

Adaptive Learning and Monetary Policy in an Open Economy: Lessons from Japan *

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Abstract

Motivated by Japan's economic experiences and policy debates over the past two decades, this paper uses an open economy dynamic stochastic general equilibrium model to examine the volatility and welfare impact of alternative monetary policies. To capture the dynamic effects of likely structural breaks in the Japanese economy, we model agents' expectation formation process with an adaptive learning framework, and compare four Taylor-styled policy rules that reflect concerns commonly raised in Japan's actual monetary policy debate. We first show that imperfect knowledge and the associated learning process induce higher volatility in the economy, while retaining *some* of the policy conclusions from rational-expectations setups. In particular, explicit exchange rate stabilization is unwarranted, and under volatile foreign disturbances, policymakers should consider targeting domestic price inflation rather than consumer price inflation. However, contrary to results based on rational expectations, we show that even though highly inflation-sensitive rules do raise output volatility, they may nevertheless improve overall welfare in an adaptive learning setting by smoothing inflation fluctuations. Our findings suggest that previous policy conclusions that are based on partial equilibrium analyses, or that ignore likely deviations from rational expectations, may not be robust.

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1. Introduction

The Japanese economy and its dramatic turns during the last two decades have generated fervent research interests, ranging from the liquidity traps, to the appropriate monetary and fiscal responses, to the structural dynamics of the underlying economy.¹ On the empirical front, several papers point out that contrary to the experiences of other major OECD economies since the 1980s, Japan did not undergo a “great moderation” in the cyclical volatility of its economic activity; rather, it may have switched from a moderate growth-low volatility regime to a low growth-high volatility regime.² What can account for these empirical patterns? Some researchers attribute the volatility to policy mistakes, arguing in particular that more desirable economic performance could have been achieved had the Bank of Japan (BOJ) adopted a looser inflation policy stance. Concerns have also been raised as to whether it was prudent for the BOJ to engage in exchange rate stabilization rather than focusing solely on output and inflation targeting.

Motivated by these discussions, this paper aims to conduct a systematic evaluation of the volatility and welfare consequences of alternative monetary policy choices, using a dynamic stochastic general equilibrium (DSGE) model with explicit micro-foundations and welfare measures. While our goal is not to explicitly model the Japanese economy and all of its intricacies, we introduce an additional element – adaptive learning – into our standard open economy model. We argue that the stock market and real estate bubbles, along with their subsequent bursts, represent important structural shifts in the Japanese economy over this period, and under these unusual circumstances, the public’s expectations of how the economy would evolve may not converge immediately to the rational expectation outcome, as standard models assume.³ The expectation-formation process may further interact with monetary policy actions to influence macroeconomic dynamics, even alter the desirability of various policy options.⁴ In other words, standard

¹ See, for example, Krugman et al. (1998), Kuttner and Posen (2001), McCallum (2003), and Svensson (2003a).

² Over the past two decades, Japan’s real GDP growth rates and its GDP per-capita growth both exhibit higher volatility than is observed in other industrialized countries, as shown in Table 1.1, and for example, Bernanke (2004), Stock and Watson (2005), Summers (2005), and Yu (2005).

³ For example, Orphanides and Williams (2007 a,b) discuss how a constant gain learning framework can reflect public agents’ concern over potential structural shifts in the economy.

⁴ Here we are not referring to the excess volatility associated with the indeterminacy of equilibria as discussed in Bernanke and Woodford (1997), Bullard and Mitra (2002), and others. We consider only

policy conclusions from rational expectation models may not always be appropriate when agents' expectations are knocked out of equilibrium by exogenous events such as structural breaks. To model such dynamics and study its implications, we assume exogenous small deviations from rational expectations and employ the adaptive learning framework developed by Evans and Honkapohja (hereafter EH, 2001).⁵ In this setup, private agents are bounded rational and have only partial information: they know the functional form but not the associated parameter values for the equations that govern the dynamics of the economy. As such, they rely on past data and a recursive learning algorithm – least squares or constant gain learning – to form their forecasts and make consumption and production decisions.⁶ They update their beliefs regarding the unknown parameters over time as new data become available.

Introducing explicit welfare evaluations and adaptive learning, this paper examines the volatility and welfare impact of alternative monetary policy rules. Our aim is to see whether the public's expectation-formation process, interacting with monetary policy choices, can induce excess volatility in the benchmark economy and/or alter the preferred policy action.⁷ To allow for explicit welfare calculations, we adopt a standard micro-founded New Keynesian open economy model, as in Gali and Monacelli (hereafter GM, 2005), and study the dynamics of the economy under both rational expectations and adaptive learning.⁸ To close the model, we envision the monetary authority to follow variants of the “operational” Taylor interest rate rule (McCallum and Nelson 1999, 2004), and adjust the short-term nominal interest rate linearly in response to deviations of the observed data from their target levels.⁹ We consider four monetary policy rules that

learnable or expectationally stable equilibria in this paper, which means that economic agents can coordinate to reach them.

⁵ We choose the adaptive learning setup for its relative ease of implementation as well as certain technical advantages over alternative methods. For a detailed discussion, we refer interested readers to EH (2001).

⁶ Specifically, agents estimate the parameters in the reduced-form equilibrium laws of motions for the economy. See Section 4 for more details.

⁷ We emphasize that deviations from rational expectation and the learning behavior are especially well-justified when the economy is experiencing parameter instabilities or has undergone structural shifts.

⁸ We follow the previous literature, e.g., McCallum (2003) and McCallum and Nelson (2000), in applying a small open economy model to analyze the Japanese monetary policy. In addition, we note that the goal of this paper is not to provide a realistic model for the Japanese economy specifically; rather, our research questions are motivated by the Japanese experience.

⁹ We assume the monetary authority can commit to a simple operational rule, and abstract away from discretionary optimal monetary policy considerations. In addition, since the monetary rule is based on observable data, our model does not assume any information asymmetry between the public and the central

encapsulate the major points raised in the discussions concerning Japan's recent monetary policy actions. The first rule, which we treat as a benchmark, is a Taylor rule with the standard weights of 1.5 and 0.5 on lagged inflation and output gap deviations respectively. The second policy rule, capturing “the tighter rule” commonly discussed, is more aggressive on inflation control. The third rule captures exchange rate stabilization motives and targets the terms of trade in addition. Lastly, motivated by parallel discussions in the rational expectations-based monetary policy literature, we consider a rule that targets *domestic producer price* (DPP) inflation instead of CPI inflation.¹⁰ For each of these rules, we examine how the volatilities of output and inflation differ, and then use a second-order approximation of the representative consumer’s utility function to compute the welfare losses under rational expectations, least squares learning, and constant gain learning.¹¹

Our simulation results show that first of all, the learning process introduces excess volatility in the economy, leading to significant increases in the variances of both output and inflation from the rational expectation results. This finding suggests that the volatility impact of structural shifts in an economy may be amplified by the uncertainty and learning dynamics they generate, as agents can only revise expectation errors over time. This offers another potential explanation for the aforementioned empirical patterns observed in Japan. Second, even though tighter inflation control can lead to excess output volatility as a trade-off, in a learning environment, it may dampen inflation volatility significantly, thus *improve* overall welfare. This finding shows that it may not be prudent to judge policy rules against the same optimal benchmark when agents’ expectations may be deviating from the rational expectations equilibrium, such as right after major structural shifts. Lastly, we show that rules that depend on the terms of trade, either explicitly or through a CPI target, generate substantially higher welfare loss than rules that focus on DPP inflation. Especially when an economy is subject to persistent

bank. Note also that under operational rules, the central bank does not need to engage in any learning behavior.

¹⁰ See Aoki (2001) and Woodford (2003), among others.

¹¹ The expected welfare loss of a policy rule that deviates from the optimal first-best policy can be approximated by a weighted sum of the variances of *domestic producer price* inflation and the domestic output gap. See Woodford (2003), GM (2005), and Section 3.2 for further discussions.

and volatile foreign shocks, stabilizing DPP inflation dominates CPI inflation targeting under both rational expectations and adaptive learning.¹²

While our simple model is too stylized to capture the richness of Japan's actual economy, our findings, based on a structural general equilibrium model with a welfare-theoretic loss function, support some of the views raised in the literature; namely, the high output volatility observed may be the result of an overly restrictive monetary policy and engagement in exchange rate stabilization. However, we note that despite raising output volatility, tighter inflation control may nevertheless *improve* overall welfare when agents have imperfect knowledge, and the optimal rule derived from rational expectation models may no longer apply.

The rest of the paper is organized as follows. Section 2 reviews recent literature on Japan's monetary policy and motivates the policy rules we choose to evaluate. Section 3 presents the open economy general equilibrium model and specifies the four monetary policy rules. Section 4 discusses the equilibrium concepts and solution methodology for rational expectations and adaptive learning. Section 5 describes the calibration and simulation procedures and presents our findings. Section 6 concludes.

2. Monetary Policy in Japan

The economic bubble Japan experienced in the 1980s and the economy's ensuing downturn have stimulated extensive research and discussions. While problems with the banking sector, corporate structure, and excessive speculative behavior are all major contributing factors, this paper draws specifically from two debates concerning the Bank of Japan's monetary policy stance during this period. The first questions whether the BOJ should have adopted a lower interest rate, and the second asks whether exchange rate stabilization was prudent.

A common criticism of BOJ's policy is that it was overly restrictive, arguing that a lower interest rate on several occasions, both pre- and post-collapse of the bubble, would

¹² While previous studies based on rational expectations such as GM (2005) reach a similar conclusion concerning domestic inflation targets, they do not consider adaptive learning interacting with policy rules that are second best. We have already shown that policy conclusions based on rational expectations may not always carry over to the learning framework. In fact, under learning, a domestic inflation target is not *always* preferred, but depends on the relative sizes of foreign shocks versus domestic shocks (see Chen and Kulthanavit 2008 for further details.)

have brought about more favorable economic outcomes more quickly. This view is commonly justified by comparing BOJ's actual policy with some variants of the benchmark Taylor rule that sets the interest rate response to CPI inflation gap (deviation from its target) to be 1.5, and the response to the output gap to be 0.5, while assuming a 2 percent per annum real interest rate. Following this approach, Bernanke and Gertler (1999), Jinushi et al. (2000), and McCallum (2000, 2003), for example, all conclude that BOJ's policy was too tight during some sub-periods over the 1980s-1990s.¹³ Figure 1 shows that compared to the operational, or *lagged data-based*, version of the benchmark Taylor rule, BOJ's actual rate was indeed high, especially between 1981 and 1989.¹⁴

During the aftermath of the bubble, many argue that the BOJ kept the interest rate high for too long, failing to properly accommodate the structural shift. Jinushi et al. (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 1999.¹⁵ In March 2000, the BOJ temporarily abandoned the ZIRP and raised the call rate for a year, drawing widespread criticism. Ito and Mishkin (2004), for example, call this interest rate hike "a clear policy mistake." Using a monetary-base rule instead to analyze Japanese monetary policy-setting, McCallum (2003) reaches a similar conclusion: BOJ's policy had been too tight since the mid-1990s.¹⁶

A second debate in this literature concerns the merit of exchange rate stabilization. Several studies point out that in practice, the BOJ often engaged in exchange rate management, rather than focusing solely on output and inflation targeting. According to McKinnon and Ohno (1997), for a decade since 1985, the BOJ systematically reacted to the Yen/Dollar real exchange rate by adjusting the instrument rate to counter yen

¹³ We note that these papers don't always agree on the exact periods over which the policy was too tight. Bernanke and Gertler (1999), for example, consider the policy to be too tight since 1992, but too lax over 1987-89. Generally, a tight or overly restrictive monetary policy refers to a case where the actual instrument rate is above the target rate suggested by the benchmark Taylor rule.

¹⁴ We see that based on Japanese data, the mechanical benchmark Taylor rule may at times suggest an interest rate below the zero lower bound. We do not address the practical and modeling difficulties associated with hitting the zero lower bound in this paper. However, we consider alternative inflation targets and find the qualitative conclusions to be the same.

¹⁵ Under ZIRP, the BOJ vowed to keep the call rate at zero until concern about deflation was dispelled.

¹⁶ One difficulty in 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, Kuttner and Posen 2004). 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.

appreciation and promote yen depreciation. Similarly, Andrade and Divino (2005) and Jinushi et al. (2000) maintain that the BOJ was implicitly targeting exchange rate stability. Yu (2005) further attributes the high output volatility observed in Japan during the period 1993-2001 to an interest rate policy aimed at stabilizing the yen/dollar real exchange rate. On the other hand, advocates in favor of exchange rate management point out that under zero nominal interest rate, the short-term nominal rate and monetary base are ineffective as policy instruments. As such, purchasing unconventional assets such as long-term government bonds, foreign currencies, or even real estate may represent the only viable alternative.¹⁷ In particular, purchasing foreign exchange may help depreciate the yen and stimulate aggregate demand via boosting net export. While this is surely a “beggar-thy-neighbor” policy, 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 depreciates the yen/dollar real exchange rate when either inflation or output falls below their target values.

Much of the above debate is either conceptual in nature or relies mainly on partial equilibrium analyses in a rational expectation framework. Our paper aims to examine these policy choices more systematically in a general equilibrium optimization framework that allows for explicit quantifications of welfare as well as learning behavior.

3. The Open Economy Model and Monetary Policy Rules

We take as our baseline the open economy rational expectations model from GM (2005), and discuss in Section 5 its calibration to the Japanese economy. The model is a small open economy version of the Calvo (1983) sticky price model commonly used for closed economy monetary policy analyses, where the equilibrium dynamics are described by a new Keynesian Phillips curve and a forward-looking IS equation (see Clarida et al. 1999, for example.) International asset markets are assumed to be complete, and *purchasing power parity* holds. We close the dynamic system with alternative monetary policies, all expressed as lagged data-based Taylor rules. As the focus of this paper is to study the dynamics of this model in a learning framework, below we present a brief sketch of the

¹⁷ 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.

basic model setup and the associated reduced-form dynamic equilibrium equations. We refer interested readers to GM (2005) for more detailed derivations and discussions.

3.1 The New Keynesian Open Economy Model

Following GM (2005), our world consists of a continuum of identical small open economies uniformly distributed on the unit interval. As preferences, production technology, and market structures are symmetric, below we present the optimization problems facing the representative household and firm from the perspective of one of these economies, indexed by H (*Home*). We treat the rest of the *world* as a foreign block, with corresponding variables denoted by a subscript F.¹⁸

The Representative Household

The home economy is inhabited by a representative household which at time 0, maximizes the following expected lifetime utility:

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

where C_t and N_t are overall consumption and labor supplied. β is the household's discount factor, σ is the coefficient of relative risk aversion, and φ is the inverse of labor supply elasticity. Consumption index C_t is a CES composite of domestic and foreign goods (imports), defined by:

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

where $\eta > 0$ measures the elasticity of substitution between domestic and foreign consumption baskets $C_{H,t}$ and $C_{F,t}$. Each of these baskets is in turn a CES aggregate of a continuum of differentiated goods, with elasticities of substitution between varieties given by $\varepsilon > 1$ and $\gamma > 1$ for the home and foreign indices respectively.¹⁹ $\alpha \in [0, 1]$ is

¹⁸ See GM (2005) for a more detailed discussion of this world setup and the exact modeling of the foreign block.

¹⁹ To be more precise, γ is the substitutability between good baskets produced in different foreign countries. Each of these baskets, identical to the *Home* setup, is a CES aggregate of a variety of differentiated goods with an elasticity of substitution equal to ε . See GM (2005).

the (exogenous) share of the domestic consumption allocated to imported goods; it can be interpreted as a measure of trade openness.

The consumer faces the following sequence of period-by-period budget constraints:

$$P_{H,t}C_{H,t} + P_{F,t}C_{F,t} + E_t [Q_{t,t+1}D_{t+1}] \leq D_t + W_tN_t + T_t \quad \forall t$$

where $P_{H,t}$ and $P_{F,t}$ are the CES aggregated price indices of domestically-produced and imported goods respectively. $Q_{t,t+1}$ denotes the stochastic discount factor for one-period ahead nominal payoffs, and D_{t+1} is the nominal payoff in period $t + 1$ of the household's portfolio at the end of period t . W_t is the nominal wage, and T_t is lump-sum transfers/taxes. We assume complete asset markets.

The consumer price index (CPI) at *Home* is given by:

$$P_t \equiv \left[(1-\alpha)(P_{H,t})^{1-\eta} + \alpha(P_{F,t})^{1-\eta} \right]^{1/(1-\eta)}$$

and CPI inflation, π_t , is then $\pi_t = p_t - p_{t-1}$ where $p_t = \log(P_t)$.

Domestic Producers

On the production side, we assume a continuum of monopolistically competing firms each using a linear production technology which depends on the economy-wide stochastic labor productivity A_t :

$$Y_t(j) = A_t N_t(j)$$

where $Y(j)$ and $N(j)$ are the output and employment of firm j respectively.

Firms set prices in a staggered fashion à la Calvo (1983). Parameter θ denotes the fraction of firms that faces nominal rigidity each period, so at any time t , a fraction $1 - \theta$ of randomly selected firms gets to set new prices optimally to maximize expected discounted profits. A typical firm j sets its new price $\bar{P}_{H,t}$ in period t to maximize the following:

$$E_t \sum_{k=0}^{\infty} \theta^k \left\{ Q_{t,t+k} \left[Y_{t+k}(j) (\bar{P}_{H,t} - MC_{t+k}^n) \right] \right\}$$

subject to the period-by-period demand constraint:

$$Y_{t+k}(j) \leq \left(\frac{\bar{P}_{H,t}}{P_{H,t+k}} \right)^{-\varepsilon} (C_{H,t+k}(j) + C_{F,t+k}(j))$$

where MC_t^n is nominal marginal cost the firm faces, and $C_{H,t}(j)$ and $C_{F,t}(j)$ the total consumption of good j from home and abroad.²⁰ As is well known in the literature, this optimal price will involve a forward-looking term in addition to the standard monopolistic mark-up over contemporaneous marginal cost, reflecting the firm's concern over the future dynamics of marginal costs up to the next price-changing opportunity. Using lower case letters to denote the logs of the respective variables, we obtain the following log-linear approximation for the optimal price:²¹

$$\bar{p}_{H,t} = \log(\bar{P}_{H,t}) = \log\left(\frac{\varepsilon}{\varepsilon-1}\right) + (1-\beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \{ mc_{t+k} + p_{H,t} \}.$$

Equilibrium

Goods-market clearing, together with log-linear approximations of the equilibrium aggregate demand equations around the appropriate steady states, imply a forward-looking dynamic IS equation in the domestic output gap and inflation:

$$x_t = E_t x_{t+1} - \frac{1}{\sigma_\alpha} (r_t - E_t \pi_{H,t+1} - \bar{r}_t) \quad (1).$$

The output gap variable, x_t , is defined as the deviation of log domestic output from its equilibrium level in the absence of any nominal rigidities (the flexible-price level). Parameter σ_α is a function of the degree of openness and the substitutability between domestic and foreign goods; it captures the sensitivity of home output to terms-of-trade fluctuations.²² The home interest rate, r_t , is the monetary policy instrument set by the Central Bank. $\pi_{H,t} = p_{H,t} - p_{H,t-1}$ is *domestic producer price* (DPP) inflation, with $p_{H,t}$ being the (log) domestic price index. The last term, \bar{r}_t , is the domestic natural interest rate and one of the three stochastic driving variables in our dynamic system. It depends

²⁰ Since all firms are symmetric, they use the same optimal price-setting rule. We can thus drop the firm-specific index j .

²¹ The log-linear approximation is taken around the zero-inflation, balanced-trade steady state.

²² Expressed in terms of the structural parameters defined earlier,

$$\sigma_\alpha \equiv \sigma / [1 - \alpha + \alpha\sigma\gamma + (1 - \alpha)(\sigma\eta - 1)].$$

on the degree of openness, the expected *world* output growth $E_t \Delta y_{t+1}^*$, and the domestic labor productivity shock a_t , which we assume to follow a stationary AR(1) process.²³

On the supply side, we assume the presence of an employment subsidy that leaves the monetary policy authority with the sole task of correcting the distortion from price rigidity. Under this assumption, the optimal monetary policy is one that replicates the flexible price equilibrium resource allocation.²⁴ Aggregating firms' optimal pricing condition above and relating their real marginal cost to the output gap, we can express the domestic inflation dynamics by the New-Keynesian Phillips curve (NKPC) below:

$$\pi_{H,t} = \kappa_\alpha x_t + \beta E_t \pi_{H,t+1} + u_t \quad (2)$$

where κ_α depends on the degree of openness and how employment and the terms of trade respond to domestic output shifts.²⁵ We further assume that DPP inflation is affected by a stochastic cost push shock, u_t , which captures determinants of marginal costs that do not move proportionally with the output gap. u_t is the source of nominal disturbance in our dynamic system.²⁶

Equations (1) and (2) above are the by-now standard reduced-form equations that describe the structural economy in terms of output gap and DPP inflation. In order to model Taylor rules that stabilize CPI inflation, we next relate CPI inflation, π_t , to DPP inflation, $\pi_{H,t}$, and rewrite equations (1) and (2) in terms of CPI inflation. To do so, we note that under *purchasing power parity* (PPP), the relationship between π_t and $\pi_{H,t}$ is given by:

$$\pi_t = \pi_{H,t} + \alpha \Delta s_t \quad (3)$$

where $s_t \equiv p_{F,t} - p_{H,t}$ is the (log) effective terms of trade for the home country; $p_{F,t}$ is the (log) price index for imported goods, expressed in domestic currency. To describe the dynamics of the terms of trade, s_t , we note that under the assumption of complete

²³ See GM (2005) and Appendix A for more details.

²⁴ The assumption of an output or employment subsidy that offsets the distortion from the monopolistically competitive price/wage-setters' market power has been widely used since Rotemberg and Woodford (1999). See Woodford (2003) and Section 3.2 for further discussions.

²⁵ Expressed in terms of the structural parameters, $\kappa_\alpha \equiv (1 - \beta\theta)(1 - \theta)(\sigma_\alpha + \varphi) / \theta$

²⁶ We note that when this small open economy is in perfect autarky ($\alpha = 0$), the dynamic equations (1) and (2) are identical to the dynamic IS and NKPC equations, respectively, in a standard closed economy setup. See, for example, Clarida et al. (1999) and Woodford (2003).

international asset markets, the expected depreciation of the home currency reflects international interest rate differentials according to the *uncovered interest parity* (UIP) condition:

$$E_t[\Delta e_{t+1}] = r_t - r_t^* \quad (4)$$

where e_t is the (log) nominal effective exchange rate and r_t^* the *world* interest rate. Assuming that the *law of one price* holds for each product, $p_{F,t} = e_t + p_t^*$ where p_t^* is the log *world* price index, we can relate terms-of-trade changes to home currency depreciation, home deflation, and the aggregate inflation in the *world* market as follows:

$$\Delta s_t = \Delta e_t + \pi_t^* - \pi_{H,t} \quad (5)$$

where $\pi_t^* = p_t^* - p_{t-1}^*$ is *world* inflation. Combining (5) with the UIP condition (4), we obtain:

$$s_t = E_t s_{t+1} - (r_t - E_t \pi_{H,t+1}) + (r_t^* - E_t \pi_{t+1}^*) \quad (6).$$

From the perspective of the home economy, world interest rates and expected inflation are exogenous, so we define $v_t = (r_t^* - E_t \pi_{t+1}^*)$ as the third/foreign shock that drives our dynamic system.

Using equation (3), we can express equations (1), (2), and (6) in terms of the CPI inflation. The open economy IS, NKPC, and terms-of-trade dynamics can then be expressed by the following three stochastic difference equations:

$$x_t = E_t x_{t+1} - \frac{1}{\sigma_\alpha} (r_t - E_t \pi_{t+1} - \bar{r}) - \frac{1}{\sigma_\alpha} \alpha E_t s_{t+1} + \frac{1}{\sigma_\alpha} \alpha s_t \quad (7),$$

$$\pi_t = \beta E_t \pi_{t+1} + \kappa_\alpha x_t - \alpha \beta E_t s_{t+1} + \alpha (1 + \beta) s_t - \alpha s_{t-1} + u_t \quad (8),$$

$$s_t = E_t s_{t+1} - \frac{1}{(1-\alpha)} (r_t - E_t \pi_{t+1}) + \frac{1}{(1-\alpha)} v_t \quad (9).$$

Monetary Policy Rules

To close the model, we assume the policymaker is able to commit to following policy rules in the form of an operational Taylor (1993) rule, which sets the domestic interest

rate r_t in response to observable lagged data. While the literature offers extensive discussions on the stability and learnability of equilibria under various forms of Taylor rules, we follow McCallum and Nelson (1999, 2004) in pointing out that it may be unrealistic to assume policymakers can condition policy on current/contemporaneous variables or on accurate private expectations. As our focus is to assess the likely quantitative importance of the learning process, we restrict our analyses to the set of equilibria that is determinate and stable under learning.²⁷

The first rule we consider is a CPI-inflation-based Taylor rule. Under this policy rule, the policymaker sets the interest rate r_t in response to deviations of lagged CPI inflation and the output gap from their target levels:

$$r_t = \rho + \pi^T + \varphi_\pi(\pi_{t-1} - \pi^T) + \varphi_x x_{t-1} \quad (10)$$

where π^T is the targeted CPI inflation. Parameters φ_π and $\varphi_x > 0$ capture how aggressive the policymaker is in response to deviations of CPI inflation and the output gap from their target values: π^T and zero, respectively. The time discount rate $\rho = \beta^{-1} - 1$ can be interpreted as the riskless return in the steady state. Note that reacting to CPI inflation implies that the policymaker reacts to the terms of trade.

We consider next a managed exchange rate (ER) policy rule where the policymaker engages in exchange rate stabilization, instead of focusing solely on output and inflation targeting. This rule takes the form:

$$r_t = \rho + \pi^T + \varphi_\pi(\pi_{t-1} - \pi^T) + \varphi_x x_{t-1} + \varphi_s s_{t-1} \quad (11)$$

where $\varphi_s > 0$ measures the sensitivity of the policy to movements in the terms of trade.

²⁷ Howitt (1992) and Bullard and Mitra (2002), among others, point out that in the learning framework, convergence to a determinate rational expectations equilibrium (REE) should not be taken for granted, as it is not clear whether or how 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) find that rules obeying the ‘‘Taylor principle’’ based on current expectations can assure learnable equilibria. They also find that rules that respond to lagged values of inflation and output deviations may not generate determinacy, and the determinate REE are not necessarily learnable. For a more detailed discussion on the conditions for determinacy and stability under learning for different classes of monetary policy, see Bullard and Mitra (2002, 2007), EH (2003a, 2003b, 2006) and Waters (2007). Llosa and Tuesta (2008) and Bullard and Schaling (2006) provide similar analyses for the open economy setup.

The last policy rule we consider is a Domestic Focus Taylor rule, under which the policymaker targets DPP inflation instead of CPI inflation. This policy rule takes the form:

$$r_t = \rho + \pi_H^T + \varphi_{\pi_H} (\pi_{H,t-1} - \pi_H^T) + \varphi_x x_{t-1} \quad (12)$$

where π_H^T is a targeted DPP inflation, and $\varphi_{\pi_H} > 0$ measures how aggressive the policymaker is in reacting to any deviations of DPP inflation from its target, π_H^T .

3.2 Welfare Calculation

Before evaluating alternative monetary policy, one needs to specify what other policy instruments, if any, are available to the social planner, thereby pinning down the specific distortions monetary policy aims to address. While it may not always lead to the globally welfare maximizing outcome, it is customary in the literature to assume the presence of an employment subsidy that eliminates relevant economic distortions and renders the flexible price equilibrium allocation optimal.²⁸ In the rational expectation framework, the sole objective of monetary policy, or the optimal policy, is then to correct the distortion caused by price rigidities and to replicate the flexible price equilibrium. The advantage of this assumption is that the undistorted, flexible price steady-state production and employment levels provide computational convenience for approximating the representative household's welfare under various policies, as first discussed in Rotemberg and Woodford (1999).

In this paper, we compare the welfare outcome of four alternative Taylor rules, none of which is necessarily equivalent to the welfare-maximizing policy discussed above.²⁹ We motivate the choice of these sub-optimal interest rate rules by actual policy debates

²⁸ In the close economy, this outcome is achieved by a subsidy that exactly neutralizes the distortion caused by the market power of the monopolistically-competing firms. In the open economy setting, additional subsidy is required to eliminate the incentive for the monetary authority to engage in “beggar-thy-neighbor” policies, i.e. manipulate the terms of trade (See Benigno and Benigno 2003, for example.) Gali (2003) and GM (2005) show that under certain parameter restrictions, this level of subsidy can be derived analytically.

²⁹ In the monetary policy literature, a *specific targeting rule* is where policymakers set interest rate via a feedback rule to meet the optimal targeting condition. On the other hand, the Taylor rule belongs to the class of *instrument rules*, which are considered suboptimal as the rate is set to respond to macroeconomic variables without explicitly optimizing any policy objective function. See Svensson (2003b) and McCallum and Nelson (2004b) for a survey on a targeting rule vs. an instrument rule.

and practical implementation considerations discussed earlier. For each rule, the representative household's expected utility can be approximated locally around the flexible price steady state using a second-order Taylor expansion, which gives us a measure of the utility loss relative to the optimal policy. Measured as fractions of the steady-state consumption level, we express the expected welfare loss associated with a policy rule as the weighted sum of the variance of DPP inflation and the variance of the output gap, as shown below:

$$EW = -\frac{(1-\alpha)}{2} \left[\frac{\varepsilon}{\lambda} \text{var}(\pi_{H,t}) + (1+\varphi) \text{var}(x_t) \right] \quad (13)$$

where λ is defined as $(1-\beta\theta)(1-\theta)/\theta$.³⁰ We use equation (13) to evaluate the performances of alternative monetary policy rules in Section 5.

4. Models of Expectation Formation

While the assumption of rational expectations has become the standard methodology for studying macroeconomic dynamics, it should not be taken for granted. As discussed in EH (2001), amongst others, expectations can be out of equilibrium, at least in the short run, as a result of exogenous events such as structural shifts. Given Japan's experiences over the past decades, we believe this is a relevant element to incorporate into our DSGE model. The normative implication of this off-equilibrium assumption is that monetary policy may help minimize the instabilities that can arise from agents' expectation errors and learning behavior. Below we present the expectation-formation processes under rational expectations and adaptive learning. We also give a brief conceptual interpretation of the adaptive learning process.

4.1 Rational Expectations

Rational expectations (RE) can be viewed as the equilibrium or convergence between stochastic macroeconomic dynamics and economic agents' forecasts of them. RE is defined as the mathematical conditional expectation of the particular variable, and it assumes the optimal/efficient use as well as the availability of all relevant current

³⁰ See GM (2005).

information, such as the true structure of the economy, the stochastic process governing exogenous shocks, and/or the policy formation process. Under RE, economic agents, having perfect knowledge about the structure of the economy, *know* the rational expectations equilibrium (REE) of the economy.

In the context of our model described above, we solve for the REE of the dynamical system given by equations (7), (8) and (9), together with a monetary policy rule, Eq. (10) or (11).³¹ The reduced-form system can be expressed as the following:

$$y_t = A + BE_t y_{t+1} + Cy_{t-1} + Dw_t \quad (14)$$

$$w_t = \rho_w w_{t-1} + \varepsilon_t \quad (15)$$

where $y_t = [x_t, \pi_t, s_t]'$ is a vector of the three endogenous variables, $w_t = [\bar{r}_t, u_t, v_t]'$ the exogenous variables, which we assume to follow a stationary vector autoregressive process, and $\varepsilon_t = [\varepsilon_{\bar{r},t}, \varepsilon_{u,t}, \varepsilon_{v,t}]'$ is a vector of white noise. A, B, C, and D are vector and matrices of coefficients. Following McCallum (1983, 1998), we solve for the REE by focusing on the *Minimum State Variable* (MSV) solutions to the system, which are linear functions of the following form:

$$y_t = \bar{a} + \bar{b}y_{t-1} + \bar{c}w_t \quad (16)$$

where matrices \bar{a} , \bar{b} and \bar{c} can be solved by the method of undetermined coefficients.³²

To summarize, under the RE assumption, agents know the correct form of the REE, Eq.(16), and its relevant parameters (\bar{a} , \bar{b} and \bar{c} .) Agents make use of this knowledge to form their expectations of future y .

4.2 Learning

Structural changes, new policy regimes, and other unexpected shifts in the economy may all disturb the REE discussed above. In order to capture such off-equilibrium dynamics, we incorporate into the open economy model the adaptive learning process proposed by

³¹ Under the DPP targeting rule, we complement the system given by (1), (2) and (6) with policy rule (12).

³² The MSV solutions are generally considered equilibria that are free of bubble and sunspot components. A system may be *indeterminate* with multiple stationary REE, but we restrict our analyses to systems with a unique stationary solution, which is the MSV solution. See McCallum (1983, 1998).

EH (2001) and Orphanides and Williams (hereafter OW, 2005). In contrast to RE, the learning framework assumes that optimizing agents are bounded rational and do not have perfect information about the dynamic equations governing the evolution of the economy (such as the values of \bar{a} , \bar{b} and \bar{c} in Eq. 16.) At each time t , agents rely on observable data and an adaptive learning algorithm to obtain the relevant parameter estimates, and form expectations accordingly. As new data become available, they revise their estimates so forecast errors are corrected gradually over time. Under certain conditions, the REE is a fixed point of the learning dynamics and the economy eventually converges to it; however, this may not happen as discussed at length in EH (2001), among others.³³

We consider two types of learning algorithms commonly used in the literature: least squares learning and constant gain learning. In least squares learning, agents use all available past data and a least squares regression to deduce the parameters of interest. As a conceptual comparison, it can be viewed as a *decreasing gain* learning in that as time goes by, the relative importance of newly arrived information diminishes in shaping agents' estimates and forecasts. Under constant gain learning, on the other hand, agents update their expectations over time by looking at a fixed-width but rolling window of past data, so new information is always incorporated into their forecasts with equal weights.³⁴ Conventionally, a smaller gain means that agents use longer series of lagged data to form their forecasts. In our setup, the gain constant, g , indicates that agents look at $2/g$ lags of data at each time. So for $g = 0.02$, a common calibration used in the literature, agents form their forecasts using 25 years of historical data (100 quarters.)

An advantage of the constant gain setup is that by varying g , one can capture the degree of rationality. A smaller gain may represent a higher degree of rationality, as it more closely resembles least squares learning, which eventually converges to REE. In addition, as discussed in Waters (2007), agents may choose a smaller gain 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

³³ The economy may or may not converge to the REE asymptotically. When it does, the REE is considered to be “stable under learning” (see EH 2001, 2003a, 2003b, 2006, and Bullard and Mitra 2002). In this paper, we focus on cases where we have stability under least squares learning. With constant gain learning, the economy does not converge to the REE, and the learning is “perpetual.”

³⁴ OW (2005) considers constant gain learning to be more appropriate in situations where agents remain alert to any potential structural change in the economy.

weight on the most recent news, but rather 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 have in mind a *Perceived Law of Motion* (PLM) for the economy, which has the same functional form as the rational expectations MSV solutions described in Eq. (16). The exogenous shocks, w_t , as well as lagged data y_{t-1} are observed by all, but agents do not know the true parameter values \bar{a} , \bar{b} and \bar{c} associated with the MSV REE. Instead, at each time t , they use past data and a learning algorithm (described below) to obtain parameter estimates a_t , b_t , and c_t . They perceive the economy to evolve according to the following law of motion (PLM),

$$y_t = a_t + b_t y_{t-1} + c_t w_t \quad (17).$$

To form their forecasts for $t + 1$, they use the PLM along with the observed w_t as follows:

$$\begin{aligned} E_t y_{t+1} &= a_t + b_t E_t y_t + c_t E_t w_{t+1}, & \text{or} \\ E_t y_{t+1} &= (I + b_t) a_t + b_t^2 y_{t-1} + (b_t c_t + c_t \rho_w) w_t \end{aligned} \quad (18)$$

where the VAR process for the exogenous shocks, or ρ_w , is also known to all agents.

At the same time t , the policymaker sets interest rate r_t based on the chosen policy rule. The resulting outcome of the economy, the *Actual Law of Motion* (ALM) for y_t , is generated according to equations (14) and (18), and can be expressed as the following:³⁵

$$\begin{aligned} y_t &= A + B \left[(I + b_t) a_t + b_t^2 y_{t-1} + (b_t c_t + c_t \rho_w) w_t \right] + C y_{t-1} + D w_t, \text{ or} \\ y_t &= \left[A + B (I + b_t) a_t \right] + (B b_t^2 + C) y_{t-1} + \left[B (b_t c_t + c_t \rho_w) + D \right] w_t \end{aligned} \quad (19).$$

This process then repeats itself at the next period, $t + 1$: agents incorporate newly available information, the actual y_t to re-estimate the PLM equation and obtain new parameter estimates a_{t+1} , b_{t+1} and c_{t+1} . Together with the observed shocks w_{t+1} , they form their forecasts for the next period. The actual y_{t+1} , or the ALM for y_{t+1} is generated

³⁵ The ALM is thus the true data generating process, and sometimes called the temporary equilibrium for the endogenous variables (see EH 2006).

together with the interest rate r_{t+1} set by the policymaker. The learning process continues in this rolling fashion.

The recursive learning algorithms agents use to update their estimates is given by the following equations:

$$\phi_t = \phi_{t-1} + g_t R_t^{-1} z_{t-1} (y_{t-1} - \phi'_{t-1} z_{t-1})' \quad (20)$$

$$R_t = R_{t-1} + g_t (z_{t-1} z'_{t-1} - R_{t-1})' \quad (21)$$

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 . The gain parameter, g_t , plays an important role in characterizing the two types of adaptive learning we consider. Under least squares learning, $g_t = 1/t$, and the updating equations (20) and (21) are equivalent to running recursive least squares regressions using all lags. On the other hand, when the gain parameter is a small constant, $0 < g_t < 1$, we are in the framework of constant gain learning. In our simulations, we consider gain values 0.01, 0.02, and 0.03, to be consistent with the range suggested in recent literature.³⁶

To summarize, under adaptive learning, the dynamics of the model are defined by the recursive updating equations (20) and (21), the expectation-formation equation (18) derived from the PLM, the reduced-form equation (14) which captures the structure of the economy and the policy rule, and the AR(1) process of stochastic shocks w_t (15).

5. Numerical Analyses and Discussion

5.1 Calibration

As the baseline for our calibration, we adopt most of the structural and preference parameter values for our model from GM (2005), as we list in Table 2. In addition, the openness parameter α is set be 0.11, which corresponds to the average share of Japanese imports over GDP during the period 1983:Q1-2005:Q2. We follow Ball (1999) and Nunes (2004) and set the discount factor β to be unity, which makes the zero steady-state output gap assumed consistent with positive steady-state inflation. The three driving

³⁶ OW (2005, 2007a, b) and Branch and Evans (2006), for example, suggest gain values in the range of 0.01 to 0.05.

shocks to our dynamic system, $\{\bar{r}_t, u_t, v_t\}$, are assumed to follow independent AR(1) processes; we discuss their calibrations in more details in Appendix A.

For the monetary policy rules, we set $\varphi_\pi = 1.5$ and $\varphi_x = 0.5$ for our benchmark rule, as suggested in Taylor (1993).³⁷ The target CPI inflation, π^T , is set to be 0.822 percent, the average of CPI inflation in Japan during the period 1983:Q1-2005:Q2.³⁸ For the rule with a tighter inflation control, we set φ_π to be 2. To capture exchange rate (ER) management behavior, we let the policymaker react to the terms of trade with $\varphi_s = 0.2$. Finally, for the domestically focus policy rule, parameters φ_{π_H} and π_H^T are set to be 1.5 and 0.822, respectively, as in the Benchmark, in order to isolate the effect of the different price index. Below is a summary of the four monetary policy rules we evaluate:

- Rule 1: $r_t = \pi^T + 1.5(\pi_{t-1} - \pi^T) + 0.5x_{t-1}$ (Benchmark)
- Rule 2: $r_t = \pi^T + 2(\pi_{t-1} - \pi^T) + 0.5x_{t-1}$ (Tight Inflation Control)
- Rule 3: $r_t = \pi^T + 1.5(\pi_{t-1} - \pi^T) + 0.5x_{t-1} + 0.2s_{t-1}$ (Managed ER)
- Rule 4: $r_t = \pi_H^T + 1.5(\pi_{H,t-1} - \pi_H^T) + 0.5x_{t-1}$ (Domestic Focus).

5.2 Simulation Results and Discussion

For our simulation exercises, we implement the learning algorithm in EH (2001, 2006), and further incorporate a “projection facility” to constrain simulation paths to be non-explosive. We provide more detailed descriptions in Appendix B.³⁹ For each scenario, the dynamics of the economy is simulated 200 times for 250 periods each, with the first 50 periods discarded to reduce the initial condition effects. We evaluate the performance of the policy rules based on the variances of the generated output gap and DPP inflation, from which we compute the welfare losses using Eq. (13).

³⁷ Recall that this is also the benchmark policy rule commonly used in prior literature to evaluate whether BOJ’s policy was overly restrictive.

³⁸ Here we do not presume that Japan’s actual policy target was indeed 0.822% or even constant over the last two decades, yet our robustness checks of alternative targets (0 and 2%) suggest that the qualitative conclusions of our analyses are robust to the exact policy targets assumed.

³⁹ The “projection facility” is commonly employed in the learning literature to rule out explosive equilibria (see Gaspar et al. 2006, OW 2007a, and Waters 2007, for example). It tends to induce higher standard deviations across simulation results, however.

Tables 3 and 4 report the variances of the output gap and DPP inflation under the four monetary policy rules. The second and third columns in each table show the results under rational expectations and least squares learning, respectively. The fourth through sixth columns report the outcomes under constant gain learning, using gain values 0.01, 0.02, and 0.03. All numbers reported are averages across simulation runs, and the standard errors across runs are reported in the parentheses. Table 5 combines the above two statistics and reports the overall welfare results of these policy rules; the reported numbers indicate percent deviations from the steady-state consumption under the optimal policy.⁴⁰

We want to emphasize the following observations.⁴¹ First, given a policy rule, the learning process invariably induces additional volatility in both the output gap and DPP inflation, compared to those obtained under RE.⁴² This is in general consistent with findings in the closed-economy learning literature, such as in Gaspar et al. (2006) and OW (2007b), although the latter reports much less pronounced differences in the variances of the output gap. Intuitively, imperfect knowledge and the learning mechanism imply expectation errors, which can propagate along with structural shocks, raising the overall volatility of macroeconomic variables. In an open economy, agents have to learn an additional process that governs the dynamics of the terms of trade (Eq. 6), which may in turn accentuate the effect of learning on output gap variability. These findings support the view that deviations from RE, possibly triggered by structural changes in the economy, may be the culprit for observed high volatility.⁴³

Next, we see that high output volatility may indeed be the result of bad policy choices or “mistakes”, as discussed earlier. Table 3 shows that, relative to the benchmark Taylor rule, tight inflation control or explicit exchange rate stabilization both lead to higher output volatility, *regardless of how private agents form their expectations*. Somewhat

⁴⁰ We do not report the welfare losses associated with the Managed ER policy rule because it is obvious from Tables 1.3 and 1.4 that this policy creates significant welfare losses.

⁴¹ We find qualitatively similar results as discussed below in our various robustness checks, including one where we assume the cost push shock to be *i.i.d.*, as suggested in Svensson (2000).

⁴² We note the exception with the Managed ER rule, which generates significantly higher volatility than other rules and the variances are not really distinguishable under learning vs. rational expectations.

⁴³ We observe in Tables 1.3-1.5 that as the gain constant increases (corresponding to learning using a smaller window of data), the resulting volatility or welfare loss tend to decline. This may be explained by the fact that higher-gain learning puts more weight on the newest information while discarding old data, which arguably are farther from the eventual steady state path.

strikingly, the Managed Exchange Rate policy rule induces drastically higher volatilities in both the output gap and DPP inflation. The additional interest rate response to the terms-of-trade beyond the weight (α) implicit in the CPI target appears to amplify output volatility approximately ten-fold. On the other side, the domestically-focused policy rule, which *removes* from the benchmark CPI rule its interest rate reaction to the terms of trade, generates significantly lower output volatility – a roughly ten-fold reduction as well (Table 3). The Domestic Focus rule appears to significantly outperform other terms-of-trade dependent rules in stabilizing output and inflation at home, as we discuss further below.

High output volatility does not by itself imply high welfare loss; Table 4 reports the variances of DPP inflation under the same four policy rules. Contrary to the results for the output gap, here we see that the expectation-formation process *does* matter: while a tighter inflation control relative to the benchmark *raises* inflation volatility under RE, it *lowers* inflation volatility under adaptive learning. In other words, imperfect knowledge affects how the inflation dynamics interact with monetary policy, as discussed in Gaspar et al. (2006) and OW (2006, 2007a, b) in a closed-economy setting. OW (2005), for example, points out that strengthening the policy response to inflation helps limit the increase in the perceived inflation persistence under learning, and through this channel, tight inflation control may reduce the volatility in both inflation and the output gap. The welfare implication of this result is presented in Table 5. We see that under RE, the benchmark Taylor rule commonly used in the literature is indeed preferable to more aggressive inflation control. However, in situations where knowledge is imperfect, it is no longer appropriate to continue evaluating policies against this benchmark, as the policy with a heavier emphasis on inflation control actually dominates this benchmark rule. Even though tighter inflation control raises output volatility, it helps agents learn the inflation dynamics better, thus reducing the overall welfare loss.⁴⁴ We note, in addition, that the welfare losses associated with the benchmark and the tight inflation control rule are smaller when agents use a shorter range of data (higher gain constant) to learn about the economy. In these two cases, the learning process and its associated

⁴⁴ In our calibration, the relative weight on inflation stabilization relative to output stabilization in the welfare loss function (Eq. 13) is roughly 18 to 1.

forecast errors induce excess volatility. Using a shorter window of past data to update the forecast functions allows agents to fix forecast errors more quickly; that is, old mistakes are forgotten more quickly. This can help reduce volatility and improve welfare.

In terms of exchange rate management, we note that regardless of the expectation-formation process, explicit exchange rate stabilization results in extremely poor performance, characterized by drastically higher volatilities and welfare costs. As CPI inflation incorporates terms-of-trade movements already ($\pi_t = \pi_{H,t} + \alpha\Delta s_t$), additional interest rate responses appear to be an overreaction, inducing high fluctuations in the economy. This finding, together with the observation that the Domestic Focus policy rule outperforms all the other policy rules in Tables 3-5, raises the obvious question of whether all reactions to the terms of trade are overreactions. In other words, is the Domestic Focus policy rule always preferred?⁴⁵

Tables 6 and 7 help shed light on the question of whether or when policymakers may want to put a stronger emphasis on the domestic variables as their policy targets. Rather than subjecting our model to all three exogenous shocks (aggregate demand, cost push, and terms-of-trade), we show in Table 6 the welfare outcome when the economy faces only one shock at a time. Isolating the impact of different structural shocks, it becomes obvious that the large stabilization advantage of the Domestic Focus rule comes through chiefly in the presence of the foreign/terms-of-trade shock, as illustrated in the last panel of Table 6. This advantage is so large that it easily overwhelms any differences in the three rules' relative performances under the other two shocks, which explains our previous finding that the Domestic Focus policy consistently outperforms the other rules. Table 7 emphasizes the importance of the foreign shock in choosing between a CPI- vs. DPP- inflation target. Here we dampen the variance of the white noise term in the foreign shocks by a factor of five (from 0.005 to 0.001), and compare the welfare losses under various policy rules. We see that the Domestic Focus rule now performs *poorly* compared to the CPI inflation targeting rules under adaptive learning. These results suggest that in an open economy subject to volatile foreign shocks, policymakers should

⁴⁵ There is a large body of literature comparing the desirability of DPP vs. CPI targeting. They mostly focus on a rational expectations setting. Chen and Kulthanavit (2008) explore this issue in an open-economy adaptive learning framework, and find the preferred policy depends on the extent of knowledge imperfection.

place more weight on stabilizing domestic prices. However, unlike policy conclusions under RE, adaptive agents may prefer a CPI inflation target when foreign shocks are relatively insignificant.

6. Conclusion

With explicit micro-foundations, our general equilibrium model provides a framework to systematically evaluate the different policy views concerning Japan's monetary policy stance since the 1980s. We also explore whether the observed output volatility may in part be caused by deviations from rational expectations, a likely scenario given the structural shifts in the Japanese economy over the last decades. We thus incorporate into our open economy model an adaptive learning algorithm, with the additional goal of analyzing whether the expectation-formation process may affect the preferred policy choice. We compare four operational Taylor rules under rational expectations and adaptive learning, and evaluate their welfare consequences using a second order approximation of the representative consumer's utility function.

We find that first of all, imperfect knowledge and the associated learning process raise output and inflation volatility. Next, even though tight inflation control relative to the standard Taylor rule can lead to excess output fluctuations, it can help dampen harmful inflation feedback in a learning framework, and lower overall inflation volatility. As such, the preferred policy in periods of economic uncertainty – when deviations from rational expectations are more likely – may deviate from the standard Taylor rule and put more weight on stabilizing inflation. A policy rule that would “too tight” under rational expectation may be appropriate under learning. We also find that explicit terms-of-trade or exchange rate targeting incurs substantial welfare costs. Finally, when an economy faces persistent volatile foreign shocks, the policy rule should target *domestic producer price* inflation instead of CPI inflation.

Appendix A: Calibration of the Exogenous Shocks

There are three stochastic driving forces $\{\bar{r}_t, v_t, u_t\}$ in our model, representing exogenous aggregate demand shifts, changes in the foreign expected real interest rate, and the cost-push shocks respectively. We calibrate their stochastic properties as follows:

The natural real interest rates, $\bar{r}_t = \rho - \sigma_\alpha \frac{1+\varphi}{\sigma_\alpha + \varphi} (1 - \rho_a) a_t$, is a function of a_t , the log labor productivity, measured as deviations from trend. We calibrate it by fitting an AR(1) process to the Japanese labor productivity data obtained from Source OECD. We obtain the following process for \bar{r}_t :

$$\bar{r}_t = 0.66\bar{r}_{t-1} + \varepsilon_{\bar{r},t}, \quad \text{with } \sigma_{\varepsilon_{\bar{r},t}} = 0.0029.$$

For the foreign real interest rate shock v_t , we follow the methodology proposed by Monacelli (2004) and fit an AR(1) process to the US real interest rate. The stochastic process for v_t is then:

$$v_t = 0.97v_{t-1} + \varepsilon_{v,t}, \quad \text{with } \sigma_{\varepsilon_{v,t}} = 0.005.$$

Finally, we assume that the domestic cost push shocks u_t follows an AR (1) process in the following form:

$$u_t = 0.4u_{t-1} + \varepsilon_{u,t}, \quad \text{with } \sigma_{\varepsilon_{u,t}} = 0.001.$$

As discussed in the text, we follow Svensson (2000) and consider the case where the cost push shocks are i.i.d. white noise as a robustness check for this assumption. We do not report the results as they support the qualitative results presented in this paper.

Appendix B: The Implementation of the Learning Algorithms

As initial conditions for each adaptive learning simulation, we perturb the rational expectations equilibrium with a small white noise as follows: $a = \bar{a} + 0.005 \times \text{random}$, $b = \bar{b} + 0.04 \times \text{random}$, $c = \bar{c} + 0.02 \times \text{random}$, where “random” is drawn from a uniform distribution. We set $y_0 = \bar{y}$ and $R_0 = \bar{R}$.

In the least squares simulations, we mitigate the initial volatility of the parameter estimates by using a small constant gain for the first 20 periods. That is, $g_t = 1/N$ for $t = 1, 2, \dots, N$ and $g_t = 1/t$ for $t > N$, with $N = 20$. The innovations in each period are drawn from normal distributions.

In addition, to keep the stochastic simulation non-explosive, we implement two additional algorithms suggested by OW (2007a) to reflect the view that in practice, private agents would reject unstable models so our analyses should similarly rule them out. In each period, we compute the roots of the 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 in the text. If not, the forecast model is not updated and the matrices ϕ and R are kept at their respective values from the previous period. We further impose the following condition to restrain explosive behavior: if any of the relevant variables exceeds, in absolute value, five times its unconditional standard deviations (computed under the assumption of rational expectations), then the variable that exceeds this bound is set to the boundary value for that period.

These two constraints are not sufficient to rule out all explosive behavior in our adaptive learning simulations. Thus, we compute relevant statistics using only simulation runs that give variable variances that are less than ten times their respective variances under rational expectations. For the last scenario (Domestic Focus policy with foreign shocks) in Table 6, we impose 10^{20} instead of ten as the cut-off, since there is little variation in the rational expectations outcomes.

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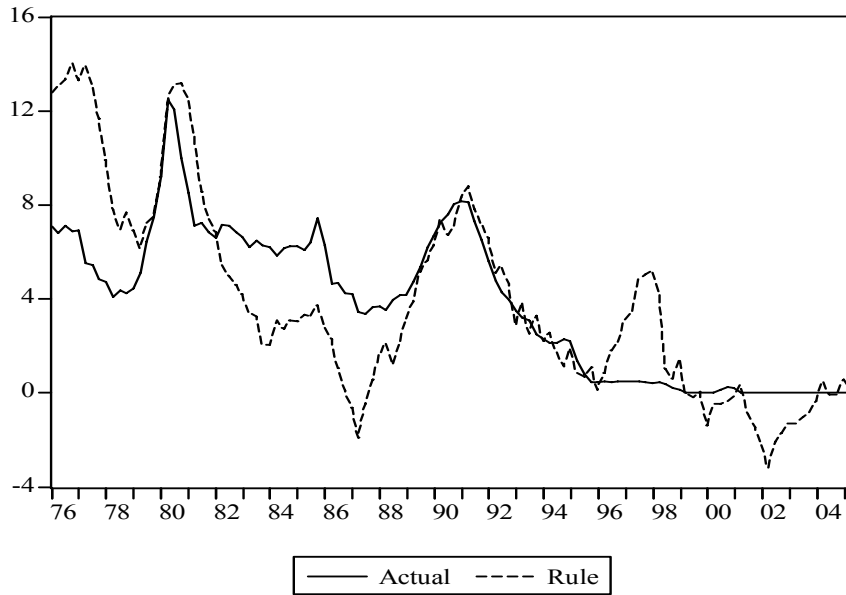
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Figure 1: Japanese Nominal Interest Rate: Actual vs. Benchmark Taylor Rule



* The benchmark operational Taylor rule takes the following form: $r_t = rr_t + \pi^* + 1.5(\pi_{t-1} - \pi^*) + 0.5x_{t-1}$, where r_t is the call rate; rr_t is the natural real rate (set to be 2 percent); π_{t-1} is the one-period lagged *CPI* inflation rate, and x_{t-1} is the one-period lagged output gap. π^* is the target *CPI* inflation, which is assumed to be 2 percent.

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

Country	Standard deviation of RGDP growth rate 1981 - 2005
Australia	2.16
Canada	2.34
France	1.23
Italy	1.66
Japan	2.25
United Kingdom	1.70
United States	1.19

Source: *International Financial Statistics*, IMF

Table 2: Parameter Values for Numerical Analysis

σ	γ	η	θ	φ	β	α
1	1	1	0.75	3	1	0.11

Source: Gali and Monacelli (2005) and authors' calculations (see main text).

Table 3: Variance of the Output Gap under Alternative Policy Rules

	Rational Expectations	Least Squares Learning	Constant Gain Learning		
			$g_t = 0.01$	$g_t = 0.02$	$g_t = 0.03$
Benchmark	0.0218 (0.0002)	0.0437 (0.0019)	0.0370 (0.0010)	0.0348 (0.0008)	0.0323 (0.0007)
Tight Inflation Control	0.0324 (0.0003)	0.0625 (0.0035)	0.0670 (0.0036)	0.0611 (0.0036)	0.0525 (0.0030)
Managed ER	0.2374 (0.0025)	0.2726 (0.0115)	0.2612 (0.0084)	0.2636 (0.0103)	0.2800 (0.0165)
Domestic Focus	0.0012 (0.00002)	0.0051 (0.0005)	0.0046 (0.0004)	0.0044 (0.0004)	0.0037 (0.0003)

Note: Numbers reported are the averaged variances of the output gap, multiplied by 100, over the 200 simulation runs. The numbers in parentheses are the standard errors of statistics. We omit results that do not satisfy the projection facility conditions, as discussed in Appendix B.

Table 4: Variance of the *Domestic Producer Price* Inflation under Alternative Policy Rule

	Rational Expectations	Least Squares Learning	Constant Gain Learning		
			$g_t = 0.01$	$g_t = 0.02$	$g_t = 0.03$
Benchmark	0.0048 (0.0001)	0.0154 (0.0008)	0.0168 (0.0008)	0.0132 (0.0006)	0.0101 (0.0004)
Tight Inflation Control	0.0053 (0.0001)	0.0078 (0.0003)	0.0095 (0.0004)	0.0080 (0.0004)	0.0068 (0.0004)
Managed ER	3.6622 (0.1337)	3.5900 (0.1348)	3.5262 (0.1286)	3.5896 (0.1320)	3.7123 (0.1456)
Domestic Focus	0.0004 (0.00001)	0.0023 (0.0002)	0.0021 (0.0002)	0.0021 (0.0001)	0.0022 (0.0001)

Note: Numbers reported are the averaged variances of the *Domestic Producer Price* Inflation, multiplied by 100, over the 200 simulation runs. The numbers in parentheses are the standard errors of statistics. We omit results that do not satisfy the projection facility conditions, as discussed in Appendix B.

Table 5: Welfare Loss under Alternative Policy Rule

	Rational Expectations	Least Squares Learning	Constant Gain Learning		
			$g_t = 0.01$	$g_t = 0.02$	$g_t = 0.03$
Benchmark	0.1931 (0.0025)	0.5704 (0.0270)	0.6048 (0.0270)	0.4859 (0.0192)	0.3813 (0.0132)
Tight Inflation Control	0.2286 (0.0023)	0.3609 (0.0159)	0.4244 (0.0184)	0.3635 (0.0191)	0.3117 (0.0171)
Domestic Focus	0.0150 (0.0002)	0.0836 (0.0054)	0.0758 (0.0055)	0.0751 (0.0051)	0.0757 (0.0044)

Note: Numbers reported are the averaged expected welfare loss computed from Equation (13), multiplied by 100, over 200 simulations. The welfare loss is measured as percent deviation from optimal steady state consumption. The numbers in parentheses are the standard errors of statistics. We omit results that do not satisfy the projection facility conditions, as discussed in Appendix B.

Table 6: Welfare Loss under Alternative Policy Rule: One Shock at a Time

	Rational Expectations	Least Squares Learning	Constant Gain Learning		
			$g_t = 0.01$	$g_t = 0.02$	$g_t = 0.03$
1) $\overline{r}_t = 0.66\overline{r}_{t-1} + \varepsilon_{\overline{r},t}$ with the standard deviation of $\varepsilon_{\overline{r},t} = 0.0029$					
Benchmark	0.0154 (0.0001)	0.0421 (0.0020)	0.0494 (0.0021)	0.0430 (0.0011)	0.0453 (0.0025)
Tight Inflation Control	0.0103 (0.0001)	0.0317 (0.0015)	0.0271 (0.0013)	0.0279 (0.0013)	0.0252 (0.0013)
Domestic Focus	0.0111 (0.0001)	0.0434 (0.0018)	0.0366 (0.0014)	0.0400 (0.0017)	0.0459 (0.0020)
2) $u_t = 0.4u_{t-1} + \varepsilon_{u,t}$ with the standard deviation of $\varepsilon_{u,t} = 0.001$					
Benchmark	0.0086 (0.0001)	0.0147 (0.0006)	0.0197 (0.0005)	0.0159 (0.0005)	0.0146 (0.0006)
Tight Inflation Control	0.0054 (0.0001)	0.0107 (0.0003)	0.0111 (0.0003)	0.0096 (0.0003)	0.0089 (0.0003)
Domestic Focus	0.0037 (0.00003)	0.0153 (0.0007)	0.0110 (0.0003)	0.0125 (0.0007)	0.0144 (0.0006)
3) $v_t = 0.97v_{t-1} + \varepsilon_{v,t}$ with the standard deviation of $\varepsilon_{v,t} = 0.005$					
Benchmark	0.1748 (0.0027)	0.2866 (0.0112)	0.4031 (0.0158)	0.2877 (0.0082)	0.2394 (0.0056)
Tight Inflation Control	0.2158 (0.0018)	0.2923 (0.0175)	0.3192 (0.0151)	0.2540 (0.0079)	0.2657 (0.0134)
Domestic Focus	2.1593 e -22 (5.19 e-23)	0.0084 (0.0005)	0.0035 (0.0001)	0.0094 (0.0004)	0.0087 (0.0004)

Note: Numbers reported are the averaged expected welfare loss computed from Equation (13), multiplied by 100, over 200 simulations. The welfare loss is measured as percent deviation from optimal steady state consumption. The numbers in parentheses are the standard errors of statistics. We omit results that do not satisfy the projection facility conditions, as discussed in Appendix B.

Table 7: Welfare Loss under Alternative Policy Rule: $v_t = 0.97v_{t-1} + \varepsilon_{v,t}$ with the standard deviation of $\varepsilon_{v,t} = 0.001$.

	Rational Expectations	Least Squares Learning	Constant Gain Learning		
			$g_t = 0.01$	$g_t = 0.02$	$g_t = 0.03$
Benchmark	0.0216 (0.0002)	0.0426 (0.0014)	0.0420 (0.0013)	0.0369 (0.0010)	0.0319 (0.0007)
Tight Inflation Control	0.0198 (0.0002)	0.0301 (0.0012)	0.0334 (0.0015)	0.0296 (0.0016)	0.0258 (0.0012)
Domestic Focus	0.0149 (0.0001)	0.0498 (0.0024)	0.0456 (0.0021)	0.0439 (0.0021)	0.0412 (0.0020)

Note: Numbers reported are the averaged expected welfare loss computed from Equation (13), multiplied by 100, over 200 simulations. The welfare loss is measured as percent deviation from optimal steady state consumption. The numbers in parentheses are the standard errors of statistics. We omit results that do not satisfy the projection facility conditions, as discussed in Appendix B.