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To: Federal Open Market Committee

From: Arthur L. Broida

Attached are the first four sections of the Interim Staff Report: Stage II for the Subcommittee on the Directive. The remaining two sections should be completed and ready for mailing early next week.

Attachment

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# INTERIM STAFF REPORT: STAGE II

# FOR THE SUBCOMMITTEE ON THE DIRECTIVE

John H. Kalchbrenner

# Interim Staff Report: Stage II
# For the Subcommittee on the Directive

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## Introduction 1/

The Subcommittee on the Directive reported its findings and conclusions from the first stage of its investigation in March 1975. While the more limited objectives of Stage I were being achieved, research proceeded on the broader inquiry encompassed by the second stage of the Subcommittee's research program. The second stage of the research program focussed on the question of the appropriate role of intermediate targets, such as the monetary aggregates, in the determination and conduct of monetary policy. The analysis of the role of intermediate targets led to investigation of such related questions as relationships among operating, intermediate and ultimate targets; the appropriate policy responses to incoming information and forecast errors; and how best to take account of uncertainties concerning the structure of the economy, the current position of the economy and the likely course of important exogenous variables.

1/ In the preparation of this report, the author received helpful guidance and comments from many individuals. Thanks are due to the members of the Subcommittee and S. Axilrod for pointing out and providing assistance in areas that needed special attention or that were inadequately developed. J. Enzler, J. Kareken, M. Keran, W. Poole and P. Tinsley were especially helpful in providing contributions, interpretations, and comments. The author also wishes to express appreciation to the individual researchers throughout the System for completing the project in a timely fashion and for providing valuable interpretations. Of course, none of those mentioned is responsible for any remaining errors in the report. Special thanks are due J. Pierce who organized the Subcommittee on the Directive research program and guided a large portion of the work to its completion. Mary Flaherty bore the burden of typing this report and numerous memoranda, as well as coordinating the duplication and distribution of the large number of research papers. Her efficiency saved the author from total innundation, and her help is gratefully acknowledged.

A major part of recent macroeconomic analysis has been conducted in the framework of single equation relationships or relatively small analytical models that include little institutional or sectoral detail. Many of the policy-related propositions that have occupied center-stage in macroeconomics in recent years have been derived from analyses of such relatively simple formulations. Unfortunately, while their simplicity makes possible rigorous analysis, this same simplicity limits the questions that can be considered or the alternative hypotheses that can be tested effectively. While progress has been evident, too many issues remain unresolved, and seemingly contradictory propositions enjoy empirical support from the same data bases.

Recent macroeconomic analysis has also been done in the context of large structural econometric models that were developed principally for short-run forecasting applications. Because of the complexity of these models and the principal use for which they were designed, they are not amenable to application of the same techniques of analysis that can be used with simple formulations. Instead, the greater part of the policy analysis that has been conducted with these models has involved simulation techniques to analyze and illustrate such matters as policy multipliers, the results of alternative policy assumptions, model stability and alternative model structures. While the results of these efforts have been instructive, there remains a need for a method of analyzing important policy questions systematically and efficiently.

In the Stage II analysis of the Subcommittee, a technique is employed that has existed in economics for over twenty-five years, but has received relatively little use. The technique is called optimal control analysis. It provides a systematic method for analyzing policy questions that is equally applicable to simple or complex model constructions. More specifically, optimal control analysis permits explicit inclusion in the analysis of different degrees of uncertainty; it takes into account complex dynamic behavior efficiently, thereby permitting analysis of questions of timing of policy actions; it incorporates means of analyzing and correcting for forecast errors in operational situations; and it provides valuable information about the characteristics of the models to which it is applied. The results of this research effort, while they do not settle many of the open questions, provide the basis for a reorientation of thinking about a number of issues that have been focal points of debate in macroeconomic and monetary analysis in recent years, as well as suggesting several avenues of further research.

This report has four principal sections. The first section contains an overview of the optimal control analysis underlying the analysis of the questions addressed in the second stage of the Subcommittee research program. Section II applies optimal control analysis to the question of the role of instruments, information variables and targets in the determination of monetary policy. The second section also discusses the extent to which the issues remain open and the appropriate strategy to follow until these questions can be answered. The third section contains a number of suggested changes in FOMC and staff procedures that could be made currently. These changes, some of which stem from optimal control analysis and some from independent analyses, are principally designed to increase the effectiveness of the information and analysis provided to the FOMC in its determination of monetary policy. The final section contains a reappraisal of the Stage I analysis and conclusions. In addition to providing a re-specification of the Stage I empirical work that confirms the earlier findings, this section also contains an optimal control analysis of the question of choice of operating instruments or targets.

The report is not highly technical, although it introduces and uses the terminology of optimal control analysis. The intent is to provide a comprehensive summary of the Stage II research program that will be accessible to economists as well as to members of the Subcommittee and the Federal Open Market Committee. It is hoped the report will provide a helpful elaboration of the matters discussed in the Subcommittee on the Directive preliminary second stage report to the Federal Open Market Committee which necessarily treats the issues in a brief manner.

## II. An Overview of Optimal Control Analysis[2/]

### Introduction

Reliance on the techniques of optimal control theory underlies much of the analysis done during Stage II of the work of the Subcommittee on the Directive. Consequently, a brief non-technical introductory survey of relevant topics from optimal control analysis should aid understanding of many of the conclusions and recommendations that resulted from these efforts.[3/] Unfortunately, control analysis is not widely understood in the economics profession because of its mathematical complexity and the belief that it is an analytical technique of interest to only a limited audience concerned with a narrowly circumscribed set of problems.

More recently, however, it has been recognized that the techniques of optimal control are applicable to a broad variety of problems in economic analysis, both macroeconomic and microeconomic. Analysis of the rational expectations hypothesis, differential game behavior in the theory of oligopoly, and the implications of including uncertainty in general equilibrium analysis are among the more important examples of areas in which optimal control techniques are being applied. These techniques have also been applied to the theory of the firm, providing a potentially powerful tool for analyzing the impact of regulation on individual bank behavior.[4/]

2/ Peter Tinsley is the co-author of this section.

3/ More detailed discussions and further references can be found in Chow (4), (5), ( 6 ), Friedman (11), Kalchbrenner and Tinsley (14), Kareken and Miller (17) and Theil (33).

4/ Technically, in each of these areas the common element has been the application of a technique for optimization of objectives subject to stochastic constraints and imperfect information.

In concept, optimal control analysis is not a recent development. The basic techniques have been employed in macroeconomics for more than twenty years in varying forms. Early work concentrated on the problems of economic stabilization policy in the context of deterministic models (i.e. models with no uncertainty), or models in which simplified representations of uncertainty could be dealt with by using the mathematical expectations of stochastic (uncertain) relationships and proceeding as if the model were deterministic. Recent work has extended the analysis to more complex non-linear models and less restrictive treatments of the nature of uncertainty in econometric models. These extensions of optimal control techniques were made possibly by generalizations of numerical techniques developed for aerospace applications in electrical engineering.

Optimal control studies have not been confined solely to theoretical analysis. Significant progress has been made in the devlopment of the computational techniques that are required to be able to apply optimal control methods to large-scale, non-linear econometric models such as the quarterly econometric model used in the Federal Reserve System.[5/] Even though theoretical questions remain unanswered and there are many unexplored applications of existing control theory, the analysis can already be applied in a limited fashion to quite complex and realistic situations.

Optimal Control Methods

In reaching policy decisions, the monetary authority has available a limited number of instruments or control variables that are under

5/ Examples of the application of control theory to large scale systems can be found in Craine, Havenner and Tinsley ( 9 ) and Kalchbrenner and Tinsley (15).

the direct control of the authority and can be manipulated in order to achieve desired broad economic objectives. The decision process is complicated first by the fact that economic behavior is imperfectly understood and is subject to change through time. The problem is further complicated by the fact that all of the likely objectives or ultimate targets cannot in general be achieved simultaneously with the limited number of policy instruments that are available.

In the context of monetary policy decision-making, the relevance of optimal control analysis stems from what might be labeled the "policy problem." The policy problem is to determine the optimal manner in which to set or manipulate the policy instruments in order to come as close to achieving the policy objectives as possible. As is the case in many problems in economic analysis, choosing the optimal policy strategy reduces fundamentally to an optimization problem of maximization or minimization. Put in simplest terms, optimal control analysis is nothing more than a set of rules for efficient calculation of solutions to the policy problem. The solution to an optimal control problem provides a rule (the policy strategy) for setting the policy instruments over a planning horizon that will minimize the (expected) deviations from desired targets, given the constraints imposed by the assumed behavior of the economic system and any further restrictions placed on the behavior of the component parts of the system. Among the constraints imposed by the economy are the limits to output at any time as determined by productive-capacity and resources, or the fact that fiscal policy actions must somehow be financed, causing secondary effects throughout the economy. Other constraints, such as concern about the effects of monetary policy on housing or state and local finance, also limit the freedom of monetary policy actions.

From this discussion, it is apparent that an explicit representation of the economic system--a model of the economy--is required in order to be able to apply optimal control analysis. This model must relate the policy instruments or control variables to the ultimate target variables, or the model provides no guidance in making policy decisions. The model itself represents a system of constraints in the sense that policy actions are transmitted by means of the given model relationships, most often indirectly.

The second principal requirement of optimal control analysis is an explicit representation of the policy objectives. This is referred to variously as the criterion, the loss function or the objective function. In economics, the loss function to be minimized has been written most often in terms of the weighted squared deviations of actual values from the desired targets or objectives. In addition to the policy objectives, the loss function often also includes additional ad hoc policy constraints, such as restrictions on the volatility of policy instruments or other variables. Conceptually, these ad hoc considerations can be accommodated by more detailed modeling of the impact of policy instruments. By definition, the optimal solution to the control problem is the solution that minimizes this loss function (or its expectation). The popularity of the quadratic form stems from its mathematical tractability, but other more complicated representations of the loss function can and have been employed in deterministic control problems.[6/]

The appropriate specification of the loss function poses one of the significant problems for application of optimal control analysis. At the theoretical level, it is often objected that the loss functions typically used are largely ad hoc and provide only a gross, perhaps badly distorted, approximation of the true objectives of policy makers or society in general. On the other hand, it should be noted that this problem exists not because a complicated objective function cannot be incorporated in optimal control analysis, but because such a function is, in fact, not known. As a consequence, the same objection can be raised in any policy decision context, and the problem does not disappear simply because no attempt is made to be explicit. In the absence of a loss function based on true social welfare criteria, it can be argued that the currently available variations on the simple quadratic form (or alternative mathematical forms) can approximate adequately the objectives that policy makers seek in practice, so long as the end results are interpreted carefully and cautiously.

Optimal control analysis can be approached from several levels of complexity and realism. The simplest case is the single-period horizon, deterministic example studied by Tinbergen where the policy objectives can be achieved exactly if the number of policy instruments equals the number of

6/ For examples, see Friedman (11), Kalchbrenner and Tinsley (15) and Ando and Palash ( 1). Also see Waud (37).

policy objectives. In this case, the settings required to achieve the objectives can be determined directly without the need to minimize a loss function.[7/] But if the number of instruments is less than the number of targets, a loss function must be employed in order to determine the solution because the structure of the model (the constraints) will generally mean that the desired target variables cannot all be achieved simultaneously. Where the desired objectives are inconsistent in this sense, the role of the loss function is to define the extent to which each objective should be achieved given the preferences and weights specified in that function. Solutions to highly oversimplified problems of this type also provide examples of the sensitivity of the solution to the choice of variables that appear in the loss function, as well as to the weights that are assigned to these variables. At the risk of belaboring the obvious, it should be noted that there will be a different optimal solution associated with each loss function. A single, global optimal solution does not exist except in the abstract world in which it is possible to posit a generalized macroeconomic social welfare function.

The second level of complexity involves the addition of additive random error terms (random intercepts) to the model in order to reflect the uncertainty associated with economic behavior as well as the inadequacies of models in representing the true economic structure. The optimal control solution in this case can be obtained by applying the certainty equivalence theorem. This theorem demonstrates that an optimal policy is obtained by deterministic solution methods after all the additive random elements are replaced by their mathematical expectations.

7/ It is usually not necessary to specify tradeoffs among policy objectives when the number of policy instruments is greater than or equal to the number of policy objectives. See Tinbergen (34).

The situation becomes more complicated when account is taken of dynamic characteristics of the economy system under uncertainty, and longer horizons are included in the solution. Under these circumstances, the optimal control solution must determine a path of settings for the policy variables that will minimize the expected value of the loss function over the entire planning horizon.

The exact specification of the policy horizon involves several issues. Theoretically, the policy horizon should approach infinity because the objectives of public policy are the objectives of a nation which has no finite life-span. In practice, however, the policy horizon that can be used will be limited by the availability of econometric models that maintain reasonable properties as the analysis is extended forward in time.

Given the long lags that most econometric studies indicate are involved in realizing major price effects, restrictions on the magnitude of changes in the policy instruments in the short run, and the likely importance of price behavior in policy objective functions, the policy horizon should be at least three to five years. Initial explorations of policy horizons of this length have uncovered stability problems with some econometric models that were designed principally for use in short-run forecasting. In addition, it becomes more important in the context of long horizon problems to investigate the implications of uncertain forecasts of non-controlled exogenous variables such as fiscal policy actions.

There are means of getting around these difficulties, even though they are not totally satisfactory. It is not difficult to use two to three year horizons in practice, and if the solutions are recalculated every quarter over a moving horizon, the dangers of myopic solutions are lessened considerably. In addition, it is possible to impose constraints on values of important variables such as the policy instruments that inhibit the solution to the optimal control problem from ignoring price or other effects beyond the horizon. Finally, the sensitivity of the control solution to alternative assumptions about the behavior of uncertain forecasts of exogenous variables can be examined in order to gain perspective on the likely risks involved.

In the extension to the multi-period policy horizon under uncertainty, there are two traditional methods of obtaining the optimal control settings. The first is an open-loop strategy based on the principle of first-period certainty equivalence, and the second is a closed-loop strategy derived by dynamic programming.

In the case of linear models and quadratic loss functions, the single-period certainty equivalence analysis has been extended to the multi-period case. As before, all random variables in the model are set at their conditional expectations, and the system is solved as a multi-period deterministic problem. However, only the policy instrument solution for the first period is executed. For this reason, this procedure is referred to as <u>first-period certainty equivalence</u>. At the end of the first period, the estimated position of the economy is then adjusted for measurements of economic activity that were received during the period.[8/] The alternating process of deterministic optimization and measurement is then repeated sequentially for each of the remaining periods in the policy horizon. This process is referred to as a feedback procedure.

For any period in the feedback procedure, the optimal instrument setting of that period is a function of both past measurements and forecasts of future behavior of the economy. Note that the forecasts of the economy are a function of the distributed lag effects of both current and future settings of the policy instruments. Thus, the optimality of the current instrument setting can only be evaluated in the context of the optimal path of the instruments over the entire planning horizon. Therefore, the planning horizon should be of some reasonable length relative to the distributed lag impact of the instrument, regardless of the fact that the plan for future instrument settings will be revised by measurements in subsequent periods.

If the solution determined for the control instruments for each period were applied without subsequent modification as new information became available, the policy strategy would be termed an open-loop strategy. As noted, only the first period choice of the instruments would be truly

8/ That is, the conditional expectations of the random variables are sequentially updated. For an example of this procedure, see Kalchbrenner and Tinsley (15).

optimal under this strategy, essentially because it ignores the fact that new information will become available on future residuals or model forecast errors. If the observations on the residuals, or the new initial conditions, are taken into account and the open-loop strategy is recalculated each period by applying first-period certainty equivalence, the policy strategy is referred to as open-loop with feedback.

Under an open-loop with feedback procedure, a path of settings for the control instruments is based on the initial conditions and the forecasts of the exogenous variables, with the knowledge that only the first period solution would be executed. The entire solution path is only conditionally optimal given current information and will be revised when future information becomes available. The path solution is recalculated each period to determine the next period control setting and the conditional path over the remainder of the horizon, based on the most recent information. Because of the need to recalculate the entire solution each period this procedure is inefficient, but it has the important advantage that it can be and is applied to complex problems in practice. It has the additional advantage of making explicit the expected results of the policy strategy each time the latest information is taken into account.

The second method of obtaining the optimal control solution is based on dynamic programming. By this method, instead of determining expected optimal instrument values for all periods in the planning horizon, the solution is in the form of a control rule or feedback control function which can be applied period-by-period, thereby automatically taking new information into account as events unfold. The instrument choice is made at the beginning of each period, for that period only, on the basis of a solution rule that indicates the optimal response to conditions at the beginning of that period. The rule itself is dependent on the loss function and the structure of the model that is employed, and will, therefore, vary according to the circumstances under which it is derived.

In contrast to the open-loop procedure, a feedback control function provides a period-by-period update and revision of the control settings for the subsequent period in response to revised initial conditions, and does not explicitly indicate what happens to future control instrument settings. Intuitively, the rule might be interpreted as relating revisions in open-loop instrument settings to realized forecast errors.[9/] Because the rule implicitly imbeds or contains allowance for future exogenous variables and other characteristics of the economic system; it is not a fixed rule in the sense of a rule dictating steady money growth or some other fixed response. The parameters of a feedback control function vary over time as the underlying situation to which it is being applied is altered.

The feedback control function is derived by dynamic programming techniques based on the principal of optimality.[10/] This principal states that an optimal policy has the property that whatever the initial conditions and the initial decision, the implied remaining decisions must be optimal with respect to the initial conditions resulting from the first decision. Determination of an optimal path can be determined most efficiently by working backward in much the same way that the most efficient way to find the path through a maze is to begin at the exit and work backward to the

9/ For linear models and quadratic loss functions, the open-loop strategy can also be formulated in an explicit feedback form. In so doing, the levels of the open-loop control settings are related to the initial conditions of the economy, and future values of the exogenous variables are implicitly imbedded in the parameters of the feedback rule. See Kalchbrenner and Tinsley (14).

10/ See Bellman ( 2).

entrance gate. By proceeding in this manner all paths that do not lead to the exit are ruled out, and this is an efficient means of ensuring that the path to the exit will be optimal from each point along the solution path. The dynamic programming method determines what is referred to as a closed-loop or explicit feedback solution to the control problem.

There are several advantages to using this solution format. In announcing the basis of the plan or the strategy, it is clear that the plan is contingent on actual occurrences. Intended actions will not be carried through unless forecasts of future events are realized, so it is not necessary to announce and explain a revised plan each time new information dictates a change. In addition, it is convenient to compare the outcome of applying the rule with competing reaction rules that are often proposed, including the no-response rule. Finally, as indicated, it is an efficient procedure that avoids recalculating the entire solution each period.

Nevertheless, there are also disadvantages to using the closed-loop approach. It appears to be an automatic reaction rule. And, without additional steps, it does not permit direct examination of the expected sequential effects of the action prescribed. Finally, except under the special case of a linear model and a quadratic loss function, the feedback control rule is difficult to compute for all but very simple models.

If the objective function is quadratic and the econometric model is linear, both the open-loop with feedback and the closed-loop approaches are equivalent. Theoretically, the latter is preferable on the grounds that it is a multi-period generalization of the certainty equivalence approach, and the only substantive task in each decision period is to provide the necessary revised estimates of model variables needed for feedback.

If the optimal control solution is derived using a non-linear model, either of these two approaches can still be employed. And, as indicated earlier, a simple quadratic objective function can be made quite complicated and still be used with either method. But, the solutions derived with a non-linear stochastic model (a model incorporating uncertainty) will no longer be optimal in a formal sense. All solutions must be approximate because the solution for the expected policy loss cannot be exactly measured. Further, approximations of the expected loss are fairly sensitive to where one expects the economy to be in the future. Because future developments will, in all probability, differ from expectations, the expected loss for any remaining periods in a policy horizon must be recalculated in response to forecast error measurements. Currently, it is believed that if a model is locally linear, obtaining solutions to non-linear models incorporating additive uncertainty does not pose serious problems in practice. Many large econometric models do appear to be locally linear. If, however, the uncertainty extends to the structure of the model (random coefficient models, discussed below), obtaining solutions becomes more difficult.

Nevertheless, if the model does not depart from linearity too importantly, variants of the methods discussed above can be used to obtain approximately optimal solutions for the instrument settings. One straightforward method is to use a linearized version of the non-linear model. Since this is usually not desirable because it reduces forecasting capabilities, an alternative is to derive the solution path using the non-linear model by means of a sequence of iterative approximations of the model that can minimize a given loss function to any desired degree of accuracy without sacrificing non-linear detail. In applications involving large, non-linear econometric models(such as the quarterly model used within the Federal Reserve System), the open-loop with feedback approach combined with iterative linearization appears preferable because of the computational expense of working with the closed-loop approach.

The final complicating factor that can be introduced into the optimal control problem is to allow for uncertainty about not only the intercepts of the econometric model (additive random error terms) but the slope coefficients as well (uncertainty in the parameters of the model). Under these circumstances the econometric model is known as a <u>random coefficient model</u>.

Allowing for random coefficients complicates optimal control analysis greatly. For this reason, very little applied work has been done with random coefficient models to date, and there is doubt that such an approach can be applied to large-scale econometric models in the foreseeable future, despite the obvious desirability of doing so.

Two important features about random coefficient models should be noted. First, if the coefficients vary over time in a predictable fashion, filtering techniques (discussed below) can be used to correct for predictable movements in the coefficients. These are corrections of the mean or first-order characteristics. Second, knowledge about the degree of uncertainty concerning the estimates of the model coefficients can be used to take into account more precisely the degree of uncertainty about the effects of changes in the policy instruments (the policy multiplier effects). These are considerations involving second-order characteristics. Given the same mean estimates of the model coefficients (i.e. identical multiplier predictions), the optimal strategy will be quite different depending on whether uncertainty is allocated to the model intercepts or to the general model structure.

Work is beginning on small manageable random coefficient models in order to gain empirical insights concerning the likely policy restrictions or responses that would be appropriate in the context of large-scale structural random coefficient models. One suggestion stemming from analysis of simple random coefficient models has an important policy implication. Analysis of these models suggests that optimal strategies under uncertainty about the coefficients will be more conservative than under more certain conditions. Intuitively, if the likely response to a given policy action is highly uncertain, then it is reasonable to proceed cautiously in changing the policy instruments. Whether optimal policy strategies would be more conservative in practice depends technically on the covariances between the model coefficients. While this is an empirical question in the last analysis, the conditions required to justify highly active policy strategies appear less likely to exist.[11/]

One interesting means of characterizing proponents of aggressive or conservative monetary policy is in terms of their implicit *a priori* judgments about model reliability. Proponents of aggressive monetary policy seem to attribute errors made by models to simple additive error processes. In this case, all that is required to follow relatively active policy strategies is that the models be adjusted appropriately to incorporate new information so that a feedback strategy can be used. Advocates of conservative policies, on the other hand, appear to assume such great uncertainty about the model coefficients that active control strategies would be imprudent if not damaging to economic stability.

11/ For more extended discussions, see Chow (4 ), Craine and Havenner (8 ), and Kalchbrenner and Tinsley (14).

Feedback and Filtering

A discussion of one additional topic, the relationship between feedback and filtering, is necessary to complete this overview of optimal control analysis. In the discussion of open-loop and closed-loop control strategies, it was noted that feedback is essentially a revision of the policy strategy (the control instrument settings) in response to information that actual economic performance had deviated from that anticipated (i.e. in response to forecast errors).

In practice, while monetary policy is conducted almost continuously, a relatively complete and reliable picture of the economy is only available at quarterly intervals, and then only with about a six-week lag.[12/] This absence of frequent complete information makes it difficult to obtain the information needed to adopt a weekly or even a monthly feedback strategy. Nevertheless, pictures of the economy can be constructed more often on the basis of data that are available with greater frequency. Judgmental forecasting techniques rely heavily on such information implicitly or explicitly to revise the estimates of the position or condition of the economy during intra-quarterly intervals. The 'add-factor' adjustments usually made to econometric models during intra-quarterly periods also rely on these partial or indirect observations. In an optimal control setting, filtering plays the same role.

Filtering, in this context, is simply a technique for estimating a set of unobservable variables by using observable variables or intermediate variables that maintain a predictable correspondence to the unobserved variables. Information from the observable variables can be exploited to

12/ Preliminary information is available with about a two-week lag, but is highly unreliable. The usefulness of these preliminary data can also be investigated by means of the techniques described in this section. See Conrad (7).

extract information about unobservable variables on the basis of structural links between the variables in an econometric model and relationships between the forecast errors of the two sets of variables.

For example, if complete information about the quarterly model data bank were available at the end of a quarter, a prediction for the entire quarterly data bank could be made for the next quarter. Once into the new quarter, intermediate information becomes available daily, weekly or monthly about some of the variables in the quarterly model data bank, or about variables that are related to that data bank. At the beginning of the quarter, forecasts of some of these intermediate variables can also be made. In general, there will be errors in these shorter-term forecasts that can be measured within the quarter as new observations become available. It is the information contained in the measurement of these errors that is useful in carrying out a frequent feedback strategy using the quarterly model. For this reason, the intermediate variables are also referred to as information variables or indicators.

If some of the more frequently measured variables are components of the quarterly model data bank, the observed forecast errors provide a certain update or correction of the forecasts of those variables as soon as they are measured. Given the relationships between the corrected variables and the remaining unobserved variables, the known forecast error can also be used to provide updated estimates of the behavior of the unobserved variables. This potential usefulness of filtering techniques provides an obvious reason for interest in structural, or more detailed, econometric models. Simple relationships between a few important economic variables cannot be used as readily to exploit the information in intermediate variables from a variety of sources.

The observable intermediate variables need not be a part of the quarterly model data bank. It is possible to apply filtering techniques to extract information from data that are not part of the quarterly data set so long as a relationship between the observable forecast errors and the errors in the quarterly set can be established. By the same token, filtering procedures can be useful to judgmental forecasters by providing forecast corrections of some important unobserved economic variables that can then be extended judgmentally to other important unobserved variables.[13/] For example, information from the industrial production index might be useful in revising forecasts of inventory behavior or investment, and therefore income and output. Or, retail sales data or data on auto sales might be used to revise consumption estimates with consequent revisions of inventory, output and income forecasts.

Any source of intermediate information is potentially a useful indicator of the current position of the unobserved portion of the economy. In practice, this does not mean that all intermediate variables are used.

13/ Examples of analysis incorporating filtering can be found in Kalchbrenner and Tinsley (14), Kareken, Muench and Wallace (18), LeRoy (20), and LeRoy and Waud (21). Applications of filtering can be found in Conrad (7), Kalchbrenner and Tinsley (15) and Tinsley (35). An alternative means of predicting unobserved macroeconomic variables is described in Porter (28) (29).

That is, filtering does not imply "looking at everything" indiscriminately. Some intermediate variables provide relatively little useful information because they are not strongly linked to variables of interest or their early measurements contains too much statistical "noise." Others are valuable for updating the information for a few important unobserved variables, but not others. In any case, a single indicator will not provide the same information content as consideration of a set of intermediate variables carefully processed through a structural model. Finally, it should be noted that the frequency of feedbacking is related to the availability of useful information. In cases where frequent measurement or filtering provide little useful information, there is little gain to be had from more frequent feedback, and, therefore, little reason to do so.

This discussion has focussed on the use of relatively frequent measurement to update the forecast of a quarterly model. The process can work in reverse as well where shorter-term models are linked to a quarterly model. For example, in the monthly money market model, a key variable is personal income, a variable that is also included in the quarterly model data bank. To the extent that personal income forecasts in the quarterly model can be revised by filtering techniques, the forecasts of the monthly model will also be revised. In this fashion, the richer detail that is typical of structural quarterly models can be exploited tc enhance the performance of less detailed shorter-term models.

For the case of models with uncertain coefficients, it has been suggested that, conceptually, filtering techniques could be used to obtain estimates of the effects of shocks to the economy on the random coefficients.

This would be an extension to a random coefficients situation of the 'add-factor' procedures typically used in current practice. Under these circumstances, the 'add-factor' adjustments would alter both the initial conditions and the expected policy multipliers associated with the model.

Further Extensions

One important area of control analysis that is not included in the preceding discussion is the question of coordination of policy instruments. 14/ In general, the greater the number of policy instruments that can be used, the closer can multiple objectives be achieved. Optimal control techniques provide a means of estimating the extent to which objectives could be achieved more closely if instrument settings were coordinated, or the extent of the constraints placed on monetary policy by a failure to coordinate actions. Given the long lags with which monetary policy effects occur, it is desirable to explore the implications of situations in which monetary policy must take as given, and respond to, independently determined fiscal policy actions.

A natural extension of the optimal control techniques discussed in this section is the provision of confidence intervals for the projections of the important ultimate variables. The availability of these intervals provides a means of determining the range of outcomes that is associated with any given choice of the instruments settings. It also provides information on the areas of the econometric model that would, if they could

14/ This issue is discussed in Ando and Palash (1) and Craine, Havenner and Tinsley (9).

be improved, yield the greatest gains in the overall performance of the model. Presenting these ranges is a simple matter in an applied control setting because filtering applications require calculation of the historical error performance of the equations in the econometric model.

Finally, it is possible to conduct sensitivity analyses related to a variety of issues in a control context. For example, for a given loss function, if the acceptable loss is increased by five or ten per cent, what is the effect on instrument variability and the behavior of the objective variables? Or, how sensitive are the instrument settings or policy strategies to such matters as changes in the variables included in the loss function or their weights, the functional form of the loss function, the length of the policy horizon or alternative model structures?

Even though most of these extensions are designed to provide analytical information about the nature of the control solution under differing circumstances, they can also be employed in an operational setting for supplementing the analysis that is provided on a regular basis. They can be useful also in providing policy makers with a better understanding of the decision environment, and of the relative importance of implicit choices of priorities. The less the sensitivity of the control solution to differences in model structure or the form and content of the loss function, the less is the necessity to focus on the specific differences involved.

Some Concluding Observations

Likely areas of benefit from the application of optimal control techniques as well as substantive problems have been discussed in this brief overview of optimal control analysis. From this discussion it should be apparent that optimal control analysis is not a panacea for policy decision problems. By the same token, however, neither is it a 'black box' approach competitive with general economic or econometric analysis that is likely to lead policy makers seriously astray. Even though optimal control techniques can be of assistance in taking into account uncertainty and model forecast errors systematically, they are not substitutes for improved economic and econometric analyses.

While much work remains to be done, it is now possible to apply optimal control analysis to complex and realistic situations in the context of large-scale structural econometric models, and early studies of the gains from filtering are quite promising. Moreover, even at the present stage of development, optimal control provides a useful conceptual framework that is both comprehensive and systematic within which policy issues can be analyzed. Because optimal control analysis is an optimization technique that can only be applied to specific economic or econometric formulations, the technique itself is neutral with respect to 'Keynesian' and 'Monetarist' issues, as well as to questions of fine tuning versus conservative policy strategies. Nevertheless, it provides a means by which the unresolved issues in these areas can be clarified and analyzed in a systematic manner.

However, care must be taken not to overstate the gains that can be expected from optimal control applications. No one, now or in the foreseeable future, seriously advocates that policy should be determined by optimal solutions of econometric models. It has been suggested that applications of these techniques are likely to (a) provide a systematic exploration of the implications for monetary policy of alternative goals, (b) permit explicit consideration of uncertainty in the formulation of strategies, (c) improve the mixed judgmental-econometric model analyses that are prepared as briefing material and (d) indicate those areas of model improvement that would most aid policy decisions.

## III. Instruments, Information Variables and Targets in the Determination of Monetary Policy

### Introduction

For all intents and purposes, monetary policy is in continuous operation, but the frequency with which monetary policy decisions can be made is limited by the fact that the information required to reach sound decisions is incomplete or available infrequently. This situation led to the well-known proposal that the monetary authority adopt monetary aggregate intermediate targets that are observable with greater frequency and bear a reasonably stable relationship with the ultimate targets of monetary policy. This proposal rests on the proposition that if short-run policy instruments are manipulated in such a way as to achieve intermediate targets thought to be consistent with some ultimate targets, then the ultimate targets will not deviate substantially from their desired paths.

The emphasis in the second stage of the Subcommittee on the Directive's investigations was on the question of whether pursuit of such intermediate targets is desirable or appropriate in formulating monetary policy. Included in the research were the related questions of the relationships between operating, intermediate and ultimate variables; the appropriate time horizon for monetary policy; the conditions under which targets should be altered in response to incoming information; and the best way to take into account the uncertainties under which policy decisions must be made. This is an area that has been plagued by semantic problems that have made it difficult to focus on the real issues involved. Analysis of these questions in an optimal control framework has provided a clarification of the issues as well as indicating that a reorientation of thinking about intermediate targets would be desirable.[15/]

In recent years, the Federal Open Market Committee has shifted its focus toward greater emphasis on monetary aggregate intermediate targets. This shift in focus and the events leading up to it resulted in wide discussion of such related issues as the controllability of money, the appropriate choice of policy instruments to control money effectively, how strategies should be altered to respond to misses in money targets, the role of money market interest rate constraints, and the appropriate period over which monetary aggregate targets should be specified. In much of this discussion, there has been an implicit assumption that the monetary aggregate targets were consistent with ultimate economic objectives that were never specified exactly. Frequently, it has not been clear exactly what the expected links were between the short-term instrument choices or settings (e.g. reserve measures and/or interest rates), the intermediate targets (e.g. various measures of money and bank credit) and the ultimate objectives (e.g. the rate of growth of real output, unemployment, the rate of change of prices and international considerations).

15/The material in this section is discussed in greater detail in Kalchbrenner and Tinsley (14), Kareken, Muench and Wallace (18), and Kareken and Miller (17). Earlier work that pointed in the same direction as the conclusions discussed here was done by Kareken (16) and Poole (26).

Analysis of these issues in an optimal control framework has the important advantage of including most of the relevant issues in the analysis simultaneously. And, once this is done, it becomes apparent that there are significant similarities between the optimal control approach and Federal Open Market Committee procedures of recent years. The latter will be brought out in greater detail below in section IV.[16/]

Optimal Control Analysis of Intermediate Targets

In order to clarify the issues more precisely when viewed in an optimal control context, it is helpful to ignore, temporarily, questions of practicality and concentrate on qualitative insights. In section II, it was indicated that an optimal control analysis of a policy problem begins with the specification of desired ultimate targets or objectives that in general cannot be achieved exactly given a limited number of instruments, the constraints represented by the model of the economy and the uncertainty inherent in economic analysis. Relying on a first-period certainty equivalence approach, the solution to the policy problem will provide settings for the policy instruments in the next period that are based on expected settings of the instruments and expectations about the behavior of the economy over the remainder of the policy horizon.

The forecast of economic behavior can only be an expectation because of the uncertainty associated with the econometric model. The forecasts of the individual variables are, in addition, conditional expectations because they depend on, or are "conditioned" by the settings of the policy

16/The correspondence between FOMC procedures and optimal control is discussed in some detail in the paper by Kareken and Miller (17).

instruments and assumptions about the other important but non-controlled exogenous variables. If monetary aggregates are viewed as being determined by an interaction between the economy and the monetary authority, they too are among the conditional expectations that result from the optimal control solution.

The important insight to be gained about the role of intermediate variables from optimal control analysis lies in the behavior of these variables relative to expectations once the policy strategy is carried out. This role can be seen clearly by tracing through the steps that would be involved if an open-loop with feedback strategy were carried out.

With the passage of time in the first period as the policy decisions are carried out, information becomes available on the behavior of the observable intermediate variables that are either variables included in the model, or excluded variables that can be related to variables in the model explicitly. Instrument settings in this context are operations affecting reserves or interest rates in the short run (Trading Desk operations), while intermediate variables include interest rates, various money and credit measures, the unemployment rate, and a variety of other real sector variables measured monthly or weekly. These observations, by definition, will be available prior to quarterly information on the behavior of the ultimate variables of concern that are included in the loss function. Because the relationships between the instruments and the intermediate variables are stochastic (or subject to uncertainty), in general the expectations held at the outset concerning the response of the intermediate variables to particular instrument settings, the values of other exogenous variables and other determinants of the initial conditions will not be realized. That is, forecast errors will generally be observed.

A filtering process can then be applied to these forecast errors for the intermediate variables to obtain revised forecasts of the unobservable variables, including the ultimate targets. These revisions will then become part of a new set of initial conditions (along with adjustments in the econometric model where indicated) that can be used in a feedback procedure to re-calculate the optimal settings of the policy instruments in the manner described earlier. Note that no adjustments would be made in the policy instrument settings (short-run monetary policy) unless information could be extracted from the forecast errors of the intermediate variables that could be used to revise the forecasts of the unobservable variables by a sufficient amount to alter the optimal control solution.

A number of points about following an optimal control procedure in this fashion should be stressed. First, the optimal control solution for the policy instruments is obtained in terms of the relationships between instruments, intermediate variables and ultimate variables. These relationships are not typically recursive in the sense of a simple sequential line of causality running from the instruments to the intermediate variables and then to the ultimate variables. Second, at the beginning of the policy period, the intermediate variables are expectations, but they become information variables that provide a monitor of the way the adopted policy strategy is working out in practice as time passes and they can be observed or measured. Third, because the intermediate variables are coupled or linked to both the instruments and the variables of ultimate interest, the interim information they provide can be used either to validate the original policy, or to serve as the basis for changing the policy when it appears expectations are not being realized. Finally, the expected values of the intermediate variables are not ends in themselves. The expected values they take on are the result of the solution process relating ultimate targets to instruments, and those values are only appropriate to the extent that the expected relationships between the instruments and the ultimate targets remain unchanged.

This same conceptual approach can be used to see the implications of treating a limited set of intermediate variables as true targets in the sense that deviations from the original intermediate expectations (i.e. forecast errors)are to be corrected by short-run monetary policy. For this to be an optimal procedure in terms of achieving the ultimate objectives, the shocks hitting the intermediate targets would have to be such that correcting the resulting forecast errors and returning the the intermediate targets to the original expected path would simultaneously correct for shocks that were displacing the ultimate targets from their desired paths or values. Otherwise, correcting errors in forecasts of the intermediate targets would push the errors into some other unknown area of the economy, thereby reducing the chances of achieving the ultimate objectives. The alternative of using a filtering-feedback procedure can provide information that yields the appropriate response, if any, to shocks or forecast errors in the intermediate variables on the basis of a specific analysis of the impact of the errors on the total linkage from policy instruments to ultimate targets.

The conclusion from optimal control analysis is that, conceptually, pursuit of intermediate targets is a sub-optimal procedure to follow. Intermediate variables should be treated as information variables to provide the basis for adjustments in policy instruments in order to achieve ultimate targets

Questions of the Definition of Instruments and Intermediate Targets in Practice

In the immediately preceding discussion, questions of practicality and the readiness or inadequacy of both econometric models and optimal control techniques were ignored. Given the discussion in section II of the problems involved in applying optimal control techniques, and the known performance of econometric models, some caveats are in order. To this end, a summary list of the likely near-term contributions of optimal control to actual monetary policy decisions was given at the end of section II.

In addition, other points were raised during the course of reviewing the research done in Stage II, although it should be noted that the soundness of the conceptual conclusions from the foregoing optimal control analysis was not questioned.[17/] The first issue is in part semantic and in part substantive. As indicated in section II, an instrument is

17/ The following material is discussed in greater detail in Dew (10), and Poole (27).

a variable that is under the direct control of the Federal Reserve. Strictly speaking, direct control means that the variable can be set exactly by the Federal Reserve with no uncertainty. Under this definition of a control instrument, the Federal Reserve controls either very short-term interest rate movements or the Federal Reserve portfolio of assets. Each of the reserve measures considered in Stage I (and reviewed in section V below), as well as the several alternative measures of money are 'intermediate variables' that respond to changes in these two fundamental policy operating instruments.

In the preceding discussion, reserve measures (or interest rates) are treated as instruments and the monetary aggregates are treated as intermediate variables or information variables. In the review of the Stage II results, this usage was challenged on the grounds that both reserve measures and the monetary aggregates are intermediate variables. Therefore, it is argued, the monetary aggregates can also be treated as instruments of monetary policy instead of as intermediate information variables.

This argument is based on the proposition that the Federal Reserve could, in fact, control monetary aggregates very closely if it set out to do so, even though this might require extensive changes in daily operating variables (the policy instruments under the strict definition given above). Control theory requires an instrument that the controller sets exactly. Therefore, if the monetary aggregates are controlled very closely, the monetary aggregates meet the definition of an instrument just as well as reserve measures.

If this argument is accepted, and the monetary aggregates are classified as policy instruments rather than as intermediate variables, the entire optimal control analysis can be applied as above with the policy instrument, money, subject to adjustment based on information concerning the behavior of the ultimate objectives derived from intermediate variables or direct observation. Under this classification, monetary aggregate measures would indeed be targets since they would be the instrument used by policy makers to carry out policy strategy.

In the discussion of the issue of whether money should properly be viewed as an instrument or an information variable, institutional changes to make money more controllable were excluded on the grounds that the institutional environment was taken as given in Stage II. Given this restriction, this issue is an empirical matter in practice rather than a matter of theory. In practice, quarterly econometric analysis within the Federal Reserve is conducted principally in the context of a large structural model that has used money (M1) as the policy instrument in the past. The model can also be used with nonborrowed reserves as the policy instrument, but this has not been done normally. Monthly and shorter-term econometric analysis has been conducted using smaller models that take the real sector as given and concentrate on financial variables.

In these models, the policy instrument can be short-term interest rates or reserve measures, and in recent periods the former has been used. The shorter-term models have only rather minor linkages to the quarterly model. model.

On the basis of these considerations, it is argued that the existing shorter-term models can be most useful in controlling money intra-quarterly, but that little information can be extracted from the variables in these models (and presumably other frequently observed variables) to revise estimates of behavior of the ultimate variables intra-quarterly. Therefore, it is argued that the control or policy procedure ought to be partitioned into (1) deciding the quarterly desired paths of money to achieve desired ultimate objectives (by the FOMC), and (2) deriving the monthly reserve paths to achieve the desired quarterly paths of money (by the Desk and the staff). Feedback could occur at weekly or monthly intervals in achieving the quarterly money targets, and quarterly in achieving the ultimate target variables.

The advantage of greater policy clarity is also cited in favor of this two-stage approach. It is felt that a policy strategy defined in terms of a reserve instrument rather than a monetary aggregate would involve more extensive changes in the instrument that are not related to changes in information about the behavior of ultimate targets so much as to changes in operating factors or regulatory changes. Variations in such factors as reserve requirement ratios, the distribution of deposits by type and class of bank, or the distribution of deposits between member and non-member banks would require changes in a reserve instrument, but no change, necessarily, in a monetary aggregate instrument. Since such instrument changes would be largely technical and would occur relatively frequently, it is argued that policy decisions would be facilitated and public understanding would be enhanced by classifying money as the instrument rather than reserves (or short-term interest rates).

Theoretically, this position can be challenged (see the discussion on pp. 31-35 above). If there is a model that relates shorter-term instruments (reserve measures or short-term interest rates) to the longer-term instrument or intermediate target (money), and there is a model that relates money to ultimate targets, then there is a model linkage relating reserves on interest rates to ultimate targets. In practice,the issue can only be resolved by determining which procedure yields the closest control over ultimate targets.

In control terminology, the question comes down to evaluating three possible strategies. The first is to pursue a quarterly open-loop with feedback strategy in terms of the relatiobships between money and the ultimate targets. Coupled to this strategy is a shorter-term (weekly or monthly) open-loop with feedback strategy relating a quarterly money target to operations of the Trading Desk, The quarterly open-loop between money and the ultimate targets could be interrupted if special circumstances dictated a change in the money instrument setting.

A second possibility is to adopt a monthly open-loop with feedback strategy relating reserves directly to the ultimate targets with the monetary aggregates serving as intermediate information variables. Coupled to this strategy is a shorter-term open-loop with feedback strategy relating a monthly reserve target to operations of the Trading Desk on a weekly basis.

The third possibility is to adopt a Federal funds rate instrument (a control instrument in the strictest sense) and relate the instrument directly to the ultimate targets by means of a frequent feedback strategy using reserves, monetary aggregates and other intermediate variables as information variables. For reasons explained in section V, this alternative is not recommended by the Subcommittee at this time, but the possible merits of such an approach will be investigated in coming months.

Stated another way, it depends on whether the forecast errors from monthly or more frequent data can be used by means of filtering techniques to revise quarterly data and vice versa. To investigate this question, a project is currently underway to determine if the quarterly and monthly models can be linked, with information flows filtered both from the monthly model to the quarterly model, and from the more detailed quarterly model to the monthly model. The results will shed light on the question of whether feedback should or can occur at quarterly or more frequent intervals, at least from the viewpoint of econometric model use.

Concluding Remarks

Optimal control analysis of the question of the desirability of specifying intermediate targets in monetary policy indicates that such a practice is sub-optimal theoretically. As a practical matter, however, the desirability of specifying intermediate monetary aggregate targets is an empirical question that remains open. Those who argue for the use of quarterly monetary aggregate intermediate targets believe the greatest policy gains would come from truly controlling money over this interval, and that more complex and frequent feedback procedures would yield small gains by comparison. Work currently underway to try to measure the gains to be derived from short-run filtering and feedback should provide at least partial answers to these questions within nine months.

Another result from this analysis concerns the recently adopted FOMC practice of announcing one-year targets for the monetary aggregates. The feedback analysis suggests that this practice would be undesirable if the announced choices were viewed as true targets, invariant with respect to economic developments. It would be preferable to treat these announced 'target' rates of growth as expectations in the same manner as the instrument paths beyond the first period of a first-period certainty equivalence solution are treated. On statistical grounds, it might be preferable to state the announced 'targets' as single values (point estimates) subject to a standard error, rather than stating target ranges. Nevertheless, a range specification might be justified by the earlier discussion of the difficulty of specifying a loss function, or doubts about the 'model' on which the policy decision was based.

In practice, the FOMC implicitly appears to have adopted a moving horizon, quarterly, open-loop with feedback strategy since the longer-term 'targets' are reconsidered and extended by one quarter at quarterly intervals. This is a contingency strategy as pointed out in the discussion in section

II of feedback control rules and feedback procedures. It would perhaps increase the flexibility of the Committee and public understanding of monetary policy if this practice were made more explicit.

In this report, the terms mathematical expectations or expected values have been used in referring to forecasts of stochastic variables because this is the correct usage in an analytic context. In the Subcommittee report to the FOMC, on the other hand, the reader will find the term intended values for reserves or monetary aggregate 'targets'. The use of the word intended rather than expected was considered preferable in a policy decision context on the grounds that once the decision is made, the FOMC indeed intends to achieve the values decided upon until the Committee decides there are sufficient grounds to change the decision. Thus, while the policy choices may well be expected values rather than invariant targets analytically, the decision element involved endows them with a dimension that the Subcommittee felt was better captured by use of intended values.

## IV. Suggested Changes in Operating Procedures Over the Near Term

A review of the analyses carried out in Stage II suggests changes that should be made in the manner in which staff materials are prepared and presented. The staff is currently in the process of adopting some of these changes and considering others. The changes involve making the interconnection and consistency between the Green Book and the Blue Book more explicit, and providing a broader analysis of the options available to the FOMC in determining monetary policy.

### Closer Integration of the Green Book and the Blue Book

Interest in making the relationships between the Green Book and the Blue Book more explicit arises from two basic considerations. First, given the complexity of the processes by which both analyses are prepared, more explicit specification of the linkages between the short-run and the long-run analyses would provide a better check on consistent projections by the staff. Second, an explicit linkage between the longer-run and shorter-run analyses, and the consequent linkage of FOMC decisions, should lessen the likelihood of inadvertently inconsistent policy decisions.

The staff has recently changed its procedures in order to improve Blue Book and Green Book consistency as described below. Prior to the change, members of the staff provided a first approximation of the likely quarterly patterns of interest rates and monetary growth that would be consistent with achieving some longer-term rate of growth of M1 within the range established by the FOMC, usually at the previous meeting. The specific longer-term rate within the range established by the FOMC to be used as the conditioning assumption in making these initial forecasts was obtained from the senior staff.

For a variety of reasons, this initial estimate often did not correspond to the patterns of interest rates and monetary growth that were discussed in or implied by the corresponding month's final Blue Book. Further, the quarterly patterns implicit in the conditional Green Book forecast were not emphasized in staff briefings or subsequent FOMC discussions. The short-term focus of the Blue Book meant that interest rate behavior over the full period of the Green Book forecast was discussed in only general terms in that document. To some extent, this general treatment of interest rates can be attributed to the difficulty of forecasting interest rates by either judgmental or econometric means.

However, it is the expected consistent patterns of quarterly interest rates and monetary growth that provide the principal link between the Green Book and the Blue Book. This is important, because it is not the case that virtually any timing of monetary growth or interest rate patterns assumed over the shorter horizon of the Blue Book will be consistent with the longer-run forecast of financial activity of the Green Book.

Although the evidence is not conclusive, it seems to indicate that the alternative financial patterns typically presented in the Blue Book differ from each other by such a small amount that they do not generate very different behavior in the nonfinancial sector over a one-year horizon.[18/] Nevertheless, the alternatives do imply different quarterly interest rate patterns and some differences in nonfinancial behavior even over this short a period. Furthermore, the differential nonfinancial effects may be enlarged over longer time periods because of the lags in the system. This information should be made available to the FOMC so comparisons between alternative short-run timing patterns can be assessed relative to the likely longer-term financial and nonfinancial market effects.[19/]

The more fundamental need for consistency between the Green Book and the Blue Book has to do with the ultimate goals of monetary policy decisions. The current Green Book forecast is not the result of an optimization procedure designed to indicate the 'best' strategy for achieving some stated objectives. Instead, it is a forecast conditioned by the assumption of relatively smooth money growth and interest rate paths that typically do not deviate substantially from recent past trend paths. Nevertheless, if the Green Book forecast does in fact indicate an outcome acceptable to the FOMC for the coming year and beyond, considering both implicit objectives and

18/ For simulation experiments using the quarterly econometric model that are related to this issue, see McElhattan (19).

19/ Comparisons between alternative short-run timing patterns might be made by using more elaborate versions of the decision tree discussed below (p. 48).

constraints, the associated consistent quarterly financial patterns must be known in order to determine the appropriate shorter-term strategy to achieve that projected outcome.

Furthermore, there is a 'best' monthly and shorter-term strategy to follow in order to achieve the quarterly financial patterns associated with the Green Book forecast of real economic activity and price behavior. It is true that a fairly wide range of short-term behavior of interest rates <u>or</u> monetary aggregates is consistent with given quarterly interest rates <u>or</u> monetary aggregates. But there is only one path of expected interest rates, <u>or</u> reserves <u>or</u> monetary aggregates that will yield, simultaneously, the same expected quarterly patterns as contained in the quarterly analysis for reserves, monetary aggregates <u>and</u> interest rates. That is the consistent path that links the Green Book and the Blue Book. Different sets of constraints placed on the quarterly and monthly process may mean that the 'best' short-term paths cannot be achieved. But, if this were a serious problem, it would be a matter of inconsistent constraints in different periods of analysis or operation rather than a matter of the nonexistence or lack of importance of consistent short-term and longer-term paths.

Uncertainty about current information, the structure of the economy or future exogenous variables does not prevent the determination of such consistent paths. With uncertainty, the appropriate consistent paths are conditional expectations subject to revision if subsequent information indicates these expectations are incorrect. As uncertainty increases, the confidence with which the expectations are held declines, and this could be noted in the analysis. In general, with the passage of time, errors in the expected consistent paths will occur. As discussed earlier, measurement of these errors used in conjunction with other incoming information, can then form the basis for monitoring progress in achieving more fundamental but unobservable goals, and may be useful for sequentially revising conditional expectations and policy. In the absence of operational filtering procedures, an alternative aid to reaching the necessary decisions is discussed below.

It is particularly important to attempt to determine the consistent short-term and long-term strategies if restrictive interest rate smoothing constraints are imposed on the monetary policy process.[20/] When such restrictions are imposed, ignoring the short-term consistency requirements increases the likelihood of not achieving the desired quarterly patterns or timing and, therefore, of not achieving the ultimate objectives.

Under the revised procedures that are being developed currently, the practice of preparing pre-Green Book conditional financial forecasts will be continued, but with greater involvement of staff members principally responsible for the preparation of the Blue Book. During the process of preparing the Green Book forecast, the accuracy and consistency of these initial estimates will be monitored more closely to take into account altered policy assumptions or new information about economic performance.

By taking a more active role in the preparation of the Green Book, staff members that prepare the Blue Book are, in effect, making early estimates of the Blue Book analysis. In turn, they are reviewing in greater detail than previously the current nonfinancial behavior that forms the basis for the Green Book conditional forecast. This improvement in exchange of information should improve the consistency of the two documents. The end

20/ In addition, Henderson (13) discusses reasons why similar restrictions on international economic variables are likely to be important. In Kalchbrenner and Tinsley (15), there is an example of the impact of a restrictive interest rate constraint on the expected path of monetary growth in the face of a substantial unanticipated change in economic conditions.

result of this interaction will be to make explicit the quarterly interest rate and monetary growth patterns underlying the Green Book, as well as providing a Blue Book analysis of the expected behavior of shorter-term financial market variables consistent with the Green Book patterns.

The Role of Alternative Conditional Forecasts in FOMC Discussions

In a formal control approach, policy alternatives are explored in a systematic and computationally efficient manner based on specification of ultimate objectives, policy constraints and a model of the economy. The result is a single conditional forecast of economic behavior over the time horizon, and a path of policy instrument settings that condition and are consistent with that forecast. Alternatives need not be considered explicitly given the model, the objectives, and constraints because the optimal control solution considers alternatives implicitly in determining the 'best' path for the policy instruments.[21/] Even though this technique cannot now be used in practice for policy purposes, it suggests changes in current procedures that should improve the usefulness of the analyses presented to the FOMC.

Under present procedures, staff presentations to the FOMC center around two analyses. The first is a single detailed consensus conditional forecast of economic behavior over a one to one and one-half year horizon in the Green Book (generally one year). The second has been a Blue Book presentation that is based on an analysis of the likely effects over the next six months of maintaining current money market conditions, as well as an assessment of the effects over the same horizon of varying reserve and money market conditions by relatively small amounts on either side of existing

21/ Strictly speaking, this statement is true only if the loss function is known. In the absence of knowledge about the characteristics of the loss function, it is prudent to test the sensitivity of the solution to changes in the loss function specification and other assumptions as noted in section II.

conditions. The discussion of each of the alternatives has usually been in terms of achieving the FOMC's stated one-year monetary growth objectives.

This procedure has been varied somewhat in recent staff presentations. In recent months, the Blue Book discussion has been extended to a one-year horizon in a general way. During chart shows, an alternative conditional forecast based on the Board's quarterly econometric model adjusted to incorporate judgmental information has been discussed. In addition, alternative econometric model simulations or conditional forecasts have always been prepared, but they have been discussed only when the issue of alternatives was raised during FOMC deliberations. No attempt has been made in the past to provide Blue Book analyses consistent with any of the alternatives.

Quite obviously, there are distinct limitations to expanding the number of alternatives presented to the FOMC because of time constraints on both the staff and the Committee. Nevertheless, it would be possible to explore the policy options of the FOMC more fully by considering a greater number of conditional forecasts on a regular basis. This would be a working approximation to a formal control approach. Initial explorations of the feasibility of providing several alternatives to the FOMC indicate that it could be accomplished, and that the use of some variant of a 'decision tree' appears to offer the most promising avenue.

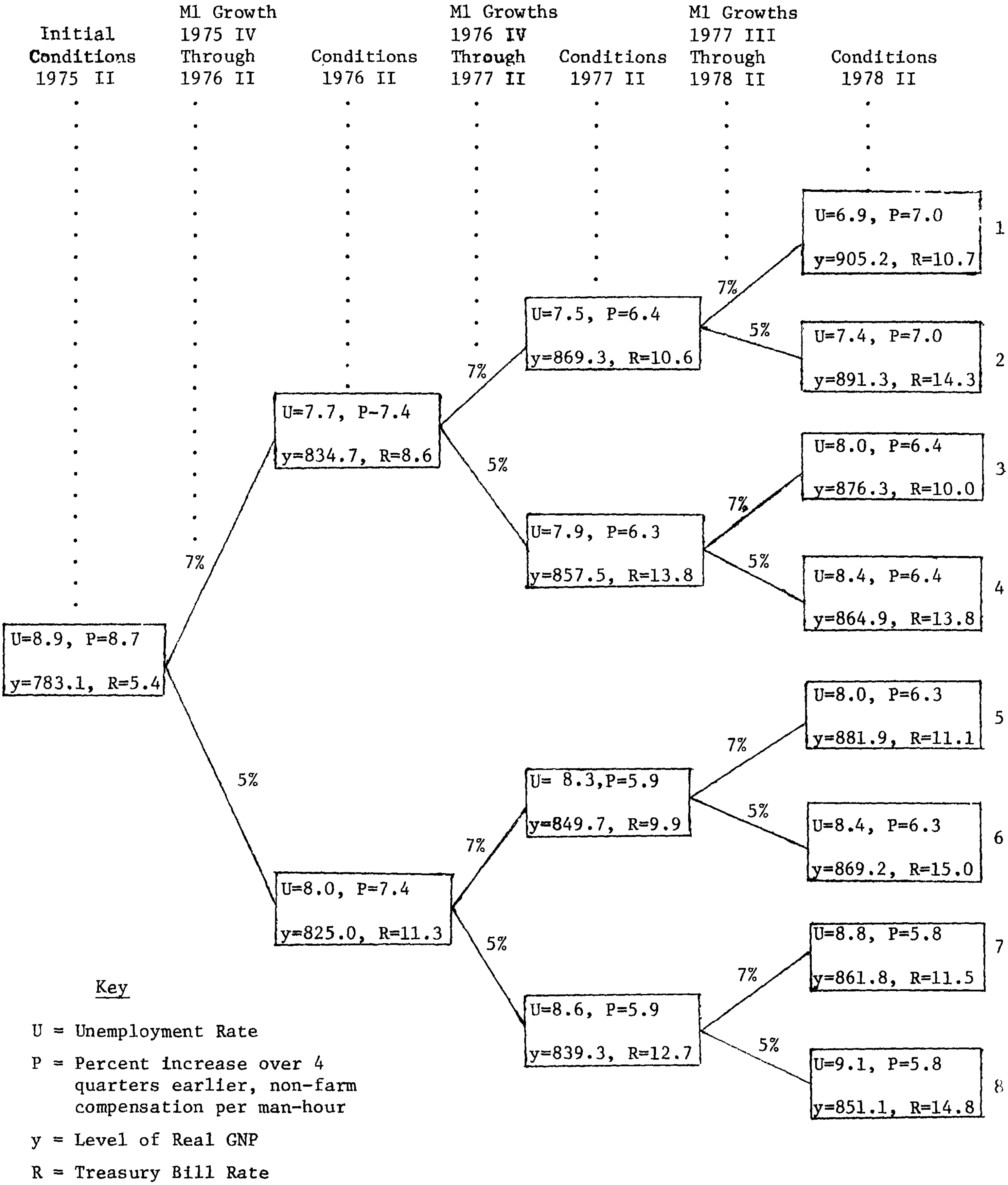
The 'Decision Tree' [22]

The amount of detail currently included in the consensus Green Book forecast precludes presentation of a number of alternatives in the same detail. In order to make it feasible to provide a number of alternatives, a 'decision tree' capability has been programmed for the quarterly model. The program permits the division of a given forecast or simulation horizon into as many periods as desired. Any combination of monetary growth rates (or some other measure of monetary policy) can be chosen for the various periods. For example, in the attached graphical representation of a decision tree, 12 quarters are divided into three one-year periods and two alternative money growth rates have been considered for each of the three periods. As shown, this results in 8 possible money growth strategies. More than three periods or two monetary growth rates could have been used.

In this decision tree representation, the number of variables shown at each stage has been limited to four. More variables could be included and they could be shown in terms of differences from a detailed central conditional forecast. By choosing the principal variables of interest, the complexity problems can be made manageable. Thus, the decision tree format provides a means of presenting a large number of alternatives economically. It also provides a convenient way to present the expected outcomes of varying rates of growth of the monetary aggregates rather than using different constant growth rate assumptions for each alternative as is now done. This permits consideration of the behavior of ultimate variables under a fairly wide number of alternative policy mixes without the necessity of specifying an explicit loss function.

22/ The suggestion that 'decision trees' might be useful arose from joint discussions between members of the Special Studies Section and the Econometric and Computer Applications Section at the Board. The capability to use this technique was developed by J. Enzler and D. Battenberg.

Projected Conditions, Alternative M1 Growth Rates



Decision tree analyses might also be used to evaluate the implications of uncertain exogenous shocks to the economy such as the possibility of further OPEC oil increases. This could be accomplished by re-running the decision tree output after making allowance for the likely impacts of some contingency, and comparing the results with an analysis based on the assumption the contingency will not occur.

A truncation of the amount of detail presented from full simulations also provides a means to deal with situations in which last-minute data revisions or new information necessitate changes in the patterns of monetary growth assumed when preparing the Green Book after the Green Book forecasting process has been completed. Similarly, the decision tree might simplify the problem of making explicit the quarterly interest rate and monetary growth patterns implied by Blue Book forecasts that are conditional on the same average money growth rate as assumed in the Green Book, but with different patterns over the year.

In the Subcommittee report to the FOMC, it is recommended that the staff be asked to present at least three alternative longer-term and shorter-term forecasts at each quarterly chart show, or more frequently under special circumstances. It is further recommended that the longer-term forecasts be prepared over a policy horizon long enough to indicate the differences in effects of the alternative policy assumptions for major variables. Finally, the report recommends that the staff develop and present the ranges of probable forecast error associated with the presentations.

The Subcommittee concluded that only a limited number of variables should be presented for the alternatives as in the preceding sample decision tree, and that the results should be expressed in terms of differences from a central detailed conditional forecast. If these alternatives are confined to smooth policy paths, the decision tree will only provide a minimal amount of information about expected dynamic policy multipliers. It would be preferable to explore alternatives that are not restricted to smooth policy instrument paths. A wide variety of alternatives could be provided currently using a more elaborate decision tree than the example shown, but the resulting complexity presents problems, particularly in the context of Committee deliberations. It is assumed that the current detailed Green Book format with accompanying text will be continued. These alternatives are viewed as an addition to current material presented to the FOMC.

The suggested changes discussed in this section are by no means derived solely from optimal control analysis, but they are consistent with that approach. The suggested changes are also consistent with both longstanding and recent developments in FOMC procedures. The FOMC has lengthened its policy horizon in recent years to take into account lagged relationships; the relationships between longer-term and shorter-term strategies have been discussed more frequently; and, it has always been a feature of FOMC procedures to consider the behavior of a large number of variables. The suggested changes are designed to enable the committee to analyze these various aspects of the decision process more effectively.