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Abstract

This paper develops an open-economy DSGE model to analyze the effects of international trade costs on monetary policy of open economies. The implications of this micro-founded New-Keynesian model are tested on a prototype small economy that is open to international trade costs shocks, Canada. When a utility-based expected loss function is considered, the central bank is found to be far from being optimal in its actions, independent of international trade costs. When an *ad hoc* expected loss function considering the volatilities in inflation, output and interest rate is considered, it is found that the actions of the central bank are explained best when international trade costs in fact exist but the central bank ignores them. Given the *ad hoc* loss function, the actions of the central bank are best explained when 70% of weight is assigned to inflation, 15% of weight to interest rate and 15% of weight to output.

JEL Classification: E52, E58, F41

Key Words: DSGE Model, Monetary Policy Rule, International Trade Costs, Inflation Targeting.

1. Introduction

Research on inflation targeting and monetary policy has focused on explaining the actual central bank behavior.[1] But, is there a role for international trade costs in explaining this behavior? This paper attempts to answer this question using a dynamic stochastic general equilibrium model (DGSE) with the addition of international trade costs to an otherwise standard New-Keynesian model of monetary policy. The implications of this micro-founded New-Keynesian model are tested on a prototype small economy that is open to international trade costs shocks, Canada. A New-Keynesian Phillips curve, together with the monetary policy rule of the Bank of Canada, is estimated for the Canadian economy. In order to analyze the effects of international trade costs on monetary policy, versions of the model are considered, with and without trade cots. It is found that under a utility-based expected loss function (i.e., the loss function based on the utility of individuals in the economy), the Bank of Canada appears to be far from optimal in its actions, independent of international trade costs. In contrast, under an *ad hoc* expected loss function, the actions of the Bank of Canada are explained best when international trade costs in fact exist, but the Bank of Canada ignores them. It is also shown that given the ad hoc loss function, the actions of the Bank of Canada are best explained when 70% of weight is assigned to inflation, 15% of weight to interest rate and 15% of weight to output.

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[1]See Taylor (1993, 2000), Goodfriend and King (1997), Clarida et al. (1998, 1999, 2000, 2001), Judd and Rudebusch (1998), Ball (1999), Carlstrom and Fuerst (1999), McCallum and Nelson (1999, 2001), Walsh (1999), Nelson (2000), Erceg et al. (2000), Svensson (2000), Dib (2001, 2003), Sutherland (2001), Ghironi and Rebucci (2002), Obstfeld and Rogoff (2000, 2002), Parrado and Velasco (2002), Benigno and Benigno (2003), Devereux and Engel (2003), Laxton and Pesenti (2003), Woodford (2001, 2003), Ambler et al. (2004), Parrado (2004), Murchison et al. (2004), Christiano et al. (2005), Corsetti and Pesenti (2005), Gali and Monacelli (2005), Huang and Liu (2005), Yazgan and Yilmazkuday (2007), Yilmazkuday (2007), among many others.

An open economy model is introduced with the home country and the rest of the world. In the model, there are three sets of agents: individuals, firms, and central bank policy makers. Individuals maximize their intertemporal lifetime expected utility function consisting of utility obtained from domestic (home) goods and foreign (imported) goods, together with disutility from supplying labor. The production of goods requires labor input combined with technology. The model employs a Calvo price-setting process, in which firms are able to change their prices only with some probability, independent of other firms and the time elapsed since the last adjustment. Firms behave as monopolistic competitors. Imported final goods are subject to symmetric international trade costs for both domestic and foreign individuals. The main nuance of the model is the inclusion of these international trade costs which is important in terms of its implications on real exchange rates and the Law-of-One-Price.[2]

The micro-foundations of the individual-firm behavior result in an IS curve and a New-Keynesian Phillips curve, both functions of international trade costs. While the New-Keynesian Phillips curve takes into account the non-zero inflation target as the steady-state inflation (similar to the studies such as Kozicki and Tinsley, 2003; Ascari, 2004; Cogley and Sbordone, 2006; Amano et al., 2006, 2007; Bakhshi et al., 2007; Sbordone, 2007), the IS curve captures the effect of international trade costs on output, which is not the usual case in the literature.[3] In particular, it is found that the output decreases with international trade costs. Moreover, an expected increase in international trade costs has a negative effect on the expected change in output gap, *ceteris paribus*. For monetary policy rule, the central bank manages a short-term nominal interest rate according to an open economy variant of the Taylor rule. Following Yazgan and Yilmazkuday (2007), the monetary policy rule of Taylor (1993) and Clarida et al. (1998, 1999, and 2000) is modified by keeping the inflation target in the final form of the rule.

Another contribution of this paper is the estimation of the New-Keynesian Phillips curve, together with the monetary policy rule, for the Canadian economy, by using the Generalized Method of Moments (GMM). However, recently, GMM estimators have been criticized on the grounds that inference based on these estimators is inconclusive. The related econometric literature indicates that there has been considerable evidence that asymptotic normality provides a poor approximation of the sampling distributions of GMM estimators. Particularly, the GMM estimator becomes heavily biased (in the same direction as the ordinary least squares estimator), and the distribution of the GMM estimator is quite far from the normal distribution (e.g. bimodal). Stock and Wright (2000) attribute this problem to "weak identification" or "weak instruments," that is, instruments that are only weakly correlated with the included endogenous variables. Stock et al. (2002) and Dufour (2003) provide a comprehensive survey on weak identification in GMM estimation. In this paper, the problem of weak identification is addressed by using two different tests. The first of these tests is the Anderson and Roubin (1949) test (AR-test) in its general form presented by Kleibergen (2002). The second test is the K-test developed by Kleibergen (2002). These two tests are robust in the case of nonlinear models (see Dufour, 2003; Stock et al., 2002), and perhaps more importantly, they are robust even to excluded instruments (see Dufour, 2003). Since it is rarely possible to use all possible instruments, this latter property is quite important from an applied point of view (see Yazgan and Yilmazkuday, 2005, 2007).

By applying a simulation based on the estimated parameters, optimal monetary policy rules under different scenarios are calculated through simulations. In particular, following the lead of Ambler et al. (2004), Cayen et al. (2006), Murchison and Rennison (2006), Ortega and Rebei (2006), which give insights about the Bank of Canada's policy-analysis models, the method of stochastic simulations is employed to determine the vector of monetary policy rule parameters that minimizes the expected loss function, given the dynamics of the Canadian economy (i.e., the IS curve and the estimated New-Keynesian Phillips curve).[4] Following Woodford (2003), first, a utility-based expected loss function is considered, and it is shown that the Bank of Canada is far from being optimal

[2] See Alessandria (2004), Caves et al. (1990), Crucini et al. (2005), Engel (1983), Engel and Rogers (1996), Krugman and Obstfeld (1991), Lutz (2004), Parsley and Wei (2000), Rogers and Jenkins (1995). Also see Obstfeld and Rogoff (2000) who show that trade cost may be important in explaining the six major puzzles in international macroeconomics.

[3] See McCallum and Nelson (1999, 2001), Walsh (2003), Woodford (2003), Parrado (2004), Gali and Monacelli (2005), Yilmazkuday (2007), Lubik and Schorfheide (2007), among many others, that consider foreign output levels in the IS curve instead of trade costs.

[4] Also see Tetlow and von zur Muehlen (1999), Erceg et al. (1998, 2000) as other studies on optimized monetary policy rules.

in such a case, independent of international trade costs. Then, an *ad hoc* expected loss function is employed, and the calculated optimal monetary rules are compared with the estimated monetary policy rule to obtain the weights assigned to inflation, output and interest rate volatilities, at which the percentage deviation of the expected loss from its optimal value takes its minimum value. An optimistic approach is followed, and these calculated weights are accepted as the Bank of Canada's policy weights. Thus, instead of assigning ad hoc weights to the mentioned variables in the loss function, they are calculated by simulation techniques.[5] The simulation results show that the actions of the Bank of Canada are best explained when international trade costs actually exist but the Bank of Canada ignores them.

The rest of this paper is organized as follows: Section 2 introduces a New-Keynesian model and illustrates a modified specification of monetary policy developed to take into account the inflation targets. Section 3 presents the main estimation results. Section 4 depicts the results and comparisons of the simulation based on the Canadian economy. Section 5 concludes. The model solution is given in the Appendix.

2. The Model

A continuum of goods model is introduced in which all goods are tradable, the representative individual holds assets, and the production of goods requires labor input. Subscripts H and F stand for domestically and foreign-produced goods, respectively. Superscript $*$ stands for the variables of the rest of the world. A bar on a variable ($\bar{\cdot}$) stands for a target value. Lower case letters denote log variables. Capital letters without a time subscript denote steady-state values.

2.1. Individuals

The *representative* individual in the domestic (i.e., home) country has the following intertemporal lifetime utility function:

$$E_t\left[\sum_{k=0}^{\infty}\beta^k\left\{U\left(C_{t+k}\right)-V\left(N_{t+k}\right)\right\}\right] \tag{2.1}$$

where $U\left(C_t\right)$ is the utility out of consuming a composite index of C_t, $V\left(N_t\right)$ is the disutility out of working N_t hours, and $0<\beta<1$ is a discount factor. The composite consumption index C_t is defined by:

$$C_t=(C_{H,t})^{1-\gamma}(C_{F,t})^{\gamma} \tag{2.2}$$

where $C_{H,t}$ and $C_{F,t}$ are consumption of home and foreign (i.e., imported) goods, respectively, and γ is the share of domestic consumption allocated to imported goods. These symmetric consumption sub-indexes are defined by:

$$C_{H,t}=\left[\int_0^1 C_{H,t}(j)^{(\theta-1)/\theta}dj\right]^{\theta/(\theta-1)} \quad \text{and} \quad C_{F,t}=\left[\int_0^1 C_{F,t}(j)^{(\theta-1)/\theta}dj\right]^{\theta/(\theta-1)} \tag{2.3}$$

where $C_{H,t}(j)$ and $C_{F,t}(j)$ represent domestic consumption of home and foreign good j, respectively, and $\theta>1$ is the price elasticity of demand faced by each monopolist. The optimality conditions result in:

$$\begin{aligned} C_{H,t}(j)&=\left[\tfrac{P_{H,t}(j)}{P_{H,t}}\right]^{-\theta}C_{H,t} \\ C_{F,t}(j)&=\left[\tfrac{P_{F,t}(j)}{P_{F,t}}\right]^{-\theta}C_{F,t} \end{aligned} \tag{2.4}$$

where $P_{H,t}(j)$ and $P_{F,t}(j)$ are prices of domestically consumed home and foreign good j, respectively. $P_{H,t}$ and $P_{F,t}$ are price indexes of domestically consumed home and foreign goods, respectively, which are defined as:

[5] See Rotemberg and Woodford (1997); Woodford (1999); Batini and Nelson (2001); Smets (2003); Parrado (2004); Yilmazkuday (2007), among many others, for different types of loss functions considered in the literature.

$$P_{H,t} = \left[\int_0^1 \left([P_{H,t}(j)] \right)^{1-\theta} dj \right]^{1/(1-\theta)} \tag{2.5}$$

and

$$P_{F,t} = \left[\int_0^1 \left([P_{F,t}(j)] \right)^{1-\theta} dj \right]^{1/(1-\theta)} \tag{2.6}$$

Similarly, the demand allocation of home and imported goods implies:

$$C_{H,t} = \frac{(1-\gamma)\, C_t P_t}{P_{H,t}} \tag{2.7}$$

and

$$C_{F,t} = \frac{\gamma P_t C_t}{P_{F,t}} \tag{2.8}$$

where $P_t = \left(P_{H,t}\right)^{1-\gamma} \left(P_{F,t}\right)^{\gamma}$ is the consumer price index (CPI). The log-linear version of CPI can be written as:

$$p_t \equiv (1-\gamma) p_{H,t} + \gamma p_{F,t} \tag{2.9}$$

where $p_{H,t}$ and $p_{F,t}$ are logs of $P_{H,t}$ and $P_{F,t}$, respectively. The (log) price index for imported goods is further given by:

$$p_{F,t} = e_t + p^*_{F,t} + \tau_t \tag{2.10}$$

where e_t is the (log) nominal effective exchange rate; $p^*_{F,t}$ is the (log) price index of domestically consumed foreign goods at the source; and τ_t is the (log) gross international trade cost, which is an income received by the rest of the world.[6] The (log) gross international trade cost directly enters the price index for imported goods, because it is assumed that the international trade costs are the same across goods, and they are symmetric. The evolution of international trade costs is given by an AR(1) process:

$$\tau_t = \rho_\tau \tau_{t-1} + \varepsilon^\tau_t \tag{2.11}$$

where $\rho_\tau \in [0,1]$ and ε^τ_t is assumed to be an independent and identically distributed (i.i.d.) shock with zero mean and variance σ^2_τ.[7]

The (log) effective terms of trade is defined as $s_t \equiv p_{F,t} - p_{H,t}$, which implies that the (log) CPI formula can be written as:

$$p_t \equiv (1-\gamma) p_{H,t} + \gamma p_{F,t} \tag{2.12}$$

Combining $s_t \equiv p_{F,t} - p_{H,t}$ and $p_{F,t} = e_t + p^*_{F,t} + \tau_t$ results in an alternative expression for the (log) effective terms of trade:

$$s_t \equiv e_t + p^*_{F,t} + \tau_t - p_{H,t} \tag{2.13}$$

which includes international trade costs.

[6] For future reference, $p^*_{H,t}$ is the (log) price index for the imported goods for the rest of the world, and $p^*_{F,t}$ is the (log) domestic price index for the rest of the world. We assume that the trade costs consist of transportation costs and transportation sector is owned by the rest of the world, so there is no transportation income received by the home country. This assumption is reasonable after considering the fact that we are analyzing the inflation targeting experience of Canada after the introduction of NAFTA. Another interpretation of this assumption would be to have iceberg trade costs. See Anderson and van Wincoop (2003) for a discussion of iceberg melt structure of economic geography literature and trade costs.

[7] The introduction of an AR(1) process for the trade costs is essential in our simulations below.

The formula of CPI inflation follows as:

$$\pi_t = \pi_{H,t} + \gamma \left(s_t - s_{t-1} \right) \tag{2.14}$$

where $\pi_t = p_t - p_{t-1}$ is CPI inflation, and $\pi_{H,t} = p_{H,t} - p_{H,t-1}$ is the inflation of home-produced goods (i.e., home inflation). Combining Equations 2.13 and (2.14) results in an alternative expression of CPI inflation:

$$\pi_t = (1-\gamma)\, \pi_{H,t} + \gamma \left(\pi^*_{F,t} + \Delta e_t + \Delta \tau_t \right) \tag{2.15}$$

which suggests that CPI inflation is a weighted sum of home inflation, foreign inflation, growth in exchange rate, and growth in international trade costs. Hence, international trade costs play an important role in the determination of CPI inflation.

The individual household constraint is given by:

$$\int_0^1 \left[P_{H,t}(j) C_{H,t}(j) + P_{F,t}(j) C_{F,t}(j) \right] \, dj + E_t \left[F_{t,t+1} B_{t+1} \right] = W_t N_t + B_t + T_t \tag{2.16}$$

where $F_{t,t+1}$ is the stochastic discount factor, B_{t+1} is the nominal payoff in period $t+1$ of the portfolio held at the end of period t, W_t is the hourly wage, and Tt is the lump sum transfers/taxes.

By using the optimal demand functions, Equation (2.16) can be written in terms of the composite good as follows:

$$P_t C_t + E_t \left[F_{t,t+1} B_{t+1} \right] = W_t N_t + B_t + T_t \tag{2.17}$$

The representative home agent's problem is to choose paths for consumption, portfolio, and the labor supply. Therefore, the representative consumer maximizes her expected utility [equation (2.1)] subject to the budget constraint [equation (2.17)]. By first order condition implies that:

$$\beta E_t \left[\frac{U_C(C_{t+1})\ P_t}{U_C(C_t)\ P_{t+1}} \right] = \frac{1}{I_t} \tag{2.18}$$

where $I_t = 1/E_t \left[F_{t,t+1} \right]$ is the gross return on the portfolio. Equation (2.18) represents the traditional intertemporal Euler equation for total real consumption. The labor supply decision of the individual is obtained as follows:

$$\frac{W_t}{P_t} = \frac{V_N \left(N_t \right)}{U_C \left(C_t \right)} \tag{2.19}$$

The problem is analogous for the rest of the world: Euler equation for the rest of the world is given by:

$$\beta E_t \left[\frac{u^*_C(C_{t+1}) P^*_t\ \Xi_t}{u^*_C(C^*_t)\ P^*_{t+1} \Xi_{t+1}} \right] = E_t \left[F_{t,t+1} \right] \tag{2.20}$$

where Ξ_t is the nominal effective exchange rate. Combining Equations (2.18) and (2.20), together with assuming $U(C_t) = \log C_t$, one can obtain:

$$C_t = C^*_t Q_t \tag{2.21}$$

for all t, where $Q_t = \Xi_t P^*_t / P_t$ is the real effective exchange rate; thus, the (log) effective real exchange rate is obtained as:

$$q_t = e_t + p^*_t - p_t \tag{2.22}$$

By using Equations (2.9), (2.10) and (2.13), together with the symmetric versions of Equations (2.9) and (2.10) for the rest of the world, we can rewrite Equation (2.22) as follows:

$$q_t = (1 - \gamma - \gamma^*) s_t - (1 - 2\gamma^*) \tau_t \tag{2.23}$$

where γ^* is the share of foreign consumption allocated to goods imported from the home country. In a special case in which the home country is a small one (i.e., γ^* is a very small number), Equation (2.23) can be approximated as:

$$q_t \approx (1-\gamma)s_t - \tau_t \tag{2.24}$$

Compared to the studies in the literature that ignore international trade costs in open economy models, such as Parrado (2004), Gali and Monacelli (2005), and Lubik and Schorfheide (2007), the presence of international trade costs is important in Equations (2.23) and (2.24). In particular, as is shown empirically by Caves et al. (1990), Crucini et al. (2005), Engel (1983), Engel and Rogers (1996), Krugman and Obstfeld (1991), Lutz (2004), Parsley and Wei (2000), Rogers and Jenkins (1995), international trade costs play a big role in the determination of real exchange rates.

Under the assumption of complete international financial markets, by combining log-linearized version of Equations (2.18), (2.20) and (2.21), together with Equation (2.22), the uncovered interest parity condition is obtained as:

$$i_t = i_t^* + E_t\left[e_{t+1}\right] - e_t \tag{2.25}$$

where $i_t = \log(I_t) = \log(1/(E_t[F_{t,t+1}]))$ is the home interest rate and $i_t^* = \log(\Xi_t/(E_t[F_{t,t+1}\Xi_{t+1}]))$ is the foreign interest rate. This uncovered interest parity condition relates the movements of the interest rate differentials to the expected variations in the effective nominal exchange rate. Since $s_t \equiv e_t + p_{F,t}^* + \tau_t - p_{H,t}$ according to Equation (2.13), we can rewrite Equation (2.25) as follows:

$$s_t = \left(i_t^* - E_t\left[\pi_{F,t+1}^*\right]\right) - \left(i_t - E_t\left[\pi_{H,t+1}\right]\right) + E_t\left[s_{t+1} - \Delta\tau_{t+1}\right] \tag{2.26}$$

where $\Delta\tau_{t+1}$ is the change in trade cost from period t to $t+1$. Equation (2.26) shows the terms of trade between the home country and the rest of the world as a function of current interest rate differentials, expected future home inflation differentials and its own expectation for the next period together with the expected future change in trade cost. Here, the evolution of foreign interest rate shock is given by:

$$i_t^* = \rho_{i^*} i_{t-1}^* + \varepsilon_t^{i^*} \tag{2.27}$$

where $\rho_{i^*} \in [0,1]$, and $\varepsilon_t^{i^*}$ is assumed to be an independent and identically distributed (i.i.d.) shock with zero mean and variance $\sigma_{i^*}^2$.

2.2. Firms

The *representative* domestic firm has the following production function:

$$Y_t(j) = Z_t N_t(j) \tag{2.28}$$

where Z_t is an exogenous economy-wide productivity parameter; and N_t is labor input. Accordingly, the marginal cost of production is given by:

$$MC_t^n = (1-\omega)\frac{W_t}{Z_t} \tag{2.29}$$

where ω is the employment subsidy. The inclusion of this subsidy is *not* arbitrary, because as discussed below, under the assumption of a constant employment subsidy ω that neutralizes the distortion associated with firms' market power, it can be shown that the optimal monetary policy is the one that replicates the flexible price equilibrium allocation in a closed economy.

Using Equation (2.19), together with assuming $V(N_t) = N_t$, the log-linearized *real* marginal cost can be written as follows:[8]

$$mc_t = \log(1-\omega) + w_t - p_{H,t} - z_t \tag{2.30}$$

Moreover, if the aggregate output in the home country is defined as as $Y_t = \left[\int_0^1 Y_t(j)^{(\theta-1)/\theta} dj\right]^{\theta/(\theta-1)}$, labor market equilibrium implies:

$$N_t = \int_0^1 N_t(j) dj = \frac{Y_t A_t}{Z_t} \tag{2.31}$$

where $A_t = \int_0^1 \frac{Y_t(j)}{Y_t} dj$ of which equilibrium variations can be shown to be of second-order in log terms. Thus, in first-order log-linearized terms, we can write:

$$y_t = z_t + n_t \tag{2.32}$$

where z_t evolves according to:

$$z_t = \rho_z z_{t-1} + \varepsilon_t^z \tag{2.33}$$

where $\rho_z \in [0,1]$ and ε_t^z is assumed to be an i.i.d. shock with zero mean and variance σ_z^2.

2.3. Market Clearing

For all differentiated goods, market clearing implies:

$$Y_t(j) = C_{H,t}(j) + C_{H,t}^*(j) \tag{2.34}$$

Using Equation (2.4), it can be rewritten as follows:

$$Y_t(j) = \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\theta} C_{H,t}^A \tag{2.35}$$

where $C_{H,t}^A = C_{H,t} + C_{H,t}^*$ is the aggregate world demand for the goods produced in the home country. Using Equation (2.7) and the symmetric version of Equation (2.8) for the rest of the world, Equation (2.35) can be rewritten as follows:

$$Y_t(j) = \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\theta} \left((1-\gamma)\frac{P_t C_t}{P_{H,t}} + \gamma^* \frac{P_t^* C_t^*}{P_{H,t}^*}\right) \tag{2.36}$$

Using $Y_t = \left[\int_0^1 Y_t(j)^{(\theta-1)/\theta} dj\right]^{\theta/(\theta-1)}$, one can write:

$$\begin{aligned} Y_t &= \left((1-\gamma)\frac{P_t C_t}{P_{H,t}} + \gamma^* \frac{P_t^* C_t^*}{P_{H,t}^*}\right) \\ &= \left(\frac{P_t}{P_{H,t}}\right) C_t \left((1-\gamma) + \gamma^* \left(\frac{P_t^* P_{H,t}}{P_t P_{H,t}^*}\right) Q_t^{-1}\right) \end{aligned} \tag{2.37}$$

which implies that Equation (2.36) can be rewritten as follows:

$$Y_t(j) = \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\theta} Y_t \tag{2.38}$$

[8] Balanced growth requires the relative risk aversion in consumption to be unity, and thus we set $U(C) = \log C$. Following the lead of Hansen (1985), we also assume that labor is indivisible, implying that the representative agent's utility is linear in labor hours so that $V(N) = N$.

Log-linearizing Equation (2.37) around the steady-state, together with using $s_t \equiv p_{F,t} - p_{H,t}$ and Equation (2.23), will transform it to the following expression:

$$y_t = c_t + \gamma s_t - \tau_t \tag{2.39}$$

Also using Equation (2.14) and the log-linearized version of Equation (2.18) (i.e., Euler), Equation (2.39) can be rewritten as follows:

$$y_t = E_t\left(y_{t+1}\right) - \left(i_t - E_t\left(\pi_{H,t+1}\right)\right) + E_t\left(\Delta\tau_{t+1}\right) \tag{2.40}$$

which represents an IS curve that considers the effect of international trade costs on output, which is not the usual case in the literature where the last term (i.e., the expected change in international trade costs) is absent. From another point of view, Equation (2.40) represents an IS curve that relates the expected change in (log) output (i.e., $E_t\left(y_{t+1}\right) - y_t$) to the difference between the interest rate, the expected future domestic inflation (i.e., an approximate measure of real interest rate that becomes an exact measure of real interest rate when the terms of trade are constant across periods), and the expected change in international trade costs.[9] An increase in the difference between the expected inflation and the nominal interest rate decreases the expected change in the output gap, with a unit coefficient. Finally, an expected increase in the international trade costs leads to a decrease in the expected change in (log) output. The latter is due to the intertemporal substitution of supply in response to a change in international trade costs.

The model employs a Calvo price-setting process, in which producers are able to change their prices only with some probability, independently of other producers and the time elapsed since the last adjustment. It is assumed that producers behave as monopolistic competitors. Accordingly, each producer faces the following demand function:

$$Y_t(j) = \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\theta} C^A_{H,t}, \tag{2.41}$$

where $C^A_{H,t} = C_{H,t} + C^*_{H,t}$ is the aggregate world demand for the goods produced. Note that this expression is the same with Equation (2.35).

Assuming that each producer is free to set a new price at period t, the objective function can be written as:

$$\max_{\widetilde{P}_{H,t}} E_t\left[\sum_{k=0}^{\infty}\alpha^k F_{t,t+k}\left\{Y_{t+k}\left(\widetilde{P}_{H,t} - MC^n_{t+k}\right)\right\}\right] \tag{2.42}$$

where $\widetilde{P}_{H,t}$ is the new price chosen in period t, and α is the probability that producers maintain the same price of the previous period. The problem of producers is to maximize equation (2.42) subject to Equation (2.41). The first order necessary condition of the firm for this maximization is:

$$E_t\left[\sum_{k=0}^{\infty}\alpha^k F_{t,t+k}\left\{Y_{t+k}\left(\widetilde{P}_{H,t} - \zeta MC^n_{t+k}\right)\right\}\right] = 0 \tag{2.43}$$

where $\zeta \equiv \theta/(\theta-1)$ is a markup as a result of market power. Using Equation (2.18), we can rewrite Equation (2.43) as follows:

$$E_t\left[\sum_{k=0}^{\infty}(\beta\alpha)^k \frac{Y_{t+k}}{C_{t+k}}\frac{P_{H,t-1}}{P_{t+k}}\left\{\frac{\widetilde{P}_{H,t}}{P_{H,t-1}} - \zeta\Pi^H_{t-1,t+k}MC_{t+k}\right\}\right] = 0 \tag{2.44}$$

where $\Pi^H_{t-1,t+k} = \frac{P_{H,t+k}}{P_{H,t-1}}$ and $MC_{t+k} = \frac{MC^n_{t+k}}{P_{H,t+k}}$.

[9] See Kerr and King (1996), and King (2000) for discussions on incorporating the role for future output gap in the IS curve with a unit coefficient.

Log-linearizing equation Equation (2.44) around trend inflation $\overline{\Pi}$ together with balanced trade results in:[10]

$$\widetilde{p}_{H,t} = \varphi + p_{H,t-1} + \overline{\Pi} E_t \left[\sum_{k=0}^{\infty} (\beta\alpha)^k \pi_{H,t+k} \right] + \overline{\Pi} (1-\beta\alpha) E_t \left[\sum_{k=0}^{\infty} (\beta\alpha)^k \widehat{mc}_{t+k} \right] \tag{2.45}$$

where $\varphi = 1 - \overline{\Pi}(1-\overline{\pi})$ and $\overline{\pi} = \log \overline{\Pi}$ are constants; $\widehat{mc}_t = mc_t - mc$ is the log deviation of real marginal cost from its steady state value, $mc = -\log \zeta$. Equation (2.45) can be rewritten as:

$$\widetilde{p}_{H,t} - p_{H,t-1} = (1-\beta\alpha)\varphi + \beta\alpha E_t \left[\widetilde{p}_{H,t} - p_{H,t-1}\right] + \overline{\Pi}\pi_{H,t} + \overline{\Pi}(1-\beta\alpha)\widehat{mc}_t \tag{2.46}$$

In equilibrium, each producer that chooses a new price in period t will choose the same price and the same level of output. Then the (aggregate) price of domestic goods will obey:

$$P_{H,t} = \left[\alpha P_{H,t-1}^{1-\theta} + (1-\alpha)\widetilde{P}_{H,t}^{1-\theta}\right]^{1/(1-\theta)} \tag{2.47}$$

which can be log-linearized as follows:

$$\pi_{H,t} = (1-\theta)\left(\widetilde{p}_{H,t} - p_{H,t-1}\right) \tag{2.48}$$

Finally, by combining Equations (2.46) and (2.48), we obtain the New-Keynesian Phillips curve:

$$\pi_{H,t} = \lambda_0 + \lambda_\pi E_t \left[\pi_{H,t+1}\right] + \lambda_m \widehat{mc}_t \tag{2.49}$$

where $\lambda_\pi = \frac{\beta\alpha}{1-(1-\alpha)(\overline{\Pi})}$, $\lambda_m = \frac{(1-\alpha)(1-\alpha\beta)}{1-(1-\alpha)(\overline{\Pi})}$, $\lambda_0 = \lambda_m \varphi$, and $\varphi = 1 - \overline{\Pi}(1-\overline{\pi})$. Note that this expression reduces to a zero-inflation steady state New-Keynesian Phillips curve when $\overline{\pi} = 0$ (i.e., $\overline{\Pi} = 1$).

2.4. Equilibrium Dynamics

Combining Equations (2.30) and (2.39) leads to an expression for real marginal cost in terms of output:

$$mc_t = \log(1-\omega) + y_t - z_t + \tau_t \tag{2.50}$$

By using the symmetric version of Equation (2.39) for the rest of the world, namely $y_t^* = c_t^* + \gamma^* s_t^* - \tau_t$, together with Equations (2.23) and (2.21), one can obtain:

$$y_t = y_t^* + s_t - \tau_t \tag{2.51}$$

As discussed in Rotemberg and Woodford (1999), under the assumption of a constant employment subsidy ω that neutralizes the distortion associated with firms' market power, it can be shown that the optimal monetary policy is the one that replicates the flexible price equilibrium allocation in a closed economy. That policy requires that real marginal costs (and thus mark-ups) are stabilized at their steady state level, which in turn implies that domestic prices be fully stabilized. However, as shown by Gali and Monacelli (2005), there is an additional source of distortion in open economy models: the possibility of influencing the terms of trade in a way beneficial to domestic consumers. Nevertheless, an employment subsidy can be found that exactly offsets the combined effects of market power and the terms of trade distortions, thus rendering the flexible price equilibrium allocation optimal. In order to show this, consider the optimal allocation from the social planner's point of view: maximize Equation (2.1) subject to Equations (2.28), (2.31), (2.37) and (2.38). This optimization results in a constant level of employment, $N_t = 1$.

On the other hand, as in Gali and Monacelli (2005), flexible price equilibrium satisfies:

$$\frac{\theta - 1}{\theta} = \overline{MC}_t \tag{2.52}$$

[10] For other closed- and open-economy specifications with non-zero steady-state inflation, see Ascari (2004), Bakhshi et al. (2007), Cogley and Sbordone (2006), Kozicki and Tinsley (2003), Amano et al. (2006, 2007), Sbordone (2007).

where $\overline{MC}_t$ stands for real marginal cost at flexible price equilibrium. If Equations (2.19), (2.29), (2.52) are combined with the optimal allocation of the social planner's problem (i.e., $N_t = 1$), one can obtain:

$$\frac{\theta - 1}{\theta} = 1 - \omega \tag{2.53}$$

which suggests that an employment subsidy can be found that exactly offsets the combined effects of market power and the terms of trade distortions.

After defining domestic natural level of output as the one satisfying flexible price equilibrium (i.e., Equation (2.50) with $mc_t = -\log \zeta$), it can be written as follows:

$$\bar{y}_t = -\log \zeta - \log (1 - \omega) + z_t - \tau_t \tag{2.54}$$

which can be rewritten by using Equation (2.53) as follows:

$$\bar{y}_t = z_t - \tau_t \tag{2.55}$$

which suggests that the domestic natural level of output is negatively affected by international trade costs. This is mostly due to the allocation of some resources to the international trade costs.

Output gap can be defined as the deviation of (log) domestic output (i.e., y_t) from domestic natural level of output as follows:

$$x_t = y_t - \bar{y}_t \tag{2.56}$$

Using Equation (2.50), one can also write the (log) deviation of real marginal cost from its steady state in terms of output gap as $\widehat{mc}_t = x_t$, which implies that the New-Keynesian Phillips curve can be written in terms of output gap as follows:

$$\pi_{H,t} = \lambda_0 + \lambda_\pi E_t \left[\pi_{H,t+1}\right] + \lambda_m x_t \tag{2.57}$$

Using Equations (2.40), (2.54) and (2.56), the IS curve can also be written in terms of output gap as follows:

$$x_t = E_t \left(x_{t+1}\right) - \left(i_t - E_t \left(\pi_{H,t+1}\right)\right) + E_t \left(\Delta z_{t+1}\right) \tag{2.58}$$

Recall Equation (2.40) that represents an IS curve capturing the effects of international trade costs on output. Similarly, a version of the New-Keynesian Phillips curve capturing the effects of international trade costs can be written (using Equations (2.55), (2.56), and (2.57)) as follows:

$$\pi_{H,t} = \lambda_0 + \lambda_\pi E_t \left[\pi_{H,t+1}\right] + \lambda_m \left(y_t - z_t + \tau_t\right) \tag{2.59}$$

Hence, the effects of international trade costs appear in both the IS curve and the New-Keynesian Phillips curve in the model.

2.5. Monetary Policy

For the monetary policy rule, the central bank manages a short-term nominal interest rate according to the Taylor rule. Following Taylor (1993) and Clarida et al. (1998, 1999, and 2000), monetary policy rule is given by:

$$\bar{\imath}_t = r + \bar{\pi} + \chi_\pi \left[E_t \left(\pi_{t+1} | \Omega_t\right) - \bar{\pi}\right] + \chi_x E_t \left(x_t | \Omega_t\right) \tag{2.60}$$

where $\bar{\imath}_t$ denotes the target rate for nominal interest rate in period t; is the information set at the time the interest rate is set; π_{t+1} denotes CPI inflation one period ahead; $\bar{\pi}$ is the target for CPI inflation; x_t is the output gap in period t; and r is the long-run equilibrium real rate.[11] As in Clarida et al. (2000), it is assumed that the real rate is stationary and is determined by non-monetary factors in the long run. Since the monthly sample over the period 1996:1 to 2006:12, in which the annual inflation target range is exactly the same (i.e., 2%, the midpoint of a control range of 1% to 3%, according to the Bank of Canada, Macklem, 2002, and Coletti and Murchison, 2002) and the long-run interest rates are pretty much stable for the Canadian economy, is considered, assuming r and $\bar{\pi}$ are time invariant is realistic.

Similar policy rules to (2.60) have been used in empirical research of several countries. However, most of these and previously mentioned studies consider a zero inflation target over the period of estimation. In this study, following the lead of Yazgan and Yilmazkuday (2007), the inflation target in the monetary policy rule is kept and Equation (2.60) is modified as follows:

$$i_t = r + \bar{\pi} + \chi_\pi \left[\pi_{t+1} - \bar{\pi}\right] + \chi_x x_t + \psi_t \tag{2.61}$$

where i_t is the actual nominal interest rate, and $\psi_t = -\chi_\pi \left[\pi_{t+1} - E_t\left(\pi_{t+1} | \Omega_t\right)\right] - \chi_x \left[x_t - E_t\left(x_t | \Omega_t\right)\right] + \mu_t$. The term μ_t captures the difference between the desired and the actual nominal interest rate, i.e. $\mu_t = i_t - \bar{\imath}_t$.[12] According to Clarida et al. (2000), this difference may result from three sources. First, the specification in Equation (2.61) assumes an adjustment of the actual overnight rates to its target level, and thus ignores, if any, the Bank of Canada's tendency to smooth changes in interest rates (this issue will be addressed below). Second, it treats all changes in interest rates over time as reflecting the Bank of Canada's systematic response to economic conditions. Specifically, it does not allow for any randomness in policy actions, other than that which is associated with misforecasts of the economy. Third, it assumes that the Bank of Canada has perfect control over the interest rates, i.e., it succeeds in keeping them at the desired level (e.g., through open market operations).

Interest rate smoothing is introduced into the model via the following partial adjustment mechanism (see Clarida et al., 1998, 2000):

$$i_t = (1 - \rho_i)\,\bar{\imath}_t + \rho_i i_{t-1} + v_t \tag{2.62}$$

where $\rho_i \in [0, 1]$ captures the degree of interest rate smoothing. Equation (2.62) postulates that in each period, the Bank of Canada adjusts the funds rate to eliminate a fraction $(1 - \rho_i)$ of the gap between its current target level and its past value. And, ν_t is an independently and identically distributed error term. Substituting Equation (2.60) into Equation (2.62) yields:

$$i_t = (1 - \rho_i)\left(r + \bar{\pi} + \chi_\pi \left[\pi_{t+1} - \bar{\pi}\right] + \chi_x x_t\right) + \rho_i i_{t-1} + \varepsilon_t \tag{2.63}$$

where $\varepsilon_t = -(1 - \rho_i)\left\{\chi_\pi \left[\pi_{t+1} - E_t\left(\pi_{t+1} | \Omega_t\right)\right] + \chi_x \left[x_t - E_t\left(x_t | \Omega_t\right)\right]\right\} + \nu_t$.

Since all the key equations of the model have been introduced, it can be solved as depicted in the Appendix.

3. Estimation

In this section, the monetary policy rule of the Bank of Canada and the New-Keynesian Phillips curve for the Canadian economy are separately estimated by using continuous updating GMM. The reason for individual GMM estimations is that joint GMM estimations can be hazardous according to Hayashi (2000, p.273): while a joint estimation theoretically provides asymptotic efficiency, it may suffer more from the small-sample bias in practice. The estimation results will not only help determine how the model explains the Canadian data, but they will also provide parameters for the simulation analysis.

[11] It should be noted that r is an "approximate" real rate since the forecast horizon for the inflation rate will generally differ from the maturity of the short-term nominal rate used as a monetary policy instrument. As noted by Clarida et al. (2000), in practice, the presence of high correlation between the short-term rates at maturities associated with the target horizon (1 year) prevents this from being a problem.

[12] We assume that μ_t is identically and independently distributed.

3.1. Data

The Canadian data cover the monthly sample over the period 1996:1 to 2006:12. The data sources are the web page of the Bank of Canada (http://www.bankofcanada.ca), the online version of the International Financial Statistics (IFS), and the Energy Information Administration.

Data downloaded from the web page of the Bank of Canada: The first log difference of monthly CPI has been used for Canadian inflation. Overnight interest rate has been used as Canadian policy (i.e., short-term interest) rate. Canadian-dollar effective exchange rate index (CERI) has been used for Canadian effective terms of trade. As an instrument in the GMM estimation, M1+ (gross) has been used for Canadian M1. The inflation target has been set to the midpoint of the target range, which is equal to 2.

Data downloaded from online IFS: Industrial production series (IPS) has been used for Canadian output. The output gap has been found by detrending Canadian IPS by using Hodrick–Prescott (HP) filter. We use the definition of Khalaf and Kichian (2004) for the measure of output gap. That is, rather than detrending the log of IPS using the full sample, T, we proceed iteratively: to obtain the value of the gap at time t, we detrend IPS with the data ending in T. We then extend the sample by one more observation and re-estimate the trend. This is used to detrend IPS and yields a value for the gap at time $t+1$. This process is repeated until the end of the sample. For foreign interest rate, government bond yield of the U.S. for 10 years has been used.

Data downloaded from Energy Information Administration: To get a measure of international trade costs, although it is necessary to measure the wedge between the price of imported goods on the domestic market and their price at the source measured in domestic currency units, as a proxy, we use "All Countries Spot Petroleum Price FOB Weighted by Estimated Export Volume (International Dollars per Barrel)". This is the best available data for trade costs to our knowledge. We have also considered using the “Couriers and Messengers Services Price Index” downloaded from Statistics Canada as an alternative for trade costs. However, the data cover only the period from 2003 to 2006, which is much shorter than our sample period. Nevertheless, from 2003 to 2006, the correlation coefficient between “All Countries Spot Petroleum Price FOB Weighted by Estimated Export Volume” and “Couriers and Messengers Services Price Index” is around 0.95, which can be seen as an indicator of robustness of our analysis.

3.2. Estimation of the Monetary Policy Rule

Let zz_t be a vector of variables, within the central bank’s information set at the time it chooses the interest rate (i.e. $zz_t \in \Omega_t$) that are orthogonal to ε_t. Possible elements of zz_t include any lagged variables that help to forecast inflation and output gap, as well as any contemporaneous variables that are uncorrelated with the current interest rate shock μ_t. In sum, we have the following orthogonality condition:

$$E_t \left[i_t - (1-\rho_i) \left\{ r + \bar{\pi} + \chi_\pi \left[\pi_{t+1} - \bar{\pi} \right] + \chi_x x_t \right\} - \rho_i i_{t-1} \left| zz_t \right. \right] = 0 \tag{3.1}$$

In Equation (3.1), the expected signs of $r, \rho, \chi_\pi, \chi_x$ are all positive. By using this orthogonality condition, we use continuous updating GMM to estimate the parameter vector $[r, \rho, \chi_\pi, \chi_x]$.[13] Since the econometric estimation procedure that we use here (GMM) requires that all the variables (including instruments) used in the estimation should be stationary, all of the variables are tested by using the Augmented Dickey-Fuller (ADF) tests. The null of unit root is rejected in all variables, at least at the 10 percent significance level, when tests are applied at different

[13] For continuous updating GMM estimators, we have modified the GAUSS code originally used by Stock and Wright (2000). All of our codes are available upon request. Gauss version 6.0 has been used.

lags.[14] The results are illustrated in Table 1. The instruments used for GMM estimation consist of twelve lags of home inflation (calculated according to Equation (2.14)), percentage change in M1 and three lags of output gap.[15]

Table 1 reports the estimates of r, χ_π, χ_x and ρ_i. All of the estimates satisfy their expected signs.[16] In particular, the estimate of the coefficient on the difference between expected and targeted inflation is around 5.50 for Canada. That is, if expected inflation were 1 percentage point above the target, the Bank of Canada would set the interest rate approximately 5.50 percent above its equilibrium value. This coefficient is significant at the 10% level when we use asymptotic normality as an approximation to the sampling distribution of GMM estimators.

The response of the Bank of Canada to the deviations of the expected output gap from its target (assumed to be zero) is around 0.09. In other words, holding other parameters constant, one unit increase in output gap induces the Bank of Canada to increase the interest rates by 9 basis points. This coefficient is again significant at the 10% level. The equilibrium real interest rate is estimated as 1.37 percent and it is significant at the 10% level using normal asymptotics. The estimation results also indicate that the smoothing parameter is highly significant and equal to 0.96. This estimate implies that the Bank of Canada puts forth significant effort to smooth interest rates.

Table 2 illustrates the test statistics for GMM estimation. The Hansen's J-statistic does not reject the null hypothesis that the overidentifying restrictions are satisfied at conventional significance levels.

Despite their significance, one should be wary about GMM-based results that are obtained under the asymptotic normality of the sampling distributions obtained under conventional asymptotics. Under weak-identification asymptotics, the sampling distributions are quite far from being normally distributed. In this paper, we address the problem of weak identification by using two different tests. The first of these tests is the Anderson and Roubin (1949) test (AR-test) in its general form presented by Kleibergen (2002). The second test is the K-test developed by Kleibergen (2002). These two tests are robust in the case of nonlinear models (see Stock et al., 2002; Dufour, 2003; Dufour and Taamouti, 2005, 2006), and perhaps more importantly, they are robust even to excluded instruments (see Dufour, 2003). Since it is rarely possible to use all possible instruments, this latter property is quite important from an applied point of view (see Yazgan and Yilmazkuday, 2005).

AR and K-test statistics are used to test the null hypothesis that:

$$H_0 : r = 1.37; \chi_\pi = 5.50; \chi_x = 0.09; \rho_i = 0.96$$

i.e., given the instruments that we used, whether the estimated parameters are compatible with the data or not.[17] Since both of these tests are fully robust to weak instruments (see Stock et al., 2002, pp.522), a non-rejection of this null hypothesis means that our estimates are also "data-admissible" even under the case of weak instruments.

As is evident from Table 2, given the high p-value of the AR-test, our parameter estimates cannot be rejected.[18] In other words, our GMM estimates of the Bank of Canada's monetary policy cannot be refuted by the Canadian data.

However, as argued by Kleibergen (2002), the deficiency of the AR-statistic is that its limiting distribution has a degree of freedom parameter equal to the number of instruments. Therefore the AR-statistic suffers from the problem of low power when the number of instruments highly exceeds the number of parameters. Kleibergen proposed a statistic (K-statistic) that remedies the drawback of the AR-statistic. Kleibergen, unlike the AR-

[14] These results are available upon request.

[15] By choosing these instruments, we implicitly assume that these variables are strong instruments for predicting inflation and output gap.

[16] Although the comparison of these estimates with the existing literature is absurd due to the differences in model specifications and sample periods, see Ambler et al. (2004), Murchison et al. (2004), Cayen et al. (2006), Ortega and Rebei (2006), Lubik and Schorfheide (2007) for other monetary policy rule estimations of the Bank of Canada.

[17] As suggested by Kleibergen (2002), the AR-test and the K-test statistics are calculated by interpreting all data matrices in the test as residuals from the projection on exogenous variables.

[18] The AR-statistics, under the above null hypothesis, has an exact Fisher distribution with k and T-k degrees of freedom (where k is the number of instruments, and T is the number of observations), given that the error terms are i.i.d. normal, and the instruments are strictly exogenous. $k \times AR$ statistics are asymptotically distributed chi-square with k degrees of freedom even without i.i.d. normal errors under standard regularity conditions (see Dufour and Jasiak, 2001, pp. 829, and Dufour 2003, pp.20).

test, does not provide a finite sample theory, but instead shows that his K-statistic follows an asymptotic $\chi^2(G)$ distribution (where G is the number of endogenous regressors) under the null hypothesis in the absence of exogenous regressors. As can be seen from Table 2, our K-statistics provides a similar result to the AR-test.

3.3. Estimation of the New-Keynesian Phillips Curve

We continue with the structural estimation of the New-Keynesian Phillips curve defined by Equation (2.49) where the expected signs of α and β are both positive. Exactly the same methodology used for the estimation of the monetary policy rule is also employed here. The estimation results are illustrated in Table 3. The instruments used for the GMM estimation consist of six lags of home inflation (calculated according to Equation (2.14)), six lags of the percentage change in terms of trade, and two lags of percentage change in M1. As is evident, both estimates satisfy their expected signs.

Although the comparison of these estimates with the existing literature is absurd due to the differences in model specifications and sample periods, see Ambler et al. (2004), Murchison et al. (2004), Dufour et al. (2006), Lubik and Schorfheide (2007) for recent New-Keynesian Phillips curve estimations of the Canadian economy. Finally, both AR-and K-statistics in Table 4 support our estimation results for the Phillips curve.

3.4. Remaining Parameters

The serial correlation parameters for productivity, international trade costs and foreign interest rate are estimated as $(\rho_z; \rho_\tau; \rho_{i^*}) = (0.98; 0.97; 0.99)$ by using the relevant AR(1) processes given in the text. Moreover, the related standard deviations, which are used to determine the size of the shocks in the simulations next section, are similarly estimated as $(\sigma_z; \sigma_\tau; \sigma_{i^*}) = (0.01; 0.09; 0.17)$. The share of domestic consumption allocated to imported goods is set to $\gamma = 0.36$, which is (implied by Equation (2.8) as) the mean ratio of the value of imports to the value of GDP over the sample period. Finally, the gross markup is set equal to $\zeta = 1.35$, which is equal to the average markup in the manufacturing sector in Canada (data obtained from Statistics Canada), and thus, it is implied that price elasticity of demand faced by each monopolist is set as $\theta = 3.85$.

4. Results and Comparisons

In order to compare the expected loss implications of alternative monetary policy rules, a criterion is needed. Two alternative approaches that are highly accepted in the literature are considered: (i) utility-based loss function, (ii) *ad hoc* loss function. While the utility-based loss function is obtained through the micro-foundations of the model, the *ad hoc* loss function is assumed to depend on the volatility in inflation, the output gap, and the interest rate.

4.1. Utility-Based Loss Function

The period specific utility from consumption, $U(C_t)$, and disutility from working, $V(N_t)$, can be second-order approximated around their steady states as follows:

$$U(C_t) = c_t + t.i.p. + o\left(\left\|a^3\right\|\right) \tag{4.1}$$

and

$$V(N_t) = n_t + \frac{1}{2}n_t^2 + t.i.p. + o\left(\left\|a^3\right\|\right) \tag{4.2}$$

where $t.i.p.$ represents terms independent of policy and $o\left(\left\|a^3\right\|\right)$ represents terms that are higher than 3rd order. The steady state relation $V_N(N)N = U_C(C)C$ together with the assumptions of $U(C) = \log C$ and $V(N) = N$ have been used to obtain Equations (4.1) and (4.2). Using Equation (2.39), its symmetric version for the rest of the world, $s_t + s_t^* \equiv 2\tau_t$, log version of Equation (2.21), and Equation (2.23), the following expression for c_t is obtained:

$$c_t = (1-\gamma)y_t + \gamma y_t^* + (1-\gamma)\tau_t \tag{4.3}$$

Defining $\tilde{c}_t = c_t - \bar{c}_t$ as the deviation of (log) consumption from its flexible pricing equilibrium, it can be written that:

$$c_t = (1-\gamma)x_t + (1-\gamma)\bar{y}_t + \gamma\bar{y}_t^* + (1-\gamma)\bar{\tau}_t \tag{4.4}$$

which can be inserted into Equation (4.1). Related to Equation (4.2), after defining $\tilde{n}_t = n_t - \bar{n}_t$ as the deviation of (log) employment from its flexible pricing equilibrium, using the log version of Equation (2.31), one can write:

$$n_t = x_t + a_t + \bar{y}_t - \bar{z}_t \tag{4.5}$$

where $a_t = \log\left(\int_0^1 \frac{Y_t(j)}{Y_t}dj\right) = \log\left(\int_0^1 \frac{P_{H,t}(j)}{P_{H,t}}dj\right)$ by using Equation (2.38) and we have used $\bar{a}_t = 0$ which is implied by the definition of flexible pricing. Then, by using Equations (4.4) and (4.5), it can be written that:

$$U(C_t) - V(N_t) = -\left(\gamma x_t + a_t + \frac{1}{2}\left(x_t + a_t + \bar{y}_t - \bar{z}_t\right)^2\right) + t.i.p. \tag{4.6}$$

The following lemmas are helpful for our analysis.

Lemma 1. $a_t = \frac{\theta}{2}var_i\left(p_{H,t}(i)\right) + o\left(\left\|a^3\right\|\right)$.

Proof: See Gali and Monacelli (2005), p.732.

Lemma 2. $\sum_{t=0}^{\infty}\beta^t var_i\left(p_{H,t}(i)\right) = \frac{1}{\lambda_w}\sum_{t=0}^{\infty}\beta^t\pi_{H,t}^2$ where $\lambda_w = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}$.

Proof: See Woodford (2003), Chapter 6.

According to our lemmas and Equations (2.27), (2.51), (2.56), (4.6), we can write the utility-based welfare function as follows:

$$E_t\sum_{k=0}^{\infty}\beta^{t+k}\left(U\left(C_{t+k}\right) - V\left(N_{t+k}\right)\right) = E_t\sum_{k=0}^{\infty}\beta^{t+k}\left(\log\zeta + \tau_{t+k} - \gamma\right)s_{t+k} \tag{4.7}$$

where $\lambda_w = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}$; $\zeta \equiv \theta/(\theta-1)$ is a markup as a result of market power; $\theta > 1$ is the price elasticity of demand faced by each monopolist; s_t is the (log) effective terms of trade; γ is the share of domestic consumption allocated to imported goods; $t.i.p.$ represents terms independent of policy; and finally, $o\left(\left\|a^3\right\|\right)$ represents terms that are equal to or higher than 3rd order.

Note that the utility-based welfare function depends on the volatility in inflation and output gap as well as the international trade costs and the terms of trade. It is derived explicitly as a quadratic approximation to the utility function of the representative household. However, the welfare comparisons below are made on the basis of a linearized model. We know on the results of Kim and Kim (2003) that this can be misleading, because linear approximate methods fail to take into account the impact of uncertainty (stochastic shocks) on the expected values of the endogenous variables. In order to remedy this problem, following Erceg et al. (2000), recall that we have introduced taxes and subsidies into the model such that the steady state of the economy is Pareto optimum (see Equations (2.16) and (2.29)).

The utility-based loss function implied by Equation (4.7) is as follows:

$$E_t\sum_{k=0}^{\infty}\beta^{t+k}L_{t+k}^{ub} = E_t\sum_{k=0}^{\infty}\beta^{t+k}\left(\frac{\theta\left(1-\log\zeta-\tau_{t+k}\right)\left(\pi_{H,t+k}\right)^2}{2\lambda_w} + \frac{\left(x_{t+k}\right)^2}{2} - \left(\log\zeta + \tau_{t+k} - \gamma\right)s_{t+k}\right) \tag{4.8}$$

The estimated policy function is evaluated relative to the optimal policy as follows:

Exercise 1 Since a typical central bank determines its policy considering the dynamics of the economy (i.e., the IS curve and the New Keynesian Phillips curve), given these dynamics, following the lead of Ambler et al. (2004), Cayen et al. (2006), Murchison and Rennison (2006), and Ortega and Rebei (2006), we search for the optimized monetary policy rules under possible types of shocks. In particular, we use the method of stochastic simulations to determine the vector of parameters that minimizes the expected loss function; i.e., for each possible combination of ρ_i, χ_π, and χ_x values in Equation (2.63), we calculate the expected loss value by Equation (4.8).

Exercise 2. We compare the performance of the estimated monetary policy rule of the Bank of Canada with the optimized monetary policy rule (obtained by Exercise 1) in terms of expected loss in the economy (i.e., Equation (4.8)).

In both exercises, a combination of three possible types of shocks, namely a trade cost shock, a technology shock, a foreign interest rate shock are considred. These shocks are determined by Equations (2.11), (2.27) and (2.33). The sizes of the shocks are set equal to one standard deviation of the relevant shock variables as described in the data section, above.[19] In other words, we compute the standard deviation of the observed shocks and use them in the simulation.

The results of both exercises are given in Table 5 which compares optimal monetary policy rules and historical (i.e., estimated) monetary policy rules. Note that we have considered the cases of with and without international trade costs to show their relative implications. While the case with international trade costs refers to the unrestricted version of our model, the case without international trade costs refers to the restricted version of our model in which international trade costs are ignored (i.e., $\tau_t = 0$ for all t). In both cases, optimal χ_π and χ_x values are much higher than the estimates of historical monetary policy rule of the Bank of Canada. Nevertheless, ρ_i values are very close to each other. In other words, *given* the utility-based welfare function, the Bank of Canada places much lower weight upon inflation and output than the optimal monetary policy, while it gives approximately the same weight to smoothing the interest rate.

When the welfare loss values calculated by Equation (4.8) are compared, the historical monetary policy rule is far from optimal. Moreover, when the discounted (lifetime) value of the deviation of consumption between optimal and historical monetary policy rules are compared, the consumption implied by the historical rule deviates around 50% from the one implied by the optimal rule, in the case with international trade costs. This deviation increases to around 90% in the case without international trade costs. This brings another possibility into the picture: What if the Bank of Canada has its own expected loss function rather than the utility-based loss function? We consider this possibility in the following subsection by considering an *ad hoc* loss function.

4.2. Ad Hoc Loss Function

Similar to Svensson (1997), Rotemberg and Woodford (1997), Rudebusch and Svensson (1998), Woodford (1999), Batini and Nelson (2001), Smets (2003), the *ad hoc* intertemporal loss function is assumed to depend on the deviations of inflation and output from their steady state values, and the volatility of the policy instrument. It can be demonstrated as follows:

$$E_t \sum_{k=0}^{\infty} \kappa^k L_{t+k}^{ah} \tag{4.9}$$

where κ is the discount factor of the central bank (which can be different from the consumer discount factor, β), and the period loss function, following Smets (2003), is given by:

$$L_t^{ah} = \psi_\pi \left(\pi_{H,t}\right)^2 + (1-\psi_\pi)\left(\psi_x \left(x_t\right)^2 + (1-\psi_x)\left(\Delta i_t\right)^2\right) \tag{4.10}$$

[19] MATLAB version 7.1.0.246 R(14) Service Pack 3 has been used for the simulation. The codes are available upon request.

where $0 \leq \psi_\pi \leq 1$ and $0 \leq \psi_x \leq 1$. While the inclusion of inflation and output into the loss function is almost standard, as Cayen et al. (2006) point out, the policy instrument may enter as an argument of the loss function for three different reasons: (i) big and unexpected changes to interest rates may cause problems for financial stability (Cukierman 1990; Smets 2003), (ii) the policy-makers may be concerned about hitting the lower nominal bound on interest rates (Rotemberg and Woodford 1997; Woodford 1999; Smets 2003), or (iii) in reality, the monetary authority (and other agents) may be uncertain about the nature and the persistence of the shocks at play in the economy at the time it must make a decision about its policy instrument.

Following Rudebusch and Svensson (1998), we consider the limiting case of the central bank discount factor satisfying $\kappa = 1$ in order to interpret the intertemporal loss function as the unconditional mean of the period loss function, which is equal to the sum of the unconditional variances of the goal variables:

$$E\left[L_t^{ah}\right] = \psi_\pi Var\left[\pi_{H,t}\right] + (1-\psi_\pi)\left(\psi_x Var\left[x_t\right] + (1-\psi_x) Var\left[\Delta i_t\right]\right) \tag{4.11}$$

Instead of assuming specific values as in the related empirical literature (see Batini and Nelson, 2001; Rudebusch and Svensson, 1998; Cayen et al., 2006), different possible values for ψ_π and ψ_x are considered in the analysis. In particular, the following exercises are employed:

Exercise 1. By considering all possible values for ψ_π and ψ_x, we analyze the performance of our estimated model (i.e., by using the estimated parameters of the New Keynesian Phillips curve and monetary policy rule) in terms of the expected loss function, after possible types of shocks.

Exercise 2. Since a typical central bank determines its policy considering the dynamics of the economy (i.e., the IS curve and the New Keynesian Phillips curve), given these dynamics, following the lead of Ambler et al. (2004), Cayen et al. (2006), Murchison and Rennison (2006), and Ortega and Rebei (2006), we search for the optimized monetary policy rules under possible types of shocks, again by considering all possible values for ψ_π and ψ_x.

Exercise 3. By considering the expected loss functions calculated by Exercise 1 and Exercise 2, we compare the performance of the estimated monetary policy rule of the Bank of Canada with the optimized monetary policy rule in terms of expected loss in the economy. By this comparison, we search for the weights assigned to inflation, output and interest rate volatilities in the loss function at which the Bank of Canada is most successful. We follow an optimistic approach and accept these calculated weights as the Bank of Canada's policy weights.

In all exercises, three possible types of shocks, namely a negative foreign interest rate shock, a negative trade cost shock and a positive technology shock, are considered. The sizes of the shocks are again set equal to one standard deviation of the relevant shock variables as described in the data section.

4.2.1. Exercise 1

This subsection calculates the expected loss function given by Equation (4.11) considering the estimated model parameters in Section III (i.e., the estimated parameters of the New Keynesian Phillips curve and monetary policy rule) together with all possible ψ_π and ψ_x values. We also consider two cases: one with trade cost, the other without international trade costs. The results are given in Figure 1 and Figure 2. As is evident, roughly speaking, the expected loss function decreases in ψ_π and increases in ψ_x for Figure 1, while it is slightly different for Figure 2. The intuition behind this result will be clearer by the following exercises.

4.2.2. Exercise 2

This subsection searches for the optimized monetary policy rules (MPRs) with and without international trade costs. As before, following the lead of Cayen et al. (2006), and Murchison and Rennison (2006), we use the method of stochastic simulations to determine the vector of parameters that minimizes the expected loss function. In particular, for each possible combination of ρ_i, χ_π, χ_x and χ_s values in Equation (2.63), we calculate the variance of inflation, the output gap, and the change in the level of the interest rate to find the minimized expected loss, after simultaneous shocks of technology, trade cost and foreign interest rate. Again, all possible (ψ_π, ψ_x) pairs are considered in the analysis. The grid search in the existence of international trade costs results in the expected loss values in Figure 3 which are computed through Equation (2.63) by using the calculated optimal monetary policy coefficients given in Figures 4-6.

As is evident from Figure 3, the expected loss function under optimal policy rules increases in ψ_x while it takes its lowest value when we move toward $\psi_\pi = 1$. When the optimal monetary policy rules under possible (ψ_π, ψ_x) pairs in Figures 4-6 are considered, the optimal χ_π, χ_x and ρ_i take higher values when ψ_π decreases.

When the same analysis is repeated in the absence of international trade costs, the effects of the inclusion of international trade costs become clearer. The results are given in Figures 7-10.

Figures 3-10 show that the loss function specification of the central bank (i.e., the (ψ_π, ψ_x) values) together with the inclusion of international trade costs plays a big role in the determination of optimized MPRs. This information is used to compare the performance of estimated MPR with the optimized MPRs in the following exercise.

4.2.3. Exercise 3

By considering the expected loss functions calculated by Exercise 1 and Exercise 2, this subsection compares the performance of the estimated (historical) monetary policy rule of the Bank of Canada with the performance of the optimized monetary policy rule in terms of expected loss in the economy, under all possible (ψ_π, ψ_x) pairs together with considering the effect of international trade costs. By this comparison, we search for the weights assigned to inflation, output and interest rate volatilities in the loss function by which the actions of the Bank of Canada are explained best.

In particular, three different cases are considered:

Case 1. The presence of international trade costs, i.e., the unrestricted version of our model.

Case 2. The absence of international trade costs, i.e., the restricted version of our model in which $\tau_t = 0$ for all t.

Case 3. The hybrid case in which international trade costs exist, but the Bank of Canada ignores them.

For Case 1, the expected loss values in Figure 1 and Figure 3 are compared. This comparison is achieved by calculating the percentage deviation of the expected loss under estimated monetary policy from the one under optimal monetary policy. The results are given in Figure 11. As is evident from Figure 11, the percentage deviation takes lower values towards $(\psi_\pi, \psi_x) = (0.9, 0.7)$ at which it reaches its minimum. According to these values, for Case 1, it follows that the Bank of Canada assigns 90% of weight to inflation, 7% of weight to output gap and 3% weight to interest rate in the loss function.

According to the calculated weights, the optimal MPR for Case 1 is implied as follows:

$$\chi_\pi^o = 2.2; \chi_x^o = 0.08; \rho_i^o = 0.57$$

Compared to the estimated/historical MPR in Table 1, the optimal $\chi_\pi^o = 2.2$ and $\rho_i^o = 0.57$ values are lower while the optimal $\chi_x^o = 0.08$; value is almost the same.

For Case 2, the expected loss values in Figure 2 and Figure 7 are compared. This comparison is again achieved by calculating the percentage deviation of the expected loss under the estimated monetary policy from the one under optimal monetary policy. The results are given in Figure 12. As is evident from Figure 12, the percentage deviation takes lower values toward $(\psi_\pi, \psi_x) = (0.1, 0.1)$ at which it reaches its minimum. According to these values, for Case 2, it is implied that the Bank of Canada assigns 10% of weight to inflation, 9% of weight to output gap and 81% weight to interest rate in the loss function.

According to the calculated weights, the optimal MPR for Case 2 is implied as follows:

$$\chi_\pi^o = 0.9; \chi_x^o = 0.27; \rho_i^o = 0.85$$

Compared to the estimated/historical MPR in Table 1, the optimal $\chi_\pi^o = 0.9$ and $\rho_i^o = 0.85$ values are lower while the optimal $\chi_x^o = 0.27$; is higher.

For Case 3, the expected loss values in Figure 2 and Figure 3 are compared. This comparison is again achieved by calculating the percentage deviation of the expected loss under the estimated monetary policy from the one under optimal monetary policy. The results are given in Figure 13.

As is evident from Figure 13, the percentage deviation takes lower values toward $(\psi_\pi, \psi_x) = (0.7, 0.5)$ at which it reaches its minimum. According to these values, for Case 3, it is implied that the Bank of Canada assigns 70% of weight to inflation, 15% of weight to output gap and 15% weight to interest rate in the loss function.

According to the calculated weights, the optimal MPR for Case 3 is implied as follows:

$$\chi_\pi^o = 2.2; \chi_x^o = 0.08; \rho_i^o = 0.57$$

which is the same as in Case 1.

Now, a criterion is needed to evaluate which case is more likely to represent the actions of the Bank of Canada. This is achieved by considering the percentage deviation of the historical monetary policy rule from the optimal monetary policy rule in terms of expected loss values for each case. The results are given in Table 6. As is evident, the minimum percentage deviation is achieved by the Hybrid Case, which suggests that the actions of the Bank of Canada are explained best when international trade costs in fact exist but the Bank of Canada ignores them. [20]

4.3. Impulse Response Functions

This subsection compares the impulse response functions under the estimated (historical) monetary policy with the ones under optimal monetary policy (both utility-based and ad hoc), after possible types of shocks. We consider the cases with international trade costs in the analysis. The results under simultaneous shocks of technology, international trade costs, and foreign interest rate are given in Figures 14-17. Simultaneous shocks are considered rather than individual shocks, because, according to the data, they are the possible shocks that the economy can experience in a typical period.

Figure 14 compares the response of output gap to three simultaneous shocks under estimated and optimal MPRs. As is evident, the volatility in output gap is best controlled under estimated MPR, while it is highest under optimized MPR found by the ad hoc expected loss function. Nevertheless, it is the opposite case for inflation when we consider Figure 15: the volatility in inflation is best controlled under optimized MPR found by the ad hoc expected loss function, while it is highest under estimated MPR. Similar comparisons can be made in Figures 16 and 17.

5. Conclusion

An open economy DSGE model has been introduced to analyze the effects of international trade costs on the actual central bank behaviour. The log-linearized model is expressed in terms of four blocks of equations: aggregate demand (i.e., the IS curve), aggregate supply (i.e., the New-Keynesian Phillips curve), monetary policy rule, and stochastic processes. For model parametrization, the New-Keynesian Phillips curve for the Canadian economy, together with the monetary policy rule of the Bank of Canada, has been estimated.

[20] When we compare the discounted (lifetime) value of the deviation of consumption between optimal and historical monetary policy rules, we see that the consumption implied by the historical rule deviates around 101% from the one implied by the optimal rule, in the presence of trade costs. The deviation is around 118% in the absence of trade costs. In the Hybrid Case, the deviation is calculated as 99%.

By considering the dynamics of the Canadian economy (i.e., the New-Keynesian Phillips curve and the IS curve), optimal monetary policy rules under different scenarios have been calculated and compared with the estimated monetary policy rule to evaluate the performance of the Bank of Canada. When a utility-based expected loss function is considered, it is found that the actions of the Bank of Canada are far from being optimal. When an *ad hoc* expected loss function based on inflation, output and interest volatilities is considered, it is found that the actions of the Bank of Canada are best explained by a model in which international trade costs actually exist in the economy but the Bank of Canada ignores them. Finally, we find that the Bank of Canada assigns 70% of weight to inflation, 15% of weight to interest rate and 15% of weight to output in its *ad hoc* loss function.

Many things remain to be done, in terms of either modeling or empirical analysis: what if international trade costs affect both final good and intermediate input prices; what is the relation between capital (utilization) and international trade costs (and/or oil prices); is there any difference in terms of the trade cost effects between the monetary policy of developing and developed countries (e.g., small versus large economies)? These are possible topics of future research.

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Table 1 - GMM Estimates of the Monetary Policy Rule

r	χ_π	χ_x	ρ_i
1.37	5.50	0.09	0.96
(0.8441)	(4.1913)	(0.0616)	(0.0258)
[0.0523]	[0.0946]	[0.0835]	[0.0000]

Notes: Standard errors calculated using the Delta method are in parentheses and p-values are in brackets. The sample size is 114 after considering data availability and instruments used which consist of twelve lags of home inflation, percentage change in M1 and three lags of output gap.

Table 2 - Test Statistics for GMM Estimation of the Monetary Policy Rule

$AR-$stat		$K-$stat	$J-$stat	Adjusted R^2
$F(27;87)$	$\chi^2\,(27)$	$\chi^2\,(2)$	$\chi^2\,(25)$	
0.74	19.87	2.39	15.53	0.99
[0.82]	[0.84]	[0.30]	[0.93]	

Notes: P-values are in brackets.

Table 3 - GMM Estimates of the New Keynesian Phillips Curve

α	β	λ_π	λ_m
0.99	0.99	1.09	0.01
(0.02)	(0.01)	(0.00)	(0.00)
[0.00]	[0.00]	[0.00]	[0.00]

Notes: Standard errors are in parentheses and p-values are in brackets. The sample size is 127 after considering data availability and instruments used, which consist of six lags of home inflation, six lags of the percentage change in terms of trade and two lags of percentage change in M1. The standard errors of λ_π and λ_m have been calculated by using the Delta method.

Table 4 - Statistics for GMM Estimation of the New Keynesian Phillips Curve

$AR-$stat		$K-$stat	$J-$stat	Adjusted R^2
$F(14;113)$	$\chi^2\,(14)$	$\chi^2\,(2)$	$\chi^2\,(13)$	
0.65	9.03	0.05	11.99	0.86
[0.82]	[0.83]	[0.98]	[0.53]	

Notes: P-values are in brackets.

Table 5 - Optimal vs. Historical Monetary Policy Rule

	χ_π	χ_x	ρ_i	Welfare Loss
Optimal MPR with Trade Costs	18.5	0.37	0.97	1.11×10^{-5}
Optimal MPR without Trade Costs	13.0	0.36	0.95	2.29×10^{-5}
Historical MPR with Trade Costs	5.5	0.09	0.96	12.76
Historical MPR without Trade Costs	5.5	0.09	0.96	13.65

Table 6 - Expected Loss Values

	Monetary Policy Rule		Percentage
Case	Estimated MPR	Optimized MPR	Deviation
Presence of Trade Costs	3.77×10^{-6}	3.44×10^{-6}	9%
Absence of Trade Costs	1.60×10^{-6}	2.34×10^{-8}	422%
Hybrid Case	4.40×10^{-6}	4.40×10^{-6}	0%

Notes: MPR stands for Monetary Policy Rule. Percentage deviation is defined as 100 times the log difference between the expected loss functions under estimated MPR and optimized MPR.

Figure 1 - Expected Loss Values for Historical MPR in the presence of Trade Costs

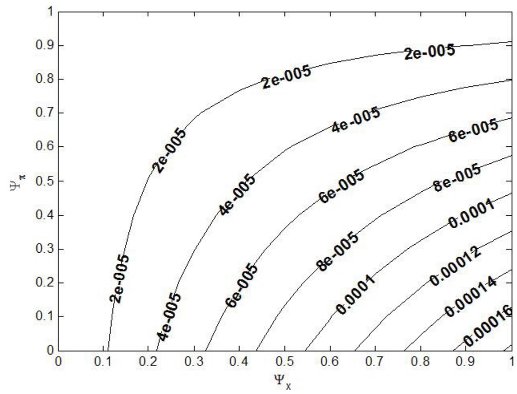


Figure 2 - Expected Loss Values for Historical MPR in the absence of Trade Costs

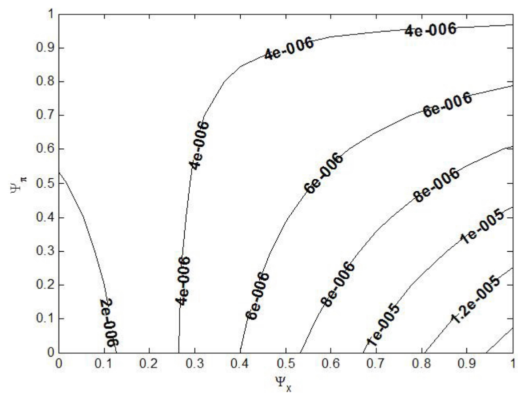


Figure 3 - Expected Loss Values for Optimal MPR in the presence of Trade Costs

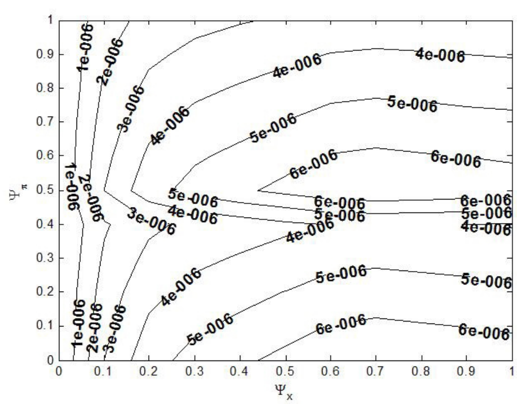


Figure 4 - Optimal Coefficient of Inflation in the presence of Trade Costs

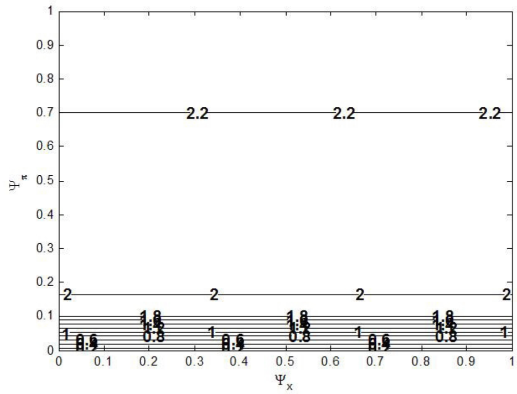


Figure 5 - Optimal Coefficient of Output in the presence of Trade Costs

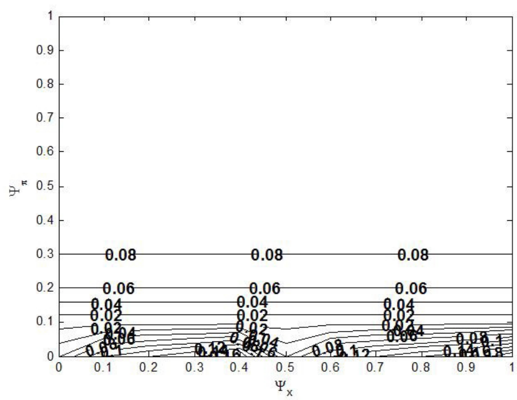


Figure 6 - Optimal Coefficient of Interest Rate in the presence of Trade Costs

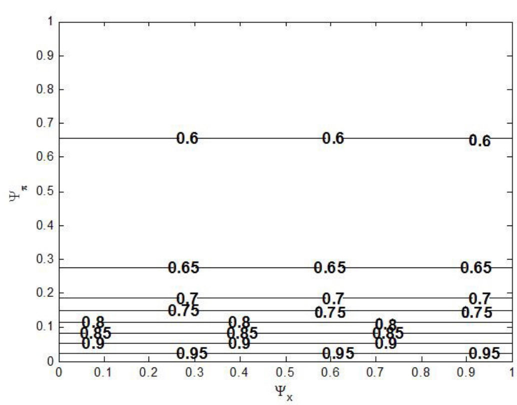


Figure 7 - Expected Loss Values for Optimal MPR in the absence of Trade Costs

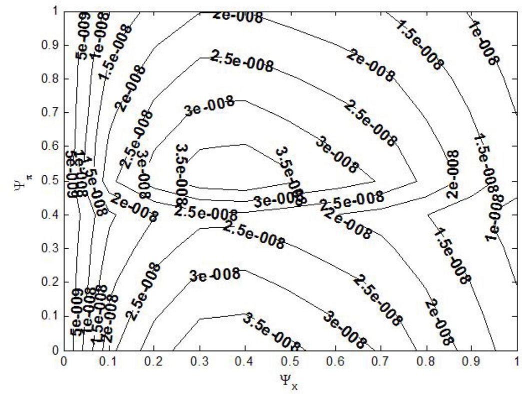


Figure 8 - Optimal Coefficient of Inflation in the absence of Trade Costs

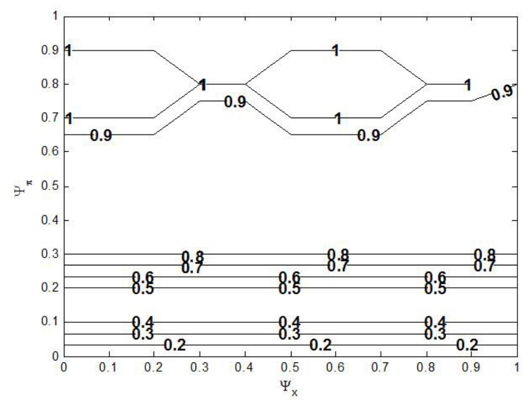


Figure 9 - Optimal Coefficient of Output in the absence of Trade Costs

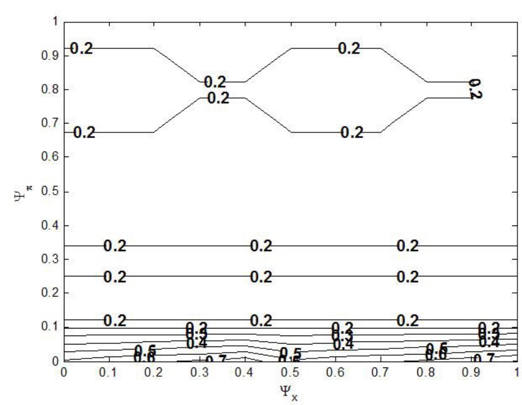


Figure 10 - Optimal Coefficient of Interest Rate in the presence of Trade Costs

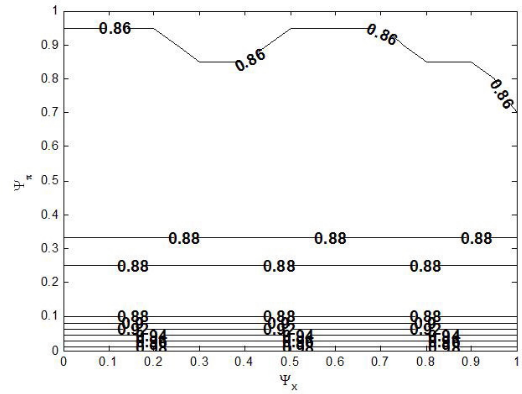


Figure 11 - Percentage Deviation from Optimal Expected Loss in the Presence of Trade Costs

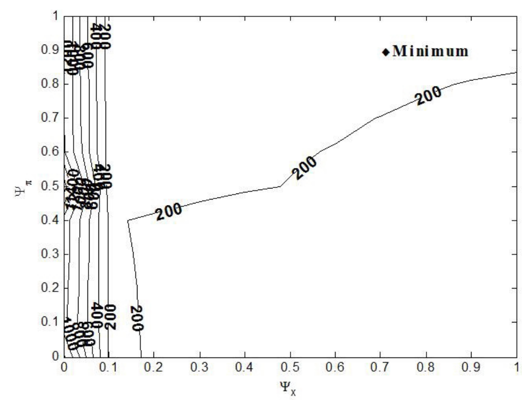


Figure 12 - Percentage Deviation from Optimal Expected Loss in the Absence ofTrade Costs

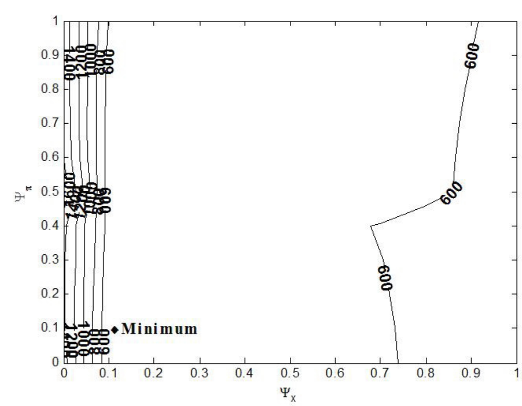


Figure 13 - Percentage Deviation from Optimal Expected Loss for the Hybrid Case

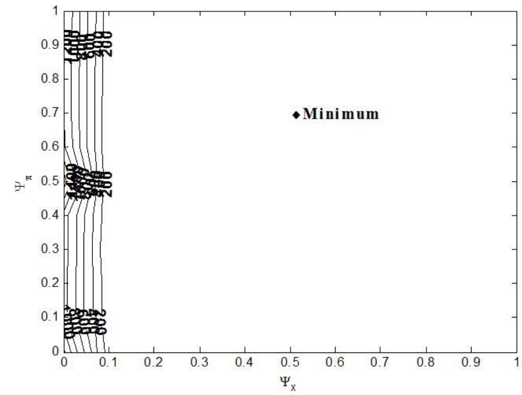


Figure 14 - Response of Output Gap

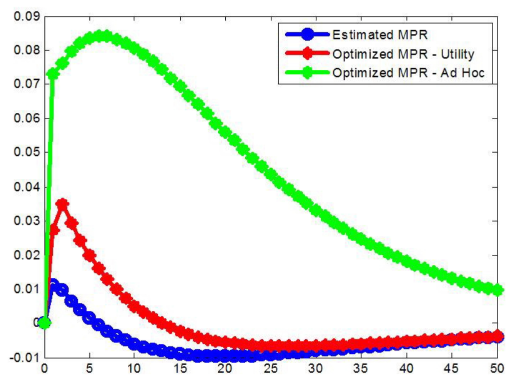


Figure 15 - Response of Inflation

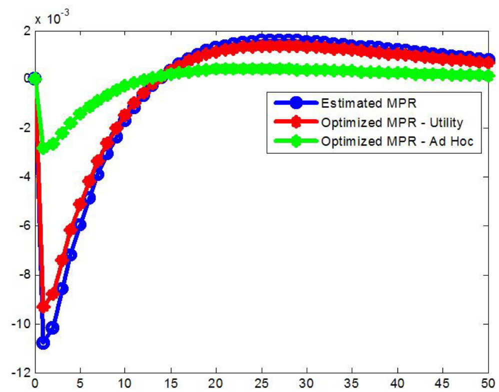


Figure 16 - Response of Nominal Interest

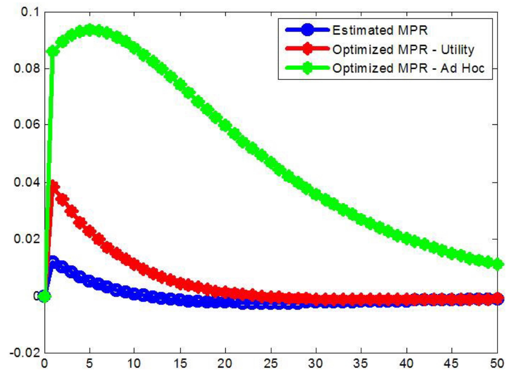
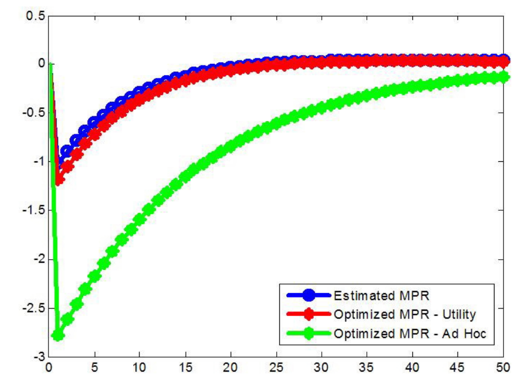


Figure 17 - Response of Real Exchange Rate



6. Appendix - Model Solution

The dynamic system is given by the main Equations (2.14), (2.26), (2.58), (2.63), (2.57), by the exogenous shock Equations (2.11), (2.27), (2.33), by the definition of domestic inflation $\pi_{H,t} = p_{H,t} - p_{H,t-1}$ and by the definition of output gap $x_t = y_t - \bar{y}_t$ and Equation (2.54). For simplicity, after substituting $x_t = y_t - \bar{y}_t$ and Equation (2.54) into Equations (2.58), (2.63), (2.57) and after substituting Equation (2.14) into Equation (2.63), we can rewrite the equations used in the solution of the model as follows:

$$y_t + \tau_t - E_t\left(y_{t+1} + \tau_{t+1}\right) + \left(i_t - E_t\left(\pi_{H,t+1}\right)\right) = 0 \tag{6.1}$$

$$\pi_{H,t} - \lambda_\pi E_t\left[\pi_{H,t+1}\right] - \lambda_m\left(y_t - z_t + \tau_t\right) = 0 \tag{6.2}$$

$$s_t - i_t^* + \left(i_t - E_t\left[\pi_{H,t+1}\right]\right) - E_t\left[s_{t+1} - \tau_{t+1} + \tau_t\right] = 0 \tag{6.3}$$

$$\begin{aligned} &i_t - \rho_i i_{t-1} - (1-\rho_i)\chi_\pi\left[E_t\left(\pi_{H,t+1}\right)\right] - (1-\rho_i)\chi_x\left[E_t\left(y_t - z_t + \tau_t\right)\right] \\ &-\gamma(1-\rho_i)\chi_\pi\left[E_t\left(s_{t+1} - s_t\right)\right] = 0 \end{aligned} \tag{6.4}$$

$$\pi_{H,t} - p_{H,t} + p_{H,t-1} = 0 \tag{6.5}$$

$$i_t^* = \rho_{i^*} i_{t-1}^* + \varepsilon_t^{i^*} \tag{6.6}$$

$$\tau_t = \rho_\tau \tau_{t-1} + \varepsilon_t^\tau \tag{6.7}$$

$$z_t = \rho_z z_{t-1} + \varepsilon_t^z \tag{6.8}$$

where we have set all the constants equal to zero.[21] Following the lead of Uhlig (1997), the vector of endogenous state variables is $x_t = \begin{bmatrix} i_t & p_{H,t} & y_t & s_t \end{bmatrix}'$, the single vector of non-predetermined variable (jump variable) is $y_t = \left[\pi_{H,t}\right]$ and the vector of shock variables is $z_t = \begin{bmatrix} i_t^* & \tau_t & z_t \end{bmatrix}'$. The model in matrix form is thus:

$$\begin{aligned} Ax_t + Bx_{t-1} + Cy_t + Dz_t &= 0 \\ E_t\left[Fx_{t+1} + Gx_t + Hx_{t-1} + Jy_{t+1} + Ky_t + Lz_{t+1} + Mz_t\right] &= 0 \\ z_{t+1} &= Nz_t + \varepsilon_{t+1} \end{aligned} \tag{6.9}$$

In our case, we will rewrite Equation (6.5) in matrix form as follows:

$$Ax_t + Bx_{t-1} + Cy_t + Dz_t = 0 \tag{6.10}$$

where $A = \begin{bmatrix} 0 & 1 & 0 & 0 \end{bmatrix}$, $B = \begin{bmatrix} 0 & -1 & 0 & 0 \end{bmatrix}$, $C = [1]$, and $D = \begin{bmatrix} 0 & 0 & 0 & 0 \end{bmatrix}$.

We can write Equations, (6.1),(6.2), (6.3) and (6.4) in matrix form as follows:

$$E_t\left[Fx_{t+1} + Gx_t + Hx_{t-1} + Jy_{t+1} + Ky_t + Lz_{t+1} + Mz_t\right] = 0 \tag{6.11}$$

where

[21] Setting all constants equal to zero doesn't affect our results at all

$$F = \begin{bmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & -\gamma\left(1-\rho_i\right)\chi_\pi \end{bmatrix}, \quad G = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -\lambda_m & 0 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & -\left(1-\rho_i\right)\chi_x & \gamma\left(1-\rho_i\right)\chi_\pi \end{bmatrix},$$

$$H = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -\rho_i & 0 & 0 & 0 \end{bmatrix}, \quad J = \begin{bmatrix} -1 \\ -\lambda_\pi \\ -1 \\ -\left(1-\rho_i\right)\chi_\pi \end{bmatrix}, \quad K = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix},$$

$$L = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \quad M = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & -\lambda_m & \lambda_m & 0 \\ -1 & -1 & 0 & 0 \\ 0 & -\left(1-\rho_i\right)\chi_x & \left(1-\rho_i\right)\chi_x & 0 \end{bmatrix}.$$

Finally, we can rewrite Equations (6.6), (6.7) and (6.8) in matrix form as follows:

$$z_{t+1} = Nz_t + \varepsilon_{t+1} \tag{6.12}$$

where

$$N = \begin{bmatrix} \rho_{i^*} & 0 & 0 \\ 0 & \rho_\tau & 0 \\ 0 & 0 & \rho_z \end{bmatrix}, \quad \varepsilon_{t+1} = \begin{bmatrix} \varepsilon_{t+1}^{i^*} \\ \varepsilon_{t+1}^{\tau} \\ \varepsilon_{t+1}^{z} \end{bmatrix}$$