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THE COST OF CONFLICTING OBJECTIVES IN POLICY FORMULATION*

BY ROBERT S. PINDYCK

By applying Nash solution strategies for a linear-quadratic discrete-time differential game to a macroeconometric model, stabilization policies can be determined for the case when fiscal and monetary control are exercised by independent authorities who have conflicting objectives. Here we use the Nash algorithm to calculate the increased cost to each authority resulting from a conflicting objective of the other authority. These results can be applied to the analysis of recent monetary and fiscal policy in the United States.

1. INTRODUCTION

One of the limitations of recent applications of optimal control theory to economic stabilization policy [3, 4, 5, 7, 10, 11, 12, 13, 14] has been a failure to account for the fact that macroeconomic control in the United States is decentralized. In particular, monetary and fiscal policy are exercised by separate authorities that are largely independent of each other, and that may have conflicting objectives. This separation of monetary and fiscal control may considerably limit the ability of *either* authority to stabilize the economy, particularly when the conflict over objectives is at all significant. Because monetary policy operates with long lags and fiscal policy with short lags, the proper time-phasing of the two can be critical. Thus monetary and fiscal policies designed with different objectives in mind may result in economic performance that is far from either objective.

In a previous paper [15] this author studied the problem of decentralized policy making with conflicting objectives by calculating open-loop and closed-loop Nash strategies for a linear-quadratic discrete-time differential game, and applying the strategies to a small macroeconomic model. The results seemed to indicate that conflict situations could indeed result in a deterioration of economic performance, particularly in the short term. Of course Nash strategies are based on a restricted set of assumptions about the nature of the conflict and the characteristics of the decision making processes, and alternative assumptions (e.g. Stackleberg strategies or more complicated strategies) could yield different results about the effects of conflicting objectives. The use of Nash strategies, however, at least provides a first approach to the problem, and has an advantage of computational tractability.

In this paper we review the approach and results described in [15]. In addition, we use the Nash algorithm and the small econometric model to calculate the increased cost to each authority resulting from a conflicting objective on the part of the other authority. This allows us first to quantify the "sub-optimality"

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resulting from conflict, and second to better determine which, if any, authority (fiscal or monetary) has an advantage—i.e. is better able to reach its own objectives.[1] Finally, we evaluate the implications of these results for macroeconomic policy.

2. Stabilization Policies Under Decentralized Control

Our analysis begins with the assumption that each authority arrives at its policy using the same econometric model (i.e. each has the same view of the way the world works), but that the two have different sets of objectives. The econometric model is linear, so that we can represent it in state variable form as

$$x_{t+1} - x_t = Ax_t + B_1 u_{1t} + B_2 u_{2t} + Cz_t \tag{1}$$

with initial condition $x_0 = \xi$. Here x_t is a vector of n state variables, u_{1t} and u_{2t} are vectors of r_1 and r_2 control (policy) variables manipulated by the fiscal and monetary authorities respectively, and z_t is a vector of s uncontrollable exogenous variables whose future values are known or can be predicted. A, B_1, B_2, and C are $n \times n$, $n \times r_1$, $n \times r_2$, and $n \times s$ matrices respectively.

Each authority chooses an optimal trajectory (a "strategy") for its own set of control variables over the time period $t = 0, 1, \ldots, N-1$. The first authority chooses its strategy $\{u_{1t}\}$ to minimize its cost functional

$$J_1 = 1/2(x_N - \hat{x}_{1N})'Q_1(x_N - \hat{x}_{1N}) + 1/2 \sum_{t=0}^{N-1} \{(x_t - \hat{x}_{1t})'Q_1(x_t - \hat{x}_{1t}) + (u_{1t} - \hat{u}_{1t})'R_{11}(u_{1t} - \hat{u}_{1t}) + (u_{2t} - \hat{u}_{2t})'R_{12}(u_{2t} - \hat{u}_{2t})\} \tag{2}$$

and the second authority chooses its strategy $\{u_{2t}\}$ to minimize its cost functional

$$J_2 = 1/2(x_N - \hat{x}_{2N})'Q_2(x_N - \hat{x}_{2N}) + 1/2 \sum_{t=0}^{N-1} \{(x_t - \hat{x}_{2t})'Q_2(x_t - \hat{x}_{2t}) + (u_{1t} - \hat{u}_{1t})'R_{21}(u_{1t} - \hat{u}_{1t}) + (u_{2t} - \hat{u}_{2t})'R_{22}(u_{2t} - \hat{u}_{2t})\}. \tag{3}$$

Here $\hat{x}_{1t}$ and $\hat{x}_{2t}$ represent nominal (desired) values for the state variables from the points of view of authorities 1 and 2 respectively, and similarly $\hat{u}_{1t}$ and $\hat{u}_{2t}$ represent nominal values of the control variables for each authority. The matrices Q_1 and Q_2 represent, for each authority, the relative weights assigned to deviations from the nominal paths for each state variable, and R_{11} and R_{22} designate the relative weights that each authority assigns to deviations from the nominal path for *its own* control variables. R_{12} and R_{21} designate the relative weights that each authority assigns to deviations from the nominal path for the *other* authority's control variables; thus these matrices indicate how important it is for each authority that the other authority stay close to its policy variable targets.[2] If R_{12} is

[1]In [15] it was found that relative advantage depended considerably on the particular objectives over which the conflict arises. Here we will consider only the objectives of reducing the unemployment rate and reducing the rate of inflation.

[2]A non-zero element in one of these matrices might indicate, for example, that the monetary authority considers it somewhat important that the fiscal authority keep government spending close to the target path for government spending *specified by the fiscal authority.*

large (relative to Q_1 and R_{11}) then authority 1 will design *its* strategy so as to force authority 2 to keep its policy variables close to their nominal paths.[3]

The deterministic discrete-time differential game described above can be "played" in two alternative ways:

(a) Each authority designs its optimal policy (based on its own objectives) at the beginning of the planning period, and then sticks to that policy throughout the entire planning period. This is called an *open-loop* strategy. In effect, the optimal controls u_{1t}^* and u_{2t}^* depend, at any time t, on the initial condition x_0.

(b) Each authority designs a *control rule* at the beginning of the planning period, and then uses that control rule, together with observations of the state of the economy, to continuously revise his policy. This is called a *closed-loop* strategy. In this case the optimal controls u_{1t}^* and u_{2t}^* depend on the current state x_t.

The closed-loop strategy should not be confused with the notion of closed-loop optimal control in the centralized case. Our planning problem is *deterministic*, so that closed-loop behavior implies adaptation not to the impact of random shocks, but rather to the evolving strategy of the other authority. A closed-loop strategy for a particular problem may differ considerably from an open-loop strategy, since it is arrived at under a very different set of assumptions. Note also that the matrices R_{12} and R_{21} are relevant only to closed-loop strategies. Non-zero values for these matrices imply that one authority will try to influence the policy of the second. In the open-loop mode the two authorities cannot influence each other's policies, and R_{12} and R_{21} do not appear in the open-loop solutions.

3. Nash Solution Strategies

Nash solutions to this differential game are defined as the trajectories (u_1^*, u_2^*) that satisfy the conditions:

(4) $$J_1(u_1^*, u_2^*) \leq J_1(u_1, u_2^*)$$

and

(5) $$J_2(u_1^*, u_2^*) \leq J_2(u_1^*, u_2)$$

for all possible u_1 and u_2. Nash solution algorithms for both the open-loop and closed-loop cases have been derived, and are described in detail elsewhere [15].

It is important to point out that Nash solutions need not be unique. Friedman [6] "proved" the uniqueness of Nash solutions for deterministic two-person decision problems with linear state dynamics and quadratic cost criteria, but in so doing he ignored the fact that alternative assumptions can be made regarding memory restrictions on the controls. As Basar [1] recently demonstrated, these alternative assumptions can result in different Nash equilibrium solutions. For

[3]Some restrictions must be placed on the matrices Q_1, Q_2, R_{11}, and R_{22}. We assume that Q_1 and Q_2 are positive semi-definite, and that R_{11} and R_{22} are positive definite. We put no restrictions on R_{12} and R_{21}. For most economic problems all of these matrices will be diagonal, although it is not essential that this be the case.

example, the open-loop solution assumes that the controls u_{1t} and u_{2t} depend only on the initial state x_0, while the closed-loop solution typically assumes that u_{1t} and u_{2t} depend only on the current state x_t. One might instead assume a dependence of the controls on last period's state, or on some weighted average of past states. These assumptions would generally yield different solutions, so that there might not be a *single* Nash equilibrium.[4]

In applying Nash solution strategies to the problem of economic stabilization policy, it seems most reasonable to work only with the simple open-loop and closed-loop cases, calculating strategies based on the usual linearity and (in the closed-loop case) "no memory" restrictions. The point here is that our objective is neither to predict nor prescribe monetary and fiscal policies for two conflicting authorities; rather it is to use the Nash solution concept as a tool to analyze the characteristics of conflicting policies and the characteristics and degree of degradation in economic performance that results from conflict. In performing this exercise we must keep in mind that we are considering only one particular set of Nash solutions, and alternative assumptions could yield different Nash solutions—just as alternative formulations of the basic conflict model could yield different *non-Nash* solutions (see [15]). We must leave to future research the problem of how alternative assumptions effect the characteristics of the solutions.

The effect of a conflict situation on macroeconomic performance was studied by applying the open-loop and closed-loop Nash algorithms described above to a small linear econometric model.[5] Despite the size and simplicity of the model, the results do illustrate some of the general characteristics of decentralized policies and some of the general implications of conflicting objectives.

We found, for example, that when the conflict is between unemployment and inflation, the fiscal objectives will be more nearly met. This is particularly the case in the closed-loop mode, and is a result of the longer lag inherent in monetary policy. Certain targets, however, can be reached only by a particular authority; rapid increases in residential investment, for example, will not be achieved unless it is an objective shared by the monetary authority or is indirectly linked to some other monetary objective. In addition, the results indicated that the "suboptimality" resulting from a conflict situation could indeed be severe, but only in the first four to six quarters of the planning period. After about six quarters a "compromise" behavior begins to occur where neither authority is as close to its targets as it would be in a cooperative situation, but there are no wide deviations from targets as a result of time-phasing problems arising from the conflict.

None of these results are particularly surprising (which reinforces the meaningfulness of Nash solution strategies). It makes intuitive sense, for example, that

[4] Assumptions can also be made regarding a *nonlinear* dependence of the controls on current and past states, and this will also result in different Nash solutions. For a discussion of this problem, see Basar [1].

[5] The results are described in [15]. The model was constructed and used by this author in earlier studies of optimal stabilization policies, and is described in detail in [13]. The model contains nine behavioral equations that explain consumption, nonresidential, residential, and inventory investment, short and long-term interest rates, the price level, the unemployment rate, and the money wage rate, as well as a single tax relation and an income identity. Fiscal control is exercised through government expenditures (the model contains a surtax as a second fiscal policy variable, but this is fixed at zero in order to simplify the experiments), and monetary control through the money supply.

over time a conflict in objectives would be "resolved" by implicit compromise. Macroeconomic policy, however, is often designed with rather short time horizons in mind, and objectives may change from year to year. Thus there is little consolation in the fact that economic performance suffers the most from conflicting objectives only in the first year or so. It would be useful to measure the economic "cost" of conflicting objectives; if that "cost" is high it might suggest the desirability of institutional changes that would result in better fiscal-monetary coordination.

4. The Costs of Conflicting Objectives

The costs of one or another economic "trajectory" have meaning in the context of particular objectives; if a low unemployment rate is a policy objective, then a cost can be associated with a high unemployment rate. When optimal economic policies are calculated in the centralized case, costs are specified through a scalar-valued cost functional, and the policies are considered optimal in that the cost functional is minimized. Presumably the cost functional reflects the overall objectives of the groups or individuals who determine or influence economic policy (although it might not reflect the objectives of a majority, or even any part, of the population).

When control is decentralized and objectives differ it is not meaningful to associate a single "cost" with a particular economic trajectory. In the context of our analysis, each authority will associate its own cost with any economic trajectory, and that cost is specified by the authority's own cost functional. We therefore measure the costs of conflicting objectives for each authority, and see how those costs depend on the policy (i.e. the extent of conflict) of the other authority.

We will examine a single example of conflict—the fiscal authority wishes only to reduce the rate of inflation (so that Q_1 has a weight only on the price level), while the monetary authority wishes only to reduce the unemployment rate (so that Q_2 has a weight only on that variable). (The costs for other conflicts are likely to be quite different, but our main purpose here is simply to illustrate an approach to the problem.)

We are interested in how the cost to each authority increases as the other authority has increasing flexibility to pursue its own conflicting objective. We therefore evaluate the cost functionals J_1 and J_2 as follows. First, the money supply is tied to its nominal path (by attaching a large weight to it in R_{22}) while government spending is allowed to move with relative flexibility (a low weight is attached to it in R_{11}). Nash solutions are determined for the econometric model, and J_1 is evaluated. Next, the money supply is allowed to move somewhat more freely by reducing its weight in R_{22}, and J_1 is again evaluated. This is repeated several times, each time reducing the weight of the money supply in R_{22}, until the money supply is given as much flexibility as is government spending. The above steps are repeated for the monetary authority, i.e. J_2 is evaluated, first with government spending tied to its nominal path, and then with government spending allowed to move more and more freely.

The Nash strategies—and resulting economic trajectories—are calculated over a time horizon of twenty quarters, beginning with 1957-I and ending with

1962-I. The nominal trajectories $\{\hat{x}_{1t}\}$ and $\{\hat{x}_{2t}\}$ are taken to be the same for both authorities, so that differences in objectives are expressed by assigning different weights in Q_1 and Q_2. This is done only to simplify the example; it is reasonable to expect different authorities to have different nominal trajectories. In particular, the price level is assigned a weight of 120 in Q_1, and the unemployment rate is assigned a weight of 4×10^7 in Q_2 (all other coefficients in Q_1 and Q_2 are zero). These weights are equivalent in terms of percentage deviations (squared) from mean values. For the nominal trajectories $\{\hat{u}_{1t}\}$ and $\{\hat{u}_{2t}\}$ we take a four percent annual rate of growth for government spending (in real terms) and a four percent rate of growth in the money supply. The matrices R_{12} and R_{21} are set equal to zero. All of the solutions are calculated under open-loop assumptions. This was done partly to minimize computational expense, but also because the open-loop assumption is most basic, and, in the case of short-term policy, probably the most realistic. Overall directions in monetary policy, and certainly fiscal policy are not usually adjusted from quarter to quarter.[6]

The results are summarized in Table 1. Note that the cost to the fiscal authority of monetary "dissension" is quite small; J_1 increases by only about 4% between runs A1 and A7. The cost of a conflict to the monetary authority can be much higher however; J_2 more than doubles between runs B1 and B7. As the fiscal authority is given more flexibility it reduces government spending (Figure 1) so as to reduce increases in the price level (Figure 2). The monetary authority incurs added costs as it attempts to compensate by increasing the money supply more rapidly (Figure 3) and as the unemployment rate becomes higher (Figure 4).

TABLE 1

COST INCREASES FOR FISCAL AND MONETARY AUTHORITIES

Run #	$R_{11}(G)$	$R_{22}(\Delta M)$	J_1	J_2
A1	30	1.5×10^4	1.000	
A2	30	5000	1.001	
A3	30	1500	1.004	
A4	30	800	1.008	
A5	30	400	1.017	
A6	30	200	1.032	
A7	30	150	1.041	
B1	1×10^5	150		1.000
B2	3×10^4	150		1.001
B3	3000	150		1.017
B4	800	150		1.066
B5	300	150		1.176
B6	80	150		1.636
B7	30	150		2.470

(Note: The numbers for J_1 and J_2 have been normalized as the ratio to their values in runs A1 and B1 respectively. In all cases $Q_1(P) = 120$ and $Q_2(UR) = 4\times 10^7$.)

[6]It might be pointed out that an equilibrium Nash solution in the class of open-loop strategies is also an equilibrium Nash solution in the class of closed-loop strategies. In particular, the open-loop strategy is that closed-loop strategy with the particular memory restriction that the controls depend only on the *initial state* x_0. Of course in our calculation of closed-loop strategies we assume the memory restriction that the controls depend only on the current state x_t.

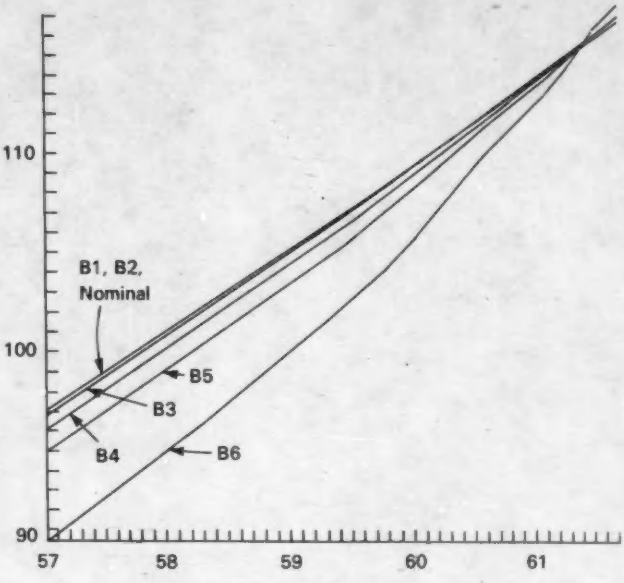

Figure 1 Government spending . . . Runs B1 to B6

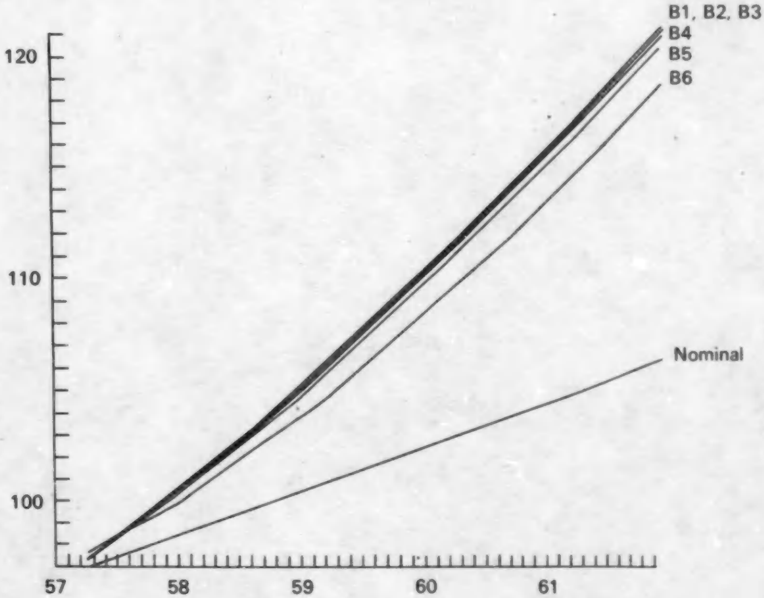

Figure 2 Price level

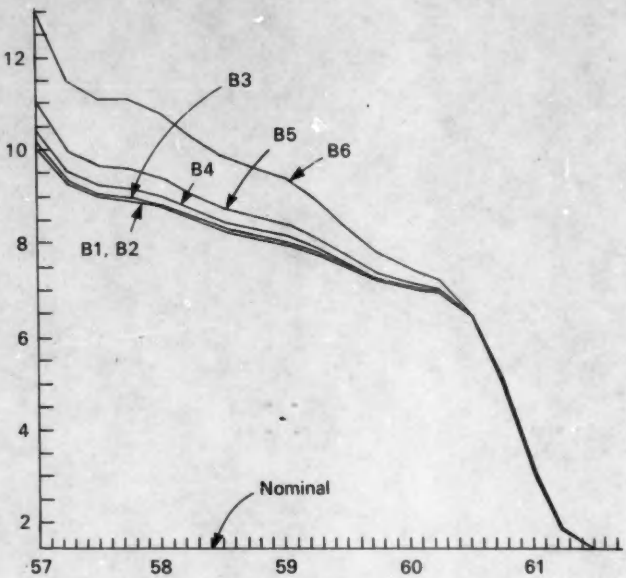

Figure 3 Quarterly change in money supply

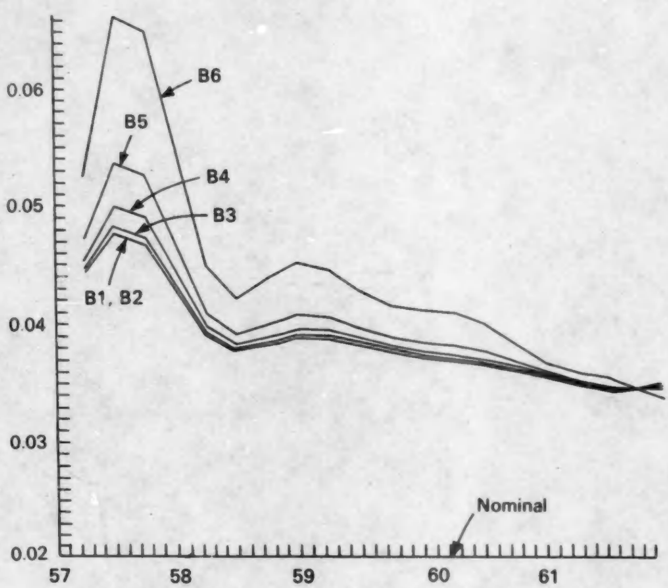

Figure 4 Unemployment rate

The difference in relative costs is not due to the fact that for the particular econometric model used here the fiscal multipliers are considerably larger than the monetary multipliers; this was already accounted for in setting the relative weights in R_{11} and R_{22}. The major reason for the difference is the longer time lag inherent in monetary policy. Several quarters must pass before changes in the money supply have any effect on GNP (and the unemployment rate), so that the fiscal authority is more "cost-effective" in reaching its targets. (The difference would be even larger if the solutions were computed using the closed-loop algorithm.)

One should not conclude from these results that monetary policy is ineffective and that there is no cost from conflicting objectives as long as you hold the same view as the fiscal authority. To begin with, a conflict can involve certain target variables over which the monetary authority has greater control (e.g. residential investment), and in this case the fiscal authority will incur the greatest cost from the conflict. However, even when the conflict is focused on the trade-off between inflation and unemployment, as it was here, it may in fact result in high costs to both authorities. The reason is that the specification of our experiments has in a way stacked the deck in favor of the fiscal authority. For while it is true that monetary policy operates with longer lags than fiscal policy, it is also the case that fiscal variables (government spending, taxes) cannot be manipulated as frequently and as freely as monetary variables. The limitation on the ability of the fiscal authority to manipulate its policy variables would probably reduce significantly the fiscal "advantage" that we observe in Table 1.

It would be interesting to repeat the analysis, but constraining government spending so that it can change in value only once per year, while the money supply is allowed to change more frequently (quarterly or monthly). Unfortunately, when the problem is framed this way, a solution becomes much more difficult to obtain. I expect, however, that were a solution to be obtained, it would indicate that the costs of conflicting objectives can be high for *both* authorities.

Our results are probably too preliminary to provide specific conclusions about the effectiveness of recent fiscal and monetary policy. The fiscal-monetary conflict over inflation and unemployment during 1974 and early 1975 is a good example (in reverse) of the hypothetical conflict that we created as an example for this paper. During these recent years, however, the fiscal authority did not enjoy the advantage that our results would have indicated. Better insight into recent fiscal-monetary conflicts might be obtained if the approach of this paper were extended in several ways. First, as suggested above it is necessary to account for the relative inflexibility of fiscal policy. Second, the analyses should include the changes in policy objectives that occur on an irregular but frequent basis. Finally, large and more realistic econometric models should be used, allowing for both a richer description of economic structure and the inclusion of a more complete set of policy variables and parameters.

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References

[1] T. Basar, "A Counter Example in Linear Quadratic Games: Existence of Non-linear Nash Solutions," *Journal of Optimization Theory and Applications*, Vol. 14, No. 4, 1974.

[2] C. Y. Chong, "On the Decentralized Control of Large-Scale Systems," MIT Electronic Systems Laboratory, Technical Report ESL-R-503, June, 1973.

[3] G. C. Chow, "How Much Could be Gained by Optimal Stochastic Control Policies," *Annals of Economic and Social Measurement*, October, 1972.

[4] J. P. Cooper and S. Fischer, "A Method for Stochastic Control of Non-Linear Econometric Models and an Application," *Econometrica*, January, 1975.

[5] R. C. Fair, "On the Solution of Optimal Control Problems as Maximization Problems," Princeton University Econometric Research Memorandum, No. 146, February, 1973.

[6] A Friedman, *Differential Games*, John Wiley and Sons, New York, 1971.

[7] B. M. Friedman, *Methods in Optimization for Economic Stabilization Policy*, North-Holland Publishing Company, 1975.

[8] Y. C. Ho, "Differential Games, Dynamic Optimization and Generalized Control Theory," *Journal of Optimization Theory and Applications*, September, 1970.

[9] Y. C. Ho and K. C. Chu, "Team Decision Theory and Information Structures in Optimal Control Problems—Part 1," *IEEE Transactions on Automatic Control*, February , 1972.

[10] R. S. Holbrook, "A Practical Method for Controlling a Large Non-Linear Stochastic System," unpublished paper, May, 1973.

[11] D. Kendrick and J. Majors, "Stochastic Control with Uncertain Macroeconomic Parameters," unpublished paper, 1973.

[12] D. A. Livesey, "Optimizing Short-Term Economic Policy," *Economic Journal*, September, 1971.

[13] R. S. Pindyck, *Optimal Planning for Economic Stabilization*, North-Holland Publishing Company, Amsterdam, 1973.

[14] R. S. Pindyck, "Optimal Policies for Economic Stabilization," *Econometrica*, May, 1973.

[15] R. S. Pindyck, "Optimal Stabilization Policies Under Decentralized Control and Conflicting Objectives," MIT Sloan School Working Paper No. 765-75, January, 1975.

[16] A. W. Starr and Y. C. Ho, "Nonzero-Sum Differential Games," *Journal of Optimization Theory and Applications*, Vol. 3, No. 3, 1969.