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Monetary Stabilization with Interest Rate Instruments in Japan: A Linear Quadratic Control Analysis

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This paper examines the relation between alternative objectives for interest rate rules in the conduct of monetary policy, and the volatility of asset prices, the exchange rate, and the M2 monetary aggregate, as well as output and inflation. We make use of a small econometric model with unexpected oil price and foreign output shocks, simulation analysis, and stochastic control methods based on linear quadratic loss functions with state-space constraints.

Our results show the stabilizing powers of a systematic feedback policy for the call rate. Whether the Bank of Japan follows a broad-based multivariate target, or specific targets, such as the exchange rate or asset prices, a feedback control policy succeeds in reducing the variability of all of the macroeconomic variables, relative to a base path in which the call rate simply followed a stochastic autoregressive process. Results based on 1,000 repeated of stochastic simulations indicate, however, that the greatest gains for all variables with call-rate feedback policy come from exchange rate targeting or broad-based targeting rather than broad money or inflation targeting.

I. Introduction

This paper examines the relation between rules for interest rates and the volatility of three asset prices, the land price index, the share price index, and the nominal exchange rate as well as the broad money aggregate, M2. Our analysis makes use of recent developments in stochastic control theory, by the application of discrete linear quadratic regulators and discrete linear quadratic estimators, to a linear macrodynamic framework with rational expectations subject to oil price and foreign output shocks, as well as exogenous or policy-induced changes in the call rate.

By monetary control we mean the design of central bank policy interest (call) rate policy as the optimization of a linear quadratic loss function, based on deviations of

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specified variables from target values, as well as on quadratic adjustment costs for the use of policy instruments. In this paper we concentrate on alternative targets for the central bank, with just one instrument, the call rate, although the framework can be easily extended for multiple instruments.

Discrete linear quadratic regulators and estimators allow the central bank to obtain feedback rules for the call rate, based on the state variables of the economy, which evolve through time as functions of their own past values and other state variables, and as functions of stochastic shocks. The optimal feedback rule depends both on the way the central bank forecasts the expected value of the state variables, through the discrete linear quadratic estimator, and on the targets the central bank specified in its objective function, through the discrete linear quadratic regulator.

The structure of the economy includes both state variables, which depend on their own past values and stochastic shocks, and forward-looking asset prices or "jump variables," which depend on their own expected future values. The evolution of the state variables comes from a supply-demand framework for real output and the broad money supply. These four equations determine output, the price level, nominal money M2, and the short-term interest rate, or *Gensaki* rate. We assume that the foreign interest rate is exogenous, and evolves as an uncontrollable process. The three forward-looking variables are the land price index, the share price index, and the nominal exchange rate.

The state and forward-looking variables of the model also respond to two stochastic shocks, unexpected changes in the price of oil and in foreign (U.S.) output. Our analysis is not concerned with the relative importance of nominal or real shocks. Rather, we concentrate on the gains or losses of monetary control, when the central bank uses a feedback rule for the call rate based on broad money or asset-price targets. For a baseline reference simulation, we assume that the call rate is set on a broad set of targets. The gain or loss is measured by a ratio equal to the standard deviation of each variable when a specific set of control targets are used, over the standard deviation of each variable in the baseline simulation, when a broad set of control targets are used for the interest rate rule.

The purpose of the analysis is both normative and positive. Given that there were periods in the past when the Bank of Japan was setting more specific targets, such as the broad money supply or the exchange rate, we examine the comparative advantage of adopting specific or broad-based targets for the call rate.

Our results show that call rate feedback-control policies aimed at reducing exchange rate volatility, or broad-based targeting, aimed at reducing the volatility of all of the variables, bring the greatest gains in terms of reduced variability of the state and forward-looking variables. Targeting other specific state variables or asset prices may bring perverse results.

Our analysis draws on recent work by Hansen and Sargent (1991), and on earlier work by Sargent and Wallace (1975).

Sargent and Wallace examined the relative merits of interest rate and money supply rules in a macro model with a Lucas supply equation and rational expectations. They found that the price level becomes indeterminate unless the interest rate is pegged to a nominal anchor, such as the price level, money supply, or exchange rate. While our model is not indeterminate with exogenous policy, our results indicate that interest policy performs best with the exchange-rate target.

Hansen and Sargent have analyzed a class of general equilibrium models with linear quadratic control methods. However, Hansen and Sargent confined their analysis to the behavior of real variables. Moreover, for the sake of analytical simplicity, they obtained the optimal paths as the outcome of a social planner's problem, rather than an explicit competitive equilibrium.

Our analysis abandons the general equilibrium framework of Hansen and Sargent, since we use neither the device of the social planner nor explicit household/firm optimization for spending and production. Rather, we directly model demand and supply relations for output and for real balances, with rational expectations in the assets markets, in the spirit of Taylor (1979). Since we consider forward-looking asset prices, we make use of the solution techniques of Blanchard and Khan (1980) for general linear difference models. With these adaptations, we make use of the same state-space algorithms for simulation and control used by Hansen and Sargent.

An important limitation of our analysis, pointed out by Hansen and Sargent, is that we are confined to linear quadratic objective functions with linear constraints. This precludes analysis of richer and more complex relationships and intertemporal trade-offs. However, the payoff of our approach is both ease and speed of computation. It also allows the derivation of restrictions on linear vector autoregressive relationships among the state and forward-looking variables, given the policy-makers' objectives. As Hansen and Sargent point out, this method combines good dynamic theory with good dynamic econometrics. While we do not generate the evolution of our variables from "deep" general equilibrium relations, as do Hansen and Sargent, our analysis attempts to bridge good dynamic theory and dynamic econometrics by relating policy objectives and reactions with time series properties of state and forward-looking variables.

Our work builds on earlier work on Japanese monetary policy by Bryant (1991), West (1991), Ueda (1991a), Okina (1991), and Yoshikawa(1991).

Bryant analyzed classes of reaction functions for monetary policy, such as proportional and derivative rules, but not in an optimal control framework. West's analysis, also making use of an aggregate demand-supply macro framework, found that the effects of monetary policy in Japan are similar to those of a constant growth rule. Like Bryant, West did not use stochastic control analysis, and he assumed that the Bank of Japan can perfectly control the value of M2.

Ueda argued that the ultimate target of Japanese monetary policy has shifted over time. Both Ueda and Okina examined the monetary transmission process, and the choice of the call rate or high powered money as the principal policy instrument. They point out that interest rate determination needs more explanation than simply supply and demand, so that signals transmitted by the Bank of Japan also play an important role. Ueda found that the call rate and bank lending cause other monetary indicators in the Granger sense. Changes in these variables will create changes in other interest rates and monetary aggregates, in turn moving real variables. Okina takes a similar position, but admits that financial liberalization and globalization is still underway, so that monetary policy is a "dialogue" between the central bank and the market, and that interest rates should have an element of being endogenous.

Yoshikawa examined the behavior of monetary policy with respect to the business cycle in Japan. He found that in about half of the period from 1958, the interest rate was either pegged or tightly smoothed, so that changes in money supply were endogenous, and simply reflected output, inflation, or portfolio shocks. He concluded that monetarism, both old and new, is "misleading in interpreting observed changes in the money supply" in Japan (Yoshikawa, 1991, p.20).

In our analysis, we treat the call rate as the instrument of monetary policy, with the broad money stock and the *Gensaki* rate as the endogenous variables. We thus follow the transmission mechanism consistent with Ueda's results. In this way, we also avoid issues of modeling the money multipliers associated with high-powered money changes.

The next section summarizes the linear quadratic control methodology, describes the macroeconomic model and reports our empirical estimates with iterative two-stage least squares. Section III describes the stochastic simulation method, the discrete linear quadratic regulator and the quadratic estimator we use in the simulations, for modeling the interest rate rule based on a broad set of targets. Section IV analyzes the impulse-response functions of the estimated model, with and without the feedback control policy, for the exogenous oil price and foreign output shocks. We also present variance-decomposition analysis, showing the percentage of the total variance of each of the endogenous variables, at differing horizons, due to the call rate policy changes, the oil-price, and foreign-demand shocks, with and without a feedback policy. Section V contains the simulation paths of the endogenous variables for the baseline run, with a stochastic call-rate policy, as well as for alternative feedback rules. We also present the average volatility gain ratios for repeated (1,000) simulations for alternative targets. The results indicate the comparative advantages of asset-price targeting for call rate instruments in monetary policy operations. The last section concludes.

II. General Framework, Model, and Estimation

A. The Linear Quadratic Control Framework

The linear quadratic control framework is based on the maximization of a linear quadratic objective function subject to a state-space system constraints:

$$\text{Max}\ \{y'Qy + u'Ru\} \tag{1}$$

subject to:

$$x_{t+1} = Ax_t + Bu_{t+1} + Ez_{t+1} \tag{2}$$

$$y_t = Cx_t + Du_t + Gz_t \tag{3}$$

where A, B, C, D, E and G are matrices of constant coefficients, x is the vector of state variables, u the vector of controls, z a vector of stochastic uncontrollable shocks, and y a vector of observables. If the state-variables are measured with perfect accuracy, then C becomes the identity matrix, and D and G are zero matrices.[1]

While the linear quadratic objective function is given by equation (1), the state-space system is represented by equations (2) and (3). Equation (2) is called the transition equation, and equation (3) the measurement equation.

This general linear quadratic control set-up has a host of applications in macroeconomics. The linear quadratic objective function may be written in terms of deviations of actual values from target values of the y vector, so that $y = Y - Y^*$. In this case, the optimization problem may be one of a social planner attempting to reduce deviations of actual consumption from target consumption paths, with the control variable u being investment, the state variable x being capital, and consumption simply a linear function of capital. In the quadratic objective function, Q represents the costs of deviations of actual from target paths, and R the "adjustment costs" of changing the stock of capital through investment.

The general framework of equations (1) through (3) may be extended to incorporate different types of capital, different types of consumption, habit persistence, and heterogeneous agents. As pointed out above, Hansen and Sargent (1991) analyze several classes of recent real models of economic activity with an adaptation of the linear quadratic control framework.

The solution of the linear quadratic control system (called the optimal linear regulator problem) gives the optimal feedback response of u in terms of x:

$$u_t = -Lx_t \tag{4}$$

where L is the quadratic gain. The solution may come from three different approaches: Lagrangean multipliers, recursions on Bellman's equation, or from computational methods for solving matrix Riccati equations through the doubling algorithm, which do

[1]A more general set-up allows for cross-products between controls and target variables y in the linear quadratic objective function (1).

not require direct iterations on the Bellman equation.[2,3]

By far the most efficient method for computing the feedback rule in equation (4) is the use of the doubling algorithm. Application of this tool has made the optimal linear regulator problem a computationally rapid and well-understood process. For this reason, a wide range of models can be represented in terms of equations (1) through (3), and optimal feedback rules in the form of equation (4) can be easily computed.

In the next two sub-sections, we specify an eight-equation macro model, in linear difference equation form, for Japan, and present the parameter estimates. In Section III, we represent the estimated macro model as a linear quadratic control or optimal linear regulator problem.

B. The Theoretical Macro Model

Our model consists of eight equations: aggregate demand and supply equations for real output and the money supply, a law of motion for the foreign interest rate, and equations for the three forward-looking asset prices, based on rational expectations. In addition, there are two forcing variables, representing shocks coming from unexpected changes in the price of oil and U.S. output.

The lower-case variables represent stationary logarithmic first differences of quarterly data. Upper-case letters represent the logarithmic levels for the same quarterly data.

Aggregate demand (y) depends on the lagged interest (*Gensaki*) rate (r), lagged real wealth ($w-p$), the lagged real exchange rate ($e-p$), as well as the foreign output shock (y^*):

$$y_t = \gamma_1 y_{t-1} + \gamma_2 r_{t-1} + \gamma_3 (w-p)_{t-1} + \gamma_4 (e-p)_{t-1} + \gamma_5 y^*_t \tag{5}$$

We assume that the interest rate has negative effects on aggregate demand, so that $\gamma_2 \leq 0$, while the real exchange rate and real wealth have positive effects, so that $\gamma_3 \geq 0$, $\gamma_4 \geq 0$. We assume that unexpected changes in foreign output have positive effects on demand, hence $\gamma_5 > 0$. Output may have a positive or negative correlation with this own lag.

Aggregate demand captures consumption, investment, and net export behavior. Consumption depends on wealth variables, investment on the interest rate, and net exports on the real exchange rate and foreign output.

In our aggregate demand relationship, we assume that the individual components of wealth have identical effects on demand. The wealth variable, expressed as rates of change, is the sum of the three wealth components: money (m), share price index (spi), and land price index (lpi):

[2] Hansen and Sargent (1991) have shown how the Lagrangean multipliers obtained in the solution of equation (4) may be interpreted as asset prices, and appropriate restrictions on the parameters of the state-space system may be used to test particular theories of efficient markets in asset-pricing models.

[3] See Hansen and Sargent (1991), chapter 9, for an extensive treatment of these solution methods.

$$(w-p) = (m+\text{spi}+\text{lpi}) - p \tag{6}$$

An aggregate supply function may be inverted to express the price as a positive function of current output (y), its own lag (p_{t-1}), and as the foreign oil price shock (p^*):

$$p_t = \Gamma_1 y_t + \Gamma_2 p_{t-1} + \Gamma_3 p_t^* \tag{7}$$

Equation (7), written in logarithmic first differences, is a straightforward transformation of the Lucas supply equation in logarithmic levels:

$$Y_t = f(P_t - P_t^e) + g(P_t^*) \tag{8}$$

where P^* is the logarithmic level of the oil price, P is the corresponding value for the domestic price, P^e the logarithmic expected domestic price level, and Y is the logarithmic level of current output.

With $P_t^e = \pi P_{t-1}$, we have,

$$Y_t = f(P_t - \pi P_{t-1}) + g(P_t^*) \tag{9}$$

With linearization, and logarithmic differencing, we have:

$$y_t = f_1 p_t - f_1 \pi p_{t-1} + g_1 p_t^* \tag{10}$$

or, in terms of equation (7):

$$p_t = (1/f_1)y_t + \pi p_{t-1} - (g_1/f_1)p_t^* \tag{11}$$

with $\Gamma_1 = (1/f_1)$, $\Gamma_2 = \pi$, $\Gamma_3 = -(g_1/f_1)$.

We assume that oil price changes will be passed on as price increases, so that $\Gamma_3 \geq 0$.

The nominal supply of broad money, m, depends on the lagged *Gensaki* rate r and on the call rate i:

$$m = \mu_1 r_{t-1} + \mu_2 i_t \tag{12}$$

We assume that a decrease in the *Gensaki* would allow commercial banks to expand their supply of loans which increases money supply, so that $\mu_1 \leq 0$. An increase in the call rate, of course, should unambiguously decrease supply of loans which decreases money supply, so that $\mu_2 < 0$.

The *Gensaki* and the call rates, r and i, are two money-market rates (among others) most closely related to the supply of broad money. We assume that the endogenous supply of loans and the supply of broad money reacts more quickly to call rate changes (given by the Bank of Japan) than to market-determined changes in the *Gensaki* rate. Thus the call rate is the current period rate, while the *Gensaki* rate is the lagged quarterly rate.[4]

[4]There is a high correlation between the levels of these two rates. In stationary first differences, which enter

The demand for real balances $(m-p)$ depends on the current *Gensaki* rate (r), current output (y), and lagged wealth $(w-p)_{t-1}$:

$$m-p = \lambda_1 r_t + \lambda_2 y_t + \lambda_3 (w-p)_{t-1} \tag{13}$$

As scale variables, output and wealth should have positive effects on the demand for money, while the interest rate normally has a negative effect. Hence $\lambda_2 \geq 0$, $\lambda_3 \geq 0$, while $\lambda_1 \leq 0$.

The foreign interest (three-month United States treasury bill) rate r^* evolves according to the following law of motion:

$$r_t^* = \rho_1 r_{t-1}^* + \rho_2 p_t^* + \rho_3 y_t^* \tag{14}$$

The foreign oil price and foreign demand shocks, p^* and y^*, directly affect the foreign interest rate r^*, since we assume that the foreign central bank reacts to these variables for purposes of stabilizing its own economy. Thus p^* affects the output supply and the foreign interest rate equations, while y^* affects output demand and foreign interest rate equations.

The land price index and the share price index, lpi and spi, depend on the same set of variables: real income (y) and their own expected opportunity cost, defined as the difference between the *Gensaki* rate r and the expected rate of change of the respective asset price, where ${}_t\text{lpi}_{t+1}$ and ${}_t\text{spi}_{t+1}$ represent the expected land and share price indices for time $t+1$ at time t:

$$\text{lpi}_t = \alpha_1 y_t + \alpha_2 [r_t - ({}_t\text{lpi}_{t+1} - \text{lpi}_t)] \tag{15}$$

$$\text{spi}_t = \beta_1 y_t + \beta_2 [r_t - ({}_t\text{spi}_{t+1} - \text{spi}_t)] \tag{16}$$

We expect that income effects are positive, with $\alpha_1 \geq 0$, $\beta_1 \geq 0$, while the opportunity cost effects are negative, so that $\alpha_2 \leq 0$, $\beta_2 \leq 0$.

The asset-pricing formulae in equations (15) and (16) are log- linear approximations to the efficient markets model studied by Shiller (1989). Here we use y_t as a proxy for the dividend yields for both land and shares.

For the nominal exchange rate e, we work with both partial and full covered nominal interest parity, with the *Gensaki* rate r serving as the proxy variable for the relevant domestic interest rate, and r^*, the U.S. treasury bill rate, serving as the proxy for the relevant foreign rate:

$$e_{t+1} = e_t + \theta_1 (r_t - r_t^*) \tag{17}$$

The parameter θ_1 indicates the degree of covered nominal parity or international interest

equation (12), the correlation is somewhat lower. However, this lower correlation may affect the effect the unbiasedness and efficiency of the estimates of equation (12). Another specification of money supply equation can be seen in Yoshino (1992) which is based on the money multiplier approach.

arbitrage. Initially we work with perfect arbitrage, with $\theta_1 = 1$, when the expected rate of depreciation is exactly equal to the interest differential, $r - r^*$. The actual rate of depreciation will be the expected rate plus the effects of unexpected shocks.

Finally the process for the call rate (for the baseline simulation) and for the stochastic shocks p^*, and y^* comes from vector autoregressive system, with four lags for quarterly data, with i, the call rate, the oil price level, p_{oil}, and U.S. output, y_{us}, as the dependent variables:

$$u = [i\, p_{oil}\, y_{us}]' = B(L)\, u + u^* \tag{18}$$

$$u^{*\prime} u^* = \Sigma^*$$

Note that the stochastic oil price and foreign demand shocks affect the macroeconomic adjustment process through three different channels. Foreign demand shocks are transmitted through the demand equation, oil price shocks through the supply equation, and both are also transmitted through the foreign interest rate equation. Both the foreign demand and oil price shocks the foreign (U.S. treasury bill) interest rate, at the same time the shocks affect domestic demand and supply. We thus assume that the foreign monetary authority cannot fully offset the demand and oil price shocks on its own interest rate.

Our model is similar to the West (1991) model, with one important exception: West imposes a constant growth rule on broad money while the interest rate rule in our model comes from explicit optimization through the linear quadratic regulators and estimators.

C. Estimation

The model was estimated with quarterly data from 1974:Q1 through 1989:Q4, obtained from the Bank of Japan and from the Economic Planning Agency statistical sources. The land price index is the price index for urban real estate. The biannual series was made into a quarterly index by a cubic spline function.

Table 1 contains the results of an iterative two-stage least squares estimation of the model. The instrumental variables are the lags of output, the price level, the *Gensaki* interest rate, and the wealth variable, as well as the exogenous shocks in the oil price, and foreign output. The inclusion of additional instrumental variables did not substantially affect the estimation results.

Fair and Taylor (1988) have proposed an iterative full information maximum likelihood method for estimation of models with rational expectations. In this method, cross-equation restrictions implied by rational expectations are imposed, and the expected variables (such as the expected exchange rate, expected land price, and expected share price) are initially specified. Once the model is estimated, it is solved for new values of the expected variables, and then re-estimated. This process is repeated until there is reasonable convergence of the estimated coefficient values.

Table 1
Two Stage Least Squares Estimates, 1974:Q1 - 1989:Q4
(t-statistics in parentheses)

Wealth:

$$w-p = (m + \text{lpi} + \text{spi}) - p$$

Output (y):

$$\underset{(0.172)}{y = -\ 0.026\ y_{-1}} - \underset{(2.50)}{0.027\ r_{-1}} + \underset{(4.53)}{0.360\ (w-p)_{-1}} + \underset{(1.81)}{0.046\ (e-p)_{-1}} + \underset{(3.40)}{0.634\ y^*}$$

$\sigma = 0.011$ DW $= 2.23$

Price level (p):

$$p = \underset{(3.34)}{1.088\ y} - \underset{(6.63)}{0.681\ p_{-1}} + \underset{(0.97)}{0.038\ p^*}$$

$\sigma = 0.028$ DW $= 1.30$

Nominal money supply (m):

$$m = \underset{(0.300)}{-0.012\ r_{-1}} - \underset{(0.045)}{0.002\ i}$$

$\sigma = 0.025$ DW $= 0.086$

Real money demand ($m-p$):

$$m-p = \underset{(0.049)}{-0.027\ r} + \underset{---}{1.00\ y} + \underset{---}{1.00\ (w-p)_{-1}}$$

$\sigma = 0.044$ DW $= 3.01$

Land price index (lpi):

$$\text{lpi} = \underset{(6.54)}{2.13\ y} - \underset{(0.499)}{0.0282\ [r - ({}_t\text{lpi}_{t+1} - \text{lpi})]}$$

$\sigma = 0.029$ DW $= 0.947$

Share price index (spi):

$$\text{spi} = \underset{(4.91)}{3.27\ y} - \underset{(0.789)}{0.044\ [r - ({}_t\text{spi}_{t+1} - \text{spi})]}$$

$\sigma = 0.060$ DW $= 1.59$

Nominal exchange rate (e):

$${}_te_{t+1} = \underset{--}{e} + \underset{--}{r} - \underset{--}{r^*}$$

Foreign interest rate (r^*):

$$r^* = \underset{(1.76)}{-0.532\ r^*_{-1}} + \underset{(1.94)}{0.388\ p^*} + \underset{(4.29)}{9.82\ y^*}$$

$\sigma = 0.159$ DW $= 1.65$

Instruments:

y_{-1}, p_{-1}, r_{-1}, $(w-p)_{-1}$, i, p^*, y^*

Notes: σ: regression std. error; DW: Durbin-Watson statistic

We use an iterative two-stage least squares approach, on the grounds that full information methods would magnify specification error. We impose restrictions on coefficients within equations. We do not use the Fair-Taylor iterative method for the expected future values of the asset prices. Rather, we set the expected values as forecasts coming from regression with the instrumental variables.[5]

The results show that real wealth and foreign output are significant and positive for aggregate demand, while the real exchange rate and the interest rate have the expected signs. For the price level, output is both significant and of the expected sign, while the lagged price level is significant but negative. Thus, there is evidence of negative serial correlation in the price level first-differences.[6]

In the monetary sector, both the *Gensaki* interest rate and the call rate (i) have the expected sign, but neither are significant.[7] For real money demand, the *Gensaki* rate has the expected sign. Both the income and wealth elasticities were restricted to be unity, to ensure balanced growth.

For the land and share price indices, real output is positive and significant. While the expected opportunity cost variable has the correct sign for both, it is marginally significant only for the share price.

We imposed unitary restrictions on the expected exchange rate and the domestic and foreign interest rates in the nominal exchange rate equation.

The last equation for the evolution of the foreign interest rate shows that only foreign output shocks are significant.

Our estimation results are consistent with those of West (1991), who estimated his model with monthly data, beginning in 1976. He found significant wealth effects on aggregate demand, and significant output effects on the price level.

Table A-1 in the Appendix contains six diagnostic tests for the regression estimates reported in Table 1. Most of the statistics are significant for the Lagrange Multiplier test for serial correlation. The Chow test for a structural break at the end of 1985 is significant for money demand and for the land and share price equations. The equation with the least diagnostic problems is the foreign interest rate equation.

The estimated variance-covariance matrix for the unexpected oil price and foreign output shocks, given by equation (15), is the following matrix:

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[5]Since the estimated model in Table 1 does not have constant terms, the R-squared statistics are not reported.

[6]The negative coefficient for the lagged price level may be the result of high collinearity with p^*, the oil-shock variable.

[7]As pointed out above, collinearity of the call rate i and lagged *Gensaki* rate r may affect the precision of their point estimates.

$$\Sigma^* = \begin{pmatrix} 0.0178 & 0.0066 & -0.0002 \\ 0.0066 & 0.0097 & -0.0001 \\ -0.0002 & -0.0001 & 0.0001 \end{pmatrix}$$

The estimated model of Table 1 is simulated in repeated experiments to evaluate the volatility of the state and forward-looking asset price variables, under alternative assumptions about targets for monetary control. In our experiments, the stochastic shocks will be in the form of oil price and real output disturbances, as well as for the value of the call rate in the baseline simulation without feedback control. Given the high likelihood of serial correlation reported in the regression diagnostics, we generate the disturbances according to an autoregressive process of the following form:

$$u_t^* = \Phi\, u_{t-1}^* + v_t^* \tag{19a}$$

$$\Phi = 0.98\, I_3 \tag{19b}$$

where $u^* = [i\, p^*\, y^*]'$, I_3 is the three-by-three identity matrix, and v^* is a three-by-one normally distributed random vector with mean zero, and variance-covariance matrix Σ^*.

III. Simulation and Control Methodology

Since the model presented in Section II has state variables which depend on past values, and forward-looking asset prices which depend on future values, special approaches are need for stable solutions. The discrete linear quadratic regulator and estimator, for determining the evolution of the call rate i, are based on the stable solutions of the linear difference model.

A. Design of Simulations

The model summarized above is expressed in the following state-space form:

$$x_{t+1} = (A_0)^{-1} A_1\, x_t + (A_0)^{-1} B_1\, v_{t+1}^* \tag{20a}$$

$$= A^*\, x_t + B^*\, v_{t+1}^* \tag{20b}$$

where x is the vector $[y\, p\, m\, r\, r^*\, \text{lpi spi}\, e]'$, $v^* = [i\, p^*\, y^*]$. A_0, A_1, and B_1 are the following coefficient matrices:

$$A_0=\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -\Gamma_1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ -\lambda_2 & -1 & 1 & -\lambda_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_1=\begin{bmatrix} \gamma_1 & -(\gamma_3+\gamma_4) & \gamma_3 & \gamma_2 & 0 & \gamma_3 & \gamma_3 & \gamma_4 \\ 0 & \Gamma_2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mu_1 & 0 & 0 & 0 & 0 \\ 0 & -\lambda_3 & \lambda_3 & 0 & 0 & \lambda_3 & \lambda_3 & 0 \\ 0 & 0 & 0 & 0 & \rho_1 & 0 & 0 & 0 \\ \alpha_1/\alpha_2 & 0 & 0 & 1 & 0 & (\alpha_2-1)/\alpha_2 & 0 & 0 \\ \beta_1/\beta_2 & 0 & 0 & 1 & 0 & 0 & (\beta_2-1)/\beta_2 & 0 \\ 0 & 0 & 0 & \theta_1 & -\theta_1 & 0 & 0 & 1 \end{bmatrix}$$

$$B_1=\begin{bmatrix} 0 & \gamma_5 & \gamma_6 \\ 0 & \Gamma_3 & \Gamma_4 \\ \mu_2 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & \rho_2 & \rho_3 \\ 0 & \alpha_3 & \alpha_4 \\ 0 & \beta_3 & \beta_4 \\ 0 & \theta_2 & \theta_3 \end{bmatrix}$$

Following Blanchard (1985), Blanchard and Khan (1980), and Cardia (1991), the state-space model is written in the following recursive form:

$$x_t^s = A_{11}\, x_{t-1}^s + A_{12}\, x_{t-1}^F + B_{11}\, v_{t-1}^* \tag{21a}$$

$$x_t^F=(C_{22})^{-1}\, C_{21}\, x_t^s-(C_{22})^{-1} \sum_{i=0}^{\infty} (J_2)^{-(1+i)}[C_{21}B_{11}+C_{22}B_{12}]\Phi^i\, v_t^* \tag{21b}$$

$$= \hat{A}_{21}\, x_t^s + \hat{B}_{12}\, v_t^* \tag{21c}$$

where x^S and x^F are the vectors for the pre-determined state and forward-looking jump variables, A_{11} is the five-by-five partition of A^*, expressing the effect of past state variables on current state variables, A_{12} the partition of A^* with the effects of jump variables on current state variables, while C and J are the matrices of the left eigenvectors and eigenvalues (serving as the diagonal elements of J) from the matrix A^*, after the imaginary roots are suppressed. These matrices are partitioned so that the roots outside the unit circle are in the lower three-by-three block of J, and the eigenvectors are in the last three columns of C. B_{11} and B_{12} are the partitions of B^*, showing the effects of the three shocks on the state and forward-looking variables.

Blanchard and Khan point out that a unique and non-explosive solution for the state-space system requires that the number of eigenvalues of A^* outside the unit circle must be equal to the number of forward-looking jump variables. This is so in our case. The matrices $\hat{A}_{21}$ and $\hat{B}_{12}$ represent the Blanchard-Khan solutions of the system for the unique stable paths.

The system (21a) and (21c) is solved so that both the state and forward-looking variables evolve according to the state-space system (20b):

$$\begin{bmatrix} I_5 & -A_{12} \\ 0_{53} & I_3 \end{bmatrix} \cdot \begin{bmatrix} x^S_{t+1} \\ x^F_{t+1} \end{bmatrix} = \begin{bmatrix} A_{11} & 0_{5,3} \\ \hat{A}_{21} & 0_{3,3} \end{bmatrix} \cdot \begin{bmatrix} x^S_t \\ x^F_t \end{bmatrix} + \begin{bmatrix} B_{11} \\ \hat{B}_{12} \end{bmatrix} \cdot V^*_{t+1} \tag{22a}$$

or simply,

$$A^{**} x_{t+1} = \hat{A}^{**} x_t + \hat{B}^{**} v^*_{t+1} \tag{22b}$$

so that,

$$x_{t+1} = (A^{**})^{-1} \hat{A}^{**} x_t + (A^{**})^{-1} \hat{B}^{**} v^*_{t+1} \tag{22c}$$

$$= \ A\, \widetilde{x}_t + B\, \widetilde{v}^*_{t+1} \tag{22d}$$

where I_3 is a three-by-three identity matrix, and $0_{5,3}$ and $0_{3,3}$ are zero matrices of order five-by-three and three-by-three.

System (22d) is the starting-point of our repeated simulation experiments, both for the baseline simulations without controls and for the simulations with alternative monetary targets.

B. Solution for Optimal Linear Regulators

The model is complete with the determination of the feedback rule for i, the call rate. The optimal control methods involve the use of discrete dynamic linear quadratic regulators and estimators. With these tools, we form a state-space system of the central bank, in which the target variables, coming from the economy, become the inputs which generate the controls, which in turn supplement the shocks affecting the economy.[8]

The dynamic linear quadratic regulator is a optimization mechanism for minimizing the linear quadratic loss function F:

$$F = x'\, Q\, x + u^{c\prime}\, R\, u^c \tag{23}$$

where x is the vector of state and forward-looking variables, expressed as logarithmic

[8]Our description of the control, estimator, and state-space formulation of the central bank behavior is based on Grace, Laub, Little, and Thompson (1990).

first-differences, u^c is the control variable, the call rate i, Q is the eight-by-eight symmetric positive semi-definite matrix for determining the losses from changes in the state and forward-looking variables, and R is a symmetric positive definite matrix for determining the losses or costs coming from the use of the policy instrument or control variables, u^c.

Since the state and forward-looking variables are expressed in logarithmic first-differences, we assume that the target for each variable is zero. Thus the goal of the policy-maker is to minimize variation in the endogenous variables.

Equation (23) is minimized subject to the state-space constraint given by (22d). The method will give a policy feedback rule specifying u^c as a function of the five state-variables in the model:

$$u_t^c = -K x_t^s \tag{24}$$

where K is the optimal feedback gain matrix. Note that u^c is a linear function of all of the state variables, even though the objective function may specify a subset of the state variables, or forward-looking variables, as the policy targets. The reason is that the central bank can form expectations about the evolution of these state variables, and from this, the behavior of the target variables. Forward-looking variables, by definition, are not predictable on the basis of past values. The state variables which are not the targets variables are information variables, since they help predict the evolution of the target variables. There are no intermediate targets.[9]

In a stochastic framework, we assume that the central bank has to forecast the values of the state variables at time t+1 on the basis of the observed state and forward-looking variables at time t, using the parameters of the state-space system (22), since the state variables at time (t+1) are not known with complete certainty at time t. Furthermore, the central bank knows that its own actions will affect the outcomes at time (t+1) with varying degrees of credibility or effectiveness. Thus, there is need to forecast optimally the evolution of the state-variables when the central bank decides to act as a controller. For these forecasts, the central bank uses both the state-space model of system (22), and its past forecast errors. The Kalman gain matrix L is given by the following error-correction mechanism:

$$\bar{x}_{t+1}^s = \bar{x}_t^s + L\,(x_t - \hat{x}_t) \tag{25}$$

where $\bar{x}_{t-1}^s$ is the optimal forecast of the state variables at time t, and $\hat{x}_t$ is the forecast of both state and forward-looking variables at time t from the state-space system (22). Thus, the controller uses current state and forward variables as well as their model forecast errors to revise and form optimal forecasts of the state- variables for guiding the policy

[9]See Friedman (1990) for a discussion of the issue of information variables vs. intermediate targets for the conduct of monetary policy.

feedback mechanism. In this sense, there is learning behavior on the part of the controller.

The use of the Kalman gain matrix L adds a note of informational realism into the policy-making problem. The calculation of the gain matrix L requires the specification of the state-space system of equation (22) as well as a measure of informational uncertainty about x^S from the model predictions of x. We measure this uncertainty by the estimated variance-covariance matrix of the residuals generated by system (22), $\bar{Q}$.

The calculation of K and L come from the solution of similar linear stochastic control problems. The feedback gain matrix K is the solution for minimization of the quadratic loss function (23), subject to the constraints of the state-space difference equation system in (22) and the evolution of the controls in (24). Similarly, L is the solution of minimization of a quadratic loss function equal to the square of equation (25), subject to the state-space (22).[10]

With the specification of the state-space system (22), the linear quadratic regulator K and the gain matrix L, we form the controller/estimator system, which gives the control variable u_t^c as the output of a state-space system for the central bank, in which the forcing variables are the forecasts of x^S, with x evolving by system (22), and the control variable determined by the optimal regulator:

$$\bar{x}_{t+1}^{s} = \bar{A}\,\bar{x}_t^S + \bar{B}\,\hat{x}_t \tag{26a}$$

$$u_t^c = K\bar{x}_t^S \tag{26b}$$

$$\bar{A} = \tilde{A}_{11} - \tilde{A}_{11}LA - (\tilde{B}_1^c - \tilde{A}L\tilde{B}^c)\,E\,(K - K\,L\,\tilde{A}) \tag{26c}$$

$$\bar{B} = \tilde{A}_{11}\,L - (\tilde{B}_1^c - \tilde{A}_{11}L\,\tilde{B}^c)\,EKL \tag{26d}$$

$$E = (I_1 - K\,L\,\tilde{B}^c)^{-1} \tag{26e}$$

where $\tilde{A}_{11}$ is the five-by-five partition of $\tilde{A}$, showing the effect of the five current state variables on the next period state variables, B^c is the eight-by-one partition of B, giving the effects of the call rate changes on the system in (22), and B_1^c is the partition of B^c, giving the effect of the call rate changes on the state variables.

The state-space system describing the economy in equation system (22) is joined to the state-space system describing the reaction function of the central bank, described by equation system (26), in a feedback system.

The control variable u^c is one instrument, changes in the call rate. Following Damiani and Panattoni (1992), we assume that the policy-maker uses the state-space model (22) and starts from a baseline simulation, with the instrument assuming initial values, computed by the stochastic autoregressive process governing the evolution of the

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[10]As pointed out above, Hansen and Sargent (1991), chapter 9, discuss the efficient methods for computing solutions to the linear quadratic regulator and estimator problems.

call rate along with unexpected oil and foreign output shocks. Then, based on an set of objectives, given by Q in (23), with the costs of varying the instrument given by R in (23), and the informational uncertainty of the state-variables given by $\bar{Q}$ in (25), the policy-maker sets the values for the call rate instrument. In Table 2 we summarize the procedure for policy-formulation with discrete quadratic control and estimation.

Depending on the policy preferences in Q, we derive different series for the call rate, the only policy instrument in our model. From this we compute the time path of the state and forward-looking variables under the different policy-targets in Q, relative to the baseline simulation. In our simulation analysis in Section V, we compare the alternative outcomes by computing both the time paths of state and forward-looking variables and volatility ratios for alternative policy targets, when the state-space system of the economy, given in (22d) is joined to the central bank feedback system (26a) and (26b). The volatility ratios are measured as the standard deviation of each variable under the policy target, divided by the standard deviation of the respective variable under a baseline simulation, given by the state-space system (22d), with a purely autoregressive call rate policy. We thus follow the tradition begun by Poole (1970), who ranked alternative instruments of monetary policy by the volatility measures of endogenous variables.

The simulations based on optimal control, of course, are open to the Lucas critique (1976). Following McCallum (1990), we believe that because of the surprises in the supply sector, given by equation (6), it is that sector that would be most susceptible to the Lucas criticism. However relations among variables of one type, either nominal or real, would be "less likely to experience major shifts in response to policy changes" (McCallum, 1990, p.22). For this reason, we focus our discussion on the relationships between feedback control of the call rate and the time paths of asset prices and nominal aggregates, we well as inflation.

Table 2
Stages of Policy Formulation

1:	Specify objective matrix Q
2:	Specify adjustment cost matrix R
3:	Specify model
4:	Obtain feedback gain K
5:	Calculate model uncertainty: $\bar{Q}$
6:	Obtain Kalman gain L
7:	Obtain state-space system for policy reaction: $\bar{A}$, $\bar{B}$, K, L for setting controls from model predictions

IV. Impulse-Response Functions and Variance Decomposition

Before turning to stochastic simulation with and without feedback control, we examine the deterministic state-space system (22d), with an autoregressive call rate process, and the optimal deterministic state-space feedback system, in which (22d) is joined to (26a) and (26b), with impulse-response functions and variance-decomposition analysis.

With impulse-response functions, the state-space system is inverted via the Wold transformation into a moving-average process. The time path of the impulse-response function gives the percentage change in each endogenous variable for a temporary unit shock at time $t=0$, in one of the three exogenous factors: the call rate, the oil price, and foreign demand, with all variables and other shocks set at zero at time $t=0$. With impulse response functions, we can thus examine the relative size and persistence effects of the policy changes as well as the demand and supply shocks on the endogenous variables.

Variance decomposition analysis allows an examination of the percentage of total forecast-error variance of each variable explained by each of the three exogenous factors, at different horizons. One can thus determine the relative importance of the foreign demand, oil price, and call rate shifts in both the short- and long-term, for assessing the variability of each variable.[11]

Figures 1 through 3 show the reactions of the five state and three forward-looking variables for temporary unit changes in the call rate, the foreign oil price, and foreign output. The solid lines are the impulse-response function when there is no feedback rule for the call rate policy; the broken curves are the functions derive for a feedback rule based on minimizing the sum of squared exchange rate deviations.[12]

Figure 1 shows that the use of the feedback policy does lower the variability of each variable relative to the base paths with no feedback rule.

The initial response of output is an increase, followed by a quick fall. This response is understandable if one remembers that the shock is a one-period *temporary* increase in the call rate. Related literature on the non-neutrality of money with unexpected and expected money, and transitory or permanent policy shifts produce similar results.[13] With forward-looking expectations in the assets markets, the interest rate increase brings expectations of a fall, so there is temporary expansionary effect. The price level initially

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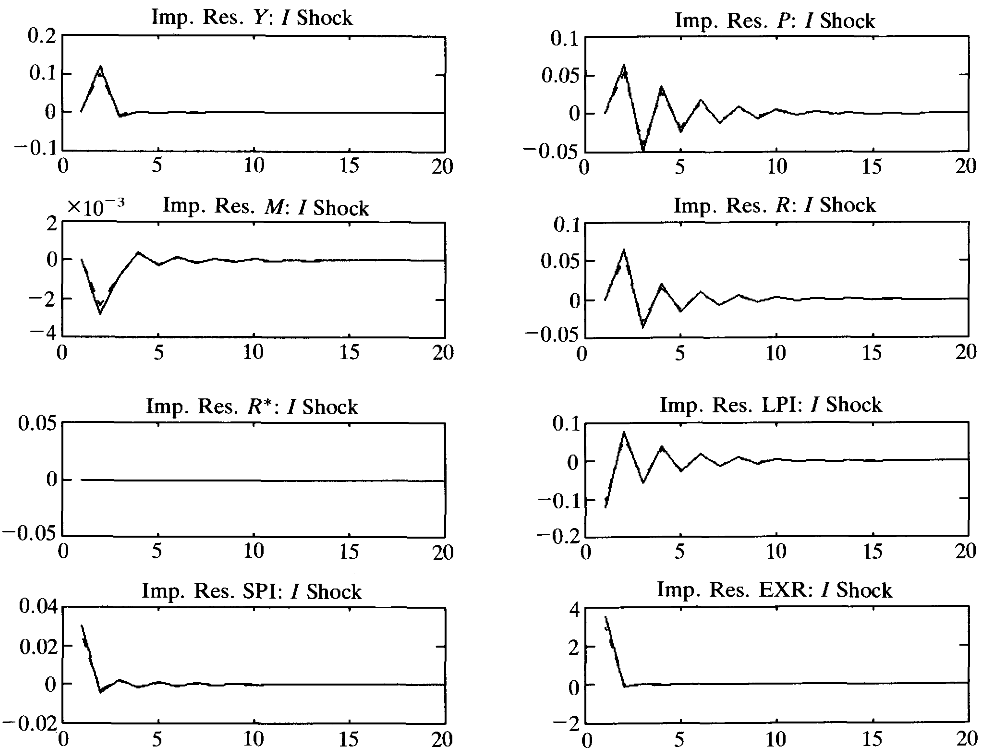
[11]See Judge, Hill, Griffiths, Lutkepohl, and Lee (1988), pp. 771-6, for further information on the impulse-response and variance-decomposition methods.

[12]As shown below, this policy target dominates most other targets. Thus, matrix for the objective function was set at unity for the exchange rate and zero for other variables; the adjustment cost matrix for call rate changes was set at 0.02; further changes in this parameter had little effect on the results.

[13]See Fischer (1979) for an analytical treatment of these different types of monetary policy on output and the price level.

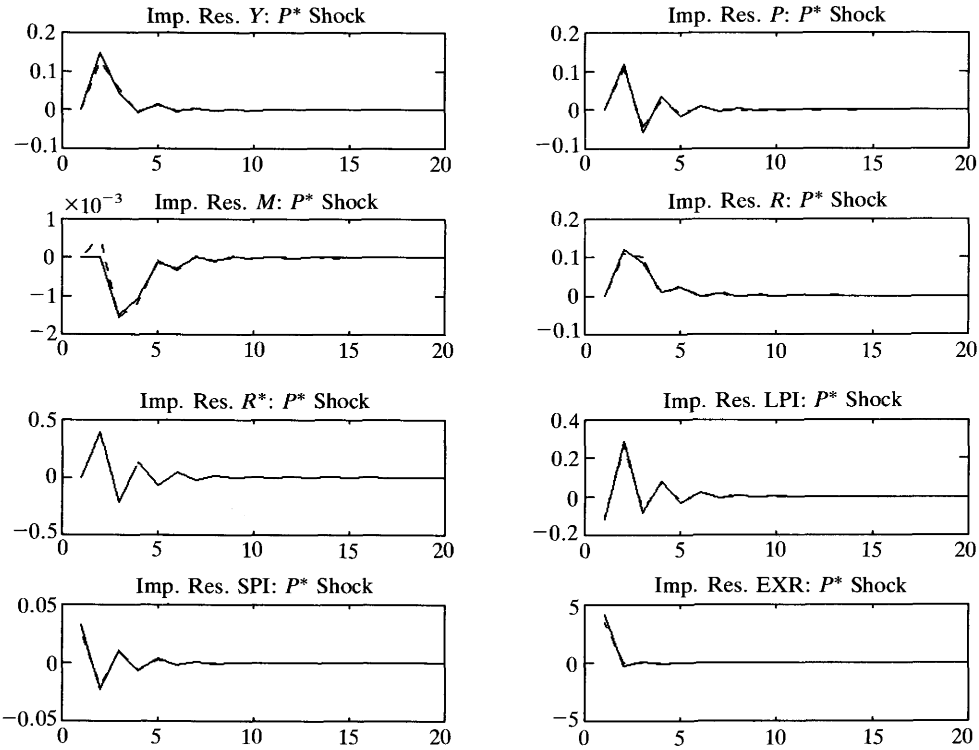
Figure 1
Impulse Response for I



rises, due to the expected fall in the call rate, and then falls below its initial and final equilibrium level. The rise in the call rate, as expected, causes a temporary fall in the broad money stock, and a rise in the *Gensaki* rate. The impulse response function of the foreign interest rate remains unchanged, since the call rate has no effect on this variable. Finally, the three asset price show different behavior. Both the share price and the exchange rate initially jump and then decline, while the land price index initially has a slight fall before rising above its initial level. The land price oscillates much longer and more strongly than the other asset prices. Finally, the effect of the temporary call rate change is stronger on the exchange rate than on the share and land price indices, since interest rates are directly related to this asset price through the covered interest parity mechanism.

The same broad pattern in Figure 1 is evident in Figure 2. As before, the impulse-response paths are slightly modulated when there is a feedback rule. The effect of the feedback rule is most apparent in the impulse-response path of M, broad money. Without

Figure 2
Impulse Response for P^*

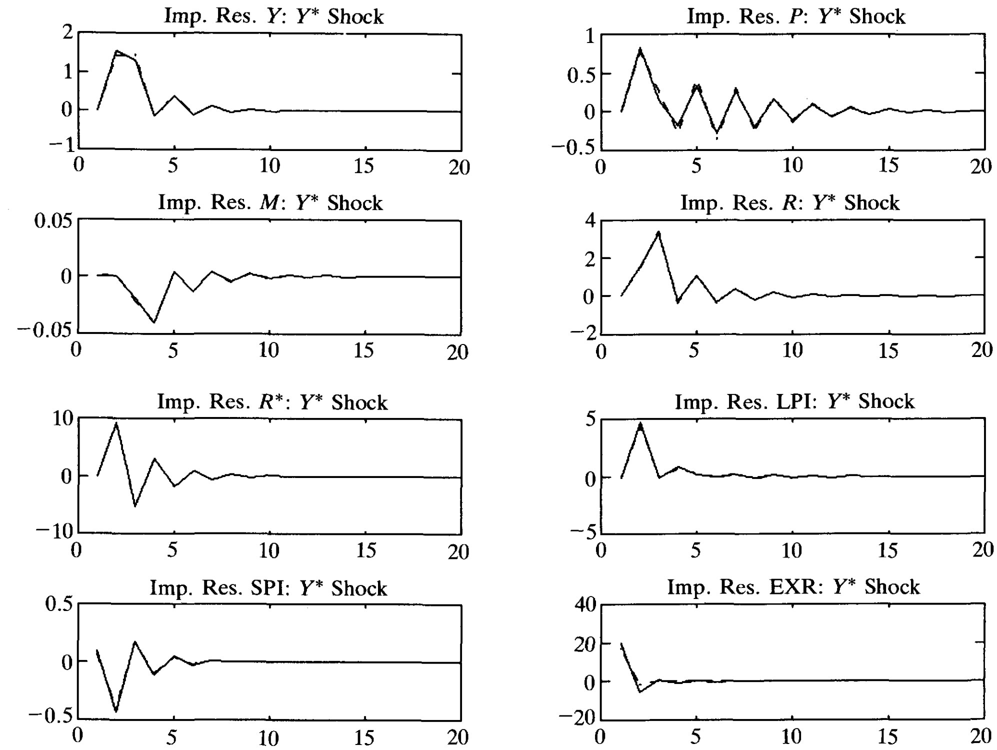


a feedback rule, the money stock is constant and then falls after a temporary oil price increase; with the feedback rule, money slightly rises, before falling. Figure 2 also shows that the foreign interest rate also reacts to the oil price change, in a cyclical manner. Both the land and share prices oscillate, while the exchange rate instantaneously rises before falling to its long-run value.

Figure 3 pictures impulse responses following the foreign demand shock with considerably higher values than the impulse responses for the call rate and oil price changes. Both output and the price level rise, but oscillations persist longer in the price level. The money stock falls, after a delay, while the *Gensaki* rate rises. In the assets markets, the land price index rises whereas the stock price index initially falls. The rise of the exchange rate is instantaneous, but it returns to its long-run level quickly.

The much larger effect of the foreign output shocks on the impulse response values may be due in large part to the aggregation bias of the estimates of our model. The demand equation which responds to foreign output is a composite demand equation

Figure 3
Impulse Response for Y^*



representing domestic consumption, investment, and exports. Unspecified domestic taste shocks for consumption, government spending, as well as "animal spirits" for investors, may well be correlated with the foreign demand disturbances which affect exports.[14] Thus, the "foreign demand" shock should be broadly interpreted, as representing both foreign demand and other exogenous factors affecting consumption and investment.

Tables 3(a) and 3(b) give the percentage of total variance of each variable at different horizons, due to the three different shocks, without and with feedback for the call rate. Both tables show the overwhelming importance of the demand shock for explaining the variance of each variable both in the short and long run.

[14]Shiller (1989) has pointed out that a myriad of shocks, some quantifiable and some not, may be driving the macro adjustment process, and thus it may be impossible to distinguish the sources of macroeconomic volatility.

Table 3(a)

Horizon	Percentage of Variation in Y Due to:					
	i	p^*	y^*	i	p^*	y^*
	No Feedback			Feedback		
1	0.5852	0.9255	98.4894	0.4800	0.7765	98.7436
5	0.3415	0.5810	99.0775	0.2354	0.4513	99.3133
10	0.3268	0.5609	99.1123	0.2229	0.4354	99.3417
15	0.3254	0.5588	99.1158	0.2218	0.4339	99.3442
20	0.3254	0.5588	99.1158	0.2218	0.4339	99.3442
30	0.3254	0.5588	99.1158	0.2218	0.4339	99.3442
40	0.3254	0.5588	99.1158	0.2218	0.4339	99.3442
Horizon	Percentage of Variation in p Due to:					
	i	p^*	y^*	i	p^*	y^*
	No Feedback			Feedback		
1	0.5789	1.9798	97.4412	0.4748	1.8510	97.6742
5	0.8887	2.3515	96.7598	0.6460	1.9159	97.4381
10	0.8946	1.9690	97.1364	0.5278	1.2866	98.1856
15	0.7914	1.6862	97.5224	0.4485	1.0641	98.4875
20	0.7912	1.6857	97.5231	0.4483	1.0638	98.4878
30	0.7912	1.6857	97.5232	0.4483	1.0638	98.4878
40	0.7912	1.6857	97.5232	0.4483	1.0638	98.4878
Horizon	Percentage of Variation in M Due to:					
	i	p^*	y^*	i	p^*	y^*
	No Feedback			Feedback		
1	100.0000	0.0000	0.0000	45.8804	2.2519	51.8678
5	2.2942	0.5879	97.1179	1.2849	0.5615	98.1536
10	0.4110	0.1589	99.4301	0.2733	0.1785	99.5482
15	0.4030	0.1555	99.4415	0.2670	0.1748	99.5582
20	0.4030	0.1555	99.4415	0.2670	0.1748	99.5582
30	0.4030	0.1555	99.4415	0.2670	0.1748	99.5582
40	0.4030	0.1555	99.4415	0.2670	0.1748	99.5582
Horizon	Percentage of Variation in R Due to:					
	i	p^*	y^*	i	p^*	y^*
	No Feedback			Feedback		
1	0.1723	0.6007	99.2270	0.1320	0.5257	99.3423
5	0.0421	0.1693	99.7887	0.0276	0.1586	99.8138
10	0.0436	0.1584	99.7980	0.0277	0.1486	99.8238
15	0.0437	0.1561	99.8002	0.0276	0.1467	99.8258
20	0.0437	0.1561	99.8002	0.0276	0.1467	99.8258
30	0.0437	0.1561	99.8002	0.0276	0.1467	99.8258
40	0.0437	0.1561	99.8002	0.0276	0.1467	99.8258

Table 3(b)

Horizon	Percentage of Variation in LPI Due to:					
	i	p^*	y^*	i	p^*	y^*
	No Feedback			Feedback		
1	0.0268	0.3703	99.6029	0.0180	0.3405	99.6415
5	0.0418	0.4007	99.5574	0.0280	0.3604	99.6116
10	0.0520	0.4235	99.5245	0.0344	0.3747	99.5908
15	0.0534	0.4220	99.5246	0.0351	0.3717	99.5932
20	0.0534	0.4220	99.5246	0.0351	0.3717	99.5932
30	0.0534	0.4220	99.5246	0.0351	0.3717	99.5932
40	0.0534	0.4220	99.5246	0.0351	0.3717	99.5932
Horizon	Percentage of Variation in SPI Due to:					
	i	p^*	y^*	i	p^*	y^*
	No Feedback			Feedback		
1	0.0104	0.2787	99.7109	0.0043	0.2478	99.7479
5	0.0114	0.2888	99.6998	0.0050	0.2568	99.7382
10	0.0125	0.2954	99.6920	0.0058	0.2625	99.7317
15	0.0128	0.2960	99.6912	0.0059	0.2629	99.7312
20	0.0128	0.2960	99.6912	0.0059	0.2629	99.7312
30	0.0128	0.2960	99.6912	0.0059	0.2629	99.7312
40	0.0128	0.2960	99.6912	0.0059	0.2629	99.7312
Horizon	Percentage of Variation in EXR Due to:					
	i	p^*	y^*	i	p^*	y^*
	No Feedback			Feedback		
1	0.0395	0.3477	99.6128	0.0694	0.0374	99.8932
5	0.0413	0.3576	99.6011	0.0687	0.0379	99.8934
10	0.0413	0.3605	99.5982	0.0687	0.0379	99.8934
15	0.0416	0.3608	99.5976	0.0687	0.0379	99.8934
20	0.0416	0.3608	99.5976	0.0687	0.0379	99.8934
30	0.0416	0.3608	99.5976	0.0687	0.0379	99.8934
40	0.0416	0.3608	99.5976	0.0687	0.0379	99.8934

Both Tables 3(a) and 3(b) show that the adoption of the feedback rule reduces the role, however slight, of both call rate and oil price shocks in explaining the total variation of all variables at both short and long horizons. Table 3(a) also shows the operation of call rate in a target/instrument framework in a direct way. In the short run, without feedback, 100% of money-supply variance is explained by call rate variation. With an optimal feedback rule, only 45% of the variation is due to the call rate variation; more than 50% is due to foreign demand variation, and 2% is due to oil price variation. Thus the money supply, through a call rate feedback rule, varies in the short run, in response to oil price and foreign demand shocks. At longer horizons, however, foreign demand explains more than 98% of the variance of money, with and without feedback. The call rate thus operates as an instrument through its short-run effectiveness on the money supply.

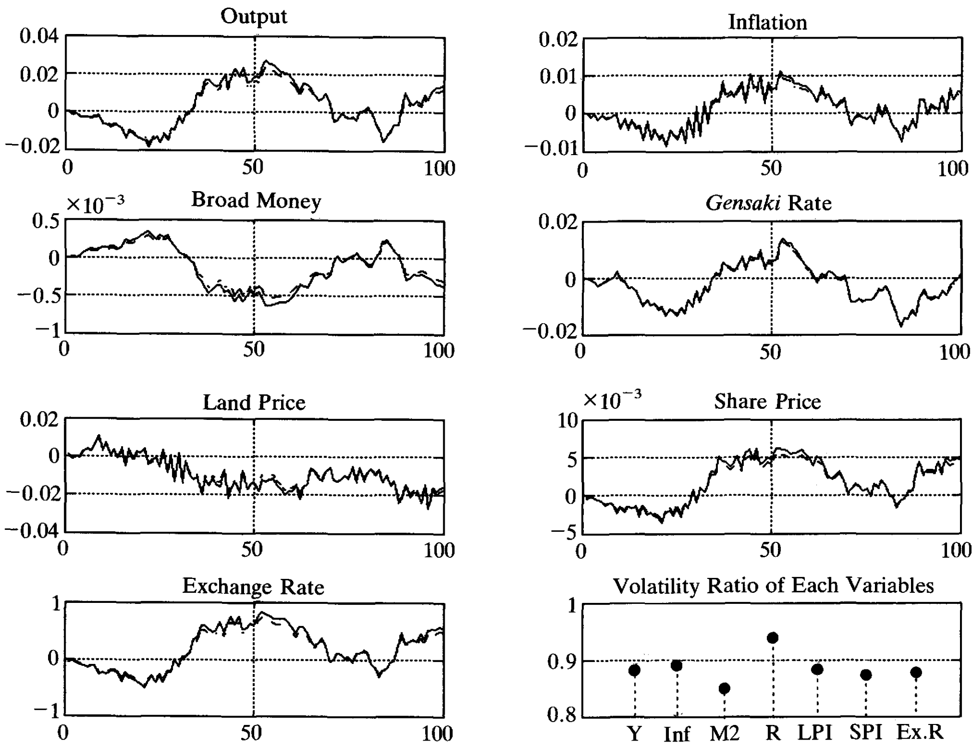
V. Simulation Analysis of Stochastic Policy Response

The dynamic adjustment paths for four state variables (output Y, inflation P, money M, and the *Gensaki* rate R) and for the three forward-looking variables (the land price index LPI, the share price index SPI, and the exchange rate EXR) for one simulation run, appear in Figure 4. The solid lines represent the base simulation, with a stochastic autoregressive call rate policy. The broken curves represent the adjustment paths with an optimal feedback rule. In this case, we show the adjustment for a call rate rule based on exchange rate targeting. Finally, the lower right picture in Figure 4, entitled "Volatility Ratio", gives the ratio of the standard deviation for each variable with the feedback rule, relative to the standard deviation of each variable without the feedback rule. This ratio is an indicator of the gain that comes from a feedback rule, in terms of reduced volatility of each of the variables.

Figure 4 shows that output, inflation, and the *Gensaki* rate follow a closely linked pattern of adjustment with each other in response to the stochastic shocks, while broad money follows a closely-linked but negatively linked pattern with these three variables. In terms of adjustment, the three asset prices do not show a common pattern. The exchange rate, expressed in a logarithmic first difference, shows the greatest variation, followed by the land price and then the share price. The share price shows a boom in the first half of the sample run, and a decline in the second half, whereas the land price shows an initial high value followed by a gradual decline. The exchange rate shows a major appreciation after the mid-point of the sample. Finally, the volatility ratio shows that the greatest gains, in terms of reduced variance, are for the three asset prices, as well as for output and inflation, and the least gain is for the *Gensaki* rate, when the call rate follows the feedback rule aimed at exchange rate stability.

The results of Figure 4, of course, are based on only one sample run, of 100 iteration, with the exchange rate as the target for the feedback rule. Further simulations for the

Figure 4
Adjustment Paths and Volatility Ratio of Each Variables



same target may produce different results, and the use of alternative targets, or multiple targets for the call rate, may not produce clear-cut gains. To asset the robustness of our results, we repeated the simulations of Figure 4, 1,000 times, for alternative targets, and a mixed set of targets, for the call rate. We then computed the average volatility ratios or gains for each target or set of targets, after the 1,000 simulations. The results appear in Table 4.

The average volatility ratios in Table 4 are quite favorable for the use of the share price or exchange rate as targets for the call rate. The results are also favorable for a multivariate targeting. When all of the variables serve as the targets, or either the exchange rate or the share price index, the volatility ratios are lower for all variables except for the land price index. For this variable, the volatility loss is only 2%.

Table 4 also shows that perverse effects may occur. Targeting the money supply or the *Gensaki* rate individually will only lead to increased volatility in all of the variables.

Table 4
Effects of Alternative Policy Targets on Volatility Behavior
1,000 Repetitions of 100 Iteratioins

	Average Volatility Ratios for Variables						
	y	*p*	*m*	*r*	lpi	spi	exr
TARGET							
All	0.9321	0.9418	0.8798	0.9807	1.0205	0.8341	0.8962
Y	1.4074	1.3283	1.8289	1.1214	0.9222	0.9277	1.6037
P	1.3270	1.2329	1.6744	1.0986	0.8339	1.7141	1.4804
M	1.0003	1.0003	1.0005	1.0001	1.0000	1.0007	1.0004
R	1.8914	1.6911	2.8595	1.2696	1.0011	3.0093	2.3129
LPI	0.3414	0.4525	1.1683	0.7911	1.5600	0.9467	0.2975
SPI	0.9632	0.9693	0.9309	0.9893	1.0136	0.9134	0.9445
EXR	0.9304	0.9406	0.8767	0.9803	1.0225	0.8291	0.8932

Similarly, targeting the land price, output, or inflation alone may reduce the volatility of other variables, but may end up increasing the volatility of the target variable itself. A narrow focus to interest rate targeting may thus be detrimental in the conduct of monetary policy. Our results thus support Ueda (1991b) and Yoshikawa (1991), who have argued against any simple rule or monetarist framework for Japanese monetary policy. A broad-based focus appear not only to be more practical, but also more efficient.

VI. Conclusion

The analysis of this paper supports the use of the call rate as an instrument based on a broad set of targets, rather than a narrow or specific set, for the operation of monetary policy. We have made use discrete linear stochastic control methods, as well as impulse response functions, and variance decomposition analysis.

An important missing ingredient in our model and policy framework is fiscal policy. Both government spending and taxes were ignored either as possible instruments or sources of shocks in the aggregate demand or supply sectors. Since our focus is the conduct of monetary policy, this omission may be tolerated. A richer analysis, which may show the advantages of stochastic control methods for policy evaluation, would imbed fiscal policy variables, and could lead to an optimal division of targets for fiscal and monetary instruments.

Appendix

Table A-1
Regression Diagnostics for Estimated Model of Table 1

	TEST					
Equation	LM[1]	J-B[2]	ARCH (4)[3]	White[4]	RESET (2)[5]	Chow[6]
Output (y)	5.70*	0.077	1.290	2.77*	3.23*	1.11
Price (p)	9.67*	23.87*	15.26*	1.96	9.00*	1.27
M2 (m)	197*	0.403	7.97*	1.47	6.63*	0.188
Mon.D. (m-p)	64.1*	4.13	5.63*	1.94	0.884	3.02
LPI (lpi)	21.6*	6.59*	11.2*	2.20*	3.06*	6.20*
SPI (spi)	6.78*	5.46	3.30*	0.543	1.37	7.59*
Ex.R. (e)	0.417	0.673	1.03	0.75	7.97	0.330
US Rate (r^*)	2.11	3.55	1.91	5.93*	3.56*	1.36

* Test is significant at the 5% level.
[1] Lagrange Multiplier test for serial correlation.
[2] Jarque-Bera test for normality of regression residuals
[3] ARCH (autoregressive conditional heteroskedasticity) test for regression residuals with 4 lags
[4] White test for heteroskedasticity
[5] Ramsey RESET (regression specification test) with first and second powers of predicted terms
[6] Chow test for structural change with 1984. 4 as break period

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