Simple Monetary Policy Rules in an Open Economy, Limited Participation Model*

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Abstract

We analyze the stabilization properties of simple monetary policy rules using a small open-economy model constructed around the limited-participation assumption. This provides an important robustness check of previous results on policy rules obtained using models that emphasize other sources of monetary non-neutrality, like rigidities in the price-setting mechanism.

While our analysis confirms some of the results in this literature (smoothing interest rates improves stabilization while explicitly reacting to exchange rates does not), it leads us to question others. Most notably, we show that monetary authorities should react to downward output pressures by *increasing* interest rates. This recommendation arises because in our environment, output and inflation move in opposite directions following most shocks. Therefore instances when output is low are typically associated with inflationary pressures. Increasing rates thus helps reduce the inflationary pressures and actually attenuate the output declines.

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1 Introduction

Since the seminal analysis of Taylor (1993), monetary policy is most often modelled as a feedback rule linking the nominal interest rate set by monetary authorities to the value of endogenous variables like inflation, output, or the exchange rate. Further, a large literature analyzes the stabilization properties of a wide range of such monetary policy rules. The majority of these exercises, however, are conducted using the 'New-Keynesian' framework of frictions in the price setting mechanism. A natural question which therefore arises is whether the insights gained using this common framework are sensitive to alternative model specifications.[1]

In that context, this paper assesses the stabilization properties of several simple monetary policy rules using a small open economy, limited participation model. Limited participation is the assumption that a segmentation in financial markets may prevent, sometimes for extended periods, financial flows between the goods market and the financial market. As demonstrated by Lucas (1990), Christiano (1991) and Fuerst (1992), this assumption is a legitimate alternative source of monetary non-neutrality, which can replicate adequately the effects of monetary policy disturbances on the real economy. It is the only source of monetary non-neutrality in our analysis and domestic prices are flexible at all times. As a result, the monetary transmission mechanism linking changes in the nominal interest rate to inflation and output is different than the one generated by price frictions. This provides a natural test of the robustness of rules to model specification. In addition, the small open economy we model comprises two traded and one non-traded goods as well as the opportunity for domestic financial intermediaries to access foreign financial markets. It is affected by shocks to technology, preferences, and foreign-determined prices and interest rates and we calibrate it to salient features of the Canadian economy. Our results thus have the potential to inform the decisions of policy makers operating within a complex and developed open economy.[2]

Our findings are twofold. On the one hand, we confirm some of the previously identified principles a rule should follow to achieve favorable outcomes. Similar to Rotemberg and Woodford (1999), we find that a high coefficient on lagged interest rates helps stabilize the economy, by enabling monetary authorities to influence long term rates even if their explicit control only extends to the short term. Moreover, reacting directly to exchange rates does not significantly affect the stabilization performance of the rules, a result in line with those of Batini et al. (2003).[3]

On the other hand, we also report results that are significantly different than those in the literature. First, we find that monetary authorities should *increase* rates when output is low,

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[1] The New Keynesian framework is described by Clarida et al. (1999) and King (2000). Its open-economy extensions originate in Obstfeld and Rogoff (1995) and include Betts and Devereux (2000), Kollmann (2001), and Chari et al. (2002). The literature on monetary policy rules is vast; contributions include the papers collected in Taylor (1999), as well as Devereux (2000), Gali and Monnacelli (2002), Batini et al. (2003), Ambler et al. (2003), and Benhabib et al. (2003). Svensson (2003) provides a critical assessment of the literature.

[2] Previous open-economy extensions of the limited participation framework (which include Ho, 1993, Schlagenhauf and Wrase, 1995 and Carlstrom and Fuerst, 1999) either do not allow borrowing from foreign markets or permit it within very stylized models. None of them distinguish between traded and non-traded goods.

[3] This does not imply that the open-economy environment of the analysis is itself irrelevant. Rather, it suggests, as Taylor (2001) points out, that the transmission channel from exchange rates to inflation is successfully internalized by a rule that responds to CPI inflation. Moreover, we find that most of the welfare improvements that arise from the rules we identify result from reductions in the variability of the consumption of imported goods, which indicates that the open-economy features of the model influence our conclusions.

seemingly exacerbating the downturns. Second, some of our results suggest that they should react to inflationary pressures by *lowering* rates instead of increasing them.

The intuition for these surprising results is as follows. In our limited participation environment, output and inflation move in opposite directions in response to most shocks. This negative correlation exists because an expected rise in inflation leads depositors to withdraw funds from financial markets. Since financial intermediaries have limited access to alternative sources of loanable funds, this restricts the supply of loans and thus causes output reductions. Lowering rates in response to an output decrease would thus likely stimulate inflation at a time when it is already increasing. This tension between output and inflation stabilization is significant, so that increasing rates when output is low becomes the best stabilization option. Further, most of the shocks affecting the economy are long-lived and the correct response of monetary policy is thus also long-lasting. In response to an inflation increase caused by a persistent adverse technology shock, for example, monetary authorities need to engineer equally persistent reductions in money-growth rates. At such long term frequencies, movements in money-growth rates, inflation and nominal rates are positively related through the Fisher relation, so that decreasing nominal interest rates actually decreases and stabilizes inflation.

Considering the sizable uncertainty about the correct model of the economy, it is important for monetary authorities to seek policy rules that perform well across a range of modelling environments.[4] One often mentioned advantage of simple rules (such as the one advocated by Taylor, 1993) is that they might be more robust than complex rules fine-tuned to one specific model.[5] Levin et al. (1999, 2003) report that rules with high degrees of interest rate smoothing, moderate responses to inflation and some response to output gaps possess favorable outcomes across several different models of the US economy. However, Côté et al. (2002) and Levin and Williams (2003) show that when similar exercises are conducted using models that differ markedly regarding important elements like the degree to which economic agents are forward-looking, robust rules are difficult to identify. The present paper's contribution to this research program is to approach robustness along the important dimension of what constitutes the main source of non-neutrality in the economy, an analysis that is presently missing from the literature. The fact that some of our results are at variance with other previously established underscores the importance of such an exercise.[6]

This remainder of this paper is organized as follows. Section 2 describes the model, while Section 3 reports the manner in which it is calibrated and solved. Section 4 assesses the model's properties, to develop intuition about its mechanisms and provide a basis upon which the normative results that follow can be evaluated. Section 5 explores the stabilization properties of various monetary policy rules ranked according to the three measures of economic loss. Section 6 discusses and synthesizes the results, highlighting the dimensions along which the introduction of limited participation impinges on the analysis. Section 7 offers some conclusions.

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[4] See McCallum (1988) for an exposition of this argument in the context of nominal income targeting rules. Alternatively, researchers study the robustness of rules with respect to uncertainty about the parameters of the model (Giannoni, 2002), the process of the exogenous shocks affecting the economy (Onatski and Stock, 2002) or the true state of the economy (when available information is imperfect; Orphanides, 2001, Aoki, 2003).

[5] See the introduction to Taylor (1999) for such a argument.

[6] Christiano and Gust (1999) use a limited participation model to discuss monetary policy rules but they do not identify specific loss-minimizing rules and restrict their analysis to a closed-economy setting.

2 The Model

The economy consists of infinitely-lived domestic producers, importers, financial intermediaries and households. All agents within a type are identical, so that we focus on the optimization problem of the representative agent; all prices are taken as given and markets are competitive.[7] This includes traded goods' prices, which are set internationally. Domestic producers use capital and labor to produce one traded good and one non-traded good. Importers purchase a second traded good on foreign markets and sell it on domestic markets. Financial intermediaries lend to producers and importers the funds necessary to their operations. Loanable funds consist of households deposits, liquidity injections from monetary authorities and net borrowing from foreign financial markets. Finally, a monetary authority sets domestic interest rates following a policy rule.

Money is introduced into the model by imposing a cash-in-advance constraint on certain household purchases, in contrasts with most of the literature, which introduces real money balances in the utility function. This provides an intuitive determination of the nominal exchange rate, as the relative price that will set foreign exchange markets in equilibrium. The presence of physical capital in the model, as well as the inclusion of adjustment costs that restrict its flow from one sector to the next, is another distinguishing feature of our modelling strategy. The literature that assesses the properties of monetary policy rules often abstracts from physical capital.

2.1 Households

The representative household seeks to maximize lifetime expected utility, subject to a number of constraints. Its optimization problem is the following:

$$\max_{\{c_{1t},c_{2t},c_{3t},n_t,M^c_{t+1},M^d_{t+1},I_{1t},I_{3t}\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t u\left(c_{1t}, c_{2t}, c_{3t}, n_t, \frac{M^c_{t+1}}{M^c_t}\right), \tag{1}$$

subject to the following constraints:

$$P_{1t}c_{1t} + P_{2t}c_{2t} + P_{3t}c_{3t} + P_{1t}I_{3t} \leq M^c_t + W_t n_t; \tag{2}$$

$$\begin{aligned} M^c_{t+1} + M^d_{t+1} \leq{}& R^d_t M^d_t + \Pi^F_t + \Pi^B_t + R_{1t}k_{1t} + R_{3t}k_{3t} + \\ &(M^c_t + W_t n_t - P_{1t}c_{1t} - P_{2t}c_{2t} - P_{3t}c_{3t} - P_{1t}I_{1t} - P_{1t}I_{3t}); \end{aligned} \tag{3}$$

$$k_{1,t+1} = (1-\delta_1)k_{1t} + I_{1t} - \frac{\phi_{I1}}{2}\left(\frac{I_{1t}}{k_{1t}} - \delta_1\right)^2 k_{1t}; \tag{4}$$

$$k_{3,t+1} = (1-\delta_1)k_{3t} + I_{3t} - \frac{\phi_{I3}}{2}\left(\frac{I_{3t}}{k_{3t}} - \delta_3\right)^2 k_{3t}; \tag{5}$$

The variables c_{1t}, c_{2t} and c_{3t} represent the household's consumption of the domestic traded good, of the imported good, and of the domestic, non-traded good, respectively; n_t represents its work effort. Unlike financial intermediaries, households do not have access to foreign financial markets.

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[7] Because we use limited participation rather than price frictions as the main source of monetary non-neutrality, we can retain the convenience of perfect competition.

The constraints have the following interpretation. Equation (2) is the cash-in-advance constraint. It states that the liquid funds households hold at the beginning of the period, M_t^c, plus wage payments, $W_t \mathrm{n}_t$, must be sufficient to cover the nominal value of consumption of each good $(P_{1t}c_{1t} + P_{2t}c_{2t} + P_{3t}c_{3t})$ and planned investment in new capital for the two (domestic) productive sectors $(P_{1t}I_{1t} - P_{1t}I_{3t})$.[8] Equation (3) is the households' end-of-period wealth constraint. Available financial wealth is the sum of the return on their deposits $(R_t^d M_t^d)$, dividends that arise from their ownership of all firms and banks $(\Pi_t^F + \Pi_t^B)$, the rental income derived from renting the capital they own to domestic firms $(R_{1t}k_{1t} + R_{3t}k_{3t})$, and any liquid funds left over from the purchases described in equation (2). They allocate this financial wealth between beginning-of-next-period liquid balances (M_{t+1}^c) and balances deposited at the financial intermediaries (M_{t+1}^d). This decision is made with information available at time t. If monetary authorities unexpectedly inject liquidity in the financial system at the beginning of period $t+1$, a financial imbalance between that sector (where liquidity will be relatively abundant) and the goods sector (where it will be relatively scarce) is created. The relative abundance of liquidity in financial markets will put downward pressure on nominal interest rates, resulting in the negative correlation between narrow money and interest rates that is difficult to generate using a model with price frictions.

Equations (4) and (5) state that the stock of physical capital in each sector consists of undepreciated installed capital (with depreciation rates δ_1 and δ_3, respectively), plus new investment directed towards that sector, net of quadratic adjustment costs. These costs limit the extent to which capital can move from one sector to the other and thus prevents excessive investment volatility.

The functional form we employ to describe current utility is the following:

$$u\left(c_{1t}, c_{2t}, c_{3t}, n_t, \frac{M_{t+1}^c}{M_t^c}\right) = \gamma_1 \ln(c_{1t} + \iota_t) + \gamma_2 \ln(c_{2t}) + \gamma_3 \ln(c_{3t} - \iota_t) + \psi(1 - n_t - AC_t), \quad (6)$$

where

$$AC_t = \frac{\phi_{pc}}{2}\left(\frac{M_{t+1}^c}{M_t^c} - \mu\right)^2 .$$

Utility is separable in its three consumption and its single leisure arguments. Leisure is defined as one minus hours worked (n_t), minus portfolio adjustment costs (AC_t). This last variable expresses the (quadratic) time costs of modifying households' financial portfolios relative to μ, the steady-state rate of monetary expansion. These costs ensure that monetary shocks have persistent effects.[9] Second, the utility flows from consumption of given levels of type 1 and type 3 goods depend on the preference shock ι_t.[10] The aggregate price index implied by this utility specification, the model equivalent to the CPI index, is as follows:

$$P_t = \frac{(P_{1t})^{\gamma_1}(P_{2t})^{\gamma_2}(P_{3t})^{\gamma_3}}{\gamma_1^{\gamma_1}\gamma_2^{\gamma_2}\gamma_3^{\gamma_3}}. \quad (7)$$

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[8] Note that investment targeted towards sector 3 (the sector producing the non-traded good) is priced at P_{1t}, because the investment good is produced in the traded sector.

[9] This follows Christiano and Gust (1999) and Cooley and Quadrini (1999). These costs reflect the time necessary to arrive at and implement a decision about one's financial portfolio.

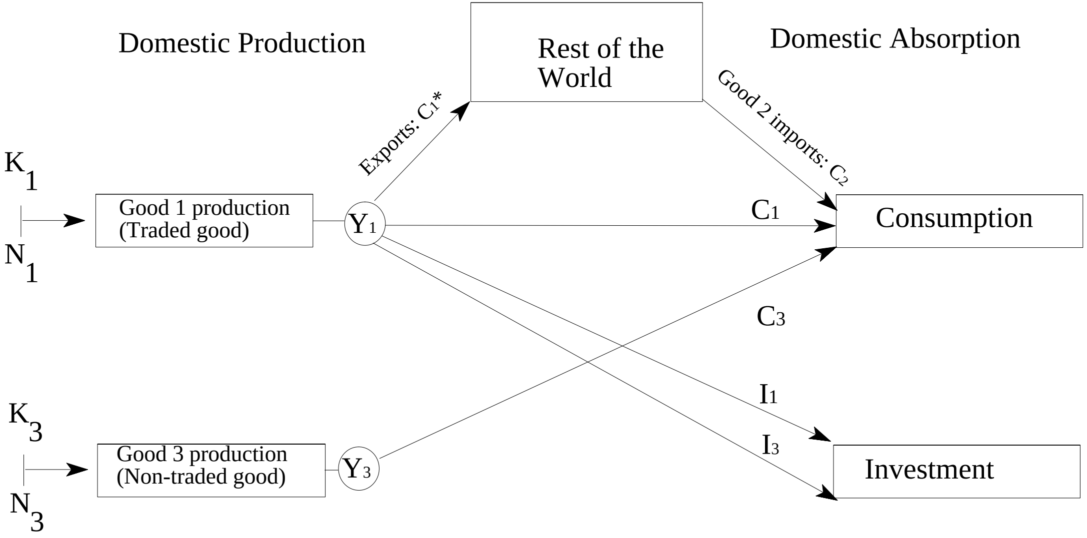
[10] This type of shock, also used by Batini et al. (2003) is meant to act as a 'demand' disturbance.

2.2 Production structure and firms

2.2.1 Production structure

Chart 1 depicts the structure of production and the flow of goods across the economy. First, good 1 is produced domestically: the inputs that enter into this production are drawn from the (domestic) stocks of physical capital and labor. Production of the good is then allocated to exports, consumption, or investment which increases the stock of capital in the two production sectors. Second, good 2 is imported from foreign markets and is allocated entirely to domestic consumption. Third, good 3 is produced domestically but is non-traded: production is thus allocated to domestic consumption.

Chart 1: Production Structure of the Domestic Economy



Only good 1 can increase the stock of physical capital; it is thus interpreted as the generic "good" of this economy. Good 3 can be understood to be its generic "service," and imports (good 2) are assumed not to include any investment goods.[11]

2.2.2 Producers of goods 1 and 3

Good 1 producers rent the necessary capital and labor inputs from households and sell their products in a competitive market. We assume that these firms must settle a portion of their wage bill before they receive the proceeds from their sales and, therefore, must borrow from financial intermediaries to cover these expenses. The optimization problem of these firms is static and is as follows:

$$\max_{\{N_{1t},K_{1t}\}} \frac{P_{1t}Y_{1t} - R_{1t}K_{1t} - J_t R_t^l W_t N_{1t} - (1-J_t)W_t N_{1t}}{P_t}, \tag{8}$$

with respect to the following production function:

$$Y_{1t} = F_1(K_{1t}, N_{1t}) = A_{1t}K_{1t}^{\alpha_1}N_{1t}^{1-\alpha_1}. \tag{9}$$

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[11] Allowing the imported good to contribute to the economy's capital stock would constitute a useful extension of the model.

R_{1t} represents the rental rate of capital, R^l_t is the lending rate on bank loans, W_t is the economy-wide nominal wage rate and, as before, P_t is the aggregate price level while P_{1t} is the price of type-1 goods. Moreover, A_{1t} represents an exogenous productivity shock that affects the production capabilities of all firms in this sector while J_t is the fraction of the wage bill that must be paid in advance and thus borrowed. The remaining fraction of the wage bill $(1 - J_t)$ can be paid out of the revenues from sales. An increase in J_t means that firms must borrow more liquidity to operate at a given scale and can thus be interpreted as an increase in the money demand of production firms.[12]

The optimization problem of firms that produce good 3 is very similar to those of good 1 producers. The only difference is that since capital goods from from type-1 goods, the capital employed by these firms is valued at the price P_{1t}). The following optimization problem thus emerges:

$$\max_{\{N_{3t},K_{3t}\}} \frac{P_{3t}Y_{3t} - R_{3t}K_{3t} - J_tR^l_tW_tN_{3t} - (1-J_t)W_tN_{3t}}{P_t}, \tag{10}$$

with respect to:

$$Y_{3t} = F_3(K_{3t}, N_{3t}) = A_{3t}K_{3t}^{\alpha_3}N_{3t}^{1-\alpha_3}. \tag{11}$$

The technology shocks A_{1t} and A_{3t} are exogenous and follow a bivariate AR(1) process, as follows:

$$\begin{bmatrix} \ln(A_{1t}) \\ \ln(A_{3t}) \end{bmatrix} = A + H \begin{bmatrix} \ln(A_{1t-1}) \\ \ln(A_{3t-1}) \end{bmatrix} + \begin{bmatrix} \varepsilon^{z1}_t \\ \varepsilon^{z3}_t \end{bmatrix}; \begin{bmatrix} \varepsilon^{z1}_t \\ \varepsilon^{z3}_t \end{bmatrix} \sim (0, \Omega_z). \tag{12}$$

In (12), the (2 by 1) vector A contains the long-run mean of the shocks and the (2 by 2) matrix H contains the feedback components. Section 4.2 discusses the calibration of this process.

The price of good 3 is determined endogenously, as part of the general equilibrium of the economy. On the other hand, the price of good 1 is exogenous because this good is traded and the domestic economy is small relative to the world. In foreign currency its price is denoted by P^*_{1t}. We assume that the law of one price holds for that good so that its domestic currency price is:

$$P_{1t} = e_tP^*_{1t}, \tag{13}$$

where e_t is the nominal exchange rate (the domestic currency price of foreign currency).[13]

2.2.3 Importers of good 2

Importers use foreign currency to buy type-2 goods. They transport them back to the domestic economy and sell them to consumers. This market is competitive. These firms must also borrow a fraction J_t of the funds necessary for their purchases. The optimization problem of these firms is as follows:

$$\max_{Y_{2t}} P_{2t}Y_{2t} - R^l_tJ_t(e_tP^*_{2t}Y_{2t}) - (1-J_t)(e_tP^*_{2t}Y_{2t}), \tag{14}$$

where P^*_{2t} is the (foreign currency) price of the good and Y_{2t} the quantity imported; $e_tP^*_{2t}Y_{2t}$ thus represents total domestic currency costs. Since importers borrow a fraction of this amount, the

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[12] We discuss the calibration of these shocks in section 4.2. This type of money demand shock is also used in Christiano and Gust (1999).

[13] An increase in e_t thus represents a depreciation of the domestic currency.

gross nominal lending rate enters the determination of the total costs. The calibration of P_{2t}^* is discussed in section 4.2. The maximization problem is trivial and results in the following arbitrage condition:

$$P_{2t} = [J_t R_t^l + (1 - J_t)] e_t P_{2t}^*. \tag{15}$$

The quantity of good 2 supplied (Y_{2t}) is determined by household demand. The presence of R_t^l in (15), which derives from our assumption that importers borrow some of their purchasing costs, introduces a wedge between P_{2t} and its determinants under the law of one price ($e_t P_{2t}^*$). For given values of the exchange rate, this creates a pass-through from interest rate increases to P_{2t} and thus to the aggregate price level; a tightening of monetary policy could thus lead to increases in prices.

2.3 Financial intermediaries

Financial intermediaries (banks) collect funds from households and lend them to firms. Their optimization problem is as follows:

$$\max_{\{L_{1t}, L_{2t}, L_{3t}, Q_{t+1}|_{t=0}^{\infty}\}} E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t \Pi_t^B, \tag{16}$$

where λ_t is the weight that a firm attaches to future profits (in equilibrium, it is equal to the households' marginal utility of income) and bank profits Π_t^B are defined as:

$$\Pi_t^B = R_t^l L_{1t} + R_t^l L_{2t} + R_t^l L_{3t} + R_t^d (M_t^d + X_t); \tag{17}$$

while the maximization is done with respect to the following constraint:

$$L_{1t} + L_{2t} + L_{3t} \leq M_t^d + X_t - e_t(q_t Q_{t+1} - Q_t). \tag{18}$$

In these expressions, L_{1t}, L_{2t}, and L_{3t} represent bank lending to the three types of domestic firms: the first three terms on the right-hand side of (16) are thus revenues from lending activities (R_t^l is the lending rate). Costs are the payments to households (at rate R_t^d) for the funds they deposited at the end of the preceding period (M_t^d) and for the current injection of liquidity (X_t) from monetary authorities.

In a closed-economy environment, bank lending could not exceed domestic savings. Here, however, we assume that banks participate in foreign financial markets. Specifically, banks can buy or sell a discount bond that pays one unit of foreign currency in the next period, at the (foreign currency) price of q_t. Equation (18) describes how this market enables banks to gather additional liquidity when lending opportunities outweigh domestic savings, or, inversely, when domestic lending opportunities are slim: any excess of domestic lending over savings balances available domestically will be covered by borrowing on international markets. Note that Q_{t+1} expresses the bank's net purchases of discount bonds and a negative value of Q_{t+1} thus corresponds to the bank borrowing on international markets.[14]

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[14] This constraint reduces the extent to which the limited participation assumption 'bites'. In the standard model, a surprise injection leaves a bank with too much liquidity and banks are forced to push nominal lending rates lower than their Fisherian fundamentals. Here, banks can, to a certain extent, lend out excess liquidity on international markets without having to lower domestic interest rates too much.

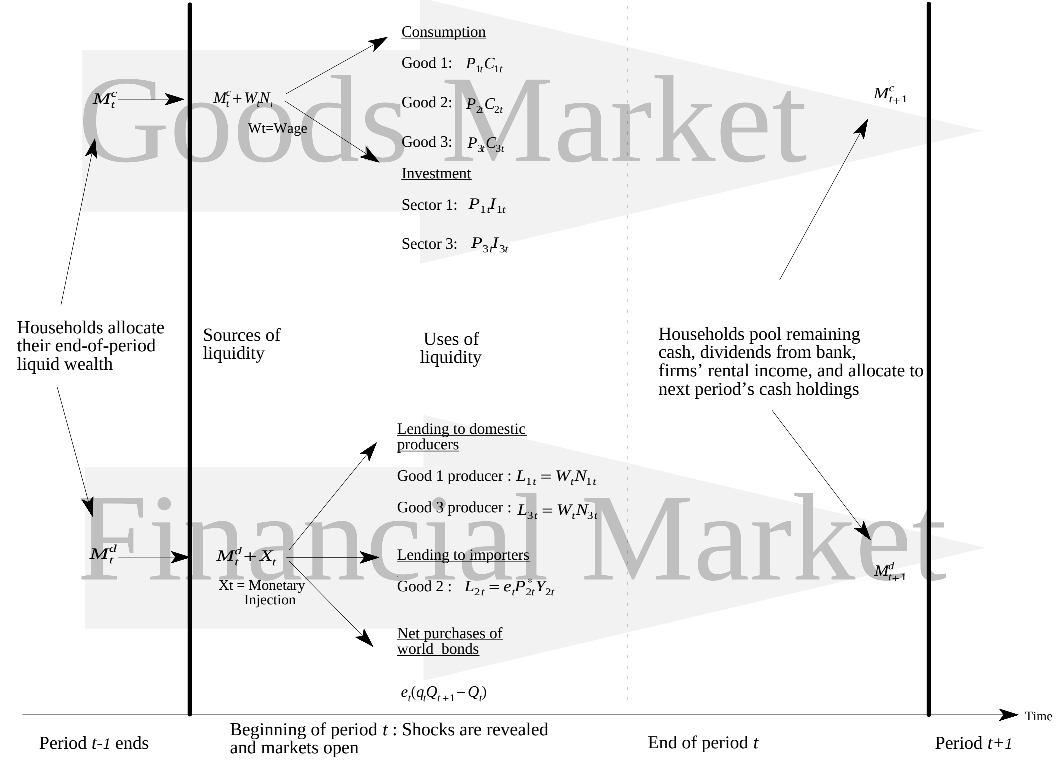
We assume that the return on these bonds, which we denote R_t^{eff},[15] is the sum of the world risk-free rate ($\widehat{R}_t^*$) and of an endogenous component that depends on the banking sector's level of foreign indebtedness. Denoting the deviation of a variable x_t from its steady-state value x by $\widehat{x}_t$, R_t^{eff} is:

$$\widehat{R}_t^{eff} = \widehat{R}_t^* - \eta \widehat{NFA}_t, \tag{19}$$

where $\widehat{NFA}_t$ is the change in the quantity of foreign bonds held by domestic banks. The lending rate on foreign borrowing can thus increase because the world rate R_t^* has increased, or because the net indebtedness of domestic banks $\widehat{NFA}_t$ has worsened. The elasticity parameter η describes the sensitivity of R_t^{eff} to that indebtedness.[16]

Chart 2 summarizes the financial flows within the economy. Households allocate their end-of-period financial wealth to either the goods sector or the financial sector by choosing M_t^c and M_t^d at the end of period $t-1$, before the value of the shocks that affect the economy in period t is known. From that moment, a segmentation exists between the two sectors that prevents liquidity (and, particularly, any new liquidity injection, X_t) from flowing from one sector to the other. Even at the end of the period, when households pool all their liquid funds and choose to allocate them between M_{t+1}^c and M_{t+1}^d, the adjustment costs continue to reduce the flexibility of their decisions.

Chart 2: Financial Flows in the Domestic Economy



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[15] Note that because $R_t^{eff} = 1/q_t$, specifying a process for R_t^{eff} or q_t is equivalent.

[16] The presence of a debt-dependent risk premium ensures that the model has a stationary steady state. See Schmitt-Grohe and Uribe (2003) for a discussion of stationarity in small open-economy models.

2.4 The central bank

Monetary policy is implemented by adjusting the supply of liquid funds (money). Injections of new money during the current period are denoted by $X_t = M_{t+1} - M_t$, where M_t is the total stock of money at the beginning of period t). The gross rate of monetary expansion, μ_t, is thus:

$$\mu_t = \frac{M_{t+1}}{M_t} = \frac{X_t}{M_t} + 1. \tag{20}$$

While the underlying instrument of monetary policy is the rate of monetary expansion, we describe monetary policy as a rule that describes a target level of nominal interest rates as a function of variables known at time t and a stochastic shock, as in the following:

$$\widehat{R}_t = \Omega(I_t) + \varepsilon_t^{MP}, \tag{21}$$

where $\widehat{R}_t$ is the deviation of the nominal rate from its steady-state level, $\Omega(I_t)$ is a (linear) reaction function and ε_t^{MP} is an exogenous disturbance to the rule, or a monetary policy shock.[17] The target for interest rates determines the demand for real money balances. Monetary authorities then set money supply equal to this demand so that the desired interest rate is achieved.

The general form in (21) can accommodate a number of rules analyzed in the literature, such as the one originally described in Taylor (1993):

$$\widehat{R}_t = 1.5\widehat{\pi}_t + 0.5\widehat{y}_t + \varepsilon_t^{MP}. \tag{22}$$

or forward looking ones where the monetary authorities react to deviations of expected future inflation from target, and, possibly smooth out movements in interest rates:

$$\widehat{R}_t = \alpha E_t[\widehat{\pi}_{t+k}] + \beta\widehat{y}_t + \gamma\widehat{R}_{t-1} + \varepsilon_t^{MP}, \tag{23}$$

where specific numerical values of the responses are replaced by generic parameters α and β. This form of rule is equivalent to the one used in the estimations of Clarida et al. (2000), which is found to fit recent monetary policy history well.[18]

Most of our results are arrived at assuming commitment when computing the model solutions. That is, the particular form of (21) under study is entered directly into the rational-expectations solution, imposing the assumption that economic agents assign a probability of zero to monetary authorities ever deviating from that rule. We have conducted some experiments with the alternative assumption of discretion. See Hendry et al. (2003) for the results.

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[17] Our interpretation of ε_t^{MP} is similar to those in the literature on identified VARs. See Christiano el al. (1999).

[18] Throughout our analysis, we assume monetary authorities respond to output deviations from steady-state. Alternatively, we could identify potential output at any point in time as the level that would have obtained were the portfolio rigidities not be present, define the output gap as the difference between actual and this measure of potential, and direct monetary policy to react to the gap. We do not pursue this route for two reasons. First, within a limited participation environment, it may not be that the output gap is a reliable forecast of inflationary pressures, as it is in models based on price rigidities. Responding to the output gap may therefore not necessary lead monetary to achieve better outcomes. Second, the ‘flexible portfolio’ definition of potential output may not correspond even roughly to the empirical measures of potential available to policy makers.

2.5 Market clearing and definition of the equilibrium

2.5.1 Foreign exchange

Domestic agents participate in a foreign currency market that determines the value of the nominal exchange rate. The supply of foreign currency is provided by the exporters: having sold a quantity c^*_{1t}, of good 1 at the (foreign currency) price P^*_{1t}, they hold $c^*_{1t}P^*_{1t}$ in foreign currency. Importers, on the other hand, want to buy Y_{2t} of foreign-made good 2 at the price P^*_{2t}. Finally, banks demand foreign currency to purchase their (net) investment of $q_tQ_{t+1} - Q_t$. Equilibrium in the foreign currency market therefore requires that:

$$c^*_{1t}P^*_{1t} = Y_{2t}P^*_{2t} + (q_tQ_{t+1} - Q_t). \tag{24}$$

2.5.2 Goods markets

Equilibrium in the market for good 1 requires that domestic production be sufficient to cover domestic consumption of that good, investment in both production sectors, and exports:

$$A_{1t}K_{1t}^{\alpha_1}K_{1t}^{1-\alpha_1} = c_{1t} + I_{1t} + I_{3t} + c^*_{1t}. \tag{25}$$

Equilibrium in the market for good 3 states that production equals domestic consumption:

$$A_{3t}K_{3t}^{\alpha_3}K_{3t}^{1-\alpha_3} = c_{3t}. \tag{26}$$

Finally, the market for good 2 is in equilibrium when the quantity that importers purchase in foreign markets is equal to households' consumption of the good:

$$Y_{2t} = c_{2t}. \tag{27}$$

2.5.3 Domestic financial market

Bank lending must be sufficient to cover the borrowing needs of the three types of firms :

$$L_{1t} = J_tW_tN_{1t}; \quad L_{3t} = J_tW_tN_{3t}; \quad L_{1t} = J_te_tP^*_{2t}Y_{2t}. \tag{28}$$

Further, banks do not hold any excess liquidity, so that the constraint (18) holds with equality:

$$e_t(q_tQ_{t+1} - Q_t) + L_{1t} + L_{2t} + L_{3t} = M_t^d + X_t. \tag{29}$$

Perfect competition in the financial market and costless intermediation implies that the lending and the deposit rates are equal; that rate is also the one targeted by monetary authorities:

$$R_t^l = R_t^d = R_t. \tag{30}$$

2.5.4 Labor and capital rental markets

Total labor supply is equal to total demand from the domestic producers of good 1 and good 3:

$$n_t = N_{1t} + N_{3t}, \tag{31}$$

while the capital in place in each of the production sectors must equal the quantity used by firms producing goods 1 and 3:

$$k_{1t} = K_{1t}; \quad k_{3t} = K_{3t}. \tag{32}$$

2.5.5 Definition of the equilibrium

Denote s_t the value at time t of the exogenous shocks that affect the economy and let $s^t = (s_0, s_1, \ldots, s_t)$ be the history of all shocks up to and including period t. An equilibrium for this economy consists of sequences of allocation functions for households $\{c_{1t}(s^t)$, $c_{2t}(s^t)$, $c_{3t}(s^t)$, $n_t(s^t)$, $M^c_{t+1}(s^t)$, $M^d_{t+1}(s^t)$, $I_{1t}(s^t)$, $I_{3t}(s^t)$, $k_{1t+1}(s^t)$, $k_{3t+1}(s^t)\}$, firms $\{N_{1t}(s^t)$, $N_{3t}(s^t)$, $K_{1t}(s^t)$, $K_{3t}(s^t)$, $Y_{2t}(s^t)\}$, and banks $\{L_{1t}(s^t)$, $L_{2t}(s^t)$, $L_{3t}(s^t)$, $Q_{t+1}(s^t)\}$; sequences of pricing functions $\{P_{1t}(s^t)$, $P_{2t}(s^t)$, $P_{3t}(s^t)$, $R_{1t}(s^t)$, $R_{3t}(s^t)$, $W_t(s^t)$, $R^d_t(s^t)$, $R^l_t(s^t)$, $P_t(s^t)\}$; a monetary policy rule that describes monetary authorities' actions (21); starting values for the state variables ($k_{1,t=0}$, $k_{3,t=0}$, M^c_0, M^d_0, $Q_0\}$; and, finally, data-generating processes for the exogenous shock variables (ι_{1t}, A_{1t}, A_{3t}, R^*_t, π^*_t, P^*_{1t}, P^*_{2t}, J_t). [19] The allocations, pricing functions, policy rule, starting values, and exogenous processes are such that (i) taking prices as given, the allocations solve the optimization problem of households described in (1) to (5) and the profit maximization problems of the three types of firms and the banks, and (ii) the market-clearing equations in (24) to (32) are respected.

A numerical representation of this equilibrium is obtained by computing a non-stochastic steady state for the economy and constructing a first-order approximation of the solution around that steady state. Details are available in Hendry et al. (2003).

3 Calibration

3.1 Parameters

The model is calibrated using several Canadian data counterparts to the steady-state properties of the model. The discount rate β is set to 0.99 so that the steady-state real annual rate of interest is 4 per cent. Next, using data from Canadian national accounts, consumption of good 1 is identified with personal consumption of goods, consumption of good 2 with imports, and consumption of good 3 with personal expenditure on services. The utility parameters are set at $\gamma_1 = 0.43$, $\gamma_2 = 0.26$, and $\gamma_3 = 0.31$, so that the relative size of the good 1 to good 3 consumption (1.41) and good 2 to good 3 consumption (0.84), in the steady state are as in the data. The production function parameters (α_1 and α_3), the labor utility parameter (ψ), and the depreciation rate δ are set such that the following are approximately as in the data: the ratio of investment to good 1 output (0.21); the ratio of good 1 to good 3 production (2.91); the total labor supply (0.18 of available time); and the ratio of wages to GDP (0.68).

The steady-state value of the net foreign indebtness of banks, Q, us set to match the corresponding ratio for Canadian banks, which is around -0.012 relative to capital. Finally, we set $\eta = 0.05$, $\phi_{PC} = 0.6$, and $\phi_{I1} = \phi_{I3} = 5.0$, so that net foreign assets are much more volatile than output; inflation and output have a positive contemporaneous correlation of about 0.2, as in the data; and investment is about four times as volatile as output.

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[19] The variable π^*_t represents foreign inflation. Even though it does not appear in the model description so far, the deflated and detrended linearized version of the model includes it.

3.2 Productivity shocks

Taking logs of the production functions in (9) and (11) and rearranging to isolate A_{it} yields:

$$\ln(A_{it}) = \ln(Y_{it}) - \alpha_i \ln(K_{it}) - (1-\alpha_i)\ln(N_{it}),\ i = 1, 3. \tag{33}$$

We match Y_{1t} and Y_{3t} with quarterly GDP at factor cost in the goods-producing sector and in the service-producing sectors, respectively. Next, the capital and labor employed in these two sectors provides us with data series for K_{1t}, K_{3t}, N_{1t}, and N_{3t}. Finally, the values of α_1 and α_3 established above allow us to compute time series for $ln(A_{1t})$ and $ln(A_{3t})$. These series are then detrended and the cyclical components are used to estimate the process given in (12) over the sample 1987Q1-2000Q4. This results in:[20]

$$\begin{bmatrix} \widehat{A}_{1t} \\ \widehat{A}_{3t} \end{bmatrix} = \begin{bmatrix} 0.70 & 0.00 \\ 0.00 & 0.51 \end{bmatrix} \begin{bmatrix} \widehat{A}_{1t-1} \\ \widehat{A}_{3t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_t^{z1} \\ \varepsilon_t^{z3} \end{bmatrix},\ \Omega_z = \begin{bmatrix} 0.00752^2 & 0.00253^2 \\ 0.00253^2 & 0.00502^2 \end{bmatrix}. \tag{34}$$

This process implies that there is little diffusion from one sector to next since the off-diagonal elements in the matrix of coefficients are essentially zero. There still exist some relationship between the two technology shocks, because the innovations ε_t^{z1} and ε_t^{z3} have a contemporaneous correlation of 0.17.[21]

3.3 Foreign shocks

There are four foreign shocks in the model: R_t^*, π_t^*, P_{1t}^*, and P_{2t}^*. The world short-term rate R_t^* is a trade-weighted average used in the projections conducted by the Bank of Canada. Inflation is the net annual rate of growth in the foreign GDP deflator.[22] The relative foreign price of good 1, P_{1t}^*, is by multiplying the nominal exchange rate by the deflator for Canadian exports (P_t^{exp}) and dividing by the world price deflator, yielding:

$$P_{1t}^* = \frac{e_t P_t^{\text{exp}}}{P_t^*}. \tag{35}$$

Similarly, using the deflator for Canadian imports leads us to the following definition for P_{2t}^*:

$$P_{2t}^* = \frac{e_t P_t^{imp}}{P_t^*}. \tag{36}$$

The four series are detrended using the HP filter and the following VAR(1) is estimated:[23]

$$\begin{bmatrix} \widehat{R}_t^* \\ \widehat{\pi}_t^* \\ \widehat{P}_{1t}^* \\ \widehat{P}_{2t}^* \end{bmatrix} = \begin{bmatrix} 0.66 & 0.06 & 0.03 & -0.02 \\ 0.19 & 0.37 & -0.002 & 0.004 \\ -0.60 & 1.97 & 0.60 & 0.24 \\ -0.53 & 1.61 & -0.35 & 1.12 \end{bmatrix} \begin{bmatrix} \widehat{R}_{t-1}^* \\ \widehat{\pi}_{t-1}^* \\ \widehat{P}_{1t-1}^* \\ \widehat{P}_{2t-1}^* \end{bmatrix} + \begin{bmatrix} \varepsilon_t^{R^*} \\ \varepsilon_t^{\pi^*} \\ \varepsilon_t^{P_1^*} \\ \varepsilon_t^{P_2^*} \end{bmatrix}, \tag{37}$$

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[20] The labor data is only available since 1987 on a sector basis.

[21] Batini et al. (2003) also find modest diffusion when calibrating their model to the UK economy.

[22] This deflator is also trade-weighted. Note that $\pi_t^* = P_t^*/P_{t-1}^* - 1$, where P_t^* is the world price deflator.

[23] Estimation using non-detrended data does not significantly affect the results.

with the estimated variance-covariance matrix for the residual vector $\left[\begin{array}{cccc} \varepsilon_t^{R^*} & \varepsilon_t^{\pi^*} & \varepsilon_t^{P_1^*} & \varepsilon_t^{P_2^*} \end{array}\right]'$:

$$\Omega_w = \left[\begin{array}{cccc} 4.95e-6 & 1.34e-6 & 1.34e-5 & 1.50e-5 \\ 1.34e-6 & 3.54e-6 & 6.09e-6 & 4.65e-7 \\ 1.34e-5 & 6.09e-6 & 4.55e-4 & 5.43e-4 \\ 1.50e-5 & 4.65e-7 & 5.43e-4 & 7.62e-4 \end{array}\right]. \tag{38}$$

These results imply that there is a significant correlation between the foreign interest rate and the inflation rate: the diffusion parameters are 0.06 and 0.19, respectively, and the contemporaneous correlation in the innovations is 0.32. Further, there are strong links between the two relative price series; most notably, the correlation between the innovations to P_{1t}^* and P_{2t}^* is 0.92.

3.4 Shocks to monetary policy, preferences and money demand

To conduct some of our experiments we use the following monetary policy rule, estimated by Ravenna (2001) using the methodology of Clarida et al. (2000) with Canadian data:

$$\widehat{R}_t = 0.333E_t[\widehat{\pi}_{t+k}] + 0.0078\widehat{y}_t + 0.84\widehat{R}_{t-1} + \varepsilon_t^{MP}. \tag{39}$$

We set the standard deviation of monetary policy shocks to 0.001 and the steady-state inflation rate at 4.5 per cent, its average in Canada over the sample used by Ravenna to estimate (39).

The consumption shock, ι_{1t} follows an AR(1) process. Its parameters are set to approximately replicate the observed volatility of consumption relative to output in Canadian data:

$$\iota_t = 0.7\iota_{t-1} + \varepsilon_t^{cons}; \qquad \varepsilon_t^{cons} \sim (0, 0.01^2). \tag{40}$$

The demand for money shock (J_t) also evolves according to an AR(1) process, whose parameters are such that the model approximately matches the relative variability of money growth and inflation:

$$\log(J_t) = 0.5\log(J_{t-1}) + \varepsilon_t^{MD}; \qquad \varepsilon_t^{MD} \sim (0, 0.001^2). \tag{41}$$

4 Model Properties

4.1 Impulse responses

Empirical studies using identified Vector Autoregressions (VARs) have, on balance, shown that a monetary policy easing has the following effects: (i) short-term interest rates decrease on impact and remain below their initial level for a few quarters; (ii) narrow money (the liquidity of financial markets) increases on impact and its return to pre-shock levels approximately mirrors that of short-term rates; (iii) output increases and remains high for several periods; (iv) inflation does not respond at first before eventually experiencing an increase that only gradually fades away; (v) nominal and real exchange rates undergo persistent depreciations, and (vi) the responses of output and inflation exhibit hump-shape patterns.[24]

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[24] Christiano et al. (1999) review this literature (see also Bernanke and Mihov, 1998). Cushman and Zha (1997), Fung and Kasumovich (1998) and Kim and Roubini (2000) provide open-economy extensions.

To verify the extent to which our model can replicate these facts, Figure 1 shows the impulse response of the model economy following a monetary policy easing. This shock is obtained by setting ε_t^{MD}, the disturbance to the rule in (39), to -0.001, which corresponds to a 60 basis points decrease in the annualized interest rate.

First, note that monetary authorities tighten money growth to decrease the interest rate (recall that money growth is the instrument by which monetary policy is implemented). The negative correlation between money growth and interest rate is typical of models based on limited participation. The initial decrease in interest rates persists in the following periods and the rates only gradually return to steady state. Second, real variables (output, consumption, hours) experience persistent increases. Moreover, the responses of the three types of consumption and of hours worked in sector 3 exhibit hump-shaped patterns; such patterns are however absent in the responses of output and hours worked in sector 1. Third, both the real and nominal exchange rates experience persistent depreciations. Finally, inflation increases relative to its steady-state value, but its movements lack the persistence and the hump-shape patterns that characterize those in empirical studies.[25]

Overall, we find a broad concordance between the model economy's response to the shock and those identified in the empirical literature. This concordance increases our confidence that the stabilization properties of the different monetary policy rules described below contain useful information for policy makers.

The model also produces plausible responses following technology and money demand shocks (not reported).[26] Following a negative shock to good-1 technology, monetary authorities react to the inflationary pressures created from the shock by decreasing money growth, thus increasing nominal rates and exacerbating the negative effects on output that stem from the reduced production capabilities. On the other hand, monetary authorities are able to fully insulate the economy from the effects of an increase in the producers' demand for money (an increase in J_t), matching this shock with an increase in money supply.

4.2 Uniqueness, indeterminacy, and explosiveness

Some rules generate equilibria that are not unique and stable, but rather indeterminate, so that episodes of self-fulfilling expectations can occur, or explosive so the economy does not converge back to its initial state after a shock. These latter two cases can be interpreted as situations where the rule followed by monetary authorities exacerbates fluctuations rather than stabilizes them, and therefore is welfare-reducing. It is therefore important to verify that our model can generate unique and stable equilibria for a wide variety of monetary policy rules.

To this end, Figure 2 illustrates the stability implications of a standard rule which reacts to deviations of inflation and output from their steady-state values as well as to lagged values of the interest rate, as follows:

$$\widehat{R}_t = \alpha\widehat{\pi}_t + \beta\widehat{y}_t + \gamma\widehat{R}_{t-1} + \varepsilon_t^{MP}. \tag{42}$$

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[25] The monetary easing has both a stimulating effect on prices (it puts more money in the hands of households) and a dampening effect on prices, because it reduces production costs. Christiano et al. (1997) show that introducing monopolistic competition and no intertemporal substitution in labor supply reinforces the supply-side effect and thus leads to a more gradual increase in prices. The addition of these features in the present model would likely also reduce the impact increase in prices.

[26] The responses are available in Hendry et al. (2003).

The three panels of the figure examine values of $\gamma = 0, 0.5$, and 1.5 respectively, and each panel explores a wide range of values for α and β.[27] For each combination of parameters, the figure shows whether the equilibrium is unique and stable (light grey), indeterminate (white), or explosive (dark grey). We indicate the rare cases where we could not find any solution in black.

The figure delivers three messages. First, a positive and vigorous response of interest rates to inflation deviations is likely to produce uniqueness and stability in the equilibrium. Second, for given values of the inflation response, smaller and maybe negative responses to output makes uniqueness and stability more likely. Note that a negative response to output would direct monetary authorities to increase rates when output is low. Finally, a significant weight of lagged interest rates in the rule (a strong smoothing behavior) also favors stability.

The finding that a strong response to inflation favors stability but that a strong response to output undermines is also an implication of the closed-economy limited participation model of Christiano and Gust (1999). This occurs because in these models, an expected rise in inflation leads agents to reduce the amount of funds they send to financial markets (the expected inflation would devalue the purchasing power of the return from saving). Banks cannot create substitutes for these deposits and must therefore reduce the total supply of loanable funds, increasing lending rates and thus creating downward pressure on output.[28] A rule that directs monetary authorities to dampen this rise in interest rates by injecting liquidity in the financial markets (i.e., a low value of α or a high value of β) may provide the support that enables a shock to expected inflation to become self-fulfilling. In contrast, a rule that responds strongly to inflation but only in a limited manner to output variability (a high value of α and a low value of β) reduces liquidity following a rise in expected inflation, and the chain that may have linked expected increases in inflation to increases in the actual rate is cut: no self-fulfilling episodes can exist.

Our inclusion of open-economy aspects does modify the results of Christiano and Gust (1999) along another dimension, however: relative to what they report, the size of the explosiveness region shrinks, with the indeterminacy and uniqueness regions expanding to cover the gap. This implies that in our analysis, the original Taylor rule with $\alpha = 1.5, \beta = 0.5$ and $\gamma = 0$ yields a stable equilibrium, while it does not in Christiano and Gust's analysis. Although an expected rise in inflation still reduces the domestic supply of liquidity to financial markets, banks have, in our framework, access to international financial markets as an alternative source of financing. Therefore, the reduction in the supply of funds is lessened, and the upward pressure on the interest rate and the downward pressure on output diminished. A strong response to output deviations (a high value of β) may not lead to the injection of new liquidity (which would help make the rise in expected inflation self-fulfilling), because the rise had a smaller impact on interest rates and output to begin with. In summary, a rule that does not contain a strong positive response to output tends to be associated with unique, stable equilibria, as does a rule that includes a strong weight on lagged interest rates.

The next section describes the stabilization properties of a wide battery of monetary policy rules. Throughout, we restrict the analysis to rules which lead to stable and unique equilibria,

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[27] We allow α and β to take negative values. The figure reveals that negative responses to output or inflation deviations can lead to unique stable equilibria.

[28] The inability of financial markets to create substitutes for household deposits can be interpreted as a situation where the supply of loanable funds is severely constrained for reasons exogenous to the model.

implicitly assuming that rules leading to indeterminate or explosive equilibria lead to significantly reduced welfare outcomes.

5 Stabilization and Monetary Policy Rules

This section describes the stabilization properties of simple monetary policy rules. Throughout, the type of a rule is the list of feedback variables to which interest rates respond; in the case of the rule in (42) for example, these are inflation, output, and lagged interest rates. The best specification within a type consists of the coefficient values that achieve the lowest loss.[29]

We also compute the globally optimal rule, which arises from a Ramsey-type problem in which monetary authorities directly optimize their loss function taking as given the decision rules of households, most notably their response to interest rate movements.[30] This rule cannot be characterized as a simple function of a few observables because it responds to all state variables, as well as to lagged Lagrangean multipliers associated with the decision rules of the agents. Because of its complexity, we consider that it is not implementable and use it as a benchmark with which to gauge the stabilization properties of simple rules.

5.1 Three measures of loss

We use three different measures of loss to rank policy rules. These measures are meant to capture the economic costs of volatility. A rule is thus judged to possess good stabilization properties if it results in a low-loss equilibrium.

The first concept of loss is utility-based. It is obtained by computing a second-order Taylor expansion of households' lifetime utility around the non-stochastic steady state of the model, which yields:

$$W \approx u^{ss} - \frac{\gamma_1}{2}\sigma^2(\widehat{c}_{1t}) - \frac{\gamma_2}{2}\sigma^2(\widehat{c}_{2t}) - \frac{\gamma_3}{2}\sigma^2(\widehat{c}_{3t}), \tag{43}$$

where W is lifetime utility, u^{ss} is the utility obtained in the steady state, and $\sigma^2(\widehat{c}_{1t})$, $\sigma^2(\widehat{c}_{2t})$, and $\sigma^2(\widehat{c}_{3t})$ are the variance in each type of consumption. Since the value of u^{ss} is common across rules (they all lead to the same steady state), the policy maker's objectives is to minimize the weighted sum of variances in (43). We thus have the following utility (or welfare)-based loss function:

$$L^1 = \gamma_1\sigma^2(\widehat{c}_{1t}) + \gamma_2\sigma^2(\widehat{c}_{2t}) + \gamma_3\sigma^2(\widehat{c}_{3t}). \tag{44}$$

Note that deviations of inflation from target do not enter the definition of L^1, as it does in models incorporating price rigidities (Rotemberg and Woodford, 1999). The reason is that in our limited participation model, there are no welfare-reducing dispersion in relative prices across producers as prices are flexible at all times.

An alternative way to measure the loss arising from economic fluctuations consists of focusing on the volatility in inflation and output. Therefore, in order to provide a comparison benchmark to

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[29] In the language of Svensson (2003) these rules are thus *instrument* based. Numerical optimization is conducted using Matlab's simplex algorithm (*fmins*).

[30] Svensson (2003) refers to such a rule as *target* based. The numerical computation of globally optimal rules is discussed in Soderlind (1999) and Dennis (2003).

our analysis using L^1, we also rank rules according to the following loss, which penalizes variability in output and inflation equally:

$$L^2 = \sigma^2(\widehat{\pi}_t) + \sigma^2(\widehat{y}_t). \tag{45}$$

The direct inclusion of inflation volatility in the loss is consistent with the objective of an inflation targeting monetary policy, while the addition of output volatility can proxy for the horizon over which monetary authorities seek to stabilize inflation.[31]

We also examine a third loss, which penalizes interest rate variability in addition to inflation and output variability. This reflects the commonly held view that policy makers prefer to change interest rates by small repeated increments rather than aggressive changes, perhaps to avoid situations where the zero lower bound on nominal interest rates becomes binding. We use a weight of 0.25 on the interest rate variability (this follows Batini et al., 2003) so that the loss is:

$$L^3 = \sigma^2(\widehat{\pi}_t) + \sigma^2(\widehat{y}_t) + 0.25\sigma^2(\widehat{R}_t). \tag{46}$$

5.2 Results: welfare-based loss function

Table 1 reports the implications of nine rules, ranking them according to the welfare-based loss function in (44). For each of the rule, the first panel reports the optimized coefficients for the rule. The second panel presents the loss associated with each rule, as well as the loss relative to the one which would be achieved using the globally optimal policy rule. The third panel of the table reports the volatility of economic variables that is implied by the rule. The last panel shows the loss associated with the rule according to the two alternative definitions, as well as the likelihood of negative nominal interest rates occurring in the simulations.[32]

Rule 1, the simple Taylor Rule with (non-optimized) coefficient of 1.5 on inflation and 0.5 on output yields a loss of 0.00314 which is 25 percent above that achieved by the global optimal. Rule 2 describes an optimized Taylor Rule, where the best values of the responses to inflation and output have been identified. Relative to that of the original rule, the loss has been reduced to only 13 percent above the one implied by the optimal rule. The third panel of the table indicate that these welfare improvements result mostly from a reduction in the variability of c_2, the consumption of imported goods. Further, the coefficient on inflation is significantly higher than 1.5 and the coefficient on output is now negative. These results are consistent with the stability analysis above, which reported that in a limited-participation environment, policy rules require high coefficients on inflation and low coefficients on output to perform well.[33]

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[31] In models featuring rigidities in the price setting mechanism, movements in output predict those in future inflation. Note that in such models the utility-based loss function can sometimes coincide with the definition of L^2. Further, some authors working with open-economy models consider adding exchange rate volatility in the loss definition in (45).

[32] Table 1 as well as Table 2 and 3 indicate that this likelihood is small for most rules. For the rules where it is significant, an important extension of the analysis would be to explicitly account for the non-linear behavior of the economy at the zero bound as well as the possible changes in the implementation of monetary policy, through direct purchases of financial assets, for example.

[33] Notice that when compared using the lifetime utility measure (W_t in expression (43)), the differences between Rule 1 and Rule 2 are small and in both cases, lifetime utility is only marginally lower that it would be in an environment where volatility was completely eliminated. The finding that moderate fluctuations have only modest welfare costs when measured using standard utility functions is common to the literature; see Lucas (1987).

Rule 3 adds a response to lagged interest rates, as in (42). Optimizing over the three coefficients leads to a further los reduction relative to the original Taylor rule: it is now only 9 per cent above that of the global optimum. This welfare improvement originates from small reductions in the variability of all three types of consumption. The coefficients on both output and inflation are negative, while the coefficient on lagged interest rates is higher than 1. In relation to the graphs shown in Figure 2, the best rule is thus located in the bottom left quadrant of panel C. The negative coefficient on inflation is not a standard feature of the literature on policy rules: it implies that monetary authorities should react to inflationary pressures by reducing interest rates. Further, the high value of the coefficient on lagged interest rates would seem to impart an explosive behavior to the economy. As discussed in section 7 below, these two results reflect the fact that the objective of stabilizing short run fluctuations can lead monetary authorities to focus on the long term effects of their interventions, particularly in a model where agents are forward-looking. Notice also that Rule 3 leads to very variable inflation, which is not a problem since the objective function L^1 does not take such volatility into account. In contrast, the second- and third-last rows of Table 1 show that Rule 3 performs worse if inflation variability appears in the loss (as in L^2 and L^3).

Rules 4, 5, and 6 explore the consequences of adding the real exchange rate, s_t, to the list of feedback variables monetary policy responds to. The respective rules differ in that the current value, the current and lagged values, or the growth rate of s_t enters the rule. Rule 4 shows that reacting only to the current level of the real exchange rate has a limited impact: the coefficient on the real exchange rate is close to zero and the welfare results, as well as the coefficients on inflation, output, and lagged interest rates, are virtually unchanged from those reported under Rule 3. Batini et al. (2003) and Côté et al. (2003) also report little benefit from reacting directly to exchange rate movements. Noticeable improvements in the welfare loss do result from reacting to both current and lagged values of the real exchange rate, as in Rules 5 and 6. The signs of the coefficients indicate that positive changes in s_t relative to s_{t-1} (real depreciations) should lead, somewhat counterintuitively, to decreases in the interest rate set by monetary authorities. We do not focus on these rules, because this is the only instance in which we find that reacting to exchange rates affects the analysis.

Rule 7 responds to inflation and lagged interest rates, as Rule 3, except that expected future deviations of inflation from steady state, rather than the current one, enter the rule. This is the type of rule estimated by Ravenna (2001) using observed monetary policy outcomes in Canada over the last decade. Note that the numerical coefficients of Rule 7 are fairly different from the estimates reported in (39). Although this modification of the rule's structure does not significantly change the coefficients on inflation and lagged interest rates, the coefficient on output is now positive. The welfare loss is also slightly lower than it was under Rule 3, consistent with the results in Batini et al. (2003), where such an inflation-forecast-based (IFB) rule is found to minimize loss.

Rule 8 reacts to lagged output and inflation deviations, rather than their current values which might not be known with certainty when monetary authorities set interest rates. Table 1 reports that this leads to a slightly higher loss than Rule 3. Further, the response to interest rates is lower, and responses to both inflation and output are positive.[34] The deterioration in welfare is caused

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[34] Rotemberg and Woodford (1999) also report slight increases in loss when the lagged values of the feedback variables are entered in a rule that responds to inflation, output, and interest rates.

by an increase in the variance of c_3, the consumption of the non-traded goods. These results suggest that there is only a slight difference in the welfare attained and the correct responses to inflation and output when monetary policy must be conducted with knowledge of only past economic outcomes.

Rule 9 includes responses to both current and future inflation in the rule. The resulting coefficients are similar to those of Rule 7, which reacts only to expected future inflation; this suggests that the key response is the one that governs the reaction to future inflation. Nevertheless, Rule 9 does produce small reductions in the loss, relative to the already low level achieved under Rule 7. Interestingly, the welfare improvements arise from a reduction in the variability of the non-traded good consumption, c_3. Finally, the last column of Table 1 shows that further reductions in the volatility of imported good and non-traded good consumption are possible using the globally optimal rule, which reacts to all shocks and state variables of the economy. Relative to the Taylor rule, the variance of good 2 consumption is reduced by 50 per cent.

In summary, we find that a rule that responds to lagged interest rates as well as to current output and inflation deviations exhibits good stabilization properties. The signs of these responses would lead monetary authorities, however, to take decisions that might appear at first counterintuitive: lowering rates when output or inflation is pushing upwards, and reacting to lagged rates with seemingly explosive force. In addition, there was little robust evidence to suggest that directly reacting to exchange rates might significantly improve welfare. Moreover, responding to current inflation, rather than expected future inflationary pressures or past values of inflation, appears to be important to lower economic loss. Finally, most of the welfare improvements that arise from choosing the better rules result from a reduction in the variability of the imported good consumption, and at the expense of inflation variability. The inclusion of open-economy features in the analysis thus has important consequences for our assessment of what a "good" monetary policy rule is, even though the inclusion of the real exchange rate in the rules does not produce significant changes to their stabilization properties. We now explore the extent to which these results depend on the loss function used to rank the rules.

5.3 The results: alternative loss functions

Table 2 reports the stabilization properties of the same types of rules when they are ranked by the loss function L^2, which weighs equally output and inflation deviations from steady state. One result that is repeated from Table 1 is that the original Taylor rule (Rule 1) can be significantly improved by using the optimized coefficients (Rule 2): this reduces the loss from 33.8 to 4.5, a decline of over 85 per cent.[35] The predominant source of this reduction is a substantial decline in the volatility of inflation. Further, as in Table 1, the optimized coefficient on inflation is positive, while the response to output is negative. The objective of limiting the variability of inflation, which was not a concern in the ranking presented in Table 1, leads monetary authorities to increase rates in response to upward pressures on inflation, the standard response discussed in the literature.[36]

Rule 3, in which the lagged value of interest rates is added to the list of feedback variables,

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[35] The absolute magnitudes of the losses are not comparable across the different specifications of the loss function.

[36] In Table 1, the rules containing a negative reaction of monetary policy to inflation who perform well under the loss L^1 do much worse under L^2 or L^3 (see the second to last, and third to last rows of Table 1).

obtains a slightly reduced loss. The signs of the output and inflation coefficients do not change, and the lagged interest rate coefficient continues to be above one, as was the case in Table 1. This better result is obtained with a reduction in output variability: compared with Rule 2, the volatility of inflation actually increases slightly.

Including the real exchange rate in the rule, the implications of which are illustrated by Rules 4, 5, and 6, does not significantly modify the results. The responses to the exchange rate are close to zero, and the coefficients on output, inflation, and lagged interest rates, as well as the values attained by the loss, are virtually unchanged from Rule 3. Reacting explicitly to exchange rates does not have much of an effect on the ability of monetary policy rules to minimize loss when measured by the sum of output and inflation variability. This is in contrast with some of the results in Table 1, which suggested that reacting to real depreciations might lead to some decreases in the loss.

Rule 7, which reacts to expected future inflation rather than current inflation, significantly worsens the loss; the results are the lowest of all rules analyzed. This is in sharp contrast with Table 1, where such a rule has a very good outcome. This result illustrates that within our flexible price model in which inflation reacts quickly and transiently to shocks, reacting only to expected future inflation is not an efficient way to limit its variability. Again, were inflation volatility to cease being a concern, such a rule would start performing better: when the rules in Table 2 are ranked according to the welfare-based loss, L^1, Rule 7 is the best.

Rule 8, in which the lagged values of inflation and output enter the rule, worsens the loss, though not as drastically as the drop associated with Rule 7. This result (and a similar one reported in Table 1) suggests that the ability to observe and react to inflation quickly is important in our framework; the quick and transient response of inflation to economic shocks plays a role in generating this result. Finally, Rule 9, which responds to both current and future inflation, performs the best of all the rules examined.

In summary, most of the general results first described in Table 1 are robust to ranking the rules according to L^2. Responding to lagged interest rates in addition to inflation and output shows the best potential for loss minimization; the response to lagged interest rates should be strong, while the coefficient on output should be weak, or even negative and, on balance, the response to the exchange rate should be zero. The results are less robust with respect to the coefficient on inflation, which is negative most of the time when ranking rules according to L^1, but positive when using L^2. Further, responding to current values of inflation is important, as the loss is significantly affected if monetary authorities react only to future or only to lagged inflation. It is important to note that the numerical values of the coefficients in the rules with good stabilization properties are quite different across loss functions, even within the same rule type. Our analysis should therefore be interpreted as identifying principles to guide monetary policy practice across a wide variety of situations, rather than finding a precise numerical rule.

Table 3 confirms that these general principles are robust to yet another measure of loss. The table illustrates the consequence of modifying loss L^2 by including the variability in interest rates in the loss, which is written as in (46). The table indicates that the loss is significantly reduced by first optimizing over the coefficients on current inflation and output (Rule 2), and then adding lagged interest rates to the rule (Rule 3). The presence of interest rate volatility in the loss significantly increases the coefficient on lagged interest rates in the rule, relative to Table 2. Again, the inclusion of an exchange rate variable has no significant impact on the analysis. Finally, the absence of current inflation from the list of variables that monetary policy responds to does not lead to good outcomes. The precise numerical values of the coefficients in the rules have again changed from Table 2 to Table 3.

5.4 Responding to the GDP deflator

To this point, the inflation variable that has been included in the rule was the model equivalent to the growth in the CPI index as defined in (7). Table 4 reports the ranking of a subset of the rules when the growth in the model equivalent to the GDP deflator is used as the measure of inflation. A majority of the rules perform substantially worse than when CPI inflation was used. Only the rule that minimizes the welfare-based loss function using domestic inflation, output, and the lagged interest rate is close to its counterpart with CPI inflation reported in Table 1. While the inflation response is negative for all but one rule, the output coefficient is negative only for the rules operating under the welfare-based loss. Interestingly, including the change in the real exchange rate in the rule (Rule 11) provides improvements to the losses, even under L^2 and L^3. This is because restraining monetary policy to only react to domestic prices excluded p_2, the price of the imported good, from the analysis: reacting to the exchange rate is one way to reintroduce a concern for the variability in the imported good consumption c_2. In summary, reacting only to the domestic portion of inflation would not be recommended by this model. If a central bank decided to follow such a strategy, however, including the change in the real exchange rate variable would improve the performance of the monetary policy rule.

5.5 Full-commitment rules and discretionary rules

The discussion so far assumes that there exists a commitment device that ensures monetary authorities will follow the specified rule until the infinite future, with zero probability of deviation. Christiano and Gust (1999) argue that this assumption might be unrealistic. Faced with a very substantial adverse-supply shock, for example, monetary authorities will need to increase interest rates significantly and damage an already fragile economy to control inflation. In such instances, there might be strong incentives for monetary authorities to deviate from their announced rules to lessen the impact of shocks to the real economy, making the full-commitment assumption less tenable.

Consequently, we also computed optimal discretionary rules, following the strategy described in Dennis (2003). These rules allow monetary authorities to re-evaluate the actions they should take every period, within a Nash game between the central bank, which chooses its rule given decision rules of private agents, and these agents, who make decisions based on what they believe the central bank is doing at the time and with the understanding that it may reoptimize in the future. Results (not reported) show that there are significant benefits from the commitment device: the loss functions decline substantially when the commitment assumption is used, relative to the discretionary equilibria.[37]

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[37] Numerical results are available in Hendry et al. (2003).

6 Discussion

6.1 Negative responses to output

Most of the rules shown in Tables 1 to 4 contain a negative response to output. A priori, raising interest rates when output is already low would seem to exacerbate fluctuations and lead monetary policy to have a destabilizing effect on economic activity. In this model, however the second-round effects of these negative responses facilitate rather than undermine stabilization.

Recall that our limited-participation model contains a channel by which shocks affect the supply of loanable funds. Expected rises in inflation lead households to withdraw funds from financial markets. Since financial institutions do not have the ability to create money substitutes, this leads to credit supply restrictions, which increase lending rates and depress economic activity. This "liquidity supply" channel thus associates inflationary pressures with declines in output, a negative correlation that does not occur in models from the New Keynesian paradigm.

Consider a policy rule that reacts to inflation with coefficient $\alpha > 1$. Abstracting from monetary policy shocks, we have:

$$\widehat{R}_t = \alpha \widehat{\pi}_t. \tag{47}$$

Under this rule, inflationary pressures lead monetary authorities to increase nominal rates. In a limited-participation model, this requires that the money-growth rate be decreased. Now consider a rule that reacts to output in addition to inflation, with a coefficient $\beta > 0$:

$$\widehat{R}_t = \alpha \widehat{\pi}_t + \beta \widehat{y}_t. \tag{48}$$

The 'liquidity-supply' channel described above implies that most shocks produce negatively correlated pressures on inflation and output. An adverse technology shock, for example, leads to decreases in output but increases in inflation. In such a context, the responses described by α and β undermine each other. The coefficient $\beta > 0$ directs monetary authorities to lower rates to attenuate the decline in output. Such rate decreases require an acceleration in the money-growth rates that exacerbate inflationary pressures. These lead to rate increases (because $\alpha > 0$) and, therefore, potentially to further output declines even though the original intent was to attenuate these declines.

By contrast, when the coefficient β is negative, the two effects work together to stabilize the economy. On the one hand, the increase in inflation requires monetary authorities, through the parameter α, to decrease money growth in order to increase nominal rates. On the other hand, the original decline in output leads monetary authorities to increase nominal rates, seemingly at the expense of output. But this action reduces the upward pressures on inflation, which reduces the extent to which monetary authorities need to fight inflationary pressures in the first place. This second-round effect is very significant in our simulations and leads a rule with $\beta > 0$ to obtain the best stabilization outcomes. interest rates by less, which stabilizes output fluctuations.

Figure 3 illustrates the situation. It depicts the response of economic variables following a shock to sector 1 productivity, under three possible rules: a constant money-growth rule, a rule that reacts only to inflation, and Rule 2 from Table 1, which reacts to inflation and output (the response to output is negative).

With no policy reaction to the shock (i.e. the constant money growth rule), inflation increases and output falls; the fall in output reduces the demand for funds, which keeps interest rates low. In contrast, under the rule that reacts to inflation but not to output, monetary authorities counteract the strong increase in inflation by reducing money-growth rates; through the liquidity effect, this keeps interest rates relatively high, and further exacerbates the reduction in output.

Finally, consider the rule with a negative response to output. The output decline initiated by the shock calls for an interest rate increase and thus further decreases in money-growth rates. Because such decreases lead to similar decreases in inflation, and because of the positive coefficient on inflation in the rule, second-round decreases in interest rates result. These decreases help alleviate the initial decline in output. In a model where the contemporaneous correlation between output and inflation was not as strongly negative as it is in the present case, these second-round effects would probably not be as pronounced and the usual intuition of a strong positive coefficient on output being able to control output fluctuations might continue to apply.

In summary, under the assumption that financial markets have limited ability (or willingness) to find substitutes to private funds in order to fund firm borrowing, the correct monetary policy response to negative output pressures might be to increase rates, to preserve the inflation stabilization objective.

6.2 Explosive responses to lagged interest rates

Tables 1 to 4 illustrate that when a response to lagged interest rates is added to the rule, the optimized value of that coefficient is most often larger than one. This might appears to lead to explosive paths and thus to be inconsistent with a stable equilibrium. In our model, however, such a potential for explosiveness helps to preserve rather than undermine stability. Consider a rule that responds to inflation one-for-one and to lagged interest rates with a coefficient of, say, 1.5:

$$\widehat{R}_t = \widehat{\pi}_t + 1.5\widehat{R}_{t-1}. \tag{49}$$

A shock of 1 per cent to inflation thus leads to an increase of 1 per cent in interest rates, starting from where rates are at their steady-state value. Abstracting from future values of inflation, this would lead to explosive responses of interest rates in the future to 1.5 per cent in the next period, 2.25 per cent in the next, etc. But within the limited-participation environment in our model, these ever-increasing interest rates would be associated with substantial reductions in money-growth rates, themselves causing future decreases in inflation and, thus, because of the presence of inflation in the rule in (49), decreases in the interest rates. Stability is preserved if the negative pressures on nominal rates emanating from those falls in future inflation overweigh the explosive nature of the coefficient on lagged interest rates.

One interpretation of this rule is that, in response to positive inflation shocks, monetary authorities are (credibly) committing themselves to embark on a series of ever-increasing tightenings, until subsequent declines in inflation become substantial enough to undermine the explosive path. Economic agents with full knowledge of the rule thus expect declines in inflation, which puts in place the conditions for those very declines to occur, or even for the initial inflation increase not to materialize. The credibility of the rule and the forward-looking behavior of agents thus enables monetary policy to affect inflation pressures without actually reacting strongly to them, by simply threatening to react strongly in the future (the coefficient on inflation could have been small in the rule in (49)).[38] An alternative way to understand high coefficients on lagged interest rates is that they allow monetary authorities to influence long-term as well as short-term interest rates. Using the expectations hypothesis, long-term interest rates consist of the discounted, weighted sum of future short rates; a rule such as (49) commits monetary policy to increase short-term rates for the foreseeable future, thus leading to immediate increases in long-term rates. In turn, an increase in the long-term rates might have a strong influence on current economic activity and help stabilize inflation quickly. For these forward-looking effects to be operative, the assumption that monetary authorities are fully committed to the rule is key.

6.3 Negative responses to inflation

Most of the rules evaluated using the welfare-based measure contain a negative response to inflation ($\alpha < 0$).[39] Again, this would appear to promote rather than mitigate instability: a burst of inflation would lead monetary authorities to lower nominal interest rates (generating increases in money-growth rates), thereby creating more inflationary pressures and further declines in interest rates, in a seemingly explosive chain.

This chain of events is broken, however, when one recalls that it is the control over money-growth rates that remains the underlying instrument of monetary policy in our model. Further, the negative correlation between money-growth and nominal interest rates is not a built-in feature of the limited-participation environment. Monetary injections, by saturating the financial market with liquidity, do tend to push interest rates lower (the liquidity effect). However, these injections, if expected to persist for long periods of time, also trigger increases in expected future inflation, pushing the nominal interest rate higher (the anticipated-inflation effect). When this latter effect dominates, the correlation between money growth and nominal interest rates becomes positive.[40]

Consider therefore a persistent, negative technology shock that increases inflation and is expected to continue to do so for a long time. To counteract this increase in inflation, monetary authorities need to generate substantial and persistent decreases in money-growth rates. The anticipated-inflation effect is thus likely to dominate under this scenario, which indicates that this long period of reduced money-growth rates will be associated with reduced nominal interest rates, generating a negative correlation between interest rates and inflation ($\alpha < 0$). Monetary authorities are thus reacting to persistent inflationary pressures by persistently lowering the inflation tax; when their objective is to reduce fluctuations in consumption (Table 1)–which may be particularly affected by this tax– such a policy turns out to be optimal.

The following interpretation of Rule 3 in Table 1 therefore emerges. The rule directs monetary authorities to raise rates when output is already low, because lowering rates would only create more inflationary pressures, and through the liquidity-supply channel exacerbate further the original declines in output. The rule also leads monetary authorities to (slightly) increase rates when

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[38] The mechanism by which high coefficients on lagged interest rates impart stability on an economy is discussed further in Rotemberg and Woodford (1999).

[39] See Table 1. Local minima with $\alpha > 0$, exist, but the global minima feature $\alpha < 0$ except when the rule does not respond to lagged interest rates (Rule 2). Rotemberg and Woodford (1999) also report negative responses to inflation for some rule specifications.

[40] See Christiano (1991) for further discussion.

inflation is already low, because, faced with very persistent shocks, the best economic stabilizer they can provide is to manipulate the inflation tax. The slight increase in rates is propagated through time by the high coefficient on lagged interest rates, and is eventually stabilized by subsequent inflation increases.

7 Conclusion

This paper quantitatively analyzes the stabilization properties of several types of monetary policy rules. The analysis is conducted using a small open-economy model with limited participation that is affected by several sources of shocks and calibrated to salient features of the Canadian economy.

Similar to other studies, we find that a strong response of monetary policy to lagged interest rates is likely to stabilize economic fluctuations. We also find little evidence that reacting to exchange rates generates significant loss reductions.

Our results do differ from those of other studies on important aspects, however. We find that negative responses to output and sometimes to inflation may be the best course for monetary policy. The negative response to output can be rationalized by the presence of limited participation and a “liquidity-supply channel” of monetary policy, which affects banks’ credit supply and produces a negative correlation between output and inflation. The negative response to inflation may be interpreted as situations where monetary authorities react to very persistent by modifying their behavior for equivalent long periods of time, so that the correlation between nominal rates and inflation is the positive one prevailing over the long term rather than the negative one that exists in the short term. To some extent, because the response of inflation in the model to most shocks is immediate and short-lived, the long-term and short-term behavior of inflation collapse into one, leading the rules we study to deviate from the standard forms they take in other models, in which short-term stabilization dominates the behavior of monetary policy. This is further evidenced by our finding that little welfare benefit is to be gained by reacting to future expected inflation rather than the current rate.

These results suggest that policy makers should maintain a battery of different monetary rules (along with the alternative policy prescriptions derived from those rules) and weigh different interest rate scenarios according to their best knowledge of the shocks or frictions most likely to affect the economy at the time of the decisions.[41] In such a context, the principles we have identified might serve to guide monetary policy during episodes when it is perceived that financial markets have lost their capability or willingness to modify credit supply to match credit demand.

To gain further insights on the robustness of monetary policy rules, it would be helpful to nest our modelling environment within one that combines prices and portfolio rigidities (as in Christiano et al., 2003). Further, it would be important to develop a framework that allows financial intermediaries to create substitutes for households deposits as sources of loanable funds (See Chari et al., 1995, for a possible direction of such an analysis).

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[41] See also Feldstein (1999) for such an argument.

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Table 1: Policy Rules Ranked According to $L^1 = \gamma_1\sigma^2(\widehat{c}_{1t}) + \gamma_2\sigma^2(\widehat{c}_{2t}) + \gamma_3\sigma^2(\widehat{c}_{3t})$

	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7	Rule 8	Rule 9	Optimal
Coefficients of the rule										
$\widehat{\pi}_t$	1.5	2.86	-0.23	-0.23	-0.16	-1.32			0.06	
$\widehat{y}_t$	0.5	-5.35	-7.47	-7.18	-0.64	4.94	1.19		0.50	
$\widehat{R}_{t-1}$			1.14	1.08	0.86	2.20	2.04	0.42	1.43	
$\widehat{s}_t$				-0.05	-0.26					
$\widehat{s}_{t-1}$					0.20					
$\Delta\widehat{s}_t$						-2.02				
$\widehat{\pi}_{t-1}$								0.22		
$\widehat{y}_{t-1}$								4.90		
$E_t[\widehat{\pi}_{t+1}]$							-0.38		-0.23	
Loss Assessment										
Loss	0.00314	0.00282	0.00272	0.00272	0.00263	0.00268	0.00271	0.00277	0.00269	0.00250
% above optimal policy	25.11	12.70	8.56	8.57	4.89	7.18	8.09	10.70	7.56	0.00
Lifetime utility	2.0177	2.0178	2.0179	2.0179	2.0179	2.0179	2.0179	2.0178	2.0179	2.018
% below steady state	0.074	0.069	0.064	0.064	0.064	0.064	0.064	0.069	0.064	0.059
Second Moments										
$\sigma(\widehat{\pi}_t)$	5.05	3.09	18.49	18.37	27.75	15.16	20.83	15.34	27.50	22.10
$\sigma(\widehat{y}_t)$	2.87	1.58	0.25	0.22	1.98	1.66	2.30	1.16	2.50	2.20
$\sigma(\widehat{R}_t)$	6.53	4.49	5.39	5.50	7.19	6.31	4.95	4.04	5.38	8.77
$\sigma(\widehat{c}_{1t})$	5.60	5.62	5.58	5.59	5.61	5.65	5.57	5.49	5.64	5.93
$\sigma(\widehat{c}_{2t})$	3.80	2.70	2.56	2.57	1.32	2.29	2.16	2.57	2.22	1.90
$\sigma(\widehat{c}_{3t})$	6.77	6.43	6.25	6.24	6.30	6.16	6.36	6.48	6.22	5.38
Other										
Loss according to L^2	33.75	12.03	342.11	337.53	774.37	232.64	439.49	236.85	762.94	493.29
Loss according to L^3	44.42	17.08	349.37	345.1201	787.30	242.62	445.63	240.94	770.20	512.53
% obs where $R_t < 0$	9.38	2.77	5.51	5.91	11.56	8.65	4.11	1.66	5.50	16.31

Table 2: Policy Rules Ranked According to $L^2 = \sigma^2(\widehat{\pi}_t) + \sigma^2(\widehat{y}_t)$

	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7	Rule 8	Rule 9	Optimal
Coefficients of the rule										
$\widehat{\pi}_t$	1.5	188.00	27.31	37.28	34.89	33.39			11.17	
$\widehat{y}_t$	0.5	-40.22	-5.55	-7.53	-7.05	-7.21	0.07		-0.48	
$\widehat{R}_{t-1}$			2.49	3.53	3.39	3.01	1.17	5.57	0.89	
$\widehat{s}_t$				0.13	0.08					
$\widehat{s}_{t-1}$					0.04					
$\Delta\widehat{s}_t$						0.02				
$\widehat{\pi}_{t-1}$								12.39		
$\widehat{y}_{t-1}$								-0.97		
$E_t[\widehat{\pi}_{t+1}]$							-0.13		-11.30	
Loss Assessment										
Loss	33.75	4.48	4.39	4.38	4.38	4.39	93.64	6.71	4.38	4.04
% above optimal	733.91	10.89	8.51	8.43	8.43	8.51	2213.52	65.94	8.23	0.00
Second Moments										
$\sigma(\widehat{\pi}_t)$	5.05	0.44	0.50	0.50	0.50	0.53	9.49	1.54	0.51	0.72
$\sigma(\widehat{y}_t)$	2.87	2.07	2.03	2.03	2.03	2.02	1.88	2.08	2.02	1.87
$\sigma(\widehat{R}_t)$	6.53	3.83	3.46	3.45	3.45	3.44	1.08	3.18	3.46	3.44
$\sigma(\widehat{c}_{1t})$	5.60	2.84	5.55	5.55	5.55	5.55	5.48	5.50	5.54	5.56
$\sigma(\widehat{c}_{2t})$	3.80	5.56	2.62	2.62	2.62	2.61	2.38	2.59	2.59	2.55
$\sigma(\widehat{c}_{3t})$	6.77	2.66	6.59	6.59	6.59	6.59	6.65	6.67	6.59	6.54
Other										
Loss according to L^1	0.00314	0.00286	0.002852	0.002853	0.002853	0.002852	0.002816	0.002862	0.002847	0.002830
Loss according to L^3	44.42	8.15	7.38	7.36	7.36	7.36	93.94	9.24	7.38	7.02
% obs where $R_t < 0$	9.38	1.23	0.63	0.63	0.63	0.62	1.01 e-13	0.34	0.65	0.62

Table 3: Policy Rules Ranked According to $L^3 = \sigma^2(\widehat{\pi}_t) + \sigma^2(\widehat{y}_t) + 0.25\sigma^2(\widehat{R}_{t-1})$

	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7	Rule 8	Rule 9	Optimal
Coefficients of the rule										
$\widehat{\pi}_t$	1.5	-9.07	23.70	70.26	42.38	24.79			-2.99	
$\widehat{y}_t$	0.5	1.63	-3.50	-10.15	-6.10	-3.67	0.06		0.73	
$\widehat{R}_{t-1}$			9.93	30.09	18.77	10.34	1.14	7.21	-1.25	
$\widehat{s}_t$				0.53	0.16					
$\widehat{s}_{t-1}$					0.20					
$\Delta\widehat{s}_t$						0.01				
$\widehat{\pi}_{t-1}$								8.40		
$\widehat{y}_{t-1}$								-0.35		
$E_t[\widehat{\pi}_{t+1}]$									-2.86	
Loss Assessment										
Loss	44.41	7.98	6.55	6.54	6.53	6.55	93.90	8.37	6.55	6.14
% above optimal	622.46	29.84	6.56	6.37	6.35	6.56	1427.35	36.15	6.56	0.00
Second Moments										
$\sigma(\widehat{\pi}_t)$	5.05	0.64	1.06	1.07	1.06	1.06	9.49	1.82	1.06	1.11
$\sigma(\widehat{y}_t)$	2.87	2.05	1.95	1.95	1.95	1.95	1.87	1.97	1.95	1.83
$\sigma(\widehat{R}_t)$	6.53	3.65	2.51	2.50	2.50	2.51	0.93	2.14	2.51	2.47
$\sigma(\widehat{c}_{1t})$	5.60	5.55	5.52	5.52	5.52	5.52	5.48	5.49	5.52	5.53
$\sigma(\widehat{c}_{2t})$	3.80	2.65	2.52	2.54	2.54	2.53	2.41	2.50	2.52	2.47
$\sigma(\widehat{c}_{3t})$	6.77	6.59	6.62	6.62	6.27	6.62	6.66	6.68	6.62	6.58
Other										
Loss according to L^1	0.003139	0.002858	0.002841	0.002842	0.002842	0.002841	0.002821	0.002845	0.002840	0.002820
Loss according to L^2	33.75	4.64	4.97	4.96	4.96	4.97	93.68	7.22	4.97	4.61
% obs where $R_t < 0$	9.37	0.92	0.03	0.03	0.03	0.03	2.59e-18	0.002	0.03	0.02

Table 4: Policy Rules Ranking: Domestic Inflation

	Rule 10	Rule 11	Rule 12	Rule 10	Rule 11	Rule 12	Rule 10	Rule 11	Rule 12	Optimal
Coefficients of the rule										
$\widehat{\pi}_t^{dom}$	-0.21	-1.00	0.90	-3.03	-6.30	-4.31	-2.99	-20.60	-5.73	
$\widehat{y}_t$	-7.04	-4.25	-6.27	0.55	1.11	0.73	0.33	2.14	0.57	
$\widehat{R}_{t-1}$	1.14	2.07	2.54	0.70	0.47	0.63	-0.27	-7.26	-1.24	
$\Delta\widehat{s}_t$		-1.45			0.49			1.74		
$\Delta\widehat{e}_t$			-2.55			0.21			0.29	
Loss Assessment										
Loss according to L^1	0.00272	0.00270	0.00269							0.00250
% above optimal policy	8.57	7.73	7.49							0.00
Loss according to L^2				6.32	5.90	6.15				4.04
% above optimal policy				56.18	45.77	51.98				0.00
Loss according to L^3							8.45	7.99	8.27	6.14
% above optimal policy							37.56	30.04	34.52	0.00

Figure 1: Responses of the Economy to a Monetary Policy Easing (Shock occurs at time $t = 5$)

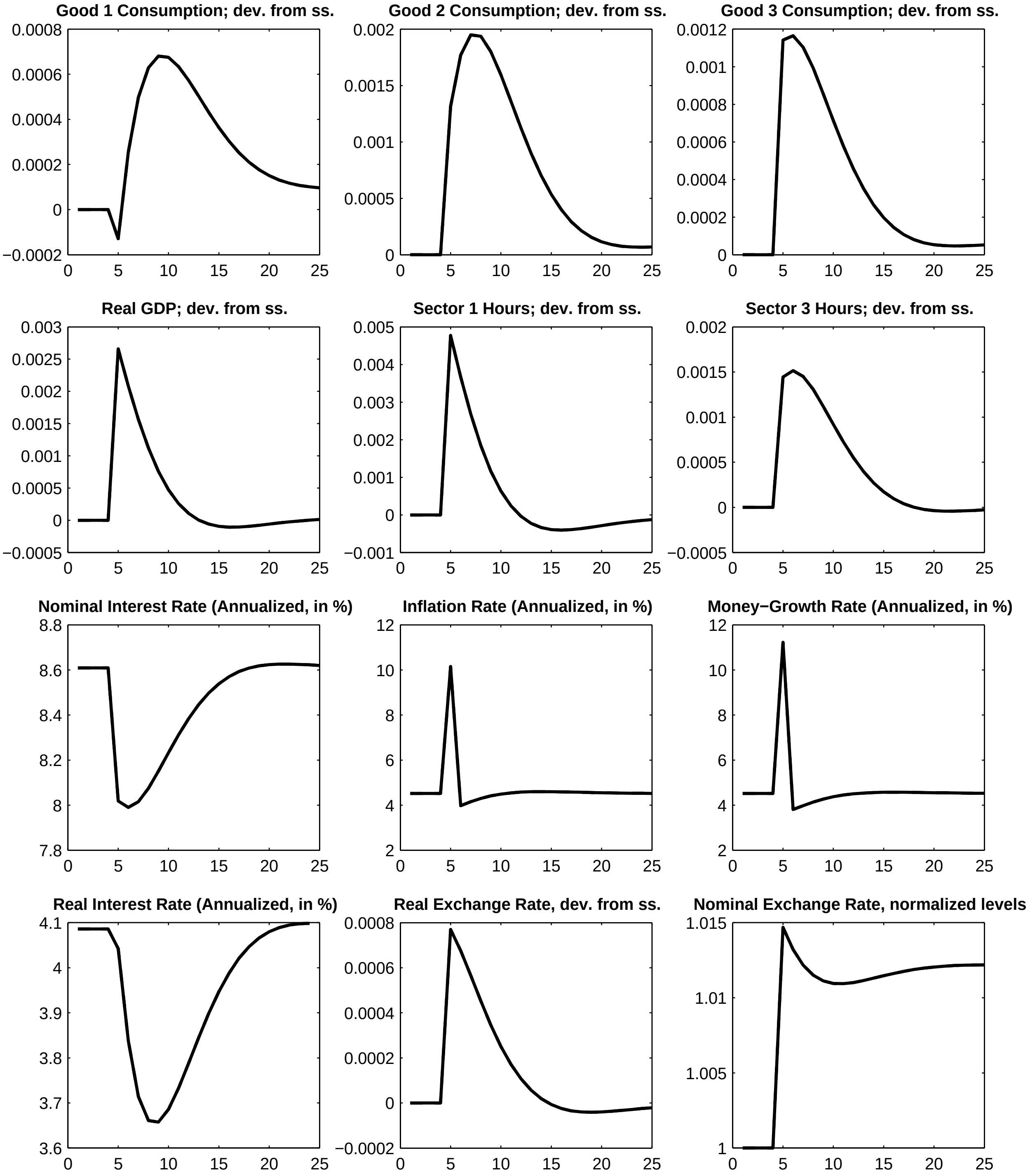
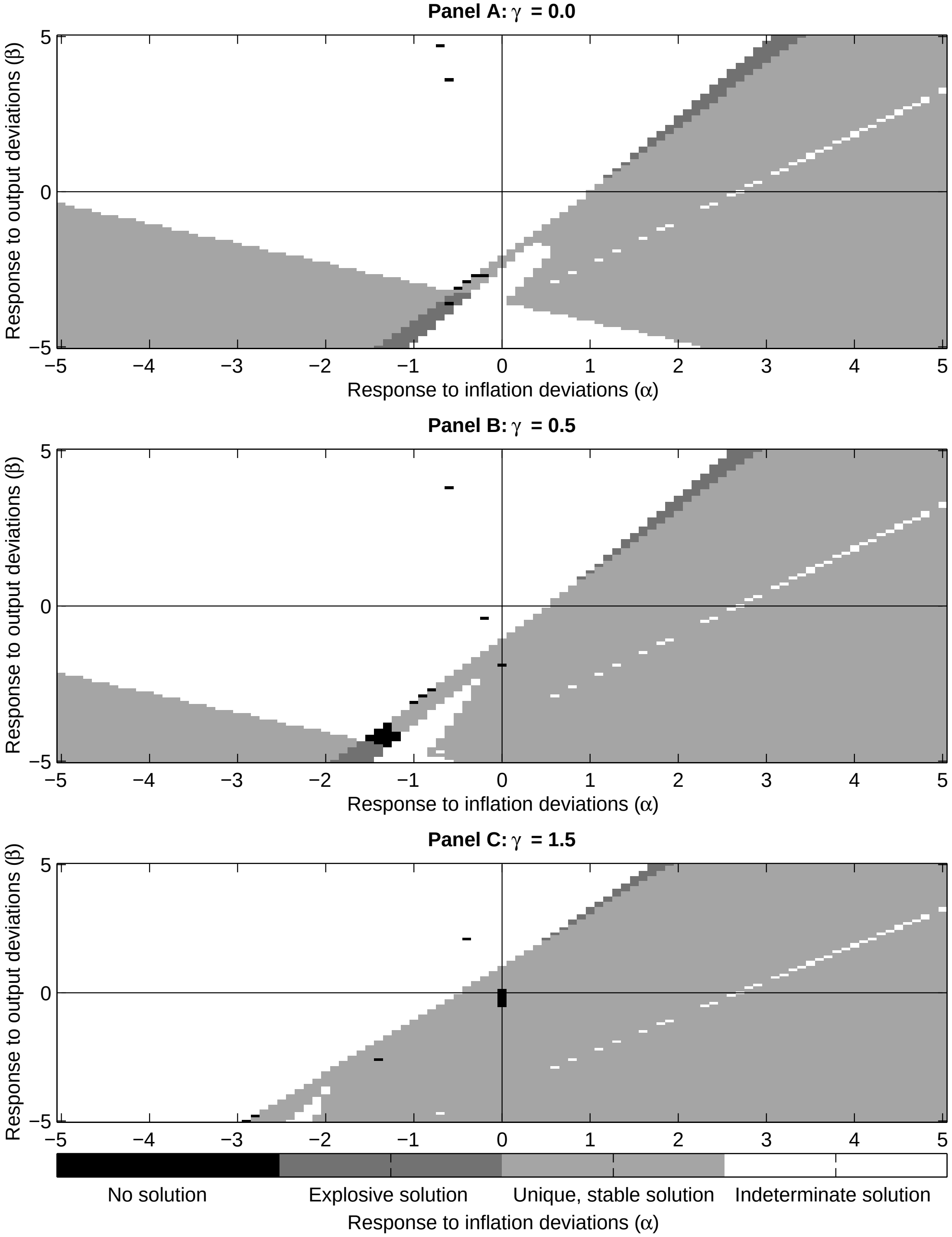


Figure 2: Stability Characteristics of the Rule

$$\hat{R}_t = \alpha\hat{\pi}_t + \beta\hat{y}_t + \gamma\hat{R}_{t-1} + \epsilon_t^{MP}$$



Panel A: γ = 0.0

Panel B: γ = 0.5

Panel C: γ = 1.5

Figure 3: Responses to a Negative Technology Shock