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Tamer Başar
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Mark Salmon

European University Institute, Florence

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BADIA FIESOLANA, SAN DOMENICO (FI)

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Credibility and the Value of Information Transmission in a Model of Monetary Policy and Inflation

Tamer Başar[1] and Mark Salmon[2]

Abstract

In this paper we solve for the optimal (Stackelberg) policy in a model of credibility and monetary policy developed by Cukierman and Meltzer (1986). Unlike the (Nash) solution provided by Cukierman and Meltzer, the dynamic optimization problem facing the monetary authority in this case is *not* of a linear quadratic form and certainty equivalence does not apply. The learning behavior of the private sector (regarding the policy maker's preferences) becomes intimately linked with the choice of the optimal policy and cannot be separated as in the certainty equivalent case. Once the dual effect of the optimal Stackelberg policy is recognized the monetary authority has an additional channel of influence to consider beyond that taken into account by suboptimal certainty equivalent Nash policy rules. Unlike Nash behavior the Stackelberg solution implies no inflationary bias, while being still (weakly) time-consistent. This makes the Stackelberg solution credible with only stagewise precommitment of the policy maker. In the absence of such a precommitment, learning behavior of the private sector does not sufficiently inhibit the incentive of the monetary authority to cheat in this model despite the fact that this learning is explicitly recognized in the Stackelberg solution.

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[1] Coordinated Science Laboratory, University of Illinois, 1101 W. Springfield Avenue, Urbana, IL 61801/USA

[2] European University Institute, Department of Economics, Florence, Italy

1 Introduction

The question of how optimal economic policy should be constructed when the private sector forms rational expectations has been a central issue in macroeconomics ever since Lucas (1976) emphasized the endogenity of rational expectations. The standard approach to this problem, following Kydland and Prescott (1977), has been to formulate the underlying decision process as a Nash game, which leads naturally to a (weakly) time consistent solution at the expense of removing the strategic dominance of the policy maker. An asymmetric (Stackelberg) solution that exploits this strategic dominance will however invariably lead to a better performance for the policy maker than what he would achieve under the Nash solution. Thus, while the possible time inconsistency of the Stackelberg solution and the presence of an incentive for the leader to renege may be seen as undesirable, there is also a credibility issue associated with the time consistent Nash solution, particularly if the follower also benefits from the leadership of the policy maker. Hence the standard argument that the Nash solution is the only meaningful resolution to such policy issues, without recourse to some exogeneous precommitment, is called into question. This is more so if the Stackelberg solution is also weakly time consistent, which means that with only stagewise (instantaneous) precommitment there is no incentive for the policy maker to renege.

In this paper we study these issues in the context of a specific stochastic model of monetary policy and inflation developed by Cukierman and Meltzer (1986) who extended the earlier repeated game analysis of Barro and Gordon (1983). This dynamic model incorporates asymmetric information between the private sector and the monetary authority, which brings forth the impact of learning as an issue of major importance in the construction of the optimal policy. Cukierman and Meltzer develop a (certainty equivalent) Nash solution to this policy problem in which each side takes the other's reaction, the policy rule and rational expectation respectively, as given. However this Nash solution, not only generates a suboptimal policy for the monetary authority, as emphasized above, but one that ignores critical aspects of information transmission and learning. In what follows we develop the optimal (Stackelberg) policy for the monetary authority that retains the natural asymmetry inherent in the problem, that will be credible with some prior commitment. The optimal policy is furthermore (weakly) time consistent, which is perhaps surprising in view of the well-acknowledged fact that Stackelberg solutions are generically time inconsistent (see, for example, Başar and Olsder (1982)). We show how the optimal policy is determined from a nonquadratic optimization problem for which certainty equivalence does not apply. The dual control aspect of this optimal policy is reflected in the recognition by the monetary authority that it may simultaneously influence the weight the private sector places on its most recent information, when updating its rational expectation of the policy maker's preference, as well as the information itself that is available to the private sector. In this way the policy maker is fully aware of the impact of his policy action on his reputation when he selects his optimal policy action.

Solutions to nonfinite state dual control problems are well recognized to be typically infeasible and approximations, such as the imposition of certainty equivalence, are invariably required in order to derive computationally tractable, albeit suboptimal, decision rules. Here, however, we make no such assumptions for the solution of the underlying dual control problem. Proceeding in stages towards an understanding of the optimal policy, we first discuss the model and alternative solution concepts and then derive a Nash solution for a two period version of the problem. Then we compare this certainty equivalent Nash solution with the Stackelberg solution under the restriction of certainty equivalence, before providing the optimal (unrestricted) Stackelberg solution for the two-period problem which captures the essential economic issues raised by information transfer through choice of policy. The complete Stackelberg solutions to the general finite-horizon and infinite-horizon problems are also provided in the paper, but without giving details of their derivation as they are highly involved mathematically (for details, see Başar (1988)). Finally we discuss aspects of time consistency and credibility of these solutions before concluding the paper.

2 The model and different equilibrium concepts

The basic model we adopt is that used by Cukierman and Meltzer (1986), but instead of taking an infinite horizon we assume here that the monetary authority faces a finite horizon policy optimization problem with objective function of the form,

$$J = E\left\{\sum_{i=0}^{N} \beta^i (e_i x_i - \frac{1}{2}(m_i^p)^2)\right\} \tag{1}$$

where the policy instrument is the planned rated of monetary growth, m_i^p. The private sector is only able to observe m_i, the actual rate of monetary growth which results after m_i^p has been affected by the random shock ψ_i associated with imperfect monetary control;

$$m_i = m_i^p + \psi_i \qquad \psi_i \sim N(0, \sigma_\psi^2) \quad i = 0, 1, \ldots \tag{2}$$

The shocks $\{\psi_i\}$ are taken to be zero mean Gaussian random variables, which are serially uncorrelated and have a fixed variance of σ_ψ^2.

The private sector is assumed to act as a "passive" decision maker which simply forms conditional expectations of the actual rate of monetary growth, given the observed history of past growth;

$$I_i = \{m_{i-1}, m_{i-2}, \ldots, m_o\}. \tag{3}$$

That is, letting d_i denote the forecast of the private sector at time i, and $\tilde{\delta}_i$, the mechanism by which rational expectations are generated, we have

$$d_i = \tilde{\delta}_i(I_i) = E[m_i | I_i], \qquad i = 0, 1, 2 \ldots \tag{4}$$

The monetary surprise, e_i, is given by

$$e_i = m_i - \tilde{\delta}_i(I_i) = m_i^p - E[m_i^p | I_i] + \psi_i \tag{5}$$

where the last relation follows from (2) and the assumption that $\{\psi_i\}$ forms an independent sequence.

The variable x_i in (1) is the preference parameter of the monetary authority which trades off the benefit from stimulating the economy through the monetary surprise, with the loss from increased inflation in period i. This basic preference parameter of the monetary authority which is unknown to the private sector, is stochastic and assumed to change over time with both permanent and transitory components, leading to what is effectively the state equation for the policy optimization problem;

$$x_i = \rho x_{i-1} + A(1-\rho) + v_i \tag{6}$$

with $v_i \sim N(0, \sigma_v^2)$, $i = 1, 2, \ldots$, and $x_0 \sim N(\bar{x}_0, \sigma_{x0}^2)$. Here again, $\{v_i\}$ is a sequence of zero mean serially uncorrelated Gaussian random variables with fixed variance σ_v^2, which are also independent of the shocks $\{\psi_i\}$. The random variable x_0 is also an independent Gaussian random variable, with mean $\bar{x}_0$ and variance $\sigma_{x_0}^2$, representing the prior beliefs of the private sector. The monetary authority constructs its optimal policy based on a knowledge of its current and past preferences as well as I_i. So in general we seek a sequence of policy rules $\{\gamma_i\}$ of the form,

$$m_i^p = \gamma_i(\eta_i), \qquad \eta_i = \{x_{i-1}, x_{i-1}, \ldots\ldots x_0, I_i\}. \tag{7}$$

Note the asymmetric form of the information structure between the monetary authority and the private sector, which enables the monetary authority to solve the private sector's prediction problem, which it will in fact do as part of the exercise when designing its optimal monetary policy.

An important feature of the formulation above is the presence of asymmetry not only in the information structure but also in the way the decision makers affect the decision process. The private sector's only role is to form conditional expectations, which however depend critically on the policy rules of the monetary authority. To indicate this dependence explicitly we introduce the notation

$$\tilde{\delta} = f(\gamma) \tag{8}$$

where $\tilde{\delta} = \{\tilde{\delta}_i\}_{i=0}^N$, $\gamma = \{\gamma_i\}_{i=0}^N$. Hence, in compact notation, the policy optimization problem faced by the monetary authority is

$$\max_\gamma J(\gamma, f(\gamma)) = J(\gamma^*, f(\gamma^*)) \tag{9}$$

where the function J is defined by (1), and the maximization is over all possible policies γ. The policy optimization problem (9) captures the general form of all similar problems where the cost function, J, does not necessarily have to be in the form (1) but where f is always the conditional expectation operator which determines the forecast rule for the passive player. Under the adopted behavioral assumptions the maximum in (9) is the best performance the policy maker can expect to achieve in this problem, and it cannot be dominated *ex ante* by any other solution.

Cukierman and Meltzer (1986) instead obtained a different type of solution for the problem. Their interest was on the characterization of a policy, $\hat{\gamma}$, for the monetary authority with the property that

$$\max_{\gamma} J(\gamma, f(\hat{\gamma})) = J(\hat{\gamma}, f(\hat{\gamma})). \tag{10}$$

There may exists multiple $\hat{\gamma}$'s (linear and nonlinear) that satisfy the above relationship (10), and it may be difficult (if not impossible) to obtain the entire set of such solutions.[3] This, in turn, makes it impossible to determine the "best" policy within this set and even if such a solution exists it will in general be different from γ^* and hence lead to an inferior overall performance for the policy maker.

It can be readily seen that (9) and (10) represent the Stackelberg and Nash solutions if the problem were set up as a dynamic game with the private sector being treated as a strategic player where the forecast rules $\tilde{\delta}_i$ are regarded as strategic variables. Toward this end we may consider the two person nonzero-sum dynamic game with the objective functions J_1 and J_2,

$$J_1(\gamma, \tilde{\delta}) = J(\gamma, \tilde{\delta}) \tag{11a}$$

$$J_2(\gamma, \tilde{\delta}) = E\left\{\sum_{i=0}^{N} (\tilde{\delta}_i(I_i) - m_i)^2 c_i\right\} \tag{11b}$$

where γ is the composite policy rule of player 1 (the monetary authority) who strives to maximize J_1, and $\tilde{\delta}$ is the composite decision rule of player 2 (the private sector) who wishes to minimize J_2, with the c_i's taken as positive weighting terms.

In the case of the Stackelberg game, we now make the useful observation that the objective function (1) can equivalently be written as

$$J = E\left\{\sum_{i=0}^{N} \beta^i [(x_i - E[x|I_i]) m_i^p - \frac{1}{2}(m_i^p)^2]\right\} \tag{12}$$

which made use of the expression for e_i as given by (5) and the nestedness property of conditional expectations:

$$\begin{aligned} E\{E[m_i^p|I_i]x_i\} &= E\{E[E\{m_i^p|I_i\}x_i|I_i]\} \\ &= E\{E[m_i^p|I_i]E[x_i|I_i]\} \\ &= E\{m_i^p E[x_i|I_i]\}. \end{aligned}$$

Note that the above implies that the leader's Stackelberg policy γ^* is also a Stackelberg policy for him in the game where the objective functions (11a)–(11b) are replaced by

$$J_1(\gamma, \delta) = E\left\{\sum_{i=0}^{N} \beta^i [(x_i - \delta_i(I_i)) m_i^p - \frac{1}{2}(m_i^p)^2]\right\} \tag{13a}$$

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[3] For the specific problem at hand, it can in fact be shown that this equilibrium is unique in the class of affine policies; see the next section and Başar and Salmon (1989b).

$$J_2(\gamma, \delta) = E\left\{\sum_{i=0}^{N}[\delta_i(I_i) - x_i]^2 c_i\right\} \tag{13b}$$

where δ is the decision rule of player 2 (private sector) who wishes to minimize J_2, that is to obtain the best estimate of government's preference parameter, x_i, at each stage of the decision process. Such an equivalence between the two formulations does not carry over to the Nash game, that is the Nash solution for the original game will be different from the Nash solution of a game with objective functions (13a)-(13b).

3 The Nash solution for a two-period problem

Consider the two-period version of the dynamic game problem of section 2, with the cost functions for the two players given by (11a) and (11b), with $N = 1$. To determine a Nash equilibrium we need to find strategies $\hat{\gamma} = (\hat{\gamma}_o, \hat{\gamma}_1)$ for the government and forecast functions $\hat{\delta} = (\hat{\delta}_0, \hat{\delta}_1)$ for the private sector which satisfy the inequalities

$$J_1(\hat{\gamma}, \hat{\tilde{\delta}}) \geq J_1(\gamma, \hat{\tilde{\delta}}) \quad \text{for all permissible } \gamma$$

$$J_2(\hat{\gamma}, \hat{\tilde{\delta}}) \leq J_2(\hat{\gamma}, \tilde{\delta}) \quad \text{for all permissible } \tilde{\delta}.$$

The following theorem provides such a solution for this two-period problem.

Theorem (Nash):

(i) A Nash equilibrium solution for the two-period problem formulated above is given by;

$$\begin{aligned}
m_1^p &= \hat{\gamma}_1(x_1) = x_1; \quad m_0^p = \hat{\gamma}_0(x_0) = Mx_0 + k \\
\hat{\tilde{\delta}}_1(m_0) &= E[m_1^p | m_0] = M\rho\bar{x}_0 + \rho\frac{M^2\sigma_{x0}^2}{M^2\sigma_{x0}^2 + \sigma_\psi^2}(m_0 - M\bar{x}_0 - k) + MA(1-\rho) \qquad (15) \\
\hat{\tilde{\delta}}_0 &= E[m_0] = M\bar{x}_0 + k
\end{aligned}$$

where M is a real solution to the third-order polynomial equation;

$$M = 1 - \beta\rho^2 \frac{M\sigma_{x0}^2}{M^2\sigma_{x0}^2 + \sigma_\psi^2} \tag{16}$$

and k is given by

$$k = -\frac{A(1-\rho)\rho\beta M\sigma_{x0}^2}{M^2\sigma_{x0}^2 + \sigma_\psi^2}.$$

(ii) The Nash equilibrium above is *unique* if either δ_1 or γ_0 is restricted to the class of general affine mappings and (16) admits a unique real solution.

Proof: The proof is omitted to conserve space but is presented in the fuller version of this paper which is available from the authors. □

By the nature of Nash equilibrium, in determining the optimal policy parameter M, the reaction of the private sector is *not* taken into account, unlike the Stackelberg case to be studied below. In effect the Nash solution is determined by the mutual consistency of two single player, certainty equivalent, optimization problems where the reaction of the other player is taken as given. Hence we refer to this Nash solution as *individually certainty equivalent* since the optimal decisions for the two players do not reflect the potential for dual control action. Furthermore the Nash solution above is only **weakly**, and **not strongly, time consistent**, using the terminology of Başar (1989).

The two period Nash solution presented above can be extended to the N period case (see Başar and Salmon (1989b)) and then to a stationary solution that coincides with the solution to the infinite horizon problem considered by Cukierman and Meltzer. The advantage of taking a finite horizon lies in the use of the Kalman filter to model the private sector's (state) learning and expectation formation process which, as we shall see, allows the possibility to monitor the evolution of credibility both in steady state and during the important transient phase of adjustment to the steady state. Whereas Cukierman and Meltzer, by adopting an infinite horizon and a Wiener filter to solve the private sector's prediction problem, are restricted to only consider credibility in steady state. In either case, in this weakly time-consistent Nash equilibrium the level of credibility at any time is determined only by structural parameters of the model, and not by the policy.

The distribution of monetary growth and hence the nonzero value of inflationary bias evolve over time; so that

$$E[m_0] = M\bar{x}_0 + k, \quad var[m_0] = M^2\sigma_{x_0}^2 + \sigma_{\psi}^2, \tag{17a}$$

$$E[m_1] = A, \quad var[m_1] = (1-\rho^2)^{-1}\sigma_v^2 + \sigma_{\psi}^2. \tag{17b}$$

In Başar and Salmon (1989b) we show how the distribution of monetary growth in a finite horizon converges to the stationary solution given in Cukierman and Meltzer (1986).

4 The myopic Stackelberg solution

We now turn to the Stackelberg formulation of the decision problem and assume first that the monetary authority acts myopically in that it only recognizes that it affects the information set available to the private sector in the following period through its decision today. Under this assumption the optimization problem (12) becomes one with a Linear Quadratic Gaussian (LQG) form which essentially decomposes the intertemporal problem into that of determining a sequence of static decisions, each one of which solves uniquely

$$\max_{m_i^p=\gamma_i(\eta_i)} E\{(x_i - E[x_i|I_i])m_i^p - \tfrac{1}{2}(m_i^p)^2\} = \tfrac{1}{2}E\{(x_i - E[x_i|I_i])^2\}$$

$$\Longrightarrow$$

$$m_i^p = \gamma_i(\eta_i) = x_i - E[x_i|I_i] \equiv x_i - \hat{x}_{i|i-1}.$$

Here $\hat{x}_{i|i-1}$, the optimal prediction (rational expectation) by the private sector of the monetary authority's preference, is generated by the Kalman filter:

$$\hat{x}_{i|i-1} = \rho\hat{x}_{i-1|i-1} + A(1-\rho), \qquad \hat{x}_{0|-1} = E[x_0] = \hat{x}_0$$

$$\hat{x}_{i|i} = \hat{x}_{i|i-1} + \frac{\sigma^2_{i|i-1}}{\sigma^2_{i|i-1} + \sigma^2_\psi}(m_i - m_{i|i-1})$$

$$\sigma^2_{i+1|i} = \rho^2\sigma^2_{i|i} + \sigma^2_v$$

$$\sigma^2_{i|i} = \frac{\sigma^2_{i|i-1}\sigma^2_\psi}{\sigma^2_{i|i-1} + \sigma^2_\psi}; \qquad \sigma^2_{0|-1} = \text{var}\,(x_0) = \sigma^2_{x0}.$$

Notice also that

$$\hat{m}_{i|i-1} := E\{m_i^p|I_i\} = E\{(x_i - E[x_i|I_i])|I_i\} = 0,$$

so given the myopic policy and the structure of the model the best conditional forecast that the private sector can make of the next period's monetary growth is zero. Hence every observation on monetary growth represents an observation on the innovation process driving the Kalman Filter. This follows directly from the form of the policy rule under the assumption of myopic decision making.

Substituting this myopic policy back into the objective function, we find

$$\max J \geq E\left\{\sum_{i=0}^{N}\frac{1}{2}\beta^i(x_i - E[x_i|I_i])^2\right\} = \sum_{i=0}^{N}\frac{1}{2}\beta^i\sigma^2_{i|i-1}$$

which provides a lower bound on the performance attainable under the optimal (nonmyopic) policy.

Comparing this myopic certainty equivalent solution with that derived under the Nash assumption in the previous section we can see that, as in the commitment (or rules) solution of Barro and Gordon (1983), there is no inflationary bias, whereas in the Nash (or discretionary) solution the bias is given by (17). The distribution of monetary growth in this case implies, for each i,

$$E[m_i] = 0; \qquad var[m_i] = \sigma^2_{\mathbf{x}} + \sigma^2_\psi.$$

5 The optimal Stackelberg policy for the two-period problem

In the previous section we obtained a lower bound for the optimal performance in the Stackelberg game, and so we know that the optimal policy will satisfy

$$\max_{\gamma_0,\ldots,\gamma_N} J \geq E\left\{\sum_{i=0}^{N} \frac{1}{2}\beta^i (x_i - \hat{x}_{i|i-1})^2\right\} = \sum_{i=0}^{N} \frac{1}{2}\beta^i \sigma^2_{i|i-1} \equiv \underline{J}_{\max}.$$

The question now becomes whether we can find a sequence of policies $\{\gamma_0, \ldots, \gamma_N\}$ which maximizes J and whether $\max J > \underline{J}_{\max}$. We approach this problem in this section by solving for the optimal policy in a two-period problem in which the dual effect is now formally recognized.

Consider the problem of maximizing the objective function (12), with $N = 1$:

$$J = E\left\{\sum_{i=0}^{1} \beta^i (x_i - E[x_i|I_i]) m_i^p - \frac{1}{2}\beta^i (m_i^p)^2\right\}.$$

For the last period, $i = 1$, there will be no issue of information transmission and so the optimal policy will be given by the myopic solution developed in section 4. So the solution will be

$$m_1^p = \gamma_1(\eta_1) = x_1 - E[x_1|I_1].$$

Now we need to consider the optimal policy for period 0 taking into account the full effect of the information transmission to period 1. The cost function for the two period problem can then be written, having substituted the optimal policy rule for the final period, as

$$\max_{m_0^p, m_1^p} J_0 = \max_{m_0^p} E\left\{\frac{1}{2}\beta(x_1 - E[x_1|I_1])^2 + (x_0 - E[x_0|I_0]) m_0^p - \frac{1}{2}(m_0^p)^2\right\}.$$

But, given that

$$I_1 = m_0 = m_0^p + \psi_0,$$

we may rewrite the innovation in period 1 as

$$x_1 - E[x_1|I_1] = \rho(x_0 - E[x_0|m_0^p + \psi_0]) + v_0$$

so the cost function becomes

$$\max_{m_0^p, m_1^p} J_0 = \frac{1}{2}\beta\sigma_v^2 + \max_{m_0^p} E\left\{\frac{1}{2}\rho^2\beta(x_0 - E[x_0|m_0^p + \psi_0])^2 + (x_0 - E[x_0|I_0]) m_0^p - \frac{1}{2}(m_0^p)^2\right\} \quad (19)$$

which may be written in terms of the yet unknown policy rule γ_0

$$\max_{m_0^p, m_1^p} J_0 = \frac{1}{2}\beta\sigma_v^2 + \max_{\gamma_0} F(\gamma_0)$$

where $F(\gamma_0)$ is the maximand on the right hand side of (19). The difficulty in solving this problem lies as discussed earlier in that the optimal policy in the initial period, m_0^p, is part of the conditioning information when the private sector's expectation of monetary growth (or the preference parameter) is taken in period 1. The way we solve the problem below is to simultaneously solve for the optimal predictor for the private sector in period 1, $\delta(I)$, and the optimal policy rule for the government in period 0, say γ. Since we know that the private sector's forecast function will depend on the government's policy rule and the government's optimal policy rule will depend on the private sector's forecast function, we need to examine the fixed points of the mappings $\delta[\gamma]$ and $\gamma[\delta]$ where in addition it should be stressed that in this Stackelberg solution δ is a *different* mapping for each γ and vice versa.

Substituting the unknown predictor function into the objective function we first define

$$G(\delta,\gamma) := E\{\frac{1}{2}\rho^2\beta(\delta(I_1)-x_0)^2+(x_0-E[x_0|I_0])m_0^p-\frac{1}{2}(m_0^p)^2\} \tag{20}$$

where

$$m_0^p=\gamma(x_0,I_0), \quad I_1=m_0^p+\psi_0$$

noting that the information set I_0 will be empty. The "policy problem" facing the private sector is to minimize its prediction error through its choice of δ and the monetary authority recognizing this will solve the following problem in order to determine its optimal γ, chosen so as to *maximize* the prediction error.

$$\max_\gamma F(\gamma)=\max_\gamma \min_{\delta(\gamma)} G(\delta,\gamma). \tag{21}$$

We next show that the function G in fact admits a unique saddle point, that is there exists a unique pair of policies (δ^*,γ^*) such that

$$G(\delta^*,\gamma^*)=\max_\gamma \quad \min_\delta \quad G(\delta,\gamma)=\min_\delta \quad \max_\gamma \quad G(\delta,\gamma)$$

or alternatively,

$$G(\delta^*,\gamma)\le G(\delta^*,\gamma^*)\le G(\delta,\gamma^*). \tag{22}$$

Clearly given any saddle-point pair (δ^*,γ^*) we have from (21) that

$$F(\gamma^*)=\max_\gamma F(\gamma) \tag{23}$$

and furthermore γ^* is the unique maximizing solution above if (δ^*,γ^*) is unique as a saddle point solution.

Before presenting the main result of this section, we first introduce some notation.

Let $L=L_0$ be a real solution to the polynomial equation

$$1-L=\frac{L\sigma_{x_0}^2\sigma_\psi^2\rho^2\beta}{(L^2\sigma_{x_0}^2+\sigma_\psi^2)^2}\equiv g(L). \tag{24}$$

and let K_0 be given by

$$K_0 = \frac{L_0 \sigma_{x_0}^2}{(L_0^2 \sigma_{x_0}^2 + \sigma_\psi^2)} \equiv \Delta(L_0). \tag{25}$$

Furthermore introduce the function

$$\Gamma(K) = \frac{(1 - K\rho^2\beta)}{(1 - K^2\rho^2\beta)} \tag{26}$$

for

$$K^2 \neq 1/\rho^2\beta,$$

and the condition

$$L_0(1 - L_0)\sigma_{x_0}^2 < \sigma_\psi^2. \tag{27}$$

Lemma (Stackelberg):

(i) The polynomial equation (24) is identical with $L = \Gamma(\Delta(L))$, and admits a maximizing real solution L_0, with $0 < L_0 < 1$.

(ii) If L_0 satisfies (27), the game G admits the *unique* saddle point solution

$$\begin{aligned} \delta^*(I_1) &= \bar{x}_0 + K_0 I_1 \equiv \bar{x}_0 + \Delta(L_0) I_1 \\ \gamma^*(x_0) &= L_0(x_0 - \bar{x}_0) \equiv \Gamma(K_0)(x_0 - \bar{x}_0) \end{aligned} \tag{28}$$

where γ^* also provides the unique solution of (23).

(iii) Condition (27) can equivalently be written as

$$1 - \Delta(L_0)^2\rho^2\beta > 0 \leftrightarrow 1 - K_0^2\rho^2\beta > 0. \tag{29}$$

Proof:

(i) Existence of L_0 follows from the simple observation that since (24) is a 5^{th} order polynomial it will admit one, three or five real solutions. Furthermore, all these solutions will lie in the open interval $(0, 1)$ since $g(L)$ is nonnegative and is zero only if $L = 0$. If the polynomial has more than one real root, let L_0 be the one that provides the largest value of $F(\gamma)$ defined following (19). If there is more than one such solution then L_0 could be taken to be any one of them which we refer to as a maximizing solution of (24). The fact that (24) is identical with the equation $\Gamma(\Delta(L)) = L$ follows from the substitution of (25) into (26).

(ii) Here we verify the pair of inequalities (22). The right hand side follows since $G(\delta, \gamma)$, given by (20), is miminized for any γ by the conditional mean of x_0 (given I_1), and when $\gamma = \gamma^*$, this conditional mean is linear in I_1 as given. For the left hand side inequality, note that $G(\delta^*, \gamma)$ is a quadratic function of γ, with the coefficient of the quadratic term being

$$-\frac{1}{2}\left(1 - \frac{L_0^2 \sigma_{x_0}^2 \sigma_{x_0}^2 \rho^2 \beta}{(L_0^2 \sigma_{x_0}^2 + \sigma_\psi^2)^2}\right) \equiv \alpha.$$

The condition $\alpha < 0$ directly implies that $G(\delta^*, \gamma)$ is a strictly concave function of γ, and being quadratic, it admits a unique solution which is

$$\gamma(x_0) = \Gamma(\Delta(L_0))(x - \bar{x}_o)$$

and by (i)

$$\gamma(x_0) = L_0(x - \bar{x}_o).$$

This verifies the left hand side of the inequality (22), under the condition $\alpha < 0$. Using the fact that L_0 satisfies (24), α can be simplified to

$$\alpha = \frac{1}{2}(L_0(1 - L_0)(\sigma_{x0}^2/\sigma_\psi^2) - 1)$$

and hence the concavity condition is indeed equivalent to (27). Note that under this condition, $G(\delta^*, \gamma)$ admits a *unique* maximum, and using the interchangeability property of multiple saddle-point equilibria [Başar and Olsder, (1982)] it readily follows that (28) is indeed the unique saddle point solution of G under (27), which also means that the maximizing solution alluded to in part (i) will have to be unique under condition (27).

(iii) This follows readily by noting that

$$\alpha = -\frac{1}{2}(1 - \Delta(L_0)^2\rho^2\beta),$$

and hence the condition $\alpha < 0$ is equivalent to (29). □

The condition (27) of the Lemma is given in terms of the solution of (24), and this depends on the parameters of the problem only implicitly. A more explicit dependence purely on the parameters σ_{x0}^2, σ_ψ^2, ρ and β can be seen in the condition

$$\sigma_{x0}^2\rho^2\beta < 4\sigma_\psi^2 \tag{30}$$

which implies (27). To see this implication, note that in view of (29), condition (27) is equivalent to

$$\frac{L_0^2\sigma_{x0}^2\sigma_{x0}^2\rho^2\beta}{(L_0^2\sigma_{x0}^2 + \sigma_\psi^2)^2} < 1$$

but since

$$\max_{L_0} \frac{L_0^2\sigma_{x0}^2\sigma_{x0}^2\rho^2\beta}{(L_0^2\sigma_{x0}^2 + \sigma_\psi^2)^2} = \frac{\sigma_{x0}^2\rho^2\beta}{4\sigma_\psi^2}$$

the preceding inequality is always satisfied under (30).

Condition (30), or the less restrictive (27), are sufficient for the linear solution γ^* given in the Lemma to be overall maximizing, but there is no indication that is is also necessary. In fact, it is quite plausible that the result is valid for all values of the parameters defining the problem. Nonsatisfaction of (27) simply means that the auxillary game G does not admit a saddle point (that is the upper value is strictly larger that the lower value); however, this does not rule out the possibility that the maximizing solution for $F(\gamma)$ is still linear.

If we restrict the monetary authority to affine policies at the outset, say of the special form

$$\gamma(x_0) = L(x_0 - \bar{x}_0),$$

then

$$E[x_0 - \bar{x}_0 | m_0 = L(x_0 - \bar{x}_0) + \psi_0] = \frac{L\sigma^2_{x_0} m_0}{(L^2\sigma^2_{x_0} + \sigma^2_\psi)}$$

and substituting this into $F(\gamma)$ we obtain

$$F(\gamma = L_0(x_0 - \bar{x}_0)) \equiv \tilde{F}(L) = \frac{1}{2}(\sigma_v^2 + \rho^2\sigma^2_{x_0}) - \frac{1}{2}\frac{\rho^2\beta L^2(\sigma^2_{x_0})^2}{L^2 + \sigma^2_\psi} - \frac{1}{2}L^2\sigma^2_{x_0} + L\sigma^2_{x_0}$$

as the function to be maximized over the scalar L. Being continuous and bounded above, $\tilde{F}$ admits a maximum, and differentiating it with respect to L and setting the derivative equal to zero we obtain the equation

$$1 - L = \frac{L\sigma^2_{x_0}\sigma^2_\psi\rho^2\beta}{(L^2\sigma^2_{x_0} + \sigma^2_\psi)^2}$$

which is (24). Hence the affine policy γ^* given in the lemma is optimal for all values of the parameters if the search is restricted to the linear class.

The lemma above can now be used to provide the following unique solution to the two-period Stackelberg problem.

Theorem (Stackelberg)

(i) The unique Stackelberg solution to two-period version of the problem of section 2, with the objective functions (11a)–(11b) is

$$m_1^p = \gamma_1^*(\eta_1) = x_1 - \hat{x}^*_{1|0}; \quad m_0^p = \gamma_0^*(\eta_0) = L_0(x_0 - \bar{x}_0) \tag{31a}$$

$$\tilde{\delta}_1^*(m_0) = \tilde{\delta}_0^* = 0 \tag{31b}$$

where L_0 is obtained as the unique solution to (24), under condition (27), and

$$\hat{x}^*_{1|0} := E[x_1 | m_0 = \gamma_0^*(\eta_0) + \psi_0] = \rho\bar{x}_0 + A(1-\rho) + K_0 m_0. \tag{31c}$$

(ii) The solution above is unique even in the absence of condition (27) if the policies of either decision maker are restricted to be affine.

(iii) If the objective functions are instead taken (equivalently) to be given by (13a)–(13b), the unique Stackelberg solution is still given as above, with only the private sector's optimal decision changed to

$$\delta_1^*(m_0) = \hat{x}^*_{1|0}; \qquad \delta_0^* = \bar{x}_0 \tag{31d}$$

where it now forecasts the policy maker's preference parameter. The optimum performance indices in the two cases are the same. □

The essential difference between the dual solution above and the certainty equivalent solution presented in section 4 lies in that although the policy is still linear in the innovation or forecast error of the private sector (with regard to the policy maker's preference parameters), the optimal policy parameter L_0 now lies in the range $(0, 1)$. Moreover in the solution process the value of L_0 has been chosen taking into account the feedback from the effect on the private sector's expectation formation process in period 0. In particular the effect of L_0 on the Kalman gain, $K_0 = \Delta(L_0)$ determines the weight attached to the most recent information and in effect the policy maker's credibility. Thus the monetary authority has the ability to directly affect his own credibility with his choice of monetary growth rate by modifying the way in which the private sector forms its rational expectation. Moreover this can be achieved without recourse to an additional policy instrument, for instance σ_ψ^2, as in the Cukierman and Meltzer (1986)'s (section 6) analysis of ambiguity.

We notice that as in the myopic certainty equivalent solution there is no inflationary bias induced by the optimal policy but the variance of moneary growth is increased over that in the certainty equivalent case. This point and those that follow will be made more apparent if we consider briefly the steady state solution of this optimization problem, which is done in the next section. But before concluding this section it is also worth pointing to an important property of the Stackelberg solution presented in the theorem, that of *weak time consistency*. This is not a feature that Stackelberg solutions generally enjoy, unless they are constructed under the explicit assumption of time consistency (which leads to feedback or stagewise Stackelberg equilibrium, generally inferior to the global Stackelberg solution; see Başar and Olsder (1982)); here, however, the unrestricted solution is also weakly time consistent (á la Başar (1989)) meaning (in this case) that the policies γ_1^* and $\tilde{\delta}_1^*$ also provide a Stackelberg solution to the static (last stage) Stackelberg game, using the objective functions (11a)–(11b) with γ_0 and $\tilde{\delta}_0$ taken at their optimum values, γ_0^* and $\tilde{\delta}_0^*$, respectively. We shall observe a more general version of this feature in the next section, for both the general finite horizon and infinite horizon versions of the problem.

6 The Stackelberg solution for the finite and infinite horizon problems and the issue of time consistency

For the general finite-horizon problem, consider the following policy for the government:

$$m_i^p = \gamma_i(\eta_i) = L_i(x_i - \hat{x}_{i|i-1}), \quad i = 0, 1, \ldots \tag{32}$$

where $\hat{x}_{i|i-1}$ is the Kalman predictor generated recursively under the policy choice (32):

$$\hat{x}_{i|i-1} = \rho\hat{x}_{i|i-1} + A(1-\rho), \tag{33a}$$

$$\hat{x}_{i|i} = \hat{x}_{i|i-1} + \frac{L_i\sigma_{i|i-1}^2}{(L_i^2\sigma_{i|i-1}^2 + \sigma_\psi^2)}(m_i - m_{i|i-1}) \tag{33b}$$

$$\sigma^2_{i+1|i} = \rho^2 \sigma^2_{i|\,i} + \sigma^2_v \tag{33c}$$

$$\sigma^2_{i|i} = \frac{\sigma^2_{i|i-1}\sigma^2_\psi}{(L_i^2\sigma^2_{i|i-1} + \sigma^2_\psi)}; \quad \sigma^2_{0|-1} = \sigma^2_{x_0}. \tag{33d}$$

Substituting this solution into the objective function (12a) with $\delta_i(I_i) = \hat{x}_{i|i-1}$, we obtain

$$\tilde{J}(L) = \sum_{i=0}^{N} \beta^i (L_i - \frac{1}{2}L_i^2)\sigma^2_{i|i-1} \tag{34}$$

as the function to the maximized subject to the dynamic constraint (33c)–(33d), to determine the optimum values for the government's policy parameters $L_0, L_1, \ldots, L_N$. It has been shown by Başar (1988) that this optimal control problem admits a solution, obtainable using dynamic programming, and that the structural restriction (32) does not bring in any loss of generality to the policy optimization. In other words, the government's Stackelberg policy is given by (32), with the L_i's determined (implicitly) from the dynamic program:

$$W_i(\sigma_i^2) = \max_{L_i}\left\{(L_i - \frac{1}{2}L_i^2)\frac{\sigma_i^2}{\sigma_\psi^2} + \beta W_{i+1}\left(\frac{\rho^2\sigma_i^2\sigma_\psi^2}{L_i^2\sigma_i^2 + \sigma_\psi^2} + \sigma_\psi^2\right)\right\}, \quad i = N, N-1, \ldots, 0 \tag{35}$$

$$W_{N+1}(\sigma^2_{N+1}) = 0$$

where $\sigma_0^2 = \sigma^2_{x_0}$, and $\sigma_i^2 := \sigma^2_{i|i}$. For the infinite horizon problem (i.e., as $N \to \infty$), the Stackelberg solution again exists, and is given by the stationary policy (see Başar (1988))

$$\gamma_i^*(\eta_i) = L(x_i - \hat{x}_{i|i-1}), i = n, n+1, \ldots \tag{36}$$

where L is a constant, lying in the interval $(0, 1)$, determined from

$$W(\bar{\sigma}^2) = \max_{L}\left\{(L - \frac{1}{2}L^2)\frac{\bar{\sigma}^2}{\sigma_\psi^2} + \beta W\left(\frac{\rho^2\bar{\sigma}^2\sigma_\psi^2}{L^2\bar{\sigma}^2 + \sigma_\psi^2} + \sigma_v^2\right)\right\} \tag{37a}$$

$$\bar{\sigma}^2 = \frac{\rho^2\bar{\sigma}^2\sigma_\psi^2}{L^2\bar{\sigma}^2 + \sigma_\psi^2} + \sigma_v^2 \tag{37b}$$

provided that n is sufficiently far away from zero. Here $\bar{\sigma}^2$ is the steady-state forecast error covarince (i.e., the limit of $\sigma^2_{i+1|i}$ given by (33c) as $i \to \infty$, and with $N \to \infty$), and when L is considered as a variable in (37b) one can show that the derivation of $\bar{\sigma}^2$ with respect to L^2 is negative. Hence, one effect of the optimal policy in the dual problem having a gain coefficient in (36) less than one is to increase the variability of moneary growth when compared with the myopic solution.

It is ambigious whether the steady state Kalman gain (in (33b)) will be an increasing or decreasing function of L, when L is again considered as a variable, but it can be seen from the objective function (34) (with $N \to \infty$ and $L_i = L$) that the government selects that policy parameter, L, and the implied level of "informational credibility", that optimally trades off the effects on the two (multiplicative) components $(L - \frac{1}{2}L^2)$ and $\sigma^2_{i|i-1}$. The first can be seen to be maximized when $L = 1$ as in the myopic solution, and the second, being a decreasing function of L^2, is maximized at zero. Hence there will be an optimal policy and a corresponding level of informational credibility that trades off the *benefits* from surprises and the *costs* of inflation that reflects the government's ability to control the extent of surprise.

For both the finite and infinite horizon problems, the $\tilde{\delta}_i^*$'s are again zero, implying that there is no inflationary bias. The fact that the optimal policy (of the government) is constructed using a dynamic program, again implies *weak time consistency*, *weak* because the future is not completely decoupled from the past, the coupling being through the current (optimal) value of the forecast error covariance $\sigma^2_{i|i-1}$. To give a precise mathematical description for this important feature, let $\gamma := \{\gamma_i\}_{i=0}^N$, $\delta := \{\delta_i\}_{i=0}^N$, $\gamma_{(n)} := \{\gamma_i\}_{i=0}^{n-1}$, $\delta_{(n)} := \{\delta_i\}_{i=0}^{n-1}$. $\gamma^{(n)} := \{\gamma_i\}_{i=n}^N$. $\delta^{(n)} := \{\delta_i\}_{i=n}^N$, where N may also be taken to be *infinity*, to capture the infinite-horizon problem as well. Then, if γ^* is the Stackelberg solution (32) (or (36)) for the government, as discussed above, and δ^* is the corresponding forecast policy of the private sector (which is identically zero), for any n, the pair $(\gamma^{(n)*}, \delta^{(n)*})$ solves the Stackelberg game with objective functions

$$J_1(\gamma^{(n)}, \gamma^*_{(n)}; \delta^{(n)}, \delta^*_{(n)}), \quad J_2(\gamma^{(n)}, \gamma^*_{(n)}; \delta^{(n)}, \delta^*_{(n)}),$$

which is the (truncated) game derived from the original decision problem, with $\gamma_{(n)}$ and $\delta_{(n)}$ fixed at their optimal values. Note that this is a property enjoyed by the feedback Stackelberg solution (see, Simaan and Cruz (1973a,b), Başar and Olsder (1982), Başar (1989)) which is generally inferior to the (unrestircted) Stackelberg solution for the leader. Here, however, we have not imposed a priori the restriction of the feedback Stackelberg solution.

An important implication of the above is that with only *stagewise precommitment* (or instantaneous precommittment, using the terminology of Cohen and Michel (1988)), any possibility of the policy maker reneging at future stages to better his performance is completely ruled out. In other words, with stagewise precommittment, the government's Stackelberg policy (leading to zero inflationary bias) is *strategically credible.*

7 Conclusion

In this paper we have provided what we believe to be the first closed form solution to a noncertainty equivalent policy problem with rational expectations. Quite generally we have stressed that the considereation of the optimal Stackelbergy policy in dynamic models with rational expectations necessarily requires that the dual effect of the policy be taken into account. In particular the interaction of the policy with the learning process of the private sector must be fully recognized. In the case of the monetary policy model first introduced by Cukierman and Meltzer (1986), such a policy delivers a zero inflationary bias mimicking the corresponding result for the analysis by Barro and Gordon (1983). Another important property of the Stackelberg policy here is that with only stagewise precommitment on the part of the policy maker, it is strategically credible, being weakly time consistent. If the stagewise precommitment is not there, however, then the incentive for the policy maker to renege will always exist in this model, as in static or repeated Stackelberg games. One reason for this lies in the fact that private sector is essentially nonstrategic here, since the only role given to it is to passively form rationaly expectations. It would therefore be extremely important to formulate and study other (stochastic) models which support a strategic role for the private sector, and generate endogenous reputational policies as a part of the solution process involving a tradeoff between learning and strategic credibility.

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References

Başar, T. (1988): "Solutions to a class of nonstandard stochastic control problems with active learning", *IEEE Transactions on Automatic Control*, *AC-33*(12), 1122–1129.

Başar, T. (1989): "Time consistency and robustness of equilibria in noncooperative dynamic games", in *Dynamic Policy Games in Economics*, edited by F. Van der Ploeg and A. de Zeeuw, pp. 9–54, North Holland.

Başar, T. and A. Haurie (1984): "Feedback equilibria in differential games with structural and modal uncertainties", in *Advances in Large Scale Systems*, edited by J. B. Cruz, Jr., pp. 163–201, JAE Press Inc., Connecticut.

Başar, T. and G. J. Olsder (1982): "*Dynamic Noncooperative Game Theory*", Academic Press, London/New York.

Başar, T. and M. Salmon (1989a): "On the convergence of beliefs and policy to a rational expectations equilibrium in a dual policy problem", in *Issues in Monetary Economics*, edited by W. Marois, A. Soubeyran and D. Laussel, pp. 207–223, Springer Verlag.

Başar, T. and M. Salmon (1989b): "Inflation and the evolution of credibility with disparate beliefs", in *Proc. IFAC symposium on Dynamic Modelling and Control of National Economics*, pp. 111–116, Edinburgh, June.

Barro, R. and D. Gordon (1983): "Rules, discretion and reputation in a model of monetary policy", *J. Monetary Economics*, *12*, 101–122.

Cohen, D. and P. Michel (1988): "How should control theory be used to calculate a time consistent government policy?", *Review of Economic Studies*, *LV*, 263–274.

Cukierman, A. and A. Meltzer (1986): "A theory of ambiguity, credibility and inflation under discretion and asymmetric information", *Econometrica*, *54*, 1009–1128, September.

Kydland, F. and E. Prescott (1977): "Rules rather than discretion, the inconsistency of optimal plans", *Journal of Political Economy*, 85, pp. 473–493, June.

Lucas, Jr., R. E. (1976): "Econometric policy evaluation: a critique", in *The Phillips curve and Labor markets*, edited by K. Brunner and A. H. Meltzer, Amsterdam, North Holland.

Lucas, Jr., R. E. and T. Sargent (1981): "*The introduction to Rational expectations and Econometric Practice*", George Allan and Unwin.

Miller, M. and M. Salmon (1985): "Policy coordination and the time inconsistency of optimal policy in an open economy", *Economic Journal*, supplement, 124–135.

Simaan, M. and J. B. Cruz, Jr. (1973a): "On the Stackelberg strategy in nonzero sum games", *Journal of Optimization Theory and Applications*, *11*(5), 533–555.

Simaan, M. and J. B. Cruz, Jr. (1973b): "Additional aspects of the Stackelberg strategy in nonzero sum games", *Journal of Optimization Theory and Applications*, *11*(6), 613–626.

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