Y}\bar{g}_t + \left(\frac{C^e}{Y} + \mu GR^k \frac{K}{Y}\right)(r_t^k + q_{t-1} + k_{t-1}) \quad (40)$$

Household Euler Equation

$$c_t = E_t c_{t+1} - r_t \quad (41)$$

Investment Demand Equation

$$r_t^k = (1 - \epsilon)(y_t - k_{t-1} - x_t) - q_{t-1} + \epsilon q_t \quad (42)$$

Investment Adjustment Equation

$$q_t = \psi(i_t - k_{t-1}) \quad (43)$$

Aggregate Supply

Production and Labor Market Equilibrium

$$a_t = (1 - \Omega(1 - \alpha)\left(\frac{1}{1 + \eta^{-1}}\right))y_t - \alpha k_{t-1} + (\Omega(1 - \alpha)\left(\frac{1}{1 + \eta^{-1}}\right))(c_t + x_t) \quad (44)$$

Credit Market

Financial Accelerator

$$E_t r_{t+1}^k - r_t = \nu(q_t + k_t - n_t) \quad (45)$$

External Finance Premium

$$efp_t = E_t r_{t+1}^k - r_t \quad (46)$$

Financial Leverage

$$lv_t = q_t + k_t - n_t \quad (47)$$

Evolution of State Variables

Law of Motion of Capital

$$k_t = \delta i_t + (1 - \delta)k_{t-1} \quad (48)$$

Law of Motion of Net Worth

$$\begin{aligned} n_t = & \gamma[R^k(K/N)(1 - \mu G)r_t^k + (K/N)(R^k(1 - \mu G) - R)(q_{t-1} + k_{t-1}) + (R/N)(N - K)r_t + Rn_{t-1}] \\ & + \frac{(1 - \alpha)(1 - \Omega)(Y/X)}{N}(y_t - x_t) \end{aligned} \quad (49)$$

Monetary Policy and Pricing

New Keynesian Phillips Curve

$$\pi_t = \kappa(-x_t) + \beta E_t \pi_{t+1} \quad (50)$$

Monetary Policy Rule and Nominal Interest Rate ⁹

$$E_t \pi_{t+1} = \phi_\pi \pi_t + \phi_y y_t - r_t \quad (51)$$

⁹This system is using the current data rule $r_t^n = \phi_\pi \pi_t + \phi_y y_t$

AR(1) Shock Processes

Productivity Shock

$$a_t = \rho_a a_{t-1} + \epsilon_{a_t} \quad (52)$$

Government Expenditure Shock

$$\bar{g}_t = \rho_g \bar{g}_{t-1} + \epsilon_{\bar{g}_t} \quad (53)$$

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