Adaptive Learning and Monetary Policy in Japan
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Abstract

This paper uses a dynamic stochastic open economy model to examine the welfare impact of monetary policy choices for Japan under both rational expectations and an adaptive learning framework. This setup allows us to assess systematically some of the debates concerning Japan’s monetary policy actions in the past two decades and explore whether the public’s expectation formation process may have contributed to the observed volatility of its economy. Focusing on a specific class of Taylor rules that react to observable data only, we find that: 1) an adaptive learning process may contribute to higher volatility in key economic variables; 2) a tight monetary policy rule that is overly sensitive to observed inflation creates excess volatility in general and incurs welfare cost; 3) explicit exchange rate stabilization is unwarranted from a welfare perspective; and 4) monetary policymaker may consider putting a stronger emphasis on domestic variables as its policy targets.

Keywords: Learning; Monetary Policy Rules; Open Economy

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1. Introduction

Japan’s economic experience in the past two decades has attracted fervent research interests, be it on the liquidity traps, the optimal monetary and fiscal responses, or the structural dynamics of its underlying economy.\(^1\) On the empirical front, several papers point out that contrary to the experiences of other major OECD economies, Japan did not undergo a “great moderation” in the cyclical volatility of its real economic activity; rather, it may have switched from a moderate growth-low volatility regime to a low growth-high volatility regime.\(^2\) Compared to other major OECD economies, the standard deviation of Japan’s real GDP growth was also high over the last two decades (see Table 1). This is true in terms of the volatility of its GDP per capita growth rates as well, as shown in Stock and Watson (2005). What account for these empirical observations? Some researchers attribute the volatility to policy mistakes; in particular, they argue that more desirable economic performance could have been achieved had the Bank of Japan (BOJ) chosen a less restrictive policy. Concerns have also been raised about the merits of BOJ engaging in exchange rate stabilization, rather than focusing solely on output and inflation targeting. Using a general equilibrium model with explicit micro-foundations, this paper attempts to systematically evaluate these arguments.

In addition to potential policy mistakes, deviations from rational expectations on the part of the public may also contribute to Japan’s economic volatility, as the public’s expectation formation process may interact with the policy rules or any underlying structural shifts in the economy to influence the time path of macroeconomic variables. Such dynamics can be modeled in a learning framework where private agents are assumed to be bounded rational: rather than having full information, they only know the correct structure of the economy but have to rely on an adaptive learning process, such as least squares learning, to obtain information on the correct parameter values for the dynamic system driving the economy. As discussed in Williams (2003), since agents can only revise any expectation errors over time, this process may generate high volatility and persistence in the economy. Another motivation for incorporating learning dynamics into

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\(^1\) See, for example, Krugman, Dominquez, and Rogoff (1998), Kuttner and Posen (2001 and 2002), McCallum (2003), and Svensson (2003a).
\(^2\) See, for example, Bernanke (2004), Stock and Watson (2005), Summers (2005), and Yu (2005).
our analyses is that a constant-gain learning framework can reflect public agents’ concern over potential structural shifts in the economy (Orphanides and Williams 2004 and 2005). Given Japan’s experiences in the past two decades – the bubble period and its subsequent burst – this seems a reasonable approach. As discussed in Bullard and Duffy (2004), structural changes in the balanced growth path interacting with agents’ constant-gain adaptive learning process may contribute to substantial output variations.3

Our paper evaluates the welfare consequences of alternative monetary policy rules for the Japanese economy under rational expectations and also in a framework where agents form their expectations and forecasts using least square and constant gain learning processes. 4 Specifically, we incorporate the learning framework of Evans and Honkapohja (2001, hereafter EH) to a dynamic stochastic open economy model with nominal rigidity, similar to that in Gali and Monacelli (2005, hereafter GM). We analyze the welfare performance of various specifications of the lagged-data-based Taylor rule that McCallum and Nelson (1999 and 2004a) call “operational.”5 We use as a benchmark a standard Taylor rule with weights 1.5 and 0.5 on lagged inflation and output gap respectively, and compare the welfare outcomes of a tighter monetary policy rule that is more sensitive to inflationary pressure. We then consider a rule that specifically targets the terms of trade, reflecting exchange rate stabilization, and a rule that targets *domestic producer price* inflation instead of *CPI* inflation. For each of these rules, we use a second-order approximation of the representative consumer’s utility function to compute

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3 Bullard and Duffy (2004) show that structural changes under constant gain learning contribute substantially to the observed variation in the post-war US output.

4 We restrict our analysis to the set of equilibria that is determinate and stable under learning, as our focus is to assess the likely quantitative importance of the learning process, not to find general conditions for learnable equilibria. Howitt (1992) and Bullard and Mitra (2002), among others, point out that the existence of a determinate REE should not be taken for granted as it is not clear whether or how economic agents can coordinate on that equilibrium. Monetary policy rules should thus pay attention to delivering a determinate REE which is learnable. Bullard and Mitra (2002) conclude that monetary policy rules obeying the “Taylor principle” could assure learnable equilibria. For a more detailed discussion on the conditions for determinacy and stability under learning for various classes of monetary policy, see Bullard and Mitra (2006), Evans and Honkapohja (2003a, 2003b, 2006) and Waters (2006). Llosa and Tuesta (2006) and Bullard and Schaling (2006) provide similar analyses for the open economy setup.

5 EH (2003a) and Waters (2006) carry out similar exercises in the closed economy setting.
the welfare losses under rational expectations, least squares learning, and constant gain learning.\textsuperscript{6}

Our simulation results show that first of all, a learning framework can lead to higher volatility in macroeconomic variables, though the result is sensitive to the specific policy rules. Second, regardless of the expectation formation process, a tight monetary policy rule relative to the benchmark tend to correspond to higher volatility in output as well as \textit{domestic producer price} inflation. Third, a policy rule that explicitly responds to terms of trade fluctuations generates substantially higher welfare cost than the rule that only reacts to the output gap and \textit{CPI} inflation. As \textit{CPI} inflation already incorporates terms of trade movements, additional exchange rate stabilization attempts would imply an overreaction by the policymaker, leading to excess volatility and welfare losses based on our utility-based welfare measurement. These findings based on a structural general equilibrium model and systematic welfare evaluations in general support discussions in the literature that the high volatility observed in the Japanese economy may have resulted from an overly restrictive monetary policy and/or BOJ’s engagement in exchange rate stabilization. Finally, our last policy experiment shows that the \textit{domestic producer price} inflation targeting rule dominates the \textit{CPI} inflation targeting rule in terms of welfare ranking under both rational expectations and learning equilibria. Thus it may be worthwhile to explore policy rules that place heavier emphases on stabilizing domestic variables.

The rest of the paper is organized as follows. Section 2 reviews Japanese monetary policy during the past two decades. Section 3 outlines the open economy general equilibrium model and discusses the monetary policy rules under examination. Section 4 presents the equilibrium concepts and solution methodology for rational expectations and adaptive learning. Section 5 discusses the calibration and simulation procedures and presents our findings. Section 6 concludes.

\textsuperscript{6} The expected welfare losses of any policy rule that deviates from optimal policy can be approximated in terms of the variances of \textit{domestic producer price} inflation and the \textit{domestic output gap} (see Woodford (2003) and Gali and Monacelli (2005) among many others).
2. Japanese Monetary Policy

There has been a great deal of debate over the Bank of Japan’s monetary policy during the bubble economy of the late 1980s and early 1990s, as well as during the ensuing economic downturn. Several studies argue that more favorable economic outcomes could have been achieved had the BOJ followed a less restrictive policy. For instance, using a simple Taylor rule with standard parameters as the benchmark, Bernanke and Gertler (1999), Jinushi, Kuroki, and Miyao (2000), and McCallum (2000 and 2003) contend that BOJ’s policy was too tight during much of the 1980s-1990s. Standard parameters refer to setting an 1.5 interest rate response to CPI inflation deviation from its target and a 0.5 response to the output gap deviation, with a 2 percent per annum real interest rate. That is, for the set of lagged-data-based operational Taylor rules, the benchmark rule takes the following form:

\[ r_t = r^* + 0.5(x_{t-1} - x^*) + 1.5(\pi_t - \pi^*) + 0.5x_{t-1} \]

where \( r_t \) is the call rate; \( r^* \) is the real rate set to be 2 percent; \( \pi_{t-1} \) is the one-period lagged CPI inflation rate and \( x_{t-1} \) is the one-period lagged output gap. \( \pi^* \) is the target of CPI inflation, which is assumed to be 2 percent.

Figure 1 shows that between 1981 and 1989 the actual BOJ policy was quite tight relative to this benchmark rule. Subsequently, during the aftermath of the burst of the bubble, some argue that the BOJ was too slow in lowering the interest rate to accommodate this structural shift. Jinushi, Kuroki, and Miyao (2000) and Ito and Mishkin (2004), for instance, argue that the BOJ should have adopted the zero interest rate policy (ZIRP) much earlier than the official announcement in February 1999. In addition, the BOJ temporarily abandoned the ZIRP by raising the call rate in March 2000 for a year, amid widespread criticism from many economists and the government. Ito and Mishkin (2004), for example, call this interest rate hike “a clear policy mistake.” Similarly, McCallum (2003), using a monetary base rule to analyze Japanese monetary

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7 Generally, an overly restrictive monetary policy refers to when the actual instrument rate is above the target rate suggested by the standard Taylor rule.

8 Under ZIRP, the BOJ vowed to keep the call rate at zero until concern about deflation was dispelled.
policy-setting, argues that BOJ’s policy was too tight for the whole period since the mid-1990s.9

It is also commonly observed in the literature that rather than focusing solely on output and inflation targeting, the BOJ also engages in exchange rate stabilization. McKinnon and Ohno (1997) find that the BOJ systematically reacts to the yen/dollar real exchange rate during the period of October 1985-July 1995. They also point out that the BOJ often adjusted the instrument rate to counter yen appreciation and promote yen depreciation. Similarly, Andrade and Divino (2005) and Jinushi, Kuroki, and Miyao (2000) maintain that the BOJ has implicitly targeted exchange rate stability, especially during the bubble period and its subsequent burst. Yu (2005) claims that the high output volatility of the Japanese economy during the period 1993:Q1-2001:Q1 may be explained by a policy to stabilize the yen/dollar real exchange rate using the short-term interest rate.

Although the majority of the literature argues that the BOJ should have eased further after the burst of the economic bubble in the 1990s, the zero-lower bound on nominal interest rates rendered the short-term interest rate ineffective as a policy instrument. Some researchers contend that the BOJ should expand the monetary base growth rate, rather than lower the call rate. However, when nominal interest rates are near zero, short-term government bills and base money essentially become perfect substitutes, and purchasing short-term government bills using base money through open market operations will have no effect on the asset markets. An alternative policy choice suggested is to purchase unconventional assets such as long-term government bonds, foreign currencies, or even real estate. The BOJ followed this strategy and raised its monthly purchase of long-term bonds from 400 billion yen to 1.2 trillion yen in several steps between August 2001 and October 2002. In addition, purchasing foreign exchange tends to depreciate the yen and could help stimulate aggregate demand via boosting net export. While this “beggar-thy-neighbor” policy is often criticized, McCallum (2003) counters that depreciating the Yen would eventually raise Japanese income and lead to higher net imports. McCallum thus proposes an exchange-rate targeting rule that

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9 One difficulty posed by using the Taylor rule to evaluate monetary policy is choosing the appropriate measure of the output gap, which can affect the policy implications (see Ito and Mishkin (2004) and Kuttner and Posen (2004) for example.) To avoid this problem, McCallum (2003) considers a monetary base rule that responds to deviations of nominal GDP growth from its target and the average rate of base velocity growth over the past four quarters.
depreciates the yen/dollar real exchange rate when inflation or output is below their target values.

In our analyses below, we will evaluate the welfare consequences of adopting policy rules with an explicit exchange rate stabilization focus, as well as one that is tighter than the standard benchmark discussed above.

3. The Open Economy Model and Monetary Policy Rules

In this section, we briefly discuss the main building blocks of our small open economy general equilibrium model, and present the four policy rules under comparison.

3.1 A Small Open Economy with Staggered Price Adjustment

We model the Japanese economy as a small open economy with Calvo (1983) staggered price-setting, following the setup in Gali and Monacelli (2005). Home economy is inhibited by a representative consumer who maximizes expected discounted utility from consumption and labor-leisure choice. (Note: in the presentation below, variables with an \( H \) subscript denote domestic (home) variables, and variables with a star superscript are for the world economy)

\[
E_0 \sum_{t=0}^{\infty} \beta^t \left[ \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{\Lambda_t^{1+\varphi}}{1+\varphi} \right]
\]

where \( \beta \) is the household discount factor, \( \sigma \) the elasticity of inter-temporal substitution, and \( \varphi \) the inverse of labor supply elasticity.

Consumption index \( C_t \) is a CES composite defined by:

\[
C_t = \left[ (1-\alpha)^{1/\eta} (C_{H,t})^{(\eta-1)/\eta} + \alpha^{1/\eta} (C_{F,t})^{(\eta-1)/\eta} \right]^{\eta/(\eta-1)}
\]

where \( \eta > 0 \) measures the elasticity of substitution between domestic and foreign goods, and \( C_{H,t} \) and \( C_{F,t} \) each are CES aggregated consumption indices of home and imported goods, with the elasticity of substitution among goods within each category given by \( \varepsilon \)
and $\gamma$ respectively. $\alpha \in [0,1]$ represents the share of domestic consumption allocated to imported goods and can be interpreted as a degree of trade openness.

International asset market is assumed to be complete, and on the production side, we assume monopolistically competing firms using a linear production technology, and they set prices in a staggered fashion a la Calvo (1983). We let parameter $\theta$ denote the fraction of firms that keep prices unchanged each period.

Solving for the market clearing conditions, our small open economy is described by the following log-linearized equilibrium dynamics, as in Gali and Monacelli (2005). The first equation is a forward-looking IS equation from the clearing of the goods market:

$$x_t = E_x x_{t+1} - \frac{1}{\sigma_a} \left( r_t - E_x \pi_{H,t+1} - \bar{r}_t \right) \quad (1).$$

Here $x_t$ and $r_t$ denote the output gap and the domestic interest rate, respectively, and $\bar{r}_t$ is the domestic natural rate of interest. $r_t$ also represents the policy instrument which is endogenously set by the Central Bank in the model. $\pi_{H,t} = p_{H,t} - p_{H,t-1}$ is the domestic producer price inflation, where $p_{H,t}$ is the (log) domestic price index. The home natural rate of interest, $\bar{r}_t$, is dependent on the expected growth rate of world output, and labor productivity $a_t$. We assume $a_t$ to follow an AR(1) process $a_t = \rho a_{t-1} + \varepsilon_t^a$.

The next equilibrium condition is the New-Keynesian Phillips curve (NKPC):

$$\pi_{H,t} = \beta E_x \pi_{H,t+1} + \kappa_a x_t + u_t \quad (2)$$

where $\kappa_a$, the slope coefficient, depends on the degree of openness and such is defined in footnote 15. $u_t$ is a cost-push shock added for simulation purposes. We note that when this small open economy is in perfect autarky ($\alpha = 0$), the dynamic equations (1) and (2)

10 For ease of presentation, we defined these new parameters in terms of the structural ones defined earlier: $\lambda \equiv \left[ (1 - \beta \theta)(1 - \theta) / \theta \right]$, $\omega \equiv \sigma \gamma + (1 - \alpha)(\sigma \eta - 1)$, $\sigma_a \equiv \sigma / \left[ 1 - \alpha + \alpha \omega \right]$ and $\kappa_a \equiv \lambda (\sigma_a + \phi)$.

11 $\bar{r}_t = \rho - \sigma_a \Gamma (1 - \rho^a) a_t + \alpha \sigma_a (\Theta + \Psi) E_t \left[ \Delta y_{t+1}^* \right]$ and $\Gamma \equiv 1 + \phi / \left[ \sigma_a + \phi \right]$, $\Psi \equiv -\Theta \sigma_a / \left[ \sigma_a + \phi \right]$ and $\Theta \equiv \omega - 1$. $\Delta y_{t+1}^*$ is the rate of growth of world output.

12 This is also suggested in Justiniano and Preston (2006).
are identical to the dynamic IS and NKPC equations, respectively, in a standard closed economy setup.\textsuperscript{13}

We further assume that the purchasing power parity (PPP) condition holds, so the relationship between CPI inflation, $\pi_t = p_t - p_{t-1}$, and domestic producer price inflation, $\pi_{H,t}$, is given by

$$\pi_t = \pi_{H,t} + \alpha s_t$$  \hspace{1cm} (3),

where $s_t \equiv p_{F,t} - p_{H,t}$ is the (log) effective terms of trade, $p_{F,t}$ is the (log) price index for imported goods (expressed in domestic currency), and $p_t$ the (log) consumer price index.\textsuperscript{14}

Using this relationship, we can express the previous two equilibrium conditions (1) and (2) in terms of CPI inflation, an indicator that fits more readily in standard Taylor rule-based monetary policy making:

$$x_t = E_x x_{t+1} - \frac{1}{\sigma_\alpha} (r_t - E_x \pi_{t+1}) - \frac{1}{\sigma_\alpha} \alpha E_x s_{t+1} + \frac{1}{\sigma_\alpha} \alpha s_t$$  \hspace{1cm} (4),

$$\pi_t = \beta E_x \pi_{t+1} + \kappa_\alpha x_t - \alpha \beta E_x s_{t+1} + \alpha (1+\beta) s_t - \alpha s_{t-1} + u_t$$  \hspace{1cm} (5).

To describe the dynamic of the terms of trade, $s_t$, we note that under the assumption of complete international asset markets, uncovered interest parity (UIP) condition is expressed as the following:

$$r_t - r_t^* = E_t [\Delta e_{t+1}]$$  \hspace{1cm} (6)

where $e_t$ is the (log) nominal effective exchange rate and $r_t^*$ is the world interest rate. Assuming that the law of one price holds for each individual good, we have $p_{F,t} = e_t + p_t^*$. where $p_t^*$ is the (log) world price index. The (log) effective terms of trade would then be $s_t = e_t + p_t^* - p_{H,t}$. This expression also implies that

$$\Delta s_t = \Delta e_t + \pi_t^* - \pi_{H,t}$$  \hspace{1cm} (7).

\textsuperscript{13} See, for example, Clarida, Gali, and Gertler (1999) and Woodford (2003).

\textsuperscript{14} Note that when the economy is completely autarkic, CPI inflation collapses to domestic producer price inflation. Thus the open economy model is identical to the closed economy counterpart.
where $\pi_t = p_t - p_{t-1}^*$ is world inflation. Combining (7) with the UIP condition (6), we obtain
\[ s_t = E_t s_{t+1} - \left( r_t - E_t \pi_{H,t+1} \right) + \left( r_t^* - E_t \pi_{t+1}^* \right) \]  
(8).

Plugging (3) into (8), we obtain the following stochastic difference equation
\[ (1 - \alpha)s_t = (1 - \alpha)E_t s_{t+1} - \left( r_t - E_t \pi_t \right) + \nu_t \]  
(9),
where $\nu_t = \left( r_t^* - E_t \pi_{t+1}^* \right)$ is a risk premium shock. Thus the small open economy is described by (4), (5), and (9), particularly when policymakers target CPI inflation.

To compare alternative policy choices, we rely on the following welfare loss evaluation. Under the assumption that firms’ monopolistic power is neutralized by a separate employment subsidy, the only distortion in our setup would be from price rigidity. As such, optimal monetary policy would be one that replicates the flexible price equilibrium allocation, and as discussed in GM (2005) and Gali (2003), which also implies a full stabilization of domestic prices. In other words, a strict domestic inflation targeting rule such that $x_t = \pi_{H,t} = 0$ for all $t$ is optimal. As discussed in GM (2005), a second order approximation for the domestic representative consumer’s utility function can be derived to capture the utility losses of any monetary policy that deviates from this optimal policy. It is expressed as a fraction of steady state consumption:
\[ W = - \frac{(1 - \alpha)}{2} \sum_{t=0}^{\infty} \beta^t \left[ \frac{\varepsilon}{\lambda} \pi_{H,t}^2 + (1 + \phi)x_t^2 \right] \]  
(10).

Taking unconditional expectations on (10) and letting $\beta \to 1$, the expected welfare losses of any policy rule that deviates from the optimal one can be expressed in terms of the variances of domestic producer price inflation and the output gap.

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15 As discussed Benigno and Benigno (2003), an employment subsidy is not sufficient to guarantee the optimality of the flexible price equilibrium allocation. GM (2005) shows that under the assumption of $\sigma = \eta = \gamma = 1$, the employment subsidy that offsets both the market power and terms of trade distortions can render the flexible price equilibrium allocation.

16 In the monetary policy literature, this type of policy is sometimes called a specific targeting rule. Policymakers would set interest rate, via an interest rate feedback rule, so that the specific targeting rule is met. In addition, the Taylor rule is sometimes called an instrument rule, which can be considered a suboptimal policy rule as $r_t$ is set to respond to key macroeconomic variables without explicitly optimizing any policy objective function. See Svensson (2003b) as well as McCallum and Nelson (2004b) for a survey on a targeting rule and an instrument rule.
\[ EW = -\frac{(1-\alpha)}{2} \left[ \frac{\varepsilon}{\lambda} \text{var}(\pi_{t,t}) + (1+\varphi)\text{var}(x_t) \right] \] (11).

This is welfare loss approximation we use to evaluate the performances of alternative monetary policy rules in Section 5.

3.2 Alternative Monetary Policy Rules

This section discusses simple monetary policy rules for setting the \textit{domestic} interest rate \( r_i \).\(^{17}\) We consider the lagged-data specification of a simple Taylor-type rule, an \textit{operational} rule.\(^{18}\) We model four specifications of monetary policy rules based on Japanese policy debates, e.g. too restrictive and/or exchange rate stabilization rules.

First, we consider the \textit{CPI} inflation Taylor rule. Under this policy rule, policymakers set the interest rate \( r_i \) to respond to lags of \textit{CPI} inflation and the output gap

\[ r_i = \rho + \pi^T + \varphi_\pi (\pi_{t-1} - \pi^T) + \varphi_x x_{t-1} \] (12)

where \( \pi^T \) is a target of \textit{CPI} inflation. Parameters \( \varphi_\pi, \varphi_x > 0 \) measure how aggressive are the policymakers to any deviation of \textit{CPI} inflation and the output gap from their target values, e.g. \( \pi^T \) and zero, respectively. Parameter \( \rho = \beta^{-1} -1 \) is the time discount rate and could be interpreted as a quarterly riskless return in the steady state. It is important to note that reacting to \textit{CPI} inflation also implies that the policymakers indirectly react to the terms of trade.

We consider next a managed exchange rate (ER) policy rule that incorporates concerns about the Bank of Japan engages in exchange rate stabilization, besides focusing solely on output and inflation targeting. This rule takes the form

\[ r_i = \rho + \pi^T + \varphi_\pi (\pi_{t-1} - \pi^T) + \varphi_x x_{t-1} + \varphi_s s_{t-1} \] (13)

\(^{17}\) Generally, the interest rate is also used to complement the dynamical system, e.g. for inflation and the output gap in the closed economy model.

\(^{18}\) EH (2003b) also point out that the policy rule that responds to private expectations might not be an operational rule because policymakers may face a problem in availability of accurate observations on such expectations.
where $\varphi_s > 0$ measures the response of the policymakers to the dynamics of the terms of trade.

The last policy rule we consider is the *domestic producer price* inflation Taylor rule under which the policymakers target *domestic producer price* inflation, rather than CPI inflation. This policy rule is given by

$$ r_t = \rho + \pi_H^T + \varphi_{\pi_H} (\pi_{H,t-1} - \pi_H^T) + \varphi_x x_{t-1} $$

(14)

where $\pi_H^T$ is a target of *domestic producer price* inflation and $\varphi_{\pi_H} > 0$ measures how aggressive are the policymakers to any deviation of *domestic producer price* from its target values.

### 4. Equilibrium Framework

As discussed previously, we consider departures from REE in order to evaluate whether in a situation with potential structural shifts the public’s expectation formation process with imperfect information can contribute to the excess volatility observed in the Japanese economy in the past two decades. Below we present the solution methodology of REE and then discuss the conceptual interpretation of learning equilibrium and its corresponding solution methodology.

#### 4.1 Rational Expectation

Under rational expectations, private agents have perfect knowledge about the structures of the economy. Private agents then efficiently use information to form their expectations. In other words, private agents know the REE.

In terms of solving the REE, we combine the dynamical system given by (4), (5) and (9) with one of the monetary policy rules (12) or (13). (Under the *domestic producer price* targeting rule, we complement the system given by (1), (2) and (8) with a policy rule (14)). Generally, the reduced form can be written as

$$ y_t = A + B E_t y_{t+1} + C y_{t-1} + D w_t $$

(15)

$$ w_t = \rho_w w_{t-1} + \varepsilon_t $$

(16)
where \( y_i = \begin{bmatrix} x_i, \pi_i, q_i \end{bmatrix} \), \( w_i = \begin{bmatrix} \pi_i, u_i, v_i \end{bmatrix} \), and \( e_i = \begin{bmatrix} e_{\pi,i}, e_{u,i}, e_{v,i} \end{bmatrix} \) with appropriate matrices A, B, C, and D. The Minimum State Variable (MSV) solution to the system given by equations (15) and (16) takes the form

\[
y_i = \bar{a} + \bar{b}y_{i-1} + \bar{c}w_i
\]

where \( \bar{a} \), \( \bar{b} \), and \( \bar{c} \) are rational expectations equilibrium with conformable matrices. In sum, under rational expectations with perfect knowledge, agents know the correct form of solution (17) and its relevant parameter values in matrices \( \bar{a} \), \( \bar{b} \), and \( \bar{c} \).

4.2 Learning

We model the learning process in this paper following the framework proposed by EH (2001, 2003a, and 2003b). In contrast to rational expectations, the learning framework assumes that agents possess imperfect knowledge about the economy. Under learning, private agents are bounded rational in the sense that they only know the correct structure of the economy, and have to rely on an adaptive learning process to obtain relevant parameter estimates and form expectations and forecasts. Forecast errors are corrected gradually over time, and under certain assumptions, the economy converges to the desired REE. We consider two types of learning: least squares learning and constant gain learning.

Least squares learning and constant gain learning are both commonly used in the literature, and here we briefly discuss some conceptual differences between the two. In essence, least squares learning can be considered a “decreasing gain learning” in the sense that as time goes by, the effect of the newest information arrival becomes less important in shaping agents’ forecasts. Constant gain learning, on the other hand, allows agents to update their expectations using a rolling window of past data, so new

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19 The MSV solution is generally considered a unique solution that is free of bubble and sunspot components. See McCallum (1983 and 1998).

20 However, the economy might not converge to the REE asymptotically. Bullard and Mitra (2002) EH (2001, 2003a, 2003b, and 2006) call stability under learning when the economy converge to the desired REE and instability under learning when the economy does not converge to the REE. In this paper, we focus on stability under least squares learning. Note that with constant gain learning, the economy no longer converges to the REE.
information is incorporated with equal weighting over time. Conventionally, a smaller gain means that agents use more lagged data to form their forecasts. Specifically in our setup, a constant gain of \( g \) indicates that agents use \( 2/g \) lags of data to form their expectations. That is, for \( g = 0.25 \), agents look at 2 years of historical data.

Another way to interpret the constant gain idea is that it reflects the degree of rationality. Since least square learning, or decreasing learning in general, “converges” to REE eventually as time horizon increases, a smaller gain may suggest a higher degree of “rationality.” In addition, as discussed in Waters (2006), the public may rely on a smaller gain learning process when they expect more stability in the economy, such as when they expect the policymaker to be credible and adhere to the announced rules. In such instances, they do not put as much weight on the most recent news, but can rely on a longer range of data to learn about the structural parameters.

The fundamental idea of adaptive learning is that at each period \( t \) private agents hold a Perceived Law of Motion (PLM) whose form is analogous to the MSV solutions in (17). Since the agents do not know the parameter values in matrices \( \bar{a}, \bar{b}, \text{ and } \bar{c} \), they rely on past data to estimate their PLM, e.g. using least squares, to obtain parameter estimates of \( a_t, b_t, \text{ and } c_t \). Agents then perceive the economic dynamic at time \( t \) to take the form

\[
y_t = a_t + b_t y_{t-1} + c_t w_t
\]

As in the learning literature, the exogenous shocks \( w_t \) are assumed to be observed by both agents and policymakers. After observing the current value of \( w_t \), agents form their forecasts using their parameter estimates and all the available information in hands up to and including period \( t - 1 \). This implies that:

\[
E_t y_{t+1} = a_t + b_t E_t y_t + c_t E_t w_{t+1}, \quad \text{or}
\]

\[
E_t y_{t+1} = (1 + b_t a_t + b_t^2 y_{t-1} + (b_t c_t + c_t \rho_w) w_t.
\]

where \( \rho_w \) is also assumed to be known by agents. At each period \( t \), the policymakers also set the interest rate \( r_t \) by following their desired rules. As a result, the Actual Law of

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21 Orphanides and Williams (2004 and 2005) call this learning process as perpetual learning which is more desirable in studying monetary policy performances. In other words, under constant gain learning agents remain alert to any potential structural change in the economy.
Motion (ALM) for $y_t$ is generated according to (15) and (16) and takes the following forms:

$$y_t = A + B \left[ (I + b_t) a_t + b_t^2 y_{t-1} + (b_t c_t + c_t \rho_w) w_t \right] + CY_{t-1} + D w_t,$$

or

$$y_t = \left[ A + B (I + b_t) a_t \right] + \left( B b_t^2 + C \right) y_{t-1} + \left[ B (b_t c_t + c_t \rho_w) + D \right] w_t \quad (20).$$

Then, at the beginning of $t+1$ agents use new available information, e.g. the previous data of relevant variables up to and including period $t$, to re-estimate the PLM and then obtain the parameter estimates $a_{t+1}$, $b_{t+1}$ and $c_{t+1}$. Once the shocks $w_{t+1}$ are realized and the interest rate $r_{t+1}$ is set, by the policymakers, the ALM for $y_{t+1}$ is generated and the learning process continues in this rolling fashion.

Under adaptive learning, the recursive least squares algorithm is given by

$$\phi_t = \phi_{t-1} + g_t R_t^{-1} z_{t-1} (y_{t-1} - \phi_{t-1}' z_{t-1})'$$

$$R_t = R_{t-1} + g_t (z_{t-1}' z_{t-1} - R_{t-1})'$$

where $\phi_t = [a_t, b_t, c_t]'$ and $z_t = [1, y_{t-1}, w_t]'$. $R_t$ is the updated matrix of second moments of the regressors $z_t$. In sum, under adaptive learning, the dynamics of the model are defined by the recursive least squares updating equations (21) and (22), the expectations formation (19) derived from the PLM, the structural model equation (15), and the AR(1) process of stochastic shocks $w_t$ (16).

The gain parameter $g_t$ plays an important role in characterizing the two types of adaptive learning we consider. When the gain parameter is decreasing over time, $g_t = 1/t$, the updating equations (21) and (22) are equivalent to recursive least squares using all lags. This type of learning is called least squares learning. On the other hand, when the gain parameter is a small constant number, $0 < g_t < 1$, we are in the framework of a constant gain learning. We incorporate both types into our analyses below.

5. Calibration and Simulation Results

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22 Evans and McGough (2005) call the ALM as the true data generating process. Also, the ALM is sometimes called the temporary equilibrium for endogenous variables.
5.1 Calibration

For calibrating our model, we adopt some of the parameter values from GM (2005). Table 2 presents these baseline parameters. The three stochastic shocks \( \{\bar{r}, \nu, u\} \) are assumed to follow independent AR (1) processes.\(^{23}\) As for the parameters governing monetary policy rules, we set \( \varphi_\pi = 1.5 \) and \( \varphi_s = 0.5 \), as suggested in Taylor (1993), for our benchmark policy rule.\(^{24}\) The target of CPI inflation, \( \pi^T \), is set to be 0.822 which is the average of CPI inflation in Japan during the period 1983:Q1-2005:Q2. To model an overly restrictive policy rule, we set the parameter \( \varphi_\pi \) to be 2, reflecting tighter inflational control. To capture a managed exchange rate (ER) policy where the policymaker reacts to the terms of trade, we set \( \varphi_s = 0.2 \). Finally, for the domestically focus policy rule, parameters \( \varphi_{\pi x} \) and \( \pi_H^T \) are set to be 1.5 and 0.822, respectively. To summarize, we look at the following four monetary policy rules:

\[
\begin{align*}
\text{Rule 1: } & \quad \pi^T + 1.5(\pi_{t-1} - \pi^T) + 0.5x_{t-1} \\
\text{Rule 2: } & \quad \pi^T + 2(\pi_{t-1} - \pi^T) + 0.5x_{t-1} \\
\text{Rule 3: } & \quad \pi^T + 1.5(\pi_{t-1} - \pi^T) + 0.5x_{t-1} + 0.2s_{t-1} \\
\text{Rule 4: } & \quad \pi_H^T + 1.5(\pi_{H,t-1} - \pi_H^T) + 0.5x_{t-1}
\end{align*}
\]

(Benchmark)  
(Restrictive)  
(Managed ER)  
(Domestic Focus).

5.2 Simulation results

We conduct simulation experiments to compare the performances of four monetary policy rules mentioned above. The learning algorithm is based on EH (2001 and 2006) and Orphanides and Williams (2006), and we provide more descriptions in Appendix B. We simulate the dynamics of the economy 200 times for 250 periods each, and evaluate the performance of policy rules based on the variances of the output gap and the domestic producer price inflation, from which we compute the welfare losses based on equation (11).

\(^{23}\) We provide more details on the calibration in Appendix A.\(^{24}\) Recall that this is the benchmark policy rule often used in the literature to evaluate whether BOJ’s policy was too tight.
Table 3 reports the variances of the output gap of based on the four monetary policy rules we analyzed. The second and third columns show the performances of policy rules under rational expectations and least squares learning, respectively. The fourth through sixth columns report the policy outcomes under constant gain learning for small gain values ($g_t$) of 0.01, 0.02, and 0.03. All numbers reported are averaged across simulation runs, and represent the percentage of steady-state consumption in deviation of that under the optimal policy.

We want to emphasize three observations from these results. First, for all four policy rules analyzed, the variances of the output gap under learning are higher than those under rational expectations. This result is contrary to Williams (2003)’s findings for a closed economy, but suggest that adaptive learning can induce higher output volatility.

Second, the high volatility can also be the result of a monetary policy that is too tight, and/or overly active exchange rate management, as argued in the policy literature. As shown, regardless of how private agents form their expectations, a restrictive policy rule induces higher volatility in the output gap relative to a benchmark policy rule. Somewhat strikingly, a managed exchange rate (ER) policy rule leads to drastically higher volatility in the output gap relative to the benchmark rule. The channel seems to be that under ER stabilization, the variance of the domestic output is amplified through parameter $\sigma_\alpha$ which contains the degree of openness ($\gamma$) and the substitutability between domestic and foreign goods ($\eta$). Lastly, we see that the domestically-focus policy rule significantly outperforms all other policy rules in terms of its impact on output volatility.

Table 4 reports the variances of domestic producer price inflation associated with these four policy rules. Under adaptive learning, the restrictive rule, relative to the benchmark, creates lower variances of domestic producer price inflation. Interestingly, regardless of the expectation formation process, the managed ER policy rule performs very poorly in causing excess variances of domestic producer price inflation as well. This finding should not be surprising because CPI inflation already incorporates terms of trade movements, $\pi_t = \pi_{H,t} + \alpha \Delta s_t$, so additional attempts to stabilize the exchange rate may imply an overreaction by the policymakers, which could leads to high, sub-optimal
fluctuations in inflation. The other channel through which the variances of inflation is amplified is through the marginal cost. Higher variances of the domestic output resulting from ER stabilization would affect the marginal cost via the employment decision of private agents. Lastly, we again that the domestic focus policy rule outperforms the other three policy rules.

Finally, the aggregate welfare advantage of the domestic focus policy rule compared to the other policy rules are shown in Table 5. Under both rational expectations and learning, the domestic producer price inflation targeting rule dominates the CPI targeting rule in terms of welfare ranking. This result suggests that it may be worthwhile for policymakers to consider putting stronger emphases on domestic variables as their policy targets.

6. Conclusion

With explicit micro-foundations, our general equilibrium model provides a framework for systematic evaluations of the various arguments made concerning the conduct of Japanese monetary policy during the past two decades. In addition, we explore whether an adaptive learning framework, under which agents update their expectation errors over time, may have contributed to the high output volatility observed in the Japanese economy over the past two decades. We evaluate the policy consequences of various types of the Taylor rules under rational expectations and adaptive learning framework and evaluate their welfare consequences using a second order approximation of the representative consumer’s utility function.

Our first finding is that a learning framework can create higher volatility in output, and regardless of how private agents form their expectations, a restrictive policy rule relative to the standard Taylor rule can contribute to undesirable fluctuations in output and domestic producer price inflation. In addition, a policy rule that systematically responds to the terms of trade or tries to stabilize the exchange rate can include substantial welfare costs. These findings in general support discussions in the literature that the high volatility of the Japanese economy may have resulted from a restrictive monetary policy.

25 We do not report the welfare losses associated with the managed ER policy rule because it is obvious from Tables 3 and 4 that this policy creates significantly welfare losses.
and/or BOJ’s engagement in exchange rate stabilization. Finally, we find that an inflation targeting rule based on *domestic producer price* outperforms the *CPI* inflation targeting rule in terms of their welfare rankings.
Appendix A: Calibration

We set the degree of openness parameter $\alpha$ to be 0.11 corresponding to the share of import to GDP in Japan during the period 1983:Q1-2005:Q2. In our model, we have three stochastic shocks $\{\bar{\rho}_t, \upsilon_t, u_t\}$. With our calibration, $\bar{\rho}_t = \rho - \sigma_a \Gamma (1 - \rho_a) a_t$, where $a_t$ is labor productivity in log deviations from a linear trend. We then generate the series using the Japanese labor productivity during the same period obtained form Source OECD. Fitting the AR(1) process to $\bar{\rho}_t$ gives

$$\bar{\rho}_t = 0.66 \bar{\rho}_{t-1} + \epsilon_{\bar{\rho},t},$$

with standard deviation of $\epsilon_{\bar{\rho},t} = 0.0029$.

We follow the methodology proposed by Monacelli (2004) to compute the process of the foreign exchange risk-premium $\upsilon_t$. We fit the AR(1) process to the US real interest rate over the same period. The stochastic process of $\upsilon_t$ takes the following form

$$\upsilon_t = 0.97 \upsilon_{t-1} + \epsilon_{\upsilon,t},$$

with standard deviation of $\epsilon_{\upsilon,t} = 0.005$.

Finally, we specify the stochastic process of the domestic cost push shocks $u_t$. We consider two processes which are $i.i.d.$ or AR (1) processes. The $i.i.d.$ process of cost push shocks is suggested by Svensson (2000). Thus $u_t$ takes one of the following forms

1) $u_t = \epsilon_{u,t}$, with standard deviation of $\epsilon_{u,t} = 0.001$, or

2) $u_t = 0.4 u_{t-1} + \epsilon_{u,t}$, with standard deviation of $\epsilon_{u,t} = 0.001$.

Appendix B: Learning algorithm setup

The initial conditions for each simulation are set to be the rational expectations equilibrium values, augmented with an additional noise to: $a = \bar{a} + 0.005 \times \text{random}$, $b = \bar{b} + 0.04 \times \text{random}$, $c = \bar{c} + 0.02 \times \text{random}$, $R = \bar{R}$, and $y_0 = \bar{y}$, where random is innovation generated from a uniform distribution. In the least squares algorithm, we mitigate the initial volatility of parameters estimates by using a small constant gain for the first 20 periods. That is, $g_t = 1/N$ for $t = 1, 2, \ldots, N$ and $g_t = 1/t$ for $t > N$, with $N = 20$. Each period, innovations are generated from normal distributions.
Furthermore, to keep a stochastic simulation non-explosive, we follow algorithms suggested by Orphanides and Williams (2006) which consider that practically private agents reject unstable models. First, each period, we compute the roots of modulus of the forecasting VAR excluding the constants. If all of the roots are in the modulus of 1, the forecast model is updated as discussed above. If not, the forecast model is not updated and the matrices $\phi$ and $R$ are set to be their respective values from the previous period. The second condition imposed to restrain explosive behavior is that if any of the relevant variables exceeds, in absolute value, five times its respective unconditional standard deviations (computed under the assumption of rational expectations), then the variable that exceeds this bound is set to be the corresponding limit in that period. However, these two constraints are still not sufficient to avoid explosive behavior for our simulation exercises. Thus we compute statistics from simulation runs that give the variances of variables under adaptive learning less than ten times their respective variances under rational expectations.

References


Figure 1: Japanese Nominal Interest Rate: Actual vs. Benchmark Taylor Rule

Table 1: Standard Deviations of the Real GDP Growth Rate for the Major OECD Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Standard deviation of RGDP growth rate 1981 - 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>2.16</td>
</tr>
<tr>
<td>Canada</td>
<td>2.34</td>
</tr>
<tr>
<td>France</td>
<td>1.23</td>
</tr>
<tr>
<td>Italy</td>
<td>1.66</td>
</tr>
<tr>
<td>Japan</td>
<td>2.25</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1.70</td>
</tr>
<tr>
<td>United States</td>
<td>1.19</td>
</tr>
</tbody>
</table>

Source: *International Financial Statistics*, IMF

Table 2: Parameter Values

<table>
<thead>
<tr>
<th>$\sigma$</th>
<th>$\gamma$</th>
<th>$\eta$</th>
<th>$\theta$</th>
<th>$\varphi$</th>
<th>$\beta$</th>
<th>$\alpha$</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.75</td>
<td>3</td>
<td>1</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Note: This value of $\beta$ is suggested in Ball (1999) and Mankiw and Reis (2002). Nunes (2004) argues that setting the discount factor to be one makes a zero output gap consistent with positive inflation at steady state.
Table 3: Variances of the Output Gap of Policy Rules

<table>
<thead>
<tr>
<th>Policy Rule</th>
<th>Rational Expectations</th>
<th>Least Squares Learning</th>
<th>Constant Gain Leaning</th>
<th>$g_t = 0.01$</th>
<th>$g_t = 0.02$</th>
<th>$g_t = 0.03$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\epsilon_{u,t}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) $u_t = \epsilon_{u,t}$ with std. of $\epsilon_{u,t}$ is 0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benchmark</td>
<td>0.0215 (0.002)</td>
<td>0.0421 (0.024)</td>
<td>0.0360 (0.015)</td>
<td>0.0342 (0.013)</td>
<td>0.0312 (0.011)</td>
<td></td>
</tr>
<tr>
<td>Restrictive</td>
<td>0.0314 (0.003)</td>
<td>0.0605 (0.041)</td>
<td>0.0690 (0.048)</td>
<td>0.0637 (0.053)</td>
<td>0.0503 (0.030)</td>
<td></td>
</tr>
<tr>
<td>Managed ER</td>
<td>0.2385 (0.031)</td>
<td>0.2924 (0.236)</td>
<td>0.2513 (0.081)</td>
<td>0.2613 (0.143)</td>
<td>0.2543 (0.139)</td>
<td></td>
</tr>
<tr>
<td>Domestic Focus</td>
<td>0.0011 (0.000)</td>
<td>0.0040 (0.002)</td>
<td>0.0045 (0.002)</td>
<td>0.0037 (0.002)</td>
<td>0.0035 (0.002)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) $u_t = 0.4u_{t-1} + \epsilon_{u,t}$ with std. of $\epsilon_{u,t}$ is 0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benchmark</td>
<td>0.0216 (0.002)</td>
<td>0.0420 (0.022)</td>
<td>0.0365 (0.015)</td>
<td>0.0340 (0.012)</td>
<td>0.0325 (0.010)</td>
<td></td>
</tr>
<tr>
<td>Restrictive</td>
<td>0.0322 (0.003)</td>
<td>0.0648 (0.047)</td>
<td>0.0724 (0.056)</td>
<td>0.0655 (0.049)</td>
<td>0.0577 (0.050)</td>
<td></td>
</tr>
<tr>
<td>Managed ER</td>
<td>0.2384 (0.039)</td>
<td>0.2576 (0.107)</td>
<td>0.2539 (0.106)</td>
<td>0.2553 (0.115)</td>
<td>0.2428 (0.070)</td>
<td></td>
</tr>
<tr>
<td>Domestic Focus</td>
<td>0.0012 (0.000)</td>
<td>0.0053 (0.003)</td>
<td>0.0046 (0.003)</td>
<td>0.0041 (0.002)</td>
<td>0.0039 (0.001)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Numbers are percentage of steady-state of consumption and in deviation from optimal policy rule. Numbers in parentheses are standard deviations of the statistics across simulations.
Table 4: Variances of Domestic Producer Price Inflation of Policy Rules

<table>
<thead>
<tr>
<th>Policy Rule</th>
<th>Rational Expectations</th>
<th>Least Squares Learning</th>
<th>Constant Gain Leaning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$g_r = 0.01$</td>
</tr>
<tr>
<td>Benchmark</td>
<td>0.0047 (0.001)</td>
<td>0.0152 (0.011)</td>
<td>0.0169 (0.012)</td>
</tr>
<tr>
<td>Restrictive</td>
<td>0.0051 (0.001)</td>
<td>0.0072 (0.003)</td>
<td>0.0099 (0.005)</td>
</tr>
<tr>
<td>Managed ER</td>
<td>3.7080 (1.913)</td>
<td>3.7569 (2.618)</td>
<td>3.5666 (1.958)</td>
</tr>
<tr>
<td>Domestic Focus</td>
<td>0.0004 (0.000)</td>
<td>0.0017 (0.001)</td>
<td>0.0017 (0.001)</td>
</tr>
</tbody>
</table>

3) $u_t = 0.4u_{t-1} + \varepsilon_{u,t}$ with std. of $\varepsilon_{u,t}$ is 0.001

<table>
<thead>
<tr>
<th>Policy Rule</th>
<th>Rational Expectations</th>
<th>Least Squares Learning</th>
<th>Constant Gain Leaning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$g_r = 0.01$</td>
</tr>
<tr>
<td>Benchmark</td>
<td>0.0047 (0.001)</td>
<td>0.0150 (0.009)</td>
<td>0.0169 (0.013)</td>
</tr>
<tr>
<td>Restrictive</td>
<td>0.0052 (0.001)</td>
<td>0.0072 (0.003)</td>
<td>0.0093 (0.005)</td>
</tr>
<tr>
<td>Managed ER</td>
<td>3.8632 (2.283)</td>
<td>3.7151 (2.227)</td>
<td>3.2168 (1.406)</td>
</tr>
<tr>
<td>Domestic Focus</td>
<td>0.0004 (0.000)</td>
<td>0.0022 (0.0001)</td>
<td>0.0021 (0.001)</td>
</tr>
</tbody>
</table>

Note: Numbers are percentage of steady-state of consumption and in deviation from optimal policy rule. Numbers in parentheses are standard deviations of the statistics across simulations.
<table>
<thead>
<tr>
<th>Policy Rule</th>
<th>Rational Expectations</th>
<th>Least Squares Learning</th>
<th>Constant Gain Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$g_t = 0.01$</td>
</tr>
<tr>
<td>Benchmark</td>
<td>0.1877 (0.040)</td>
<td>0.5616 (0.387)</td>
<td>0.6044 (0.398)</td>
</tr>
<tr>
<td>Restrictive</td>
<td>0.2203 (0.026)</td>
<td>0.3389 (0.155)</td>
<td>0.4390 (0.247)</td>
</tr>
<tr>
<td>Domestic Focus</td>
<td>0.0135 (0.002)</td>
<td>0.0631 (0.029)</td>
<td>0.0618 (0.029)</td>
</tr>
</tbody>
</table>

1) $u_t = \varepsilon_{u,t}$ with std. of $\varepsilon_{u,t}$ is 0.001

2) $u_t = 0.4u_{t-1} + \varepsilon_{u,t}$ with std. of $\varepsilon_{u,t}$ is 0.001

Note: Numbers are percentage of steady-state of consumption and in deviation from optimal policy rule. Numbers in parentheses are standard deviations of the statistics across simulations.