OPTIMAL CONTRACTS FOR CENTRAL BANKERS AND INFLATION AND EXCHANGE RATE TARGETING REGIMES

by

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Abstract

This paper analyses the implications of adding a foreign exchange rate term to the loss function in the standard model for the issues of discretion and commitment in monetary policy. It is found that neither a linear state-contingent inflation contract for the central bank nor an explicit state-contingent inflation target (that implies a state-contingent foreign exchange rate target) combined with a weight-conservative central bank can now achieve the equilibrium matching that of an optimal rule under commitment. A linear state-contingent contract in a variable that is a weighted average of inflation in excess of target and of the rate of depreciation in the foreign exchange rate in excess of target is now required to mimic the optimal rule under commitment.

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I. Introduction

From its initiation by Kydland and Prescott (1977), and through subsequent development by Barro and Gordon (1983a; 1983b), Backus and Driffill (1985a; 1985b), Canzoneri (1985), Rogoff (1985), and others, the literature on dynamic inconsistency and monetary policy demonstrates that commitment to a policy rule might be systematically better than discretion.[1] The inflationary bias shown to arise under the discretionary equilibrium has led to arguments for greater central bank independence as a means to move closer to the commitment solution. In one of the most influential papers on the subject, Rogoff (1985) shows that delegation of operational independence to a central banker with larger (finite) weight on inflation in the loss function than society, i.e. to a Rogoff weight-conservative central bank, would improve the discretionary equilibrium overall. However, the decision rule obtained would imply greater output variability and less inflation variability than would the optimal rule under commitment.

In recent analyses of the issues involved, Persson and Tabellini (1993) and Walsh (1995) take a principal-agent approach, in which costs are imposed on an instrument-independent central bank when inflation strays from target. Walsh (1995) demonstrates that a linear inflation contract results in replication of the commitment equilibrium. Should there be persistence in employment, Svensson (1997) establishes that a linear inflation contract continues to yield an equilibrium that mimics the solution under commitment, provided that it includes a state-contingent component.[2] Svensson (1997) also analyzes the role of

[1]Reviews of the literature on dynamic inconsistency and monetary policy can be found in Blanchard and Fischer (1989) and Fischer(1990).

[2]In the Svensson (1997) model, the presence of employment persistence results in a state-contingent inflation bias (as well as average and stabilization bias), hence the optimal contract has a state contingent component.

inflation-targeting in improving the discretionary equilibrium and shows that appointment of a weight-conservative central banker with an explicit state-contingent inflation target is also capable of achieving the commitment equilibrium.

The work in this paper is motivated by the observation that many developing countries try to peg the foreign exchange rate value of their currencies.[3] Chandavarker (1996) and Fry et al. (1996) report that in developing countries central banks have a large responsibility for foreign exchange rate management. Thus, many countries operate an exchange rate targeting regime, under which an agent for society, the central bank, conducts monetary policy with a specified exchange rate goal. The objective in this paper is to examine the issues raised in the literature on discretion and commitment in monetary policy, when a foreign exchange rate stabilization objective is added to the loss function in the standard model. The paper will, in particular, focus on the form of an optimal contract for the central bank when society is assumed to have a loss function quadratic in the deviations of inflation, output, and the rate of change in the price of foreign currency from their respective targets.

An exchange rate-targeting regime is taken to mean that society assigns a loss function to an instrument-independent central bank, with a specific foreign exchange rate target, inflation and output targets, and designated relative weights on output, inflation, and exchange rate stabilization.[4] The central bank then has the responsibility for minimizing the stipulated loss function. A purchasing power parity condition is imposed to ensure that the inflation and foreign exchange rate targets are consistent with one another. It is assumed that the foreign exchange rate is influenced by the supply of output relative to foreign output. The optimal money growth rule under commitment is state-

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[3]Krugman and Obstfeld (1994) note that for developing countries the peg is usually in terms of the dollar. The peg may also be in terms of some other major currency, or in terms of a basket of currencies.

[4]In terms of the distinction drawn by Debelle and Fischer (1994), an instrument-independent central bank does not determine goals. The approach in this paper is meant to be consistent with the point emphasized by Fischer (1996) that the exchange rate regime will influence inflation performance.

contingent in that it depends on lagged output. The decision rule under discretion generates average and state-contingent inflation and foreign exchange rate (depreciation) biases, and stabilization bias in response to shocks to supply and to the terms of trade and foreign output. Response in money growth to supply shocks is larger under discretion than under commitment, and response in money growth to shocks to the terms of trade and to foreign output is smaller under discretion than under commitment. Both these consequences are consistent with output varying too little under discretion compared to commitment. Inflation may be more or less variable under discretion compared to commitment with the outcome depending on parameter values and magnitudes of the variances of the random variables in the model.

A principal finding in the paper is that a linear state-contingent inflation contract for the central bank will not achieve the equilibrium corresponding to the optimal rule under commitment when an exchange rate term appears in the loss function. It is shown that a state-contingent inflation contract that eliminates average and state-contingent bias is not capable of also eliminating stabilization bias due to the appearance of a foreign exchange rate term in the loss function. In order to ensure optimal behavior by the central bank, it is now necessary for the contact to not only assess penalties when inflation deviates from the target level, but also to assess penalties when foreign exchange rate depreciation deviates from the target level. The marginal costs imposed will be state-contingent in that they will depend on lagged output. The relative importance of deviations of consumer price inflation from target and exchange rate depreciation from target in the contract for the central banker will be determined by the relative weight assigned to meeting the inflation and exchange rate targets in society's loss function.[5]

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[5]This result is consistent with the observation by Walsh (1995) that the transfer function (objective function) for the central bank that achieves the optimal monetary growth rule under commitment in the standard model is not unique. He shows that a transfer function solely in terms of inflation will not replicate the optimal rule under commitment. However, whereas in the standard model term(s) in output deviation from target must also be included in the transfer function, in the model in this paper, terms in this variable and in the deviation of foreign exchange rate depreciation from target must

It is also found that the result noted by Svensson (1997), concerning the ability of an "inflation-target-conservative" central bank combined with a weight-conservative central bank to mimic the equilibrium given by the optimal rule under commitment, does not apply when there is an exchange rate objective in the loss function. While an "inflation-target-conservative" will continue to succeed in eliminating average and state-contingent inflation bias (as shown in Svensson (1997)), the addition of weight-conservativeness is no longer sufficient to eliminate stabilization bias. This latter result follows, since in general, the degree of weight-conservativeness required to eliminate stabilization bias from supply shocks differs from that required to eliminate stabilization bias from shocks to the terms of trade or to foreign output. Since the model assumes that an "inflation-target-conservative" central bank is equivalent to a "foreign exchange rate-target-conservative" central bank, an explicit state-contingent foreign exchange rate target combined with a weight-conservative central bank will also not achieve the equilibrium matching that of an optimal rule under commitment.

The model is developed in the next section. The issues of optimal policy under commitment and of sources of inflation bias under discretion are taken up in Section III. The roles of linear state-dependent contracts for the central banker in improving the equilibrium under discretion are considered in Section IV. The influence of optimal inflation and exchange rate targets on equilibrium under discretion is analyzed in Section V. Section VI concludes.

II. The Model

The model is meant to capture an economic role for the exchange rate in the standard Kydland-Prescott (1977) and Barro-Gordon (1983a; 1983b) treatments of dynamic inconsistency and monetary policy. A Phillips-curve structure is utilized, in which society is assumed to have a loss function quadratic in the

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also be included in the transfer function.

deviation of the rate of inflation from target, in the deviation of output from a target level, and in the deviation of the rate of change in the price of foreign currency from target. The government is assumed to have the same loss function as society. The social loss function is taken to be

$$(1)\quad V = E_0\Big[\sum_{t=1}^{\infty} \beta^{t-1} L(x_t, y_t, s_t; x^0, k, s^0, a, c)\Big],$$

where E is the expectations operator, $0 < \beta < 1$ is the discount factor, and L(...) is the period loss function. L(...) is defined as

$$(2)\quad L(x_t, y_t, s_t; x^0, k, s^0, a, c) = (a/2)(x_t - x^0)^2 + (1/2)(y_t - k)^2 + (c/2)(s_t - s^0)^2,$$

where x_t is the rate of consumer price inflation, y_t is the log of domestically produced output relative to the natural level, s_t is change in the log of the spot exchange rate (the price of foreign currency), and $a > 0$, $c > 0$, $k > 0$. The assumption $k > 0$, provides an incentive for the policy maker to try to create inflation surprises. The target rate, or goal, for inflation in consumer prices, is given by x^0. The target rate of change, or "peg", in the domestic price of foreign currency (or the target rate of devaluation) is given by s^0.

The third term on the right hand side of equation (2) represents loss associated with change in the nominal exchange rate out of line with the target rate of change. The setup captures operation of a crawling peg exchange rate regime. It is contended that if a government is committed to a crawling peg, then inclusion of the exchange rate among the goals in the objective function is warranted. A similar argument is advanced by Frankel and Chinn (1995) and Cukierman et. al. (1997) for the appearance of an exchange rate term in the period loss function.

The specification for determination of the foreign exchange rate follows that in Romer (1993). It is assumed that domestically produced goods and foreign produced goods are imperfect substitutes. Higher domestic production will be assumed to force down the relative price of domestically produced goods. Thus, the change in the real exchange rate depends upon the relative growth rates in the domestic and foreign economies. If s_t represents the change in the log of the domestic price of a unit of foreign currency, π_t is the change in the log of the price of domestically produced goods, and π_t^f is the change in the log of the foreign price of foreign produced goods, the change in the real exchange rate is given by:

$$(3) \qquad s_t - \pi_t + \pi_t^f = \alpha[g^{df} + (y_t - y_{t-1}) - (y^f_t - y^f_{t-1})] + \varepsilon_t,$$

where y_t is log of supply of domestically produced output relative to the natural level, y^f_t is log of the supply of foreign produced output relative to the natural level of foreign output, and g^{df} is the difference between the trend rates of growth in the domestic economy and in the foreign sector.[6] To simplify the presentation, g^{df} is taken to be zero. ε_t, an error term capturing shocks to the terms of trade, is assumed to be independently and identically distributed with zero mean and variance V_ε.

It will be assumed that the foreign inflation rate is a constant given by π^f, and that the growth rate of output in the foreign sector relative to the "natural" rate of growth in that sector, $(y^f_t - y^f_{t-1})$, can be represented by a random term η_t, that is independently and identically distributed with zero mean and variance V_η. The exchange rate in equation (3) now becomes

$$(4) \qquad s_t - \pi_t + \pi^f = \alpha(y_t - y_{t-1}) + e_t,$$

where $e_t \equiv \varepsilon_t - \alpha\eta_t$ is independently and identically distributed with zero mean and variance $V_e \equiv V_\varepsilon + \alpha^2 V_\eta$. e_t represents shocks to the terms of trade and to foreign output.

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[6] In Romer's (1993) model, utility from consumption is a CES combination of goods produced at home and of goods produced abroad, with a parameter $\alpha < 1$ denoting elasticity of consumption between goods.

If μ represents the share of imports in GDP, then the rate of consumer price inflation is given by

$$(5) \qquad x_t = (1 - \mu)\pi_t + \mu(\pi^f + s_t)$$

From equation (4) the expression for consumer price inflation can be re-written as:

$$(5') \qquad x_t = \pi_t + \alpha\mu(y_t - y_{t-1}) + \mu e_t.$$

Thus, consumer price inflation relative to producer price inflation is influenced by the share of imports in the economy, by cyclical growth, and also by shocks to the terms of trade and by shocks to foreign output. It will be assumed that the target for consumer price inflation, x^0, satisfies the purchasing power parity condition given by $x^0 = s^0 + \pi^f$. Thus, the inflation-targeting and exchange rate-targeting regimes implicit in the setup are consistent.

The log of supply of domestically produced output relative to the natural level is given by a Lucas supply function

$$(6) \qquad y_t = b(\pi_t - \pi_t^e) + u_t,$$

where $b > 0$, π_t^e is the public's expectation of π_t, and u_t is a supply shock assumed to be independently and identically distributed with zero mean and variance V_u.[7] It is assumed that expectations are formed (i.e., wage contracts are signed) before e_t and u_t can be observed, but that the central bank can set its policy instrument after observing e_t and u_t.[8]

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[7]Persistence in output could be introduced directly into the model by adding a term ρy_{t-1} to the right hand side of equation (5). The implications of persistence in employment for results in the dynamic inconsistency literature are reported by Svensson (1997).

[8]The more realistic assumptions that the central bank observes private signals (subject to measurement errors) about e_t and u_t would not change the main conclusions of the paper.

It is usual in the type of model outlined above to treat inflation as the central bank's policy variable. Walsh (1995), however, takes the rate of growth in a monetary aggregate, m_t, to be the central bank's policy instrument. He assumes the rate of inflation (in our model, inflation in the price of domestically produced goods would seem appropriate) is given by

$$(7) \qquad \pi_t = m_t + v_t,$$

where v_t is either a velocity shock or a control error. In order to isolate the cause of differences in results concerning the design of optimal contracts for central bankers in the model in this paper from those obtained by Walsh (1995), we will follow Walsh in assuming that m_t is the central bank's policy variable, and that v_t is an exogenous white-noise process whose realization occurs after m_t is set. For a given rate of money growth, equations (7), (6) and (4) imply that a positive value for v_t raises inflation, output and the real price of a unit of foreign currency. The optimal money growth rule under commitment and the money growth rule under discretion implied by the model are obtained in the next section. The organization of the discussion owes a great deal to the analysis presented in Svensson (1997).

III. Policy under Commitment and under Discretion

III.1 Commitment

The optimal policy under commitment is obtained by minimizing expected social loss in equation (1) with respect to m_t and m^e_t (expected money growth) given that the government internalized the effects of its decision rule on expectations. The government chooses m_t and m^e_t given that expectations are rational. Given the above set up, we anticipate that m_t will depend on e_t, u_t, and y_{t-1}. The optimal rule under commitment is derived from the Bellman equation,

$$(8) \quad Z^*(y_{t-1}) = \min \; E_{t-1}\left\{(a/2)(x_t-x^0)^2 + (1/2)(y_t-k)^2 + (c/2)(s_t-s^0)^2 + \beta Z^*(y_t)\right\},$$

m_t, m^e_t

subject to the constraint that $m^e_t = E_{t-1}m_t$. Upon eliminating the Lagrangian associated with this constraint, and using the expressions relating s_t, x_t, y_t, and π_t, to m_t in equations (4), (5'), (6) and (7), the first order condition with respect to m_t and m^e_t results in the following:

$$(9) \qquad E_{e,u}\Big\{(1+\alpha\mu b)a(x_t-x^0) + b(y_t-k) + c(1+\alpha b)(s_t-s^0) + b\beta Z^{*\prime}(y_t) - E_{t-1}[\alpha\mu ba(x_t-x^0) + b(y_t-k) + \alpha bc(s_t-s^0) + b\beta Z^{*\prime}(y_t)]\Big\} = 0.$$

In equation (9), $E_{e,u}$ refers to expectation (over v) conditional on e and u, and E_{t-1} refers to unconditional expectation. The first three terms in equation (9) represent the marginal current costs from increasing consumer price inflation, output (usually negative since $k > 0$), and the rate of foreign exchange depreciation. The fourth term is the marginal discounted future loss of greater output. Future loss will be associated with the effect of y_t on subsequent consumer price inflation and foreign exchange rate depreciation. The last terms capture the marginal loss from the effect of an increase in expected inflation on output, on foreign exchange rate depreciation, and on future output.

Expectations over the first order condition in (9) (i.e., over u and e), upon eliminating y_t, s_t, x_t, and π_t, yields expected money growth

$$(10) \qquad m^{e*}_t = x^0 + (c+a\mu)\alpha y_{t-1}/[a+c],$$

where an asterisk indicates values under commitment. Using equation (10) and taking expectations over (5') and (4) yields the solutions for expected consumer price inflation and for expected exchange rate depreciation under commitment (expected producer price inflation, π^{e*}_t, equals m^{e*}_t):

$$(11) \qquad x^{e*}_t = x^0 + c(1-\mu)\alpha y_{t-1}/[a+c],$$

and

$$(12) \qquad s^{e*}_t = s^0 - a(1-\mu)\alpha y_{t-1}/[a+c].$$

If the exchange rate objective does not appear in the loss function ($c = 0$), the standard commitment result of $x^{e*}_t = x^0$ is obtained. In this case, expected producer price inflation (in equation (10)) and expected foreign exchange rate depreciation (in equation (12)) are being adjusted by exactly the amount necessary to make expected consumer price inflation in equation (11) equal to x^0. When $c > 0$, x^{e*}_t is not brought directly into line with x^0, since it is also necessary to consider how the expected rate of depreciation, s^{e*}_t, lines up in the loss function with s^0.[9]

In equations (10), (11), and (12), expected values for m, π, x, and s, are state contingent because the real exchange rate depends upon the growth rate of output, and expectations about this variable depend upon the value of lagged output. If output in the last time period was above the natural rate ($y_{t-1}>0$), cyclical growth in the current period (y_t-y_{t-1}) is likely to be negative, and thus $s^{e*}_t < s^0$ as illustrated in equation (12). In this case ($y_{t-1} > 0$), expected money growth (and expected producer and expected consumer price inflation) are set above x^0.

We now return to the first order condition in equation (9) to obtain the decision rule for rate of money growth under commitment. Given that the objective function is quadratic, it follows that $Z^*(y_{t-1})$ has the form

$$(13) \qquad Z^*(y_{t-1}) = \psi^*_0 + \psi^*_1 y_{t-1} + (1/2)\psi^*_2(y_{t-1})^2,$$

where ψ^*_0, ψ^*_1, and ψ^*_2 are to be derived. Substituting for $Z^{*\prime}(y_t)=\psi^*_1+\psi^*_2(y_t)$ in equation (9) yields the solution under commitment for money growth rule:

[9] The appearance of a state-contingent term in expected inflation and in money growth in the optimal rule under commitment noted above differs from that found by Svensson (1997) for two reasons. The first is the appearance of an exchange rate term in the loss function and the second is consumer price inflation appearing in the loss function rather than producer price inflation. For example, even if c=0 a state-contingent term continues to appear in expected money growth under commitment in equation (10).

$$(14) \qquad m^*_t = x^0 + (c+a\mu)\alpha y_{t-1}/[a+c] - [\alpha\mu a(1+\alpha\mu b)+b(1+\beta\psi^*_2)+\alpha c(1+\alpha b)]u_t/\Delta^* - [\mu a(1+\alpha\mu b)+c(1+\alpha b)]e_t/\Delta^*,$$

where $\Delta^* \equiv [a(1+\alpha\mu b)^2+b^2(1+\beta\psi^*_2)+c(1+\alpha b)^2]$. Substitution of (10) and (14) into the Bellman equation in (8) allows the coefficients ψ^*_1 and ψ^*_2 to be identified as

$$(15) \qquad \psi^*_1 = 0$$
$$\psi^*_2 = ac\alpha^2(1-\mu)^2/(a+c).$$

It is clear from equations (14) and (15), that under commitment, a supply shock that raises output, $u_t > 0$, and a shock to the terms of trade or to foreign output that tend to depreciate the domestic currency, $e_t > 0$, reduce the rate of money growth. The commitment solutions for producer price inflation, consumer price inflation, exchange rate depreciation, and for domestic production, are obtained by substituting from equations (14) and (15) into equations (7), (5'), (4), and (6), respectively, and are given by:

$$(16) \qquad \pi^*_t = \pi^{e*}_t - [\alpha\mu a(1+\alpha\mu b)+b(1+\beta\psi^*_2)+\alpha c(1+\alpha b)]u_t/\Delta^* - [\mu a(1+\alpha\mu b)+c(1+\alpha b)]e_t/\Delta^* + v_t,$$

$$(17) \qquad x^*_t = x^{e*}_t - [b(1+\beta\psi^*_2)+\alpha(1-\mu)c(1+\alpha b)]u_t/\Delta^* + [b^2\mu(1+\beta\psi^*_2)-(1-\mu)c(1+\alpha b)]e_t/\Delta^* + (1+\alpha\mu b)v_t,$$

$$(18) \qquad s^*_t = s^{e*}_t + [\alpha(1-\mu)a(1+\alpha\mu b)-b(1+\beta\psi^*_2)]u_t/\Delta^* + [b^2(1+\beta\psi^*_2)+(1-\mu)a(1+\alpha\mu b)]e_t/\Delta^* + (1+\alpha b)v_t,$$

$$(19) \qquad y^*_t = [a(1+\alpha\mu b)+c(1+\alpha b)]u_t/\Delta^* - [a\mu(1+\alpha\mu b)+c(1+\alpha b)]be_t/\Delta^* + bv_t.$$

Equations (16)-(19) show that a positive supply shock reduces consumer and producer price inflation and raises output under commitment.[10] With regard to the influence on s^*_t of positive supply shocks, the increase in output forces down the relative price of domestic goods at a faster rate ($s^*_t-\pi^*_t+\pi^f > 0$), with the result that the rate of depreciation in the foreign exchange rate must be greater than producer price inflation. Since for $u_t > 0$, the effect on π^*_t is negative, s^*_t may be either positive or negative depending on parameter values as illustrated by the ambiguous sign of the coefficient on u_t in equation (18).

A shock to the terms of trade or to foreign output that tends to depreciate the domestic currency ($e_t > 0$), causes producer price inflation (in equation (16)) to be reduced so as to stabilize the exchange rate. This negative surprise in producer price inflation causes output to fall, as indicated in equation (19). The larger the weight on the exchange rate objective, the greater the impact of an exchange rate shock on domestically produced output. The effect of $e_t > 0$ on consumer price inflation in equation (17) is ambiguous. The effect of lower producer price inflation is captured by the $-(1-\mu)c(1+\alpha b)]e_t/\Delta^*$ term and indicates that x_t should fall. This effect may be offset by higher prices for imports, captured by the $b^2\mu(1+\beta\psi^*_2)e_t/\Delta^*$ term in equation (17), that indicates that consumer price inflation should rise. The equations (16)-(19) indicate that a positive velocity shock causes inflation, output, and the rate of depreciation of the exchange rate to all increase.

III.2 Discretionary Policy

Policy under discretion is obtained by minimizing expected social loss in equation (1) with respect to m_t for given expectations about money growth, m^e_t. The decision rule under discretion is derived from the Bellman equation,

$$(19) \quad Z(y_{t-1}) = E_{t-1}\min_{m_t}\left\{(a/2)(x_t-x^0)^2 + (1/2)(y_t-k)^2 + (c/2)(s_t-s^0)^2 + \beta Z(y_t)\right\}.$$

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[10]The first term on the right hand side of equation (19) shows that optimal stabilization reduces the effect of supply shocks on output, compared to the situation in which expectations about inflation are always realized.

From the expressions for s_t, x_t, y_t, and π_t, in equations (4), (5'), (6), and (7), the first order condition is the following:

$$(20) \quad E_{e,u}\left\{(1+\alpha\mu b)a(x_t-x^0) + b(y_t-k) + c(1+\alpha b)(s_t-s^0) + b\beta Z^{*}{}'(y_t)\right\} = 0,$$

where in the discretion case $Z'(y_t) = \psi_1+\psi_2 y_t$. Eliminating y_t, s_t, x_t, and π_t, and solving (20) for m_t yields the decision rule for money growth under discretion:

$$(21) \quad m_t = m^e_t - [\alpha\mu a(1+\alpha\mu b)+b(1+\beta\psi_2)+\alpha c(1+\alpha b)]u_t/\Delta$$
$$- [\mu a(1+\alpha\mu b)+c(1+\alpha b)]e_t/\Delta,$$

where

$$(22) \quad m^e_t = x^0 + b(k-\beta\psi_1)/\Omega + \alpha(\mu a(1+\alpha\mu b)+c(1+\alpha b))y_{t-1}/\Omega,$$

$\Delta\equiv[a(1+\alpha\mu b)^2+b^2(1+\beta\psi_2)+c(1+\alpha b)^2]$, and $\Omega\equiv[a(1+\alpha\mu b)+c(1+\alpha b)]$.

Expected money growth (and expected producer price inflation) under discretion differs from m^{e*}_t in equation (10) by the presence of an average inflation bias, $b(k-\beta\psi_1)/\Omega$, and by the magnitude of the coefficient of the state contingent term. Inspection of equations (10) and (22) reveals that expected money growth varies more under discretion than under commitment for a given value of y_{t-1} since $\alpha(\mu a(1+\alpha\mu b)+c(1+\alpha b))/\Omega > \alpha(c+a\mu)/(a+c)$.

Substitution of (21) and (22) into the Bellman equation (19) allows the coefficients of y_{t-1} and y_{t-1}^2, ψ_1 and $\psi_2/2$, to be identified. The solutions are given by:

$$(23) \quad \psi_1 = \{kac[\alpha b(1-\mu)]^2\}/\{\Omega^2 +\beta ac[\alpha b(1-\mu)]^2\},$$
$$\psi_2 = ac\alpha^2(1-\mu)^2[a(1+\alpha\mu b)^2+c(1+\alpha b)^2]/\Omega^2.$$

If an exchange rate stabilization objective does not appear in the loss function, i.e., c=0, then $\psi_1 = \psi_2 =0$. The discretionary solution to the model will differ from the commitment solution to the model only by an average inflation bias, due to inability by the government to pre-commit, given by [b(k-

$\beta\psi_1)/\Omega] = bk/[a(1+\alpha\mu b)]$. When $c > 0$, average inflation bias is given by $[b(k-\beta\psi_1)/\Omega] = bk\Omega/\{\Omega^2 + \beta ac[\alpha b(1-\mu)]^2\}$.

Comparison of equations (23) and (15) will show that $\psi_2 > \psi^*_2 > 0$ when $c > 0$. This implies that $\Delta > \Delta^*$. The money growth decision rules in equations (14) and equation (21) indicate that there is a stabilization bias under discretion. Response in money growth to supply shocks is larger under discretion than under commitment, and response in money growth to shocks to the terms of trade or foreign output is smaller under discretion than under commitment.[11] Both these consequences are consistent with output varying too little under discretion compared to commitment. This can be illustrated by substituting from equations (21) and (7) into equation (6) yielding output under discretion given by

$$(24) \qquad y_t = [a(1+\alpha\mu b)+c(1+\alpha b)]u_t/\Delta - [a\mu(1+\alpha\mu b)+c(1+\alpha b)]be_t/\Delta + bv_t.$$

From equation (24) it can be seen that given $\Delta > \Delta^*$ output under discretion varies too little in response to u_t and e_t.[12] Since this requires a larger money growth response to productivity shocks and a smaller money growth response to shocks to the terms of trade or to foreign output, money growth overall may be more or less variable under discretion compared to commitment. By the same argument producer price inflation may be more or less variable under discretion compared to commitment with the outcome depending on parameter values and magnitudes of the variances of the random variables in the model. The control shock, v_t, assumed to be exogenous white noise, enters the discretion solution in the same way as in the commitment solution for output in equation (19).

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[11]Given the expressions for ψ_2 and ψ^*_2 in equations (23) and (15) it is easily established that $[\alpha\mu a(1+\alpha\mu b)+b(1+\beta\psi_2)+\alpha c(1+\alpha b)]/\Delta > [\alpha\mu a(1+\alpha\mu b)+b(1+\beta\psi^*_2) +\alpha c(1+\alpha b)]/\Delta^*$. Thus, the coefficient on u_t in equation (23) is larger in absolute value than that on u_t in equation (15). The result concerning coefficients on e_t in equations (15) and (23) follows since $\Delta > \Delta^*$.

[12]This result was noted by Svensson (1997). In the Svensson model, a output or employment term appears in the equation for employment rather than as an influence on the real exchange rate. However, the effect of such a lagged term on results is similar. The dependence of money growth or inflation on lagged output makes it more important to stabilize output.

The discretion solution for producer price inflation only differs from that for money growth rule in equation (21) by the addition of a term for shocks to velocity, bv_t. The discretion solutions for consumer price inflation and for exchange rate depreciation, are obtained by substituting from equations (21) and (23) into equations (5') and (4) and are given by:

$$(25) \qquad x_t = x^0 + b(k-\beta\psi_1)/\Omega + c(1+\alpha b)\alpha(1-\mu)y_{t-1}/\Omega$$
$$- [b(1+\beta\psi_2)+\alpha(1-\mu)c(1+\alpha b)]u_t/\Delta$$
$$+ [b^2\mu(1+\beta\psi_2)-(1-\mu)c(1+\alpha b)]e_t/\Delta + (1+\alpha\mu b)v_t,$$

and

$$(26) \qquad s_t = s^0 + b(k-\beta\psi_1)/\Omega - a(1+\alpha\mu b)\alpha(1-\mu)y_{t-1}/\Omega$$
$$+ [\alpha(1-\mu)a(1+\alpha\mu b)-b(1+\beta\psi_2)]u_t/\Delta$$
$$+ [b^2(1+\beta\psi_2)+(1-\mu)a(1+\alpha\mu b)]e_t/\Delta + (1+\alpha b)v_t.$$

The solutions for consumer price inflation and exchange rate depreciation under discretion, differ from those under commitment by the addition of the same constant average inflation term that appeared in the money growth rule in equation (22). For a given value of y_{t-1} in (25)-(26), the response in consumer price inflation is larger in absolute value under discretion than under commitment, while the response in the rate of change in the nominal exchange rate is smaller in absolute value under discretion than under commitment.

With regard to stabilization bias, note (from comparing (26) with (18)) that the exchange rate response under discretion to shocks to the terms of trade or to foreign output is larger than under commitment. The result is consistent with money growth response under discretion to e_t being not as great as under commitment. Also, (from comparing (25) with (17)) that consumer price inflation response under discretion to productivity shocks is larger than under commitment.

IV. Linear Contracts for the Central Bank

IV.1 Linear Inflation Contracts

Walsh (1995) shows that in the standard model it is possible to construct a linear inflation contract for the central bank that eliminates average inflation bias, and that yields behavior that replicates the equilibrium corresponding to an optimal rule under commitment. When the model is generalized to allow persistence in employment, Svensson (1997) demonstrates that a linear inflation contract with a state-contingent component is capable of matching the discretion equilibrium to the commitment solution. In the model in this paper, in which a foreign exchange rate term appears in the loss function, it is shown that a state-contingent linear inflation contract does not replicate the commitment solution.

The inflation contract for the central bank will be specified in terms of the consumer price index. A linear state-contingent contract in terms of producer price inflation or in terms of money growth will yield similar results.[13] Consider the addition of a state-contingent linear inflation contract to the period loss function in equation (2). The period loss function is now given by $L(x_t,y_t,s_t;x^0,k,s^0,a,c) + (f_0 + f_1y_{t-1})(x_t-x^0)$.

The first order condition from the Bellman equation is given by

$$(27) \qquad E_{e,u}\Big\{(1+\alpha\mu b)a(x_t-x^0) + b(1+\beta\psi^I_2)y_t + (1+\alpha\mu b)(f_0 + f_1y_{t-1}) - b(k-\beta\psi^I_1) + c(1+\alpha b)(s_t-s^0)\Big\} = 0,$$

where the superscript on the coefficients ψ^I_1 and ψ^I_2 indicate that a linear inflation contract is in operation. Equation (27) differs from the first order condition in the straight-forward discretion case in equation (20) by the addition of the term $(1+\alpha\mu b)(f_0 + f_1y_{t-1})$. Taking expectations over u and e yields

[13] For example, it can be shown that linear state-contingent contracts of the form $(g_0+g_1y_{t-1})(\pi_t-x^0)$, or $(g_0+g_1y_{t-1})(m_t-x^0)$, will also not replicate the optimal rule under commitment. These contracts will give the same sub-optimal money growth rule, since $E_{e,u}\Big\{(g_0+g_1y_{t-1})(\pi_t-x^0)\Big\} = (g_0+g_1y_{t-1})(m_t-x^0)$, that will be slightly different from the one derived in the text for the linear state-dependent consumer price inflation contract given by $(f_0+f_1y_{t-1})(x_t-x^0)$.

expected money growth:

$$(28) \quad m^{eI}_t = x^0 + [b(k-\beta\psi^I_1) -(1+\alpha\mu b)f_0]/\Omega + [\alpha\mu a(1+\alpha\mu b)+\alpha c(1+\alpha b)-(1+\alpha\mu b)f_1]y_{t-1}/\Omega.$$

Selection of $f_0 = b(k-\beta\psi^I_1)/(1+\alpha\mu b)$ and of $f_1 = ac\alpha^2 b(1-\mu)^2/[(a+c)(1+\alpha\mu b)]$ will eliminate average and state-contingent money growth bias and thus equate m^{eI}_t in equation (28) with m^{e*}_t in equation (10). Using these values of f_0 and f_1 allows identification of ψ^I_1 and ψ^I_2 from the Bellman equation. Matching coefficients of y_{t-1}, and then of y_{t-1}^2 in turn, in the Bellman equation yields:[14]

$$(29) \quad \psi^I_1 = bkc\alpha(1-\mu)/[(a+c)(1+\alpha\mu b)+\beta bc\alpha(1-\mu)]$$
$$\psi^I_2 = [ac\alpha^2(1-\mu)^2/(a+c)]\{1 + 2[c\alpha b(1-\mu)/(a+c)(1+\alpha\mu b)]\}.$$

The solution for ψ^I_1 implies that $f_0 = bk(a+c)/[(a+c)(1+\alpha\mu b)+\beta bc\alpha(1-\mu)]$. f_1 has already been selected to eliminate state-contingent bias from the money growth rule and is not dependent upon ψ^I_2.

The decision rule for money growth for the banker with a linear consumer price inflation contract (with a state-contingent component) that eliminates average and state contingent bias is given by

$$(30) \quad m^I_t = m^{e*}_t - [\alpha\mu a(1+\alpha\mu b)+b(1+\beta\psi^I_2)+\alpha c(1+\alpha b)]u_t/\Delta^I - [\mu a(1+\alpha\mu b)+c(1+\alpha b)]e_t/\Delta^I,$$

where $\Delta^I \equiv [a(1+\alpha\mu b)^2+b^2(1+\beta\psi^I_2)+c(1+\alpha b)^2]$. Since $\psi^I_2 > \psi^*_2$ implies $\Delta^I > \Delta^*$, stabilization bias remains a problem in equation (30). Under the linear inflation contract, money growth response to supply shocks is larger than under commitment,

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[14]Matching coefficients of y_{t-1} in the Bellman equation with period loss function of $L(x_t,y_t,s_t;x^0,k,s^0,a,c) + (f_0+f_1 y_{t-1})(x_t-x^0)$ yields $\psi^I_1 = f_0 c\alpha(1-\mu)/(a+c) = b(k-\beta\psi_1)c\alpha(1-\mu)/[(a+c)(1+\alpha\mu b)]$ and eventually the expression for ψ^I_1 in equation (29). Matching the coefficients of y_{t-1}^2 yields $(1/2)\psi^I_2 = [(1/2)ac\alpha^2(1-\mu)^2/(a+c)] + f_1 c\alpha(1-\mu)/(a+c)$. Substituting for f_1 yields the expression for ψ^I_2 in equation (29).

and money growth response to shocks to the terms of trade and to foreign output is smaller than under commitment.[15] The reason for the failure of the linear inflation contract to mimic the commitment solution is the appearance of a foreign exchange rate term in the loss function. If c = 0, then $m^I_t = m^*_t$ and a linear inflation contract yields the optimal solution.

IV.2 Linear Inflation and Foreign Exchange Rate Contract

It will now be shown that specification of a linear state-contingent consumer price inflation and exchange rate contract given by $(q_0+q_1y_{t-1})(x_t-x^0) + (n_0+n_1y_{t-1})(s_t-s^0)$ will yield results equivalent to those obtained under commitment. The period loss function is now $L(x_t,y_t,s_t;x^0,k,s^0,a,c) +(q_0+q_1y_{t-1})(x_t-x^0) +(n_0+n_1y_{t-1})(s_t-s^0)$. The first order condition from the Bellman equation is given by

$$(31) \qquad E_{e,u}\Big\{(1+\alpha\mu b)a(x_t-x^0) + b(1+\beta\psi^{IF}{}_2)y_t + (1+\alpha\mu b)(q_0+q_1y_{t-1}) + (1+\alpha b)(n_0 +n_1)y_{t-1} - b(k-\beta\psi^{IF}{}_1) + c(1+\alpha b)(s_t-s^0)\Big\} = 0,$$

where the superscript on the coefficients $\psi^{IF}{}_1$ and $\psi^{IF}{}_2$ indicate that a linear contract in terms of inflation and the foreign exchange rate is in operation. Taking expectations over u and e yields

$$(32) \qquad m^{eIF}{}_t = x^0 + [b(k-\beta\psi^{IF}{}_1) -((1+\alpha\mu b)q_0+(1+\alpha b)n_0)]/\Omega + [\alpha\mu a(1+\alpha\mu b)+\alpha c(1+\alpha b) -((1+\alpha\mu b)q_1+(1+\alpha b)n_1)]y_{t-1}/\Omega.$$

If parameters are chosen such that $((1+\alpha\mu b)q_0+(1+\alpha b)n_0)= b(k-\beta\psi_1)$ and $((1+\alpha\mu b)q_1+(1+\alpha b)n_1) = [ac\alpha^2b(1-\mu)^2/(a+c)]$, then average and state-contingent bias are eliminated (and $m^{eIF}{}_t = m^{e*}{}_t$).

[15]Further, since $\psi^I{}_2 > \psi_2$, where ψ_2 is given in equation (23), stabilization bias is greater in equation (30) than it is in the straight-forward discretion solution.

Matching coefficients of y_{t-1} in the Bellman equation yields $\psi^{IF}_1 = bkc\alpha(1-\mu)/[(a+c)(1+\alpha\mu b)+\beta bc\alpha(1-\mu)]$ and $((1+\alpha\mu b)q_0+(1+\alpha b)n_0) = [bk(a+c)(1+\alpha\mu b)]/[(a+c)(1+\alpha\mu b)+\beta bc\alpha(1-\mu)]$. For a reason that will become apparent, we will choose q_0 and n_0 such that $aq_0 = cn_0$. Matching coefficients of y_{t-1}^2 in the Bellman equation yields:

$$(33)\qquad (1/2)\psi^{IF}_2 = [(1/2)ac\alpha^2(1-\mu)^2 + (cq_1 - an_1)\alpha(1-\mu)]/(a+c).$$

Inspection of equation (33) shows that ψ^{IF}_2 can be set equal to ψ^*_2 $(ac\alpha^2(1-\mu)^2/(a+c))$ in equation (15) by setting $an_1 = cq_1$. Given the constraint that $((1+\alpha\mu b)q_1+(1+\alpha b)n_1) = [ac\alpha^2 b(1-\mu)^2/(a+c)]$, this requires that $an_1 = cq_1 = b[ac\alpha(1-\mu)]^2/[(a+c)\Omega]$. Thus, the commitment solution can be obtained by selecting a linear state-contingent inflation and exchange rate contract given by

$$(34)\qquad (q_0+q_1y_{t-1})(x_t-x^0)+(n_0+n_1y_{t-1})(s_t-s^0) = (\kappa_0 + \kappa_1 y_{t-1})\{a(x_t-x^0) + c(s_t-s^0)\},$$

where $\kappa_0 \equiv [bk(a+c)(1+\alpha\mu b)]/\{[(a+c)(1+\alpha\mu b)+\beta bc\alpha(1-\mu)]\Omega\}$ and $\kappa_1 \equiv \{ac\alpha^2 b(1-\mu)^2/[(a+c)\Omega]\}$.

Use of the linear contract in equation (34), in which costs and rewards to the central banker are state-contingent and depend upon the degree to which consumer price inflation deviates from x^0 and the degree to which foreign exchange rate depreciation deviates from s^0, results in the optimal decision rule.

$$(35)\qquad m^{IF}_t = m^*_t.$$

V. Optimal Exchange Rate and Inflation Targets

A major contribution of the paper by Svensson (1997) is analysis of the use of an inflation-targeting regime for improvement of the equilibrium under discretion. Svensson interprets an inflation-targeting regime as meaning the assignment of an explicit inflation target to an instrument-independent central bank. Svensson (1997) shows that an "inflation-target-conservative" central bank (the target is state-contingent) combined with a weight-conservative central bank is capable of mimicking the equilibrium under the optimal rule under commitment. Specifically, he demonstrates that a state-contingent inflation target succeeds in eliminating average and state-contingent inflation bias, and that the addition of weight-conservativeness results in elimination of stabilization bias.

It is shown below that in the presence of an exchange rate term in the loss function, the combination of a state-contingent inflation target and weight-conservativeness is not capable of mimicking the equilibrium given by the optimal rule under commitment. It is established that while a state-contingent inflation target will continue to succeed in eliminating average and state-contingent inflation bias, the addition of weight-conservativeness is not sufficient to eliminate stabilization bias. The difficulty is that, in general, the degree of weight-conservativeness required to eliminate stabilization bias from supply shocks is not the same as that required to eliminate stabilization bias from shocks to the terms of trade or to foreign output.

Consider appointment of a central banker with an explicit state-contingent foreign exchange rate of depreciation target given by $s^b_t = g_0+g_1y_{t-1}$. The purchasing power parity condition that was given by $x^0=s^0+\pi^f$ now becomes $x^b_t=s^b_t+\pi^f=g_0+\pi^f+g_1y_{t-1}$, where x^b_t is an explicit state-contingent inflation target. Thus, in this model an explicit foreign exchange rate target for the central bank implies an explicit inflation rate target for the central bank and vice versa. Suppose a weight-conservative central banker is also appointed with weight $\hat{a}$ on the inflation objective in the loss function. The period loss function under explicit state-contingent foreign exchange rate depreciation and inflation targets and a weight-conservative central bank is given by $L(x_t,y_t,s_t;x^b_t,k,s^b_t,\hat{a},c)$. The first order condition from the Bellman equation is given by

$$(36)\quad E_{e,u}\left\{(1+\alpha\mu b)\hat{a}(x_t-x^b_t) + b(1+\beta\psi^T_2)y_t - b(k-\beta\psi^T_1) + c(1+\alpha b)(s_t-s^b_t)\right\} = 0,$$

where the superscript on the coefficients ψ^T_1 and ψ^T_2 indicates that state-contingent targets for inflation and the foreign exchange rate are in place. Note that the weight on the inflation objective is now $\hat{a}$.

Taking expectations over u and e in equation (36) and making substitutions in terms of expected money growth we obtain

$$(1+\alpha\mu b)\hat{a}(m^{eT}_t-\alpha\mu y_{t-1}-g_0-\pi^f-g_1y_{t-1}) - b(k-\beta\psi^T_1) + c(1+\alpha b)(m^{eT}_t-\alpha y_{t-1}-g_0-\pi^f-g_1y_{t-1}) = 0.$$

Collecting terms and solving yields

$$(37) \qquad m^{eT}_t = (g_0+\pi^f) + b(k-\beta\psi^T_1)/\sigma + [\hat{a}(\alpha\mu+g_1)(1+\alpha\mu b)+c(\alpha+g_1)(1+\alpha b)]y_{t-1}/\sigma,$$

where $\sigma\equiv[\hat{a}(1+\alpha\mu b)+c(1+\alpha b)]$. Selection of $g_0 = x^0-\pi^f -b(k-\beta\psi^T_1)/\sigma$ and of $g_1 = \alpha[(c+a\mu)/(a+c)] + \alpha[\hat{a}\mu(1+\alpha\mu b)+c(1+\alpha b)]/\sigma$ will eliminate constant and state-contingent biases from money growth and set $m^{eT}_t = m^{e*}_t$. It can be shown that $g_0<x^0-\pi^f=s^0$. The assignment of an explicit inflation target x^b_t, with $g_0+\pi^f<x^0$, gives rise to the term "inflation-target-conservative" by Svensson (1997). Using these values of g_0 and g_1 allows identification of ψ^T_1 and ψ^T_2 from the Bellman equation. Solving equation (36) for the money growth rule under explicit state-contingent inflation and foreign exchange rate targets and a weight-conservative central bank yields:

$$(38) \qquad m^T_t = x^0 + (c+a\mu)\alpha y_{t-1}/[a+c] - [\alpha\mu\hat{a}(1+\alpha\mu b)+b(1+\beta\psi^T_2)+\alpha c(1+\alpha b)]u_t/\Theta - [\mu\hat{a}(1+\alpha\mu b)+c(1+\alpha b)]e_t/\Theta,$$

where $\Theta\equiv[\hat{a}(1+\alpha\mu b)^2+b^2(1+\beta\psi^T_2)+c(1+\alpha b)^2]$. Matching coefficients of y_{t-1}, and then of y_{t-1}^2 in turn, in the Bellman equation yields:

$$(39) \qquad \psi^T_1 = \{k\hat{a}c[\alpha b(1-\mu)]^2\}/\{\sigma^2+\beta\hat{a}c[\alpha b(1-\mu)]^2\},$$

$$\psi^T_2 = \hat{a}c\alpha^2(1-\mu)^2(\hat{a}(1+\alpha\mu b)^2+c(1+\alpha b)^2)/(\sigma^2).$$

The solution in equation (38) shows that average and state-contingent inflation biases are eliminated by use of the appropriate state-contingent inflation target. Stabilization bias remains, however, in that the last two terms in (38) differ from the last two terms in the solution for the optimal money supply rule under commitment in equation (14). The solution for ψ^T_2 is identical to that derived for the original discretion case given in equation (23) when $\hat{a}$=a. Adjustment of $\hat{a}$ will change the coefficients on u_t and on e_t in equation (38), but it is apparent that the degree by which $\hat{a}$ needs to be adjusted to eliminate stabilization bias in response to either supply shocks or to shocks to the terms of trade and foreign output will in general be different. Thus, it is not possible to replicate the optimal rule under commitment using a state-contingent foreign exchange rate depreciation target (and a state-contingent inflation target) and a varying weight on the inflation term in the loss function.[16]

VI. Conclusion

The analysis in this paper is prompted by the observation that since many countries follow an exchange rate-targeting regime, the issues raised in the literature on dynamic inconsistency and monetary policy should be revisited given the addition of a foreign exchange rate term to the loss function in the standard model. It was found that average, state-contingent and stabilization biases arise under discretion compared to the optimal rule under commitment. Response in money growth to supply shocks is larger under discretion than under commitment, and response in money growth to shocks to the terms of trade or foreign output is smaller under discretion than under commitment. Output varies too little under discretion compared to commitment. Inflation may be more or less variable under

[16]The same finding holds if the weight is varied on the output term in the loss function, i.e. if the coefficients a and c vary proportionately. Finally, it should be noted that in principle, it might be possible to combine state-contingent inflation (and foreign exchange rate) targeting with independent adjustments in the weights on the inflation and exchange rate terms in the loss function to replicate the equilibrium under an optimal rule under commitment.

discretion compared to commitment. It was found that neither a linear state-contingent inflation contract for the central bank, or an explicit state-contingent inflation target (that implies an explicit state-contingent foreign exchange rate target) combined with a weight-conservative central bank, can achieve the equilibrium matching that of an optimal rule under commitment when a foreign exchange rate objective appears in the loss function.

A linear state-contingent inflation contract succeeds in eliminating average and state-contingent bias but, because of the third objective in the loss function, it is not capable of also eliminating stabilization bias from the discretionary solution. In order to ensure optimal behavior by the central bank, it is now necessary for the linear contact to not only assess penalties when inflation deviates from the target level, but also to assess penalties when foreign exchange rate depreciation deviates from the target level. The relative importance of deviations of consumer price inflation from target and exchange rate depreciation from target in the contract for the central banker will be determined by the relative weight assigned to meeting the inflation and exchange rate targets in society's loss function. Inflation-targeting and foreign exchange rate-targeting regimes are the same in the model. It is shown that an explicit state-contingent foreign exchange rate target (or an explicit state-contingent inflation target) will succeed in eliminating average and state-contingent inflation and exchange rate depreciation bias, but that the addition of weight-conservativeness is not sufficient to eliminate stabilization bias.

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