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by

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OIL PRICES, WELFARE TRADEOFFS, AND INTERNATIONAL POLICY COORDINATION IN A THREE REGION WORLD MODEL: AN OPTIMIZING APPROACH *

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Abstract. The first purpose of this paper is to derive optimal oil prices by recognizing that oil price changes affect real income of oil importers and vice versa. International trade flows, income, and prices are endogenously determined in a three region world model (DCs, OPEC, Non-OPEC LDCs). Using Chow's method for stochastic control of a general nonlinear dynamic system, we then offer a characterization of the set of efficient cooperative policy strategies for the country blocks considered here, given a set weights in the welfare function. We also examine the sensitivity of the optimal policy mix to changes in the weights of the welfare function.

I. INTRODUCTION

Our first purpose in this paper is to endogenize OPEC's pricing policy recognizing that real income of oil importers is affected by oil price changes and that oil price changes are affected by real income of oil importers. Our second purpose here is to ascertain the existence of efficient cooperative policies among developed countries, OPEC, and Non-OPEC developing countries, and the extent to which alternative policies result in welfare tradeoffs for these country blocks.

In endogenizing oil prices, we relax two of the most common assumptions found in the analyses of oil price effects and of oil price determination, namely that oil price changes are exogenously given "shocks",[1] and that the oil demand that OPEC faces is either a stable function or one that shifts at a known (exogenous) growth rate.[2] Price taking behavior is an assumption that may be valid in the short-run, or for countries with very little participation in the oil market. However, for countries like the U.S., Japan, and West Germany, with oil consumption representing a large share of the international oil market, the assumption of oil price exogeneity is not tenable. An increase in oil prices affects their real income, their oil consumption, and therefore feedback to OPEC's oil revenues and oil prices.

As a corollary of removing the small country assumption, we relax the assumption of stability of the oil demand curve faced by OPEC, which is the typical assumption made in analyses of oil price determination. Assuming a stable demand curve implies that oil price changes have no effect on either the level of real income or its growth rate, which is in contrast to the "supply shock" literature and to ten years of empirical findings. Thus we can see that--up to now--the effects of oil price changes and the determination of oil prices have been analyzed in a dichotomous manner since what has been assumed as exogenous in one kind of analysis is treated as endogenous in the other and vice versa (see Fischer et. al., 1975).

In this paper we remove this dichotomy by treating oil prices and economic activity as jointly determined. This joint determination of oil prices and real income implies that OPEC faces, in addition to the problem of allocating oil production through time, a tradeoff between exploiting the direct price inelasticity of oil demand on the one hand, and avoiding the income feedback effects of oil price increases on the other. In particular, if the price path is too low, then OPEC does not exploit the price inelasticity of oil demand and thus incurs revenue losses. However, if the price path is too high, then real income of oil importers is adversely affected and this feeds back to OPEC in the form of lower oil exports and oil revenue losses.

It would seem that once we allow for the fact that oil price changes, and the associated policy responses, have implications for the world economy, the issue of international policy coordination among the country blocks we consider is a natural question to address. A good deal of attention has been given to the possibility of sub-optimal equilibrium levels with "low" levels of economic activity[3] resulting from uncoordinated macropolicies. However, the analyses have been characterized by deterministic, static, two-country models, with little or no empirical content (an exception is Oudiz and Sachs 1984). This paper also addresses the question of international policy coordination aimed at restoring a non-inflationary recovery of the world economy. But in doing so, we use a stochastic, dynamic, three-country model, which allows us also to empirically address other interesting questions:

-- What are the optimal fiscal and monetary policy responses in industrial economies to changes in oil prices?

-- What is the degree of substitutability among various policy instruments? Can lower oil price changes be a substitute for capital transfers to LDCs in acheiving a given growth target in developing countries? Can these capital transfers be avoided by coordinated expansionary fiscal policy in DCs?

-- What is the importance of income feedback effects in determining the price of oil from OPEC's perspective?

-- What is the nature and sensitivity of welfare tradeoffs among DCs, OPEC, and Non-OPEC LDCs to different coordinated policy mixes?

-- How different is the oil price path that maximizes welfare for oil exporters from the oil price path that maximizes welfare for oil importers?

Several conclusions can be drawn from our analysis. First, recognizing the income feedback effects of oil price changes raises the absolute value of the demand price elasticity and reduces the oil price path consistent with oil exporters' best interests. Second, the international transmission of oil price shocks generates changes in the distribution of income between regions; therefore, alternative coordinated policies, as developed in this analysis, have different effects on the prospects for the major regions of the world.

We begin the analysis in section II where we develop a small econometric, three-region world model to study the international transmission of oil price effects on real income, prices and international trade, assuming that oil price changes are exogenous. In section III we endogenize oil prices by applying optimal control to the econometric model to formally derive a system where oil prices--along with other exogenous variables--and real income of oil importers are simultaneously determined. We implement our approach empirically in section IV, and section V contains our conclusions.

II. A GLOBAL MODEL OF OIL PRICE EFFECTS

The model we use is simple but comprehensive and it is based on theoretical models developed by Taylor (1981) and Marquez (1983). We divide the world economy into three regions: (1) the developed economies, whose GDP is determined from the demand side; the supply side is introduced via a production function which determines prices and factor input demands; (2) the OPEC countries, for whom we only explain the recycling of oil export earnings to purchase imports of manufactures, and (3) the Non-OPEC developing countries, whose GDP is determined from the supply side using a production function. Centrally planned economies have been excluded from the present model.

The international trade flows included in the model are: (1) oil, sold by OPEC to both developed and Non-OPEC developing economies; the latter also export oil to developed economies; (2) manufactures, exported by the DCs to both OPEC and Non-OPEC LDCs; and (3) manufactures and raw materials, which are exported by the Non-OPEC LDCs to DCs. In a compact form, the model has 52 equations, 16 of which are behavioral. The parameters of the model are econometrically estimated using data for 1960-1979, although some of the relationships are estimated using data only up to 1977. The estimation method we use is OLS since the advantage of alternative parameter estimators such as 2SLS, 3SLS, and FIML need not hold for small samples such as ours (Mariano 1978). We now describe the main behavioral equations which are shown, in general form, in Table 1.

Developed Economies

Equation (1) represents private consumption, C^d, depending on a distributed lag of nominal value added $P_y^d\, Y^d$ deflated by the consumption price index P_{con}^d; the short run mpc is 0.47 and the long run income elasticity is one. Investment, I^d in equation (2), is a function of a distributed lag of both real income and the long term nominal interest rate r^d; the short run mpi is 0.13 and the long run elasticity with respect to income is 1.18; the long run elasticity with respect to the interest rate is -0.20.

Imports of raw materials from Non-OPEC developing countries, M_r^d in

Table 1
Main Behavioral Relations in
Global Econometric Model

Developed Economies

$$C^d = f(P_y^d\ Y^d / P_{con}^d) \quad (1)$$

$$I^d = f(Y^d, r^d) \quad (2)$$

$$M_r^d = f(P_r / P_m^d, Y^d) \quad (3)$$

$$\Delta\%P_m^d = f(\Delta\%P_r, \Delta\%P_\ell, \Delta\%P_{o,-1}, U_{-1}) \quad (4)$$

$$GY^d = f(L, [K, E(O,C)]) \quad (5)$$

$$O^d = f(P_o, P_c, P_\ell, P_k, GY^d) \quad (6)$$

$$\tilde{\tilde{M}}_o^d = O^d - O^d \quad (7)$$

$$\tilde{M}_o^d = \tilde{\tilde{M}}_o^d - \hat{X}_o^\ell(P_o / P_c, GY^d) \quad (8)$$

$$M_o^d = (P_o^* / P_o)(\hat{M}_o^d + \hat{X}_o^\ell) \quad (9)$$

OPEC

$$M_m^o = f(P_o(M_o^d + M_o^\ell) / P_m^d) \quad (10)$$

Non-OPEC Developing Countries

$$GY^\ell = f(K^\ell, O^\ell) \quad (11)$$

$$I^\ell = f(P_k^\ell / P_o, Y^\ell, R_{-1}^\ell / P_m^d) \quad (12)$$

$$M_m^\ell = f(I_n^\ell, R_{-1}^\ell / P_m^d) \quad (13)$$

$$X_m^\ell = f(P_m^d / P_m^\ell, Y^d) \quad (14)$$

$$O^\ell = f(P_k^\ell / P_o, GY^\ell) \quad (15)$$

$$\hat{M}_o^\ell = O^\ell - O^{s,\ell} + \hat{X}_o^\ell \quad (16)$$

equation (3), are a function of (i) present and past values of the price of raw materials, P_r, relative to the export price of manufactures of DCs, P_m^d, and (ii) real income of DCs, Y^d; the long run relative price elasticity is -0.69 and the long run income elasticity is 0.63.

The inflation rate of the export price of manufactures, $\Delta\%P_m^d$ in equation (4), depends on (i) the rate of change of nominal wages, $\Delta\%P_\ell$, with a coefficient of 0.327; (ii) the inflation rate of oil prices, $\Delta\%P_0$, lagged one period with a coefficient of 0.09; (iii) the inflation rate of raw materials' prices with a coefficient of 0.34; and (iv) a measure of capacity utilization, U, obtained as the difference between potential output and actual output.

Potential output, Y*, is estimated as a trend of actual output, but we split the period of estimation into two subperiods: 1960-1972 and 1973-1979. One reason for such a sample split is to allow for the possibility of structural changes that might have taken place after the first oil shock in 1973, such as the slowdown of productivity growth. The estimated growth rate for potential output for the period prior to 1973 is 4.7% and 2.9% for the period afterwards. A Chow test for the null hypothesis of structural parameter stability could not be accepted.

The demand for oil (in barrels), 0^d in equation (6), is a conditional demand function derived from a three level CES production function, equation (5), whose arguments are labor, L, capital, K, oil, 0, and coal, C. As a result, both capital-energy substitution possibilities and interfuel substitution possibilities are taken into account. The conditional demand for oil depends on the prices of oil, coal, labor, and the rental price of capital as well as on gross output (value added plus oil imports), GY^d. We estimate a linearized version of this demand function with a distributed lag (4 periods) for prices and income, allowing for homogeneity of degree zero in prices. In estimating this relationship, we use switching regression with a split of the sample in 1972. A Chow test for the null hypothesis of parameter stability could not be accepted. The long run oil price elasticity declines from -0.27 to -0.57. The long run coal price elasticity increases from 0.29 to 0.91. The estimated income elasticity declines from 1.70 to 1.34. The hypothesis of homogeneity of degree zero in prices cannot be rejected.

DCs' total imports of oil (in barrels), $\tilde{M}_o^d$ in equation (7), are equal to their demand for oil (in barrels) minus their exogenously given supply of oil, O^s (also in barrels). Imports of oil from OPEC, $\hat{M}_o^d$ in equation (8), are equal to total imports of oil minus imports of oil from Non-OPEC LDCs, $\hat{X}_o^{\ell}$, which in turn depend on the price of oil relative to the price of coal as well as on gross output of DCs. Since the product of total oil imports in real terms, M_o^d, and the oil price index, P_o, is identical to the product of total imports of oil in barrels, $\tilde{M}_o^d$, and the price of oil P_o^* (in dollars per barrel), we can solve from this identity for oil imports in real terms as in equation (9).

OPEC

The only behavioral relation we explain is OPEC's absorption capacity of oil revenues. For this we relate their imports of manufactures, M_m^o in equation (10), to a distributed lag of oil revenues deflated by the export price of manufactures of DCs. The absorption elasticity in the first year is 0.31, 0.36 in the second year, and 0.04 after four years. The long run absorption elasticity is 0.98.

Non-OPEC Developing Countries

Gross output (value added plus oil imports in real terms), GY^{ℓ} in equation (11), is determined using a two level nested CES production function with capital, K^{ℓ}, and oil consumption, O^{ℓ}, as arguments. The parameters of this function are estimated in two steps by using the first-order conditions for cost minimization and the production function itself. The short run elasticity of substitution between oil and capital is 0.05 and the long run elasticity is 0.73.

Following Coen (1971), we determine capital formation, I^{ℓ} in equation (12), as a function of the rental price of capital, P_k^{ℓ}, relative to the price of oil, and on gross output. We model the speed of adjustment of investment as a function of the availability of foreign exchange resources in real terms, R_{-1}^{ℓ} / P_m^d . We find an inelastic response of investment to changes in both income and relative prices. However, we find investment to be quite responsive to changes in foreign exchange reserves (an elasticity in excess of one).

Imports of manufactures, M_m^{ℓ} in equation (13), are derived using the fact that the capital stock is an aggregate of the domestic capital stock and the foreign capital stock, with a positive (but finite) elasticity of substitution. Following Marquez (1984), we obtain imports of manufactures as a function of net investment, I_n^{ℓ}, and foreign exchange reserves. Our results point to an elasticity of imports of manufactures with respect to investment of 0.8 and an elasticity with respect to (real) foreign exchange reserves in excess of one.

Exports of manufactures to DCs, X_m^ℓ in equation (14), depend on (i) the export price of manufactures of DCs relative to the export price of manufactures of LDCs, P_m^d/P_m^ℓ, and (ii) the real GDP of DCs. Oil consumption, O^ℓ in equation (15), is modeled as a conditional demand function derived from the production function, and it depends on relative factor prices and gross output, GY^ℓ. Using the identity between world consumption (in barrels) and world oil production (in barrels), we derive LDCs' imports of oil from OPEC (in barrels), $\hat{M}_O^\ell$, as the difference between LDCs' oil demand and (exogenously given) oil supply, $O^{s,\ell}$, plus exports of oil of LDCs to DCs. Finally, we link oil imports in barrels to oil imports in real value following the same steps as in equation (9) for DCs.

For the purposes of section III, it is particularly useful to express the econometric model of Table 1 in its state-space representation as:

$$\underset{\sim}{y}_t = \underset{\sim}{f}(\underset{\sim}{y}_t, \underset{\sim}{y}_{t-1}, \underset{\sim}{x}_t, \underset{\sim}{x}_{t-1}, \underset{\sim}{z}_t, \underset{\sim}{\theta}) + \underset{\sim}{e}_t , \qquad (17)$$

where

$\underset{\sim}{y}_t$ = vector of endogenous variables,

$\underset{\sim}{f}$ = vector of functions,

$\underset{\sim}{x}_t$ = vector of controllable exogenous variables,

$\underset{\sim}{z}_t$ = vector of non-controllable exogenous variables,

$\underset{\sim}{\theta}$ = vector of parameters,

$\underset{\sim}{e}$ = vector of random errors, $\underset{\sim}{e} \sim N(\underset{\sim}{0},\Omega)$,

Ω = estimated covariance matrix.

The state-space representation is obtained by redefining both endogenous and controllable variables with lags of order greater than one as new variables. In addition, we have classified exogenous variables as either instruments, $\underset{\sim}{x}_t$, or non-controllables, $\underset{\sim}{z}_t$.

III. SIMULTANEOUS DETERMINATION OF OIL PRICES AND REAL INCOME: AN OPTIMIZING APPROACH

The optimizing approach, as developed originally by Niehans (1968), contains two key ingredients. The first one is a social welfare function providing a ranking of the alternative combinations of target values. The second ingredient is the existence of a target frontier specifying the maximum value that a given target can obtain for given values of the other policy targets. The application of this optimizing approach to our problem has several advantages. First, there exists a quantitative criterion to evaluate systematically the effects of alternative instruments' paths on the behavior of the economy. Secondly, the "principle" of effective market classification is embedded in the optimizing approach. By this principle, instruments are assigned to that target on which it has relatively the strongest effect. This is an important point because the solution to an optimal control problem takes the form of an efficient "policy mix" allowing for the relative desirability of targets, the relative costs of changing the instruments, and the dynamic behavior of the economy.

An alternative to the optimizing approach is a "trial-and-error" approach where one examines the effects on the economy of a large number of alternative paths for the exogenous variables. However, and in contrast to optimal control, there is no objective criterion to choose an efficient policy mix among the alternative paths for the exogenous variables.

In order to select the best policy mix for the controlling variables, we minimize the expected cost of not achieving a given set of income growth targets for each of the regions considered here, subject to the behavioral constraints and identities embodied in the econometric model of section II:

$$\min E(W) = E\{\sum_{t=1}^{T} (y_t^* - a_t)' K (y_t^* - a_t)\}$$

$$\text{subject to } y_t = f(y_t, y_{t-1}, x_t, x_{t-1}, z_t, \theta) + e_t ,$$

where $y_t^{*'} = (y_t' \vdots x_t')$; K is a positive definite diagonal matrix of weights; a_t is a vector of desired values for targets--such as OPEC's oil revenue growth--as well as instruments--such as oil price changes. The choice of a quadratic welfare function is for mathematical convenience.

Stating the optimal control problem in this form is equivalent to maximizing the weighted sum of each regions' welfare function. Given an appropriate choice of weights (the K matrix), and under the assumption of cooperative behavior among policymakers, it can be shown (Niehans 1968, Oudiz and Sachs 1984) that the solution to the first-order conditions of the above optimal control problem (the entire path for x_t) is the efficient policy choice.[4] A policy choice is said to be efficient if there exists no other policy vector capable of reducing one country's welfare losses without increasing welfare losses to another country. Alternatively, a policy mix is said to be efficient if the associated target values belong to the target frontier.

The solution of the first-order conditions for the above minimization problem involves applying Pontryagin's minimum principle (see Marquez 1983), and it takes the form of a linear feedback rule linking real income, and other endogenous variables included in y_{t-1}, to oil prices and other exogenous variables included in x_t:

$$\underset{\sim}{x}_t = G_t(\underset{\sim}{\theta}, \underset{\sim}{a}_t, K)\, \underset{\sim}{y}^*_{t-1} \; . \tag{18}$$

Notice that G_t is a time varying matrix with elements depending on the (estimated) parameters of the model, the desired values for instruments and targets, and the elements of the K matrix. In using a feedback rule we recognize that (1) economic policies are not set once and for all, i.e., they are revised (with a lag of one period) as information about the future values of the endogenous variables becomes known, and (2) current policies have an impact on future policies. This is a relevant issue since a change in oil prices today will have a lasting influence on oil consumption and this must be taken into account when determining the price of oil.

Having derived an expression for the optimal policy path, equation (18), we combine it with the econometric model to obtain an "enlarged" econometric model where real income growth, an element of $\underset{\sim}{y}_t$, and (optimal) oil prices, an element of $\underset{\sim}{x}_t$, are jointly determined:

$$\underset{\sim}{y}^*_t = \underset{\sim}{f}(\underset{\sim}{y}_t, \underset{\sim}{y}_{t-1}, \underset{\sim}{x}_t, \underset{\sim}{x}_{t-1}, \underset{\sim}{z}_t, \underset{\sim}{\theta}) + \underset{\sim}{e}_t \; , \tag{17}$$

$$\underset{\sim}{x}_t = G_t(\underset{\sim}{\theta}, K, \underset{\sim}{a}_t)\underset{\sim}{y}^*_{t-1} \; . \tag{18}$$

To illustrate this joint determination, suppose we are given an initial path for oil price's growth, $\{\underset{\sim}{x}^1\}_t$. Using equation (17), we determine the effect that the given path of oil price changes will have on real income of oil importers. These income effects, together with the substitution effects, are transmitted to OPEC in the form of both movements along and shifts of the oil demand schedule. Using equation (18), these changes in the oil demand schedule are now taken into account by OPEC (with a lag of one period), to obtain a second oil price path $\{\hat{x}^2\}_t$ which, by equation (17), is used to recompute the effects of oil price changes on economic activity. This second round of oil price effects is, in turn, used to update the previous oil price path and so on. This iterative process between oil prices, real income, and oil demand continues until $\| \{\hat{x}^s\}_t - \{\hat{x}^{s-1}\}_t \| \to 0$, where s is the sth iteration.

IV. EXPERIMENTAL DESIGN

Description of the Welfare Function

In order to implement empirically our approach, we parametrize the welfare function as :

$$\min E(W) = E\{\sum_{t=1982}^{1990} \sum_{i=1}^{4} w_{it}(Y_{it} - a_{it})^2 + \sum_{t=1982}^{1990} \sum_{j=1}^{4} k_{jt}(X_{jt} - r_{jt})^2\},$$

where the target variables are:

Y_1= the growth rate for real oil revenues of OPEC, $\Delta\%R^o$;

Y_2= the growth rate for real income of developed economies, $\Delta\%Y^d$;

Y_3= the growth rate for Non-OPEC developing countries, $\Delta\%Y^\ell$; and

Y_4= the inflation rate of the export price of manufactures of DCs, $\Delta\%P^d_m$.

The policy instruments we use are:

X_1= the growth rate for oil prices, $\Delta\%P_o$;

X_2= long term nominal interest rates of developed economies, r^d;

X_3= real government expenditures in DCs, G^d;and

X_4= nominal net capital transfers to Non-OPEC developing countries, CF.[5]

In postulating such a welfare function we have assumed that OPEC, in order to accelerate their development process, sets the price of oil in order to secure a flow of oil export earnings large enough to finance the foreign component of their capital stock (Aperjis 1982, Marquez 1983). We also include in the welfare function growth rates for developed and Non-OPEC developing economies to study both changes in the distribution of income between DCs, OPEC, and Non-OPEC LDCs and the feasibility of a high growth path for the world economy. Finally, the inflation rate of the export price of manufactures, a proxy for the overall inflation rate, is included to capture policy makers' concern with allocative inefficiencies and distributional effects of high and uncertain inflation rates (Niehans 1968, Marquez and Vining 1984).

With respect to the instruments, we use the growth rate for oil prices since it is the instrument that OPEC uses to ensure a steady flow of export earnings. We include government expenditures and interest rates of developed economies because they allow us to study what type of coordinated fiscal, and (only indirectly) monetary policies can be implemented by developed economies in order to achieve a non-inflationary growth path for the world economy. Finally, capital transfers are included to study the financial requirements implied by sustained growth in the LDCs.[6]

By considering a number of policy instruments, we can obtain an isotarget curve by examining the extent to which instruments can substitute for each other in achieving a specific target. For instance, a particular growth path for Non-OPEC LDCs could be achieved with alternative paths for oil prices and government expenditures in DCs, and one issue that arises here is to what extent lower oil prices can be a substitute for an expansionary fiscal policy in DCs given the LDCs' growth path.

Parameters of the Welfare Function

The desired values for targets and instruments are shown in Table 2. We assume a target growth rate for developed economies of 2.5 percent in 1982, which is steadily increased to 5.8 percent in 1989 and 1990. For developing countries we assume a target growth rate of four percent in 1982, which is steadily increased to seven percent for the period 1987-1990.[7] Real oil revenues of OPEC, R^o, are targeted to grow at one percent during 1982 and 1983. Although these growth rates are small relative to the standards of the 1970's, they are ambitious in relation to the performance of real oil revenues for the 1982-1983 period. We increase this growth rate from four percent in 1984 to ten percent in 1989 and 1990. The target inflation rate of exports of manufactures is seven percent in 1982, steadily declines to five percent in 1985, and remains at five percent for the remainder of the horizon.

Nominal oil prices are targeted to have zero growth rate in 1982, a decline of 15 percent in 1983, and a six percent increase for the 1984-1990 period implying a target of one percent increase in real oil prices for this last period. Long term nominal interest rates, r^d, are targeted to decline from 14 percent in 1982 to eight percent by 1986 and to remain at this level for the remainder of the horizon. For government expenditures we assume an average annual growth rate of only 0.9 percent, reflecting the concern over increasing government deficits of current administrations. Capital transfers to LDCs in nominal terms are assumed to grow at an 8.5 percent growth rate per year starting in 1980.[8] Government expenditures and capital transfers enter in the welfare function as indices with 1982=1.0.

Our first characterization of the efficient policy mix consists of a baseline optimal control solution with an egalitarian welfare function,

Table 2

Base Optimal Control Solution
Desired Values for Targets and Instruments
(1982-1990)

Targets

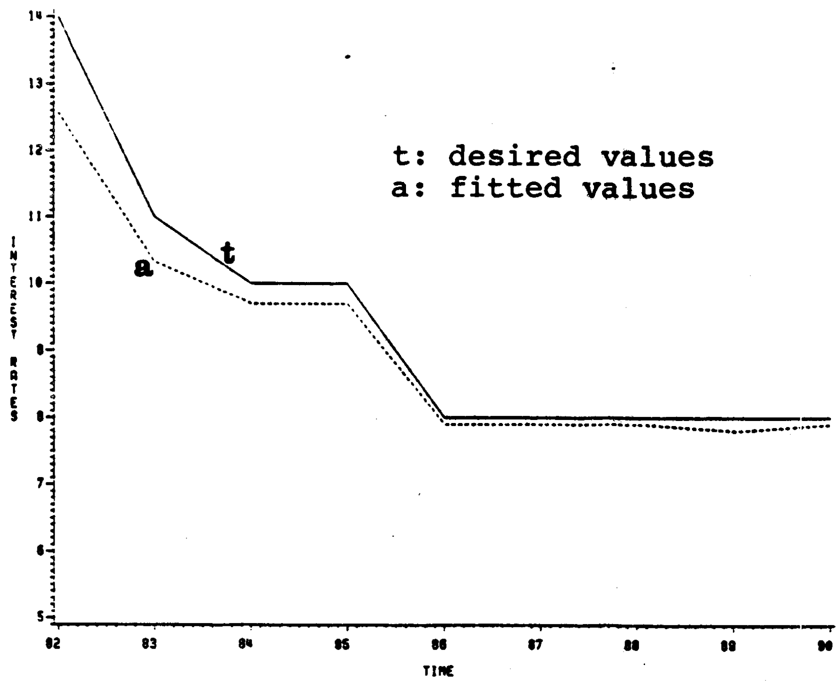
	$\Delta\%Y^d$	$\Delta\%R^o$	$\Delta\%Y^\ell$	$\Delta\%P_m^d$
1982	2.5	1.0	4.0	7.0
1983	3.4	1.0	4.8	6.5
1984	4.0	4.0	5.5	5.5
1985	4.3	6.0	6.0	5.0
1986	4.8	7.0	6.5	5.0
1987	5.2	8.0	7.0	5.0
1988	5.5	9.0	7.0	5.0
1989	5.8	10.0	7.0	5.0
1990	5.8	10.0	7.0	5.0

Instruments

	$\Delta\%P_o$	r^d	G^d	CF
1982	0.0	14	1.0	1.0
1983	-15.0	11	1.01	1.11
1984	6.5	10	1.02	1.23
1985	6	10	1.03	1.37
1986	6	8	1.04	1.52
1987	6	8	1.05	1.70
1988	6	8	1.06	1.87
1989	6	8	1.07	2.08
1990	6	8	1.08	2.31

Figure 1

Mean Fitted Values for Instruments:
Base Optimal Control Solution



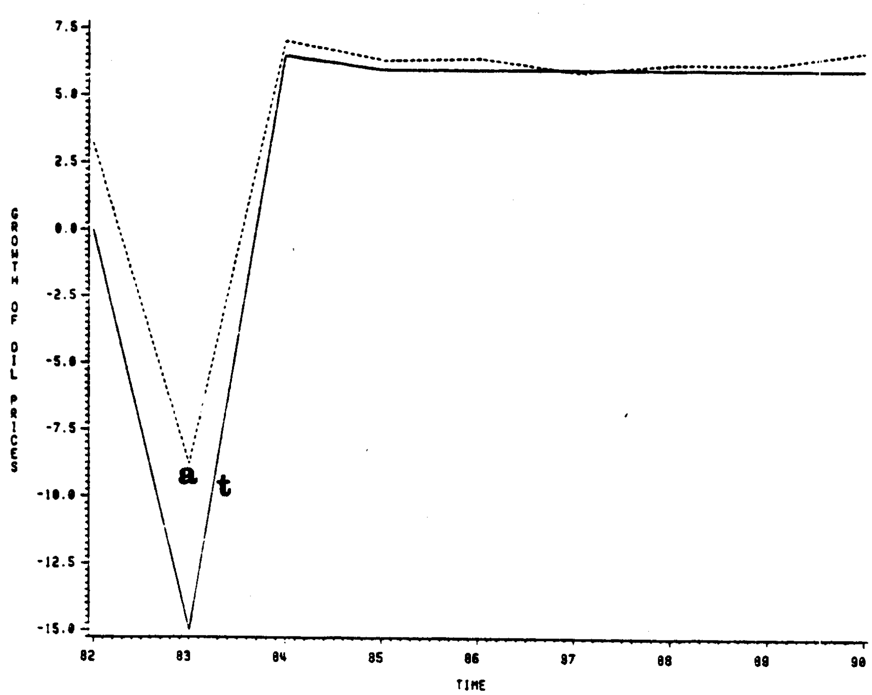


Figure 1

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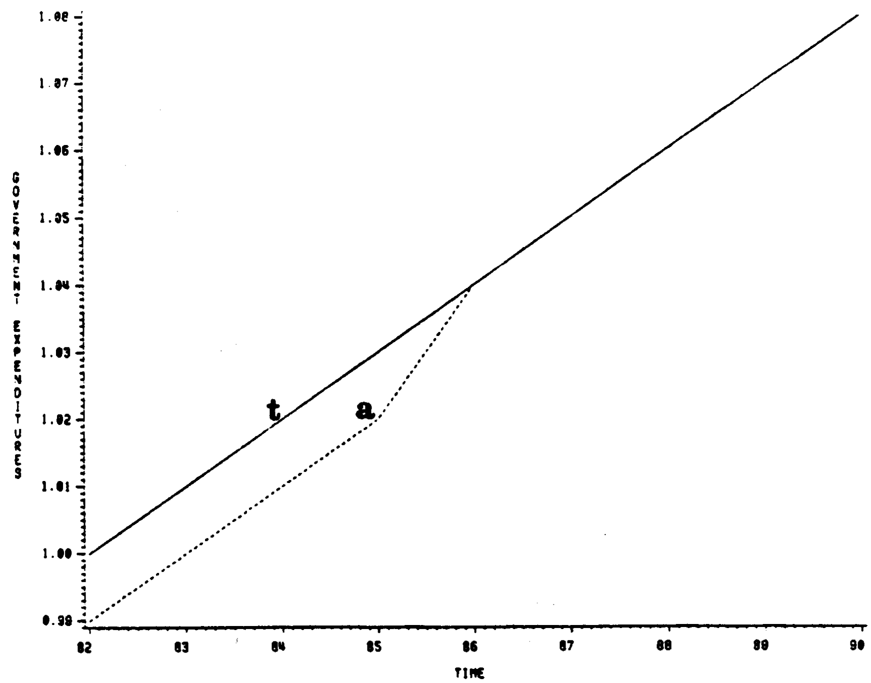


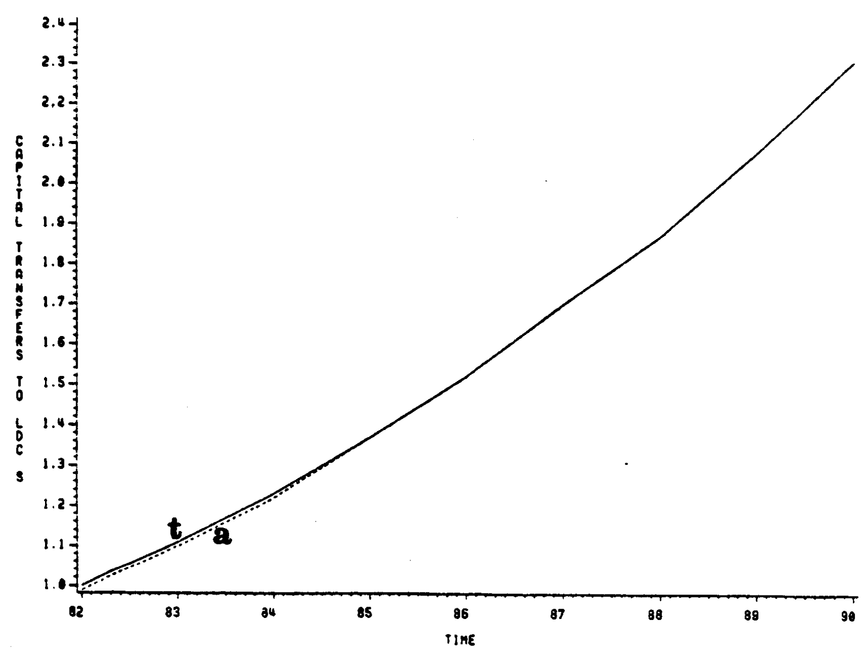
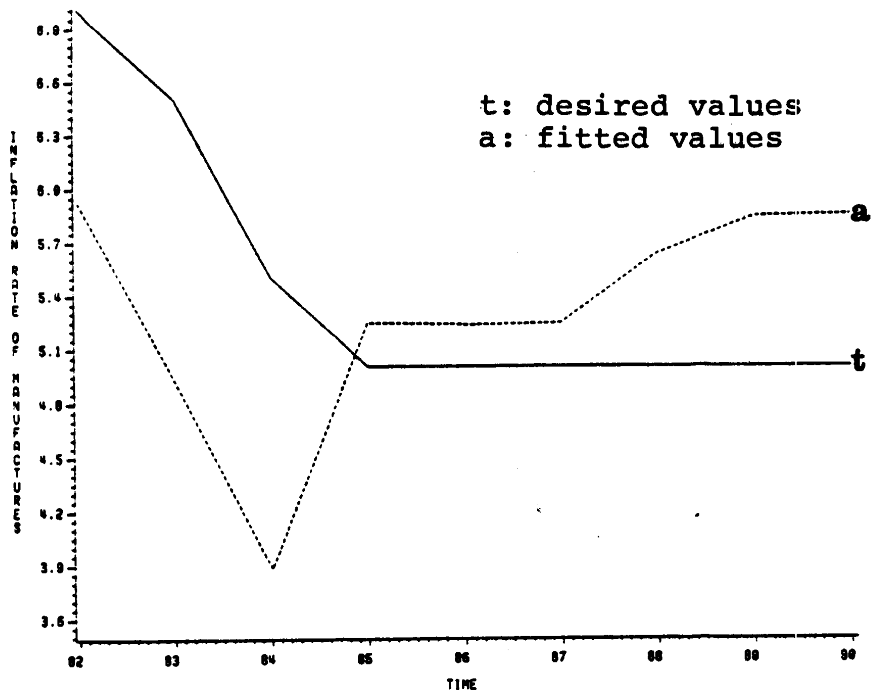


Figure 2

Mean Fitted Values for Targets:
Base Optimal Control Solution



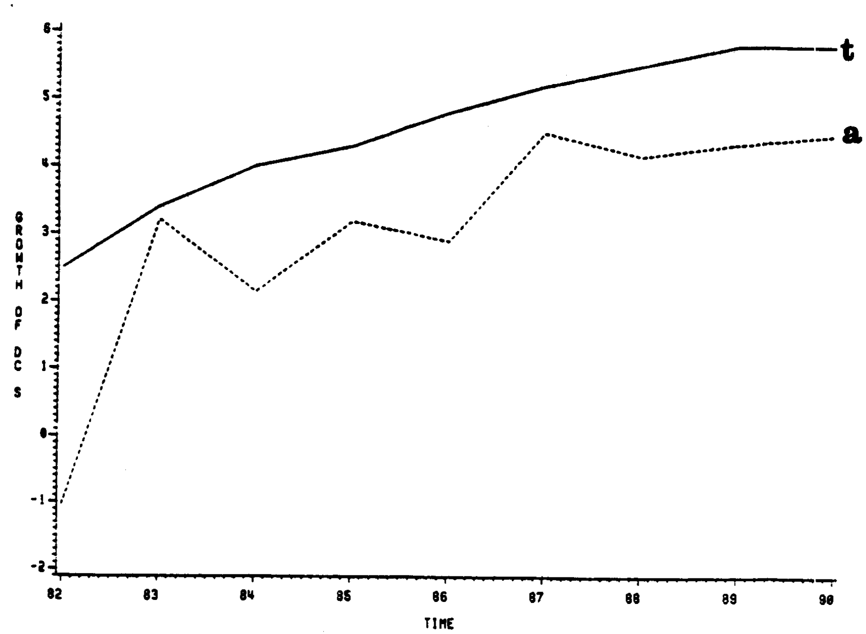


Figure 2.

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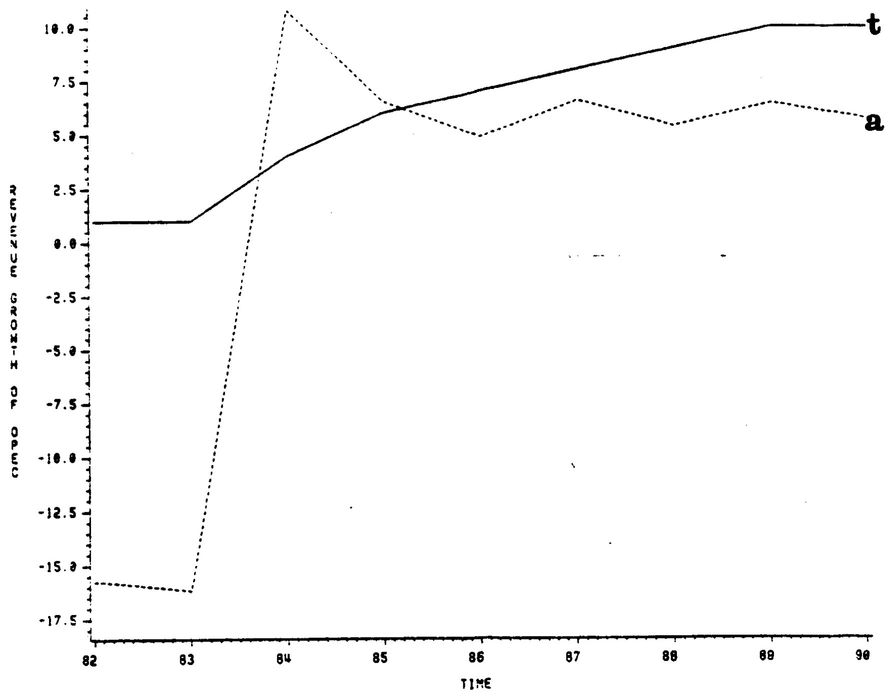
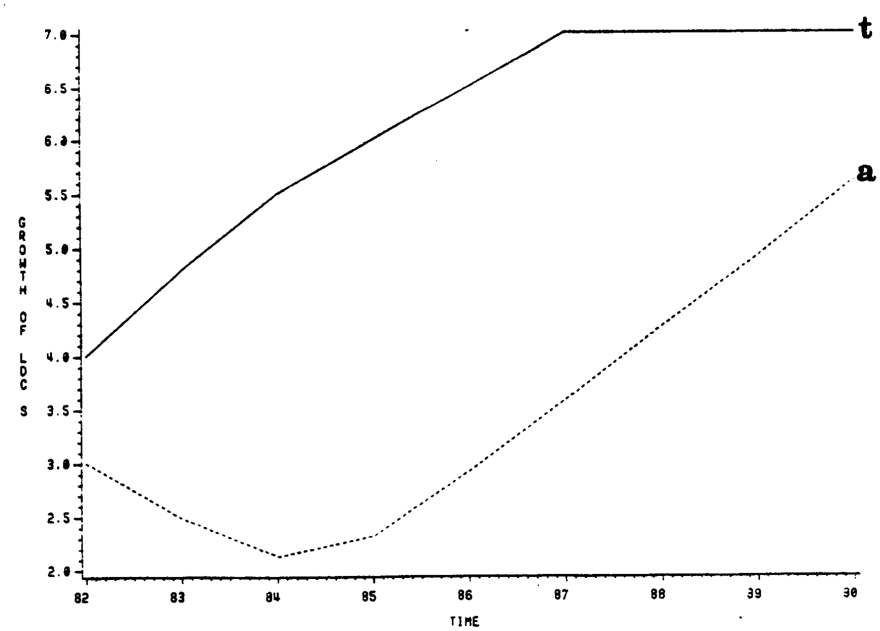




i.e., we assign a weight equal to one to each target variable. The tradeoffs between targets that may arise here are due to the behavioral constraints embedded in our model and to the values given to the instruments' weights. The iterative algorithm used (Closed Loop) is sensitive to the choice of instruments' weights, especially low values (similar findings are reported by Klein and Su 1980). We select the values for the instruments' weights taking into account that policy changes are not likely to be large or frequent (Klein 1983). Thus, we give a large weight to both real government expenditures of DCs (99999) and nominal net capital transfers to LDCs (1500). Interest rates are assigned a weight of 20 and oil prices are assigned a weight of 4.5.

Empirical Results

We apply the optimal control algorithm developed by Chow (1975, 1981) to the econometric model of section II for the period 1982-1990 given the targets and weights described above.[9] Figures 1 and 2 contain the mean fitted values for both the instruments and targets.

Starting with the instruments, we notice that the fitted values for the interest rates are very close to their desired values. Nominal oil prices increase by 3.2 percent in 1982, decline by 8.8 percent in 1983, and increase in 1984 by seven percent; for the 1985-1990 period nominal oil price changes remain in the six percent range. Finally, mean fitted values for both real government expenditures and nominal capital transfers are very close to their targeted values.

With respect to the targets, $\Delta\%P_m^d$ decreases from 5.9 percent in 1982 to 3.9 percent in 1984, but rises again to 5.8 percent by 1990. The initial decline in $\Delta\%P^d_m$ is due to both the fall in oil prices in 1983 and the reduction in economic activity of DCs in 1982. Growth in developed economies, after experiencing a decline in activity in 1982 of one percent, shows a steady increase from 3.2 percent in 1983 to 4.5 percent in 1990. OPEC's real oil revenues decline sharply in 1982 and 1983 (16 percent in each year) because of both the recession in oil importing countries and the decline in oil prices. However, these revenues increase by 10.8 percent in 1984, 6.5 percent in 1985, and maintain an annual average growth rate of 5.8 percent for the period 1986-1990. Growth in Non-OPEC developing countries is positive for the entire planning period starting with a three percent growth rate in 1982, with a small decline to 2.1 percent in 1984, and increasing steadily to 5.6 percent in 1990; the average annual growth rate is 3.5 percent.[10]

Recognizing both the limitations of our model, and given the particular weights used, we find that if international policy coordination results in (1) nominal oil prices growing at an average of six percent per year, (2) nominal capital transfers to Non-OPEC developing countries growing at 8.5 percent per year, (3) long term interest rates declining to 8.0 percent, and (4) real government expenditures continuing their (modest) expansionary path, then it is feasible to achieve relatively high growth rates for developed, OPEC, and Non-OPEC developing countries for the remainder of this decade.

The Importance of Income Feedback Effects and OPEC's Pricing Policy

One of the main contentions of this paper is that allowance for the income feedback effects of oil price changes raises the absolute value of the price elasticity of oil demand and therefore lowers the optimal price path consistent with OPEC's best interests. What is not so clear, however, is whether these feedback effects are important enough to result in significantly different oil price paths.

One way to evaluate the importance of these feedback effects is to contrast the effects on oil revenue growth of a price path where oil prices grow at a rate equal to the interest rate (Hotelling 1931, Stiglitz 1976) and thus no feedback effects are allowed, against the effects on oil revenue growth of an optimal oil price path derived using optimal control, where feedback effects are allowed. Table 3 contains our results, which are depicted in Figure 3.

For every year, except the first two, the growth path for OPEC's revenue in the no-feedback case is below the revenue growth path derived using optimal control, even though oil prices grow faster in the no-feedback case than in the optimal control case. The deterioration of OPEC's revenue growth in the no-feedback case occurs because the revenue increase arising out of short-term price inelasticity of oil demand is offset by the reduction in real income of oil importers, which dampens oil consumption and shifts to the left the export demand schedule faced by OPEC. In other words, the income feedback effect of oil price increases raises the (absolute value of) the price elasticity above 1 and therefore further price increases lead to revenue losses.[11] And what our results imply is that it is optimal to increase the price of oil until the revenue increase arising out of short-run price inelasticity is equal to the revenue loss arising out of the income feedback effects.

Sensitivity Analysis

The characterization of the efficient policy mix derived above is conditioned on both a particular weighting matrix and on the assumption of

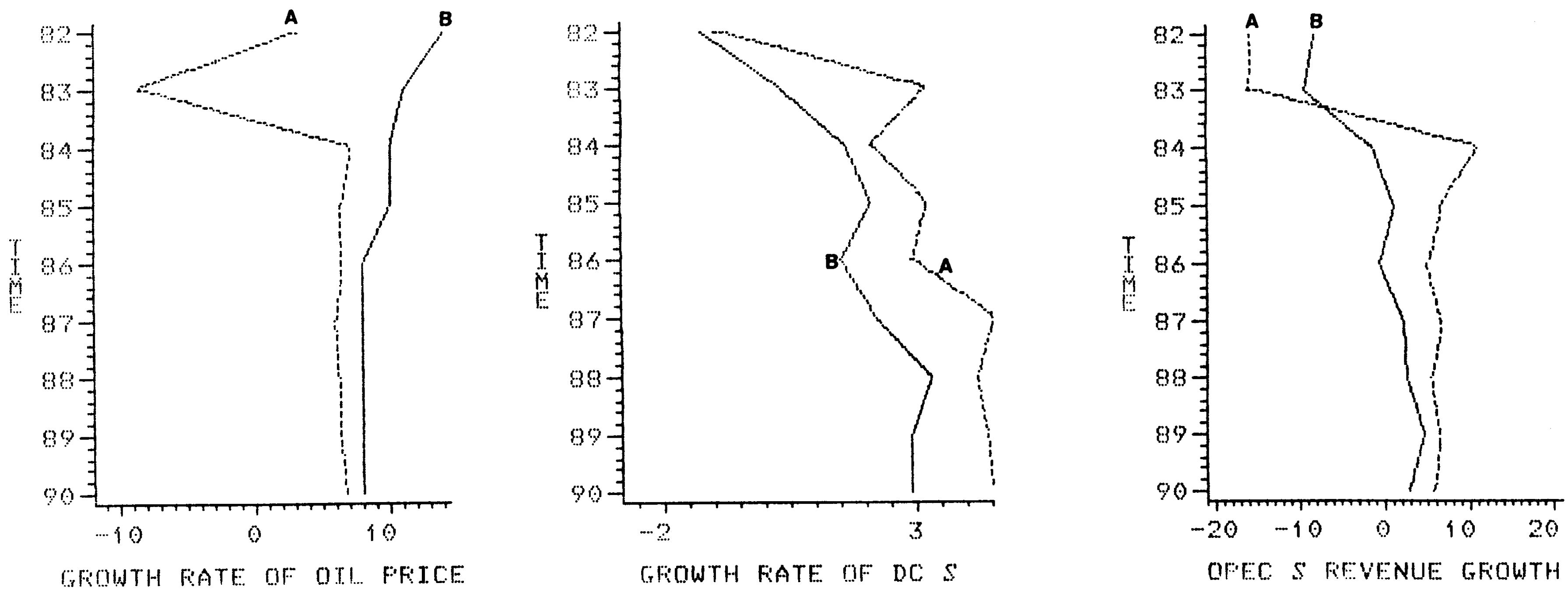
Table 3

Optimal Oil Prices With and Without Feedback Effects Allowed

	No Feedback Effects Allowed			Feedback Effects Allowed		
	$\Delta\%P_o$	$\Delta\%R^o$	$\Delta\%Y^d$	$\Delta\%P_o$	$\Delta\%R^o$	$\Delta\%Y^d$
1982	14	-8.3	-1.26	3.2	-15.8	-1.0
1983	11	-9.4	0.33	-8.8	-16.2	3.2
1984	10	-1.5	1.6	7.0	10.8	2.1
1985	10	1.2	2.1	6.3	6.5	3.2
1986	8	-0.6	1.5	6.4	4.9	2.9
1987	8	2.3	2.2	5.9	6.6	4.5
1988	8	2.7	3.3	6.2	5.4	4.2
1989	8	4.6	2.9	6.2	6.4	4.4
1990	8	2.8	2.9	6.7	5.7	4.5

Figure 3

Optimal Oil Prices With and Without Feedback Effects



a) feedback effects allowed b) no feedback effects allowed cooperation among the three blocks of countries in setting the instruments' values. Therefore, it is of interest to perform a sensitivity analysis to study the robustness of our results to changes in the values of the weights.[12] In particular, we analyze the welfare tradeoffs among OPEC, developed countries and Non-OPEC developing countries that arise as a result of changes in (1) the preference ranking of targets, and (2) the cost attached to fluctuations in the instruments, particularly oil price changes, real government expenditures, and nominal capital transfers to LDCs.

One useful definition of welfare losses, W_i, is:

$$W_i = \left(1/9 \sum_{t=1982}^{1990} (Y_{it} - a_{it})^2\right)^{1/2}, \; i=1,2,3.$$

W_i measures the average deviation of the fitted value of variable Y_i from its targeted value. Therefore, the smaller is W_i, the smaller is the "welfare" loss of the ith country block. For instance, the last row of Table 4 contains the welfare losses for the three regions considered here, under the baseline optimal control solution. Our results indicate that, on the average, the DCs' growth rate deviates 1.7 percent from the target growth rate. OPEC's revenue growth shows the greatest deviation, 8.7 percent, which could be due to either the setting of extremely ambitious targets or to the particular choice of weights. We concentrate in the remainder of this paper on the sensitivity of these welfare losses to changes only in the weights of the welfare function.

Case I: Greater Weight to OPEC's Revenue Growth Target

We now study the welfare tradeoffs between the three country blocks that arise when the weight for OPEC's revenue target is increased

Table 4

Welfare Tradeoffs
Case I: Greater Weight for OPEC's Revenue Growth Target

Weights		Welfare Losses			
K_{po}	K_g	DC's	OPEC	LDC's	$\Delta\%P_o$ [a]
4.5	99999	2.3	4.8	2.8	8.1
2.3	99999	2.0	4.9	3.0	9.9
0.1	99999	3.0	4.8	3.2	19.8
4.5	5000	2.3	4.0	2.3	6.4
2.3	5000	1.6	3.5	2.4	8.3
0.1	5000	2.0	2.1	2.6	20.6
Base Solution		1.7	8.7	2.7	4.3

[a] Average growth rate, 1982-1990.

from one to ten. A welfare tradeoff is said to occur when a decline in W_i induces an increase in some other W_j. We also examine the sensitivity of such tradeoffs to different weights for oil price changes (0.1, 2.3, 4.5) and for real government expenditures (99999, 5000). Table 4 presents the welfare losses for each country block and the average growth rate for oil prices corresponding to alternative combinations of weights; Figure 4 depicts the results of Table 4. Figures 5 and 6 illustrate the behavior of targets and instruments for selected weight values.

We begin the sensitivity analysis by increasing the preference given to OPEC's growth target while leaving unchanged all the remaining weights. We find that OPEC's welfare losses are reduced from an average of 8.7 percent for the base solution to 4.8 percent in the present case. This reduction is possible because of the average growth rate of oil prices increases from 4.3 percent to 8.1 percent. At the same time, the reduction in OPEC's welfare losses induces an increase in the welfare losses of both developed and developing economies by 0.6 percent and 0.1 percent respectively. Thus if the OPEC countries have enhanced bargaining power, then they may be able to reduce their welfare losses only by inducing an increase in welfare losses to the other countries, which shows that the income distribution for the original set of weights was efficient.

As mentioned earlier, one of the advantages of using optimal control is that the instruments are assigned to targets according to their relative efficacy. This assignment, however, depends on the relative costs attached to fluctuations in the different instruments, and for this reason we examine how sensitive is this assignment to changes in the instruments' relative weights. Suppose then that we reduce the value of the weight for changes in oil prices. Intuitively, the smaller the value of the weight for

Figure 4

SENSITIVITY OF WELFARE LOSSES TO CHANGES IN INSTRUMENT WEIGHTS CASE I

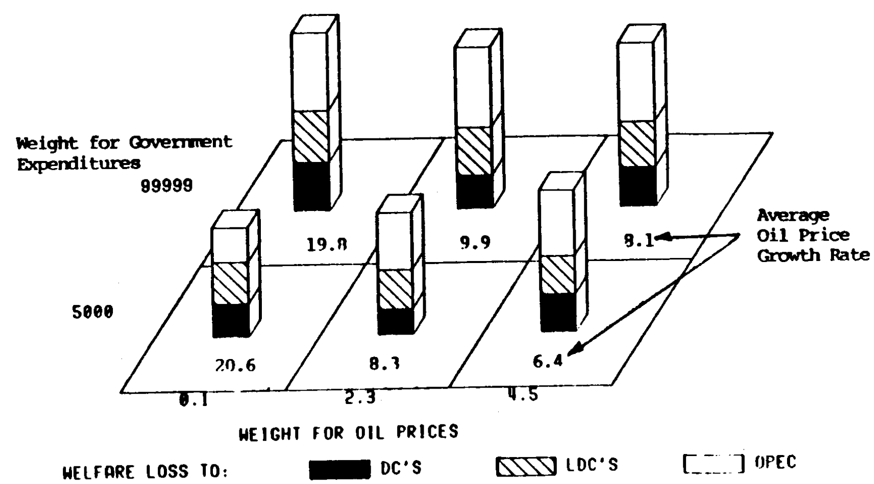
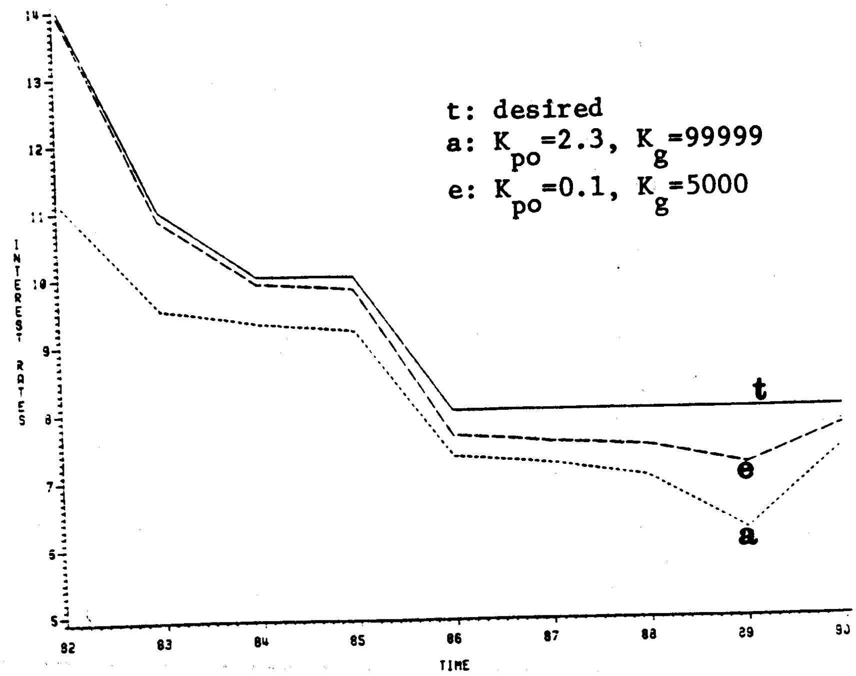


Figure 5

Mean Fitted Values for Instruments: Case I



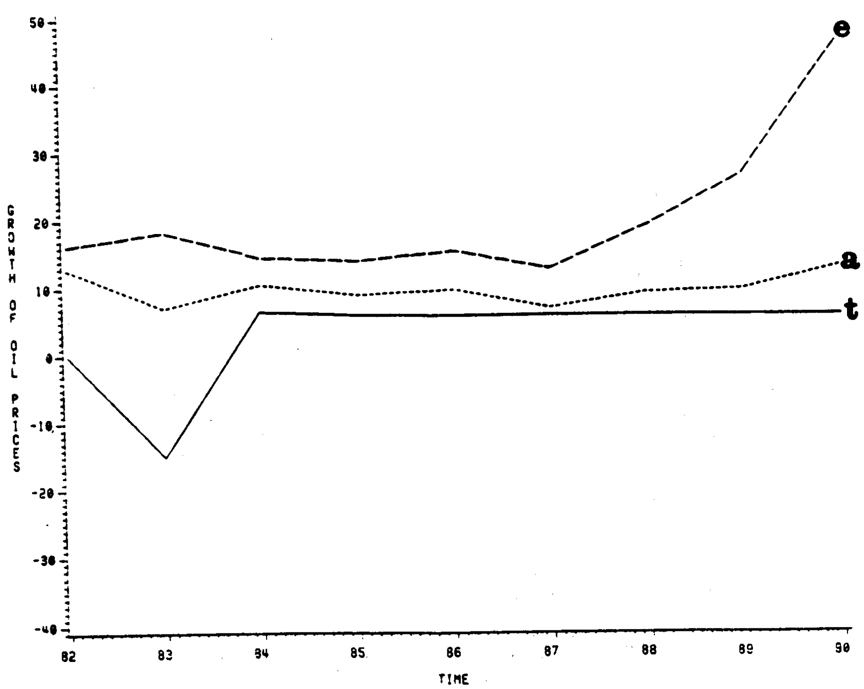


Figure 5

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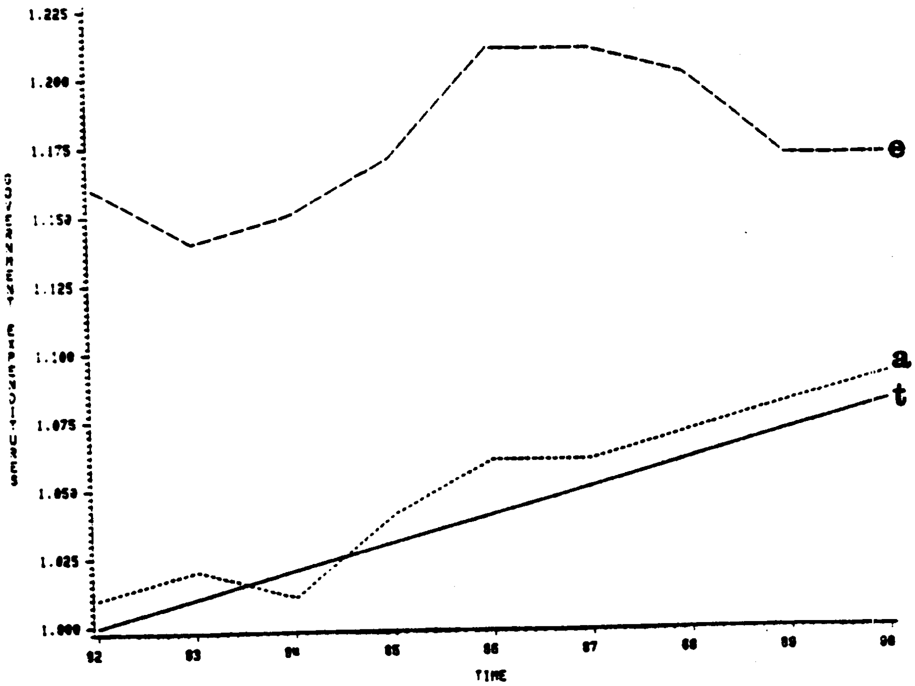


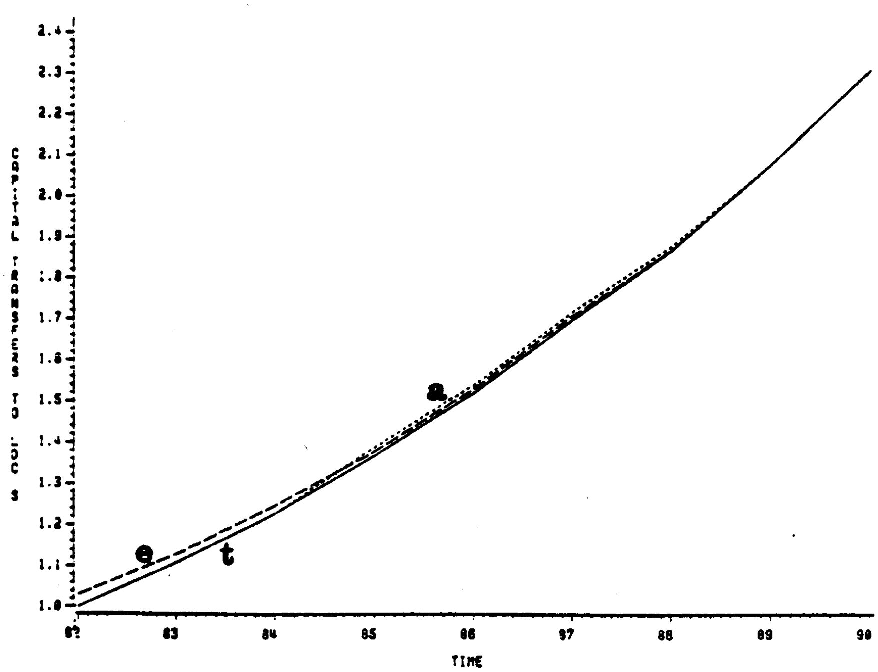
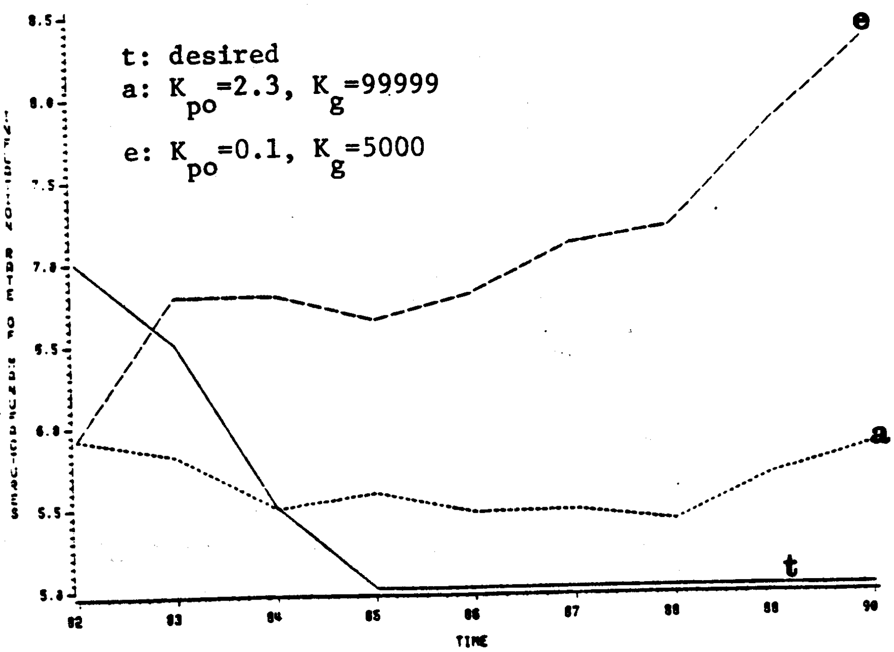


Figure 6

Mean Fitted Values for Targets: Case I



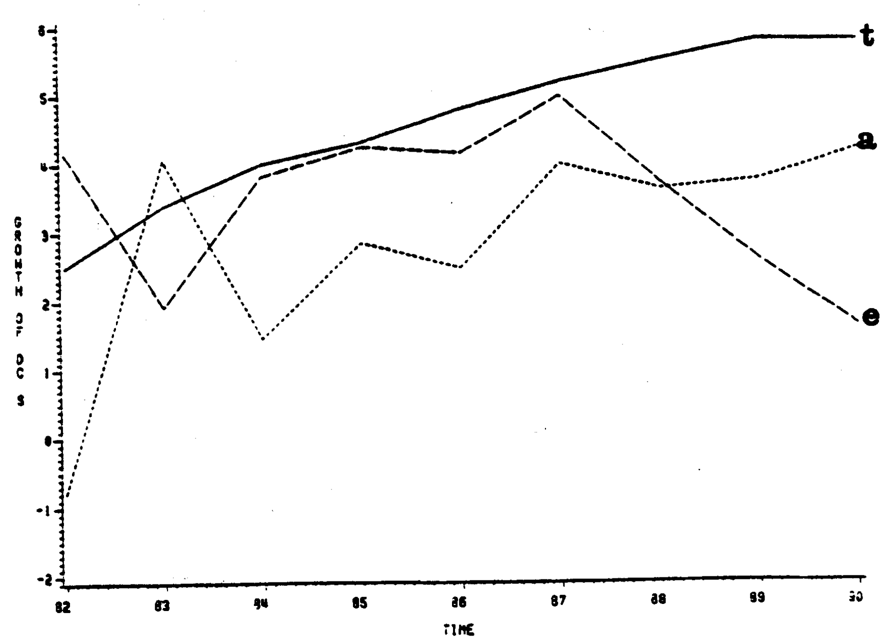


Figure 6

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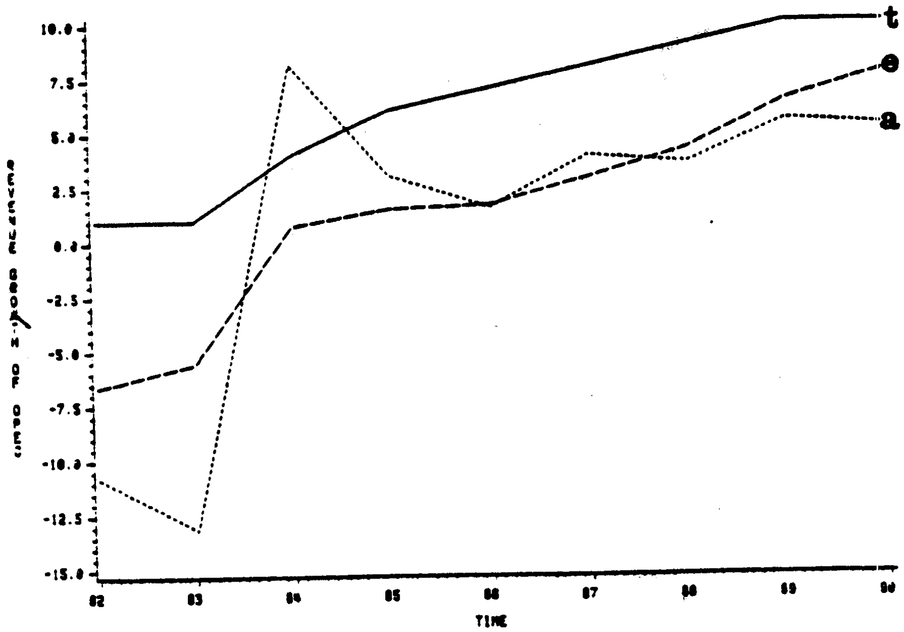

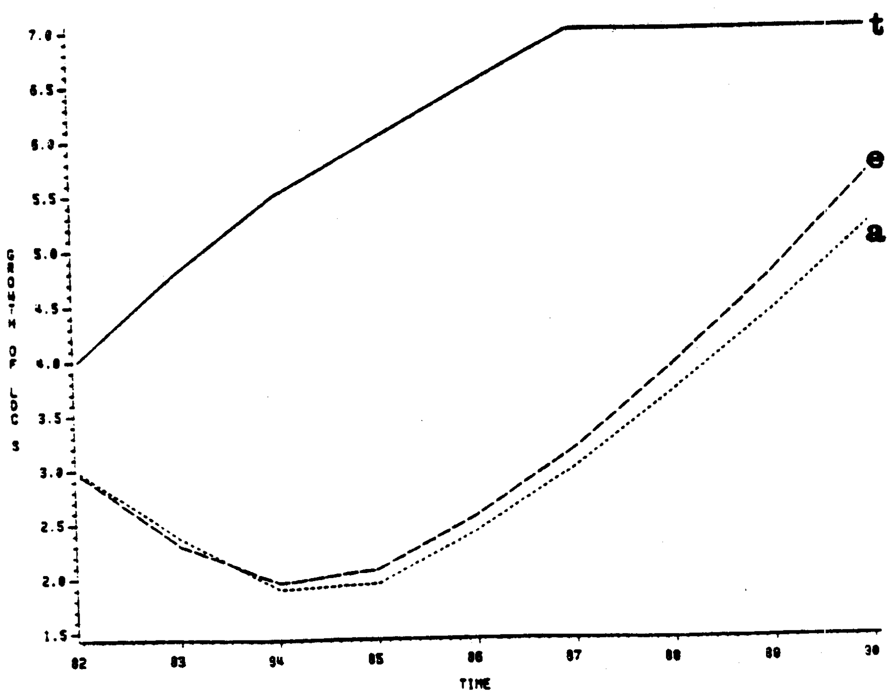

a given instrument the more willing we are to use that instrument to improve OPEC's growth target. In particular, a reduction of the weight for oil price changes from 4.5 to 0.1 has the effect of raising the average growth rate of oil prices from 8.1 percent to 19.8 percent, which increases welfare losses to both DCs and LDCs by 1.3 and 1.5 percent respectively without reducing OPEC's welfare losses. The increases in welfare losses of DCs and LDCs are not more pronounced because as the average growth rate for oil prices increases, the optimal fiscal policy response becomes more expansionary and thus tends to offset the adverse effects of increases in oil prices on income growth.

Fiscal policy in DCs might also be used as an alternative instrument to achieve OPEC's growth target. To examine this possibility we reduce the cost of fluctuations in this instrument from 99999 to 5000. As a result, we find that fiscal policy fluctuates more freely, and that it leads to an unambiguous reduction in welfare losses for each block of countries. This "Pareto" improvement is possible because the optimal response of government expenditures in developed economies is rather expansionary, exceeding its target by an annual average of $US 55 billion, whereas the optimal fiscal policy response with a large weight exceeds its target only by an average of $US 8.6 billion. As a result of this expansionary fiscal policy there is a stimulus to oil imports from OPEC which, when combined with a greater average growth rate in oil prices, explains the reduction in welfare losses to OPEC. Similarly, we find a substantial reduction in welfare losses to LDCs despite (1) increases in the average growth rate of oil prices, and (2) virtually no deviations of capital transfers from their desired values. This is because higher government expenditures in DCs serve as a substitute instrument for capital transfers to LDCs since it increases imports of DCs from LDCs and this increases foreign exchange reserves with the same impact on growth of LDCs as a transfer of capital.

Case II: Greater Weight to DCs Growth Target

In this case we begin by increasing the weight of DCs' growth target from one to ten while leaving all the other targets with a weight of one. The results are shown in Table 5 and are depicted in Figure 7. Figures 8 and 9 illustrate the behavior of targets and instruments for selected weight values.

In general, the initial impact of an increase in the weight for DCs growth target is to raise government expenditures in DCs. However, as we saw in Case I, there is a direct relation between movements in oil price changes and movements in optimal real government expenditures in DCs. This positive relationship implies that the effects of an increase in government expenditures on real income of DCs are offset by the increases in oil prices that immediately follow. This offsetting effect requires an even larger expansion of government expenditures to counteract the negative effects of higher oil prices and to achieve the growth target. However, any further increase in government expenditures is followed by another round of oil price increases which again increases government expenditures. The net effect of this process is an increase in welfare losses to DCs and LDCs but a reduction in welfare losses to OPEC. This adverse result on DCs welfare losses arises because the increase in oil prices is of a greater magnitude than the increase in government expenditure given the large weight differential between these two instruments.

In order to eliminate the influence of a large weight differential on the welfare tradeoffs, we reduce the weight of government expenditures from 99999 to

Table 5

Welfare Tradeoffs
Case II: Greater Weight for DC's Growth Target

Weights		Welfare Losses			
K_{po}	K_g	DC's	OPEC	LDC's	$\Delta\%P_o$[a]
4.5	99999	2.2	7.8	3.1	6.1
2.3	99999	2.3	7.4	3.2	7.1
0.1	99999	2.6	6.6	3.2	9.2
4.5	5000	3.0	8.3	3.1	5.6
2.3	5000	2.0	8.1	3.0	5.1
0.1	5000	1.6	5.0	3.0	10.9
Weight for DC's Growth = 50					
4.5	5000	1.3	8.3	2.8	4.7
Weight for DC's Growth = 200					
4.5	5000	0.6	7.6	2.5	5.2
Base Solution		1.7	8.7	2.7	4.3

[a] Average growth rate, 1982-1990.

Figure 7

SENSITIVITY OF WELFARE LOSSES TO CHANGES IN INSTRUMENT WEIGHTS CASE II

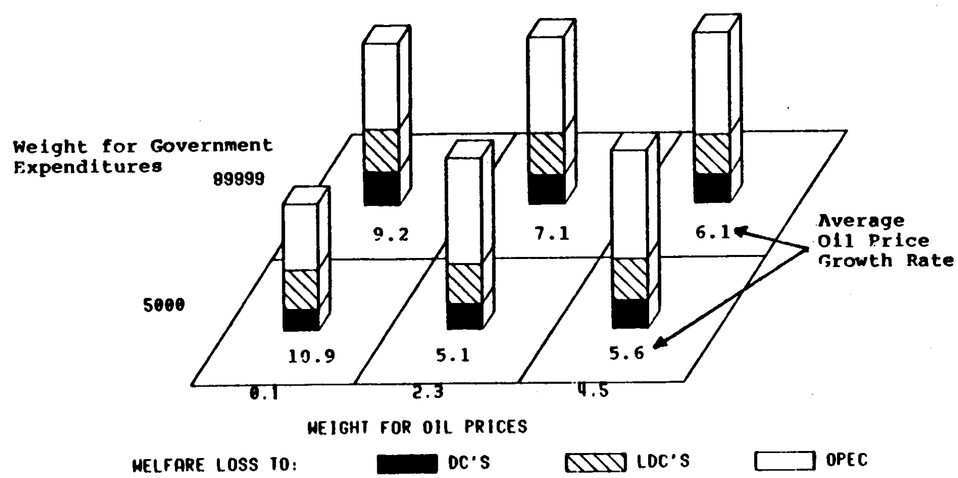

Figure 8

Mean Fitted Values for Instruments: Case II

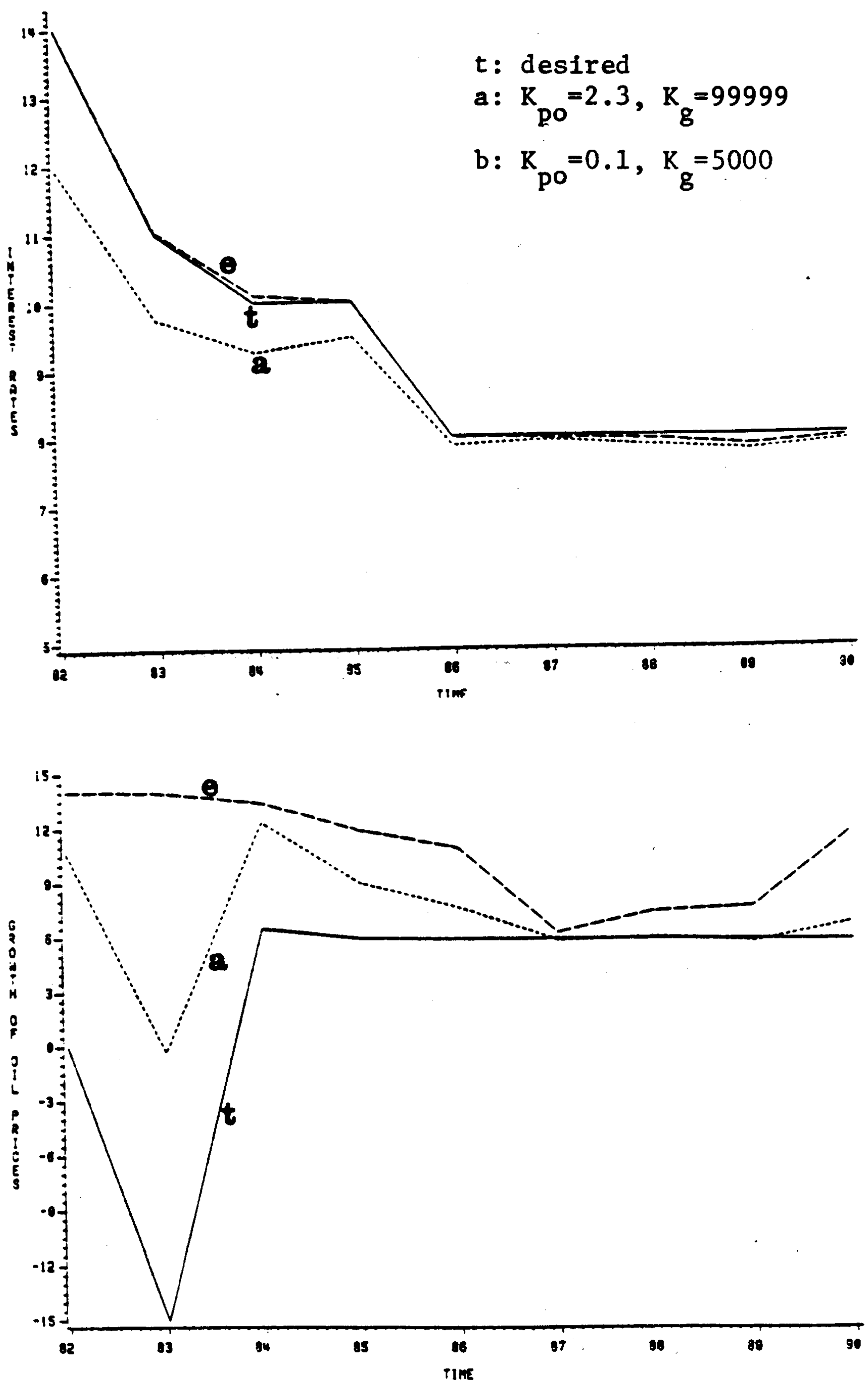

Figure 8

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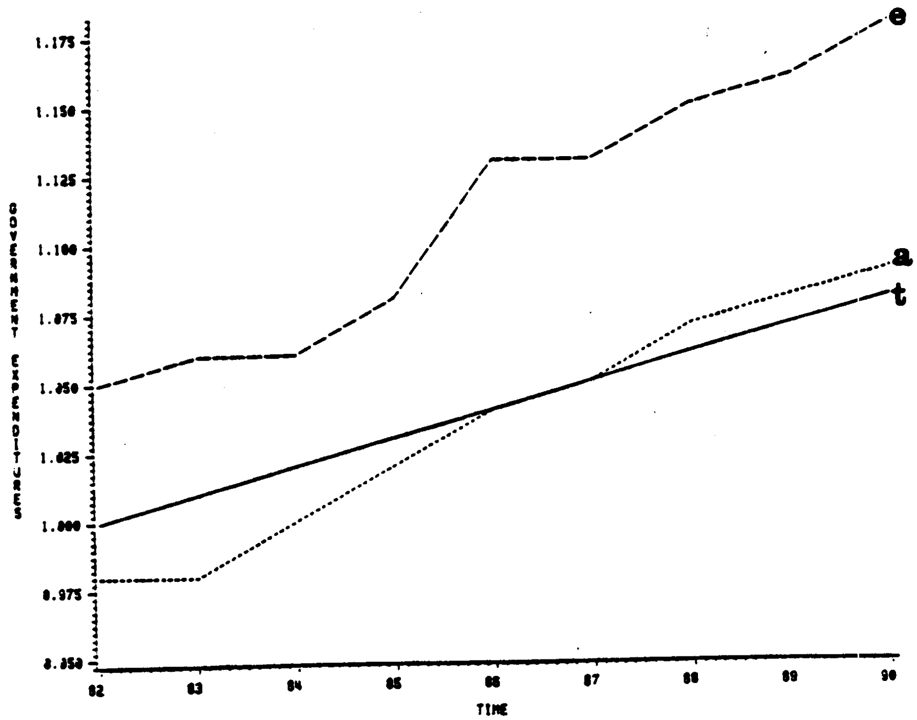


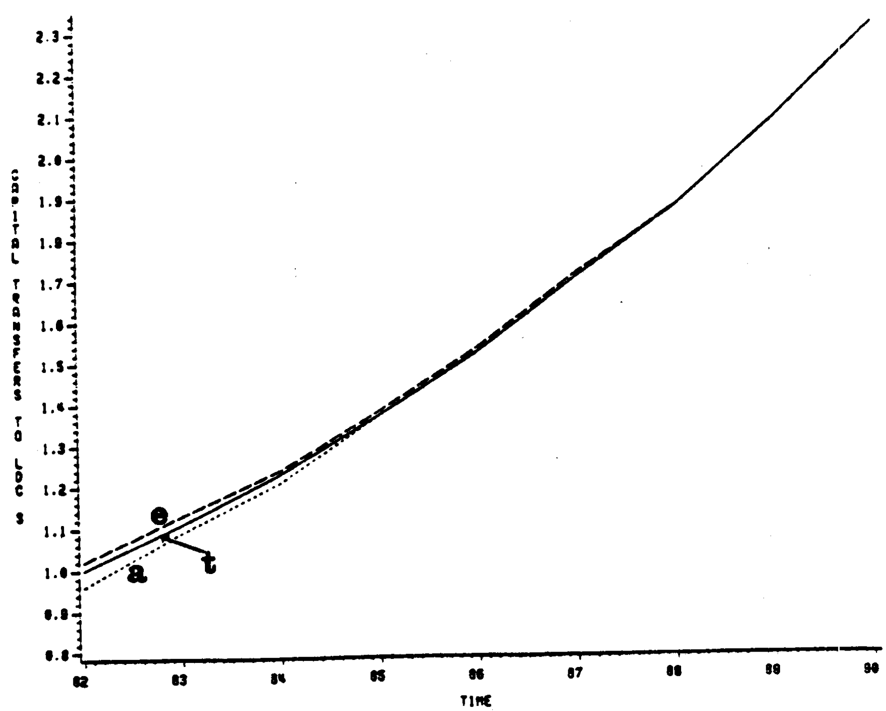
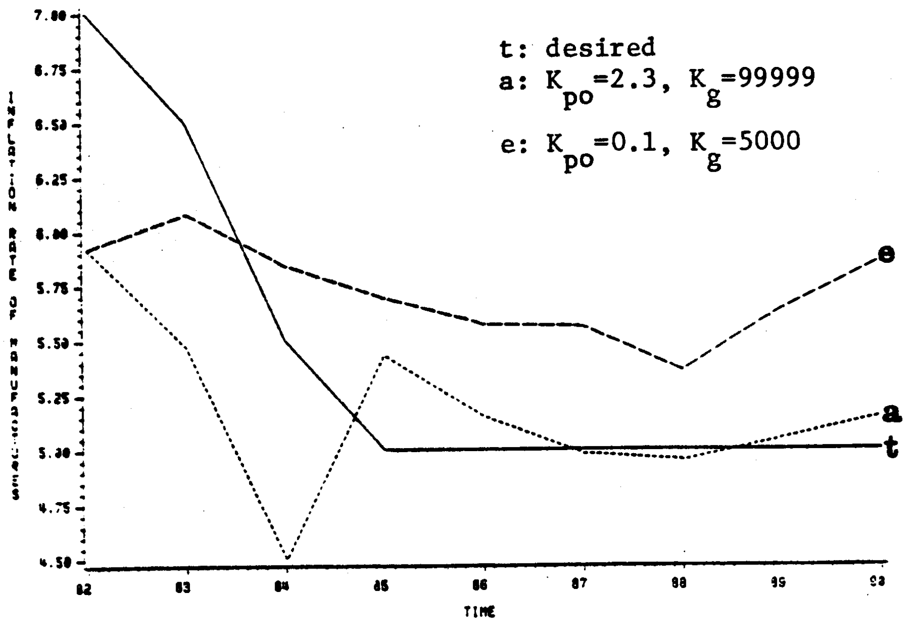


Figure 9

Mean Fitted Values for Targets: Case II



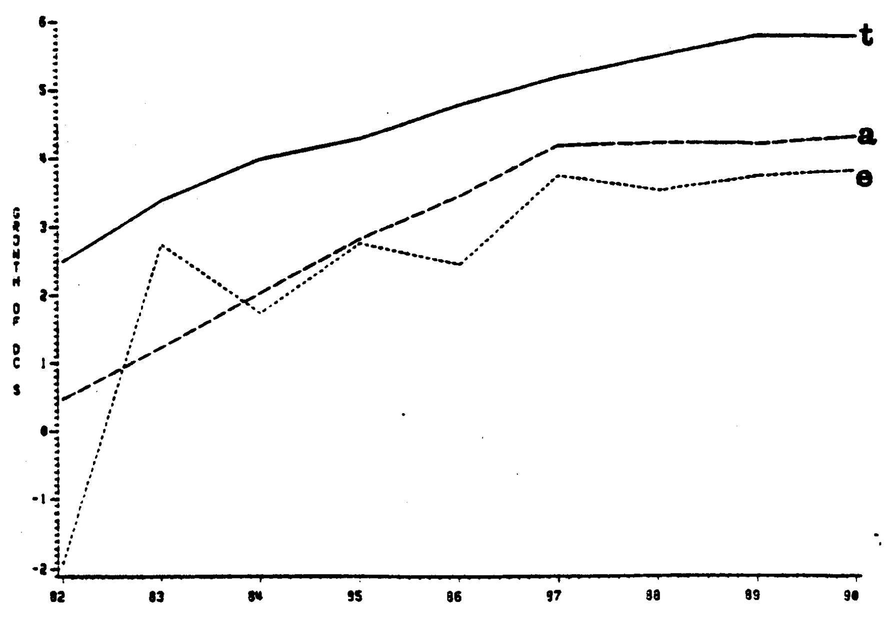


Figure 9

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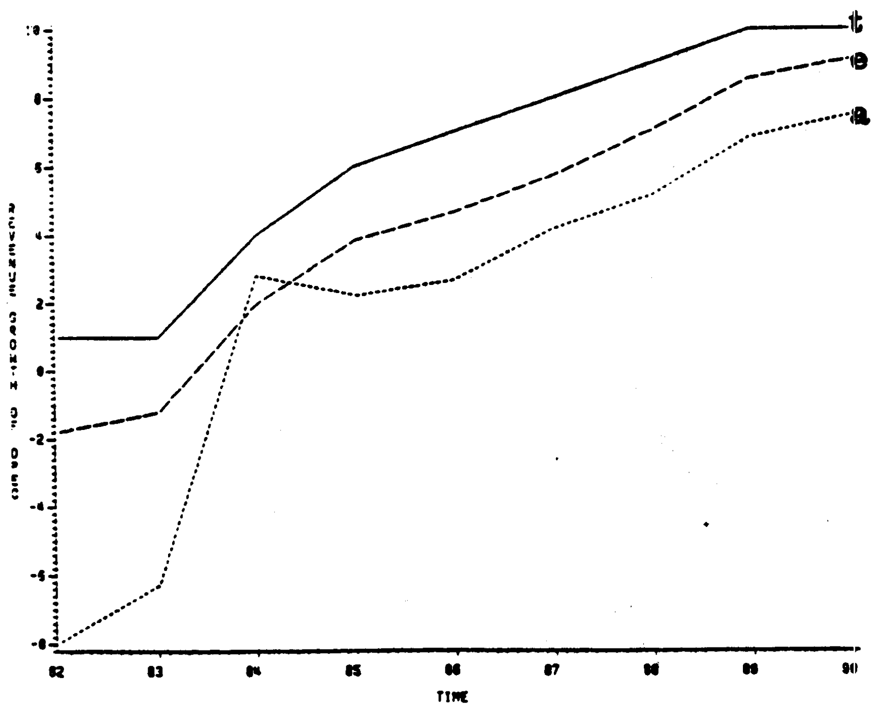
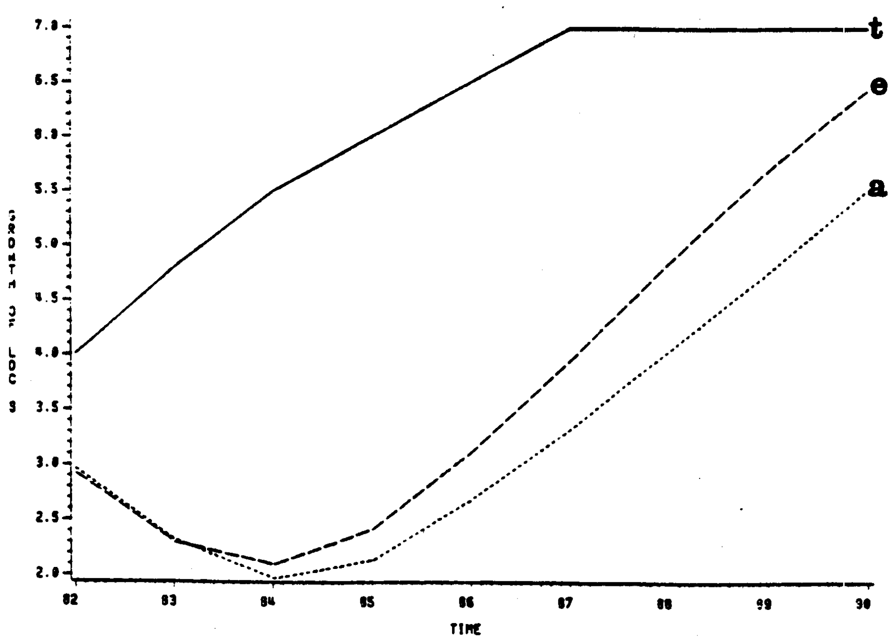




5000. We find that this weight reduction leads to a decline in welfare losses for DCs from 3.0 percent to 1.6 percent and for OPEC from 8.3 percent to 5.0 percent with almost no effect on LDCs welfare losses despite an increase of the average growth rate for oil prices from 5.6 percent to 10.9 percent. This last result suggests that the adverse effect of higher oil prices on both DCs and LDCs growth are offset by the stimulative effects of increases in government expenditures of DCs, given that this instrument can fluctuate more freely now.

We also examine the impacts of additional increases in the weight for the DCs growth target. In order to detect nonlinear intertemporal tradeoffs, we consider an increase in this weight first from 10 to 50 and then from 10 to 200, while keeping the weights for oil prices and government expenditures at 4.5 and 5000 respectively. Our results indicate that when the weight for DCs equals 200, their welfare loss declines from 3 percent to 0.6 percent. There is a small decline in welfare losses of OPEC (0.2 percent) even though the average oil price growth rate declines under the new weighting scheme. This suggests that OPEC's reduction in welfare losses arises out of the increase in oil exports induced by the higher growth in developed economies. Finally, Non-OPEC LDCs experience a decline in welfare losses from 3.1 percent to 2.5 percent because the effects of higher government expenditures (higher growth in DCs) and lower oil price growth are transmitted to them via international trade, enlarging their foreign exchange resources and thus reducing their need for capital transfers above the targeted levels. Thus, once again, we find that increases in DCs' government expenditures serve as a substitute instrument for capital transfers to Non-OPEC developing countries.

Case III: Greater Weight to LDCs Growth Target

In this case we begin increasing the weight of LDCs target growth rate from one to ten while keeping the weights for the other targets equal to one. We also increase our willingness to use capital tranfers more freely, and thus we reduce the weight for this instrument from 1500 to 100. Our results are shown in Table 6 and depicted in Figure 10. Figures 11 and 12 show the behavior of instruments and targets for selected weight values.

An increase in the weight of LDCs' target growth rate results in an unambiguous reduction in their welfare losses by an average of 1.1 percentage points with respect to the baseline solution for all the combinations of weights considered here. Moreover, we notice that even if we let oil prices fluctuate more freely, by reducing their weight from 4.5 to 0.1, there is no increase in welfare losses to LDCs despite an increase in the annual average growth rate of oil prices from 4.3 percent to 11.4 percent. This is because the adverse effects of higher oil prices are offset by higher capital transfers, which exceed their targets by an annual average of $US 19.5 billion. Additional effects of the increase in the average growth rate of oil prices are a reduction in OPEC's welfare losses from 8.6 percent to 5.6 percent and an increase in DCs' welfare losses from 1.6 percent to 2.6 percent.

The effectiveness of using government expenditures to achieve the LDCs growth target depends on the behavior of oil prices. In particular, if fluctuations in oil price changes have attached a weight of 4.5, then a reduction in the weight on government expenditures does not affect LDCs at all, and adversely affects DCs and OPEC. This is because with a weight of 4.5, oil prices tend to follow their target values quite closely, which includes a reduction in the average growth rate for oil prices. The fall in oil prices leads to a decline in government expenditures, given the positive assocation between these two instruments, which explains the adverse effects

Table 6

Welfare Tradeoffs
Case III: Greater Weight for LDC's Growth Target

Weights		Welfare Losses				
K_{po}	K_g	DC's	OPEC	LDC's	$\Delta\%P_o$ [a]	ΔCF [b]
4.5	99999	1.6	8.6	1.6	4.3	12.1
2.3	99999	1.7	7.8	1.6	5.1	13.4
0.1	99999	2.6	5.6	1.6	11.4	19.5
4.5	5000	1.9	8.7	1.6	3.8	14.3
2.3	5000	1.8	7.9	1.5	4.6	14.8
0.1	5000	2.0	4.8	1.5	11.4	17.7
Base Solution		1.7	8.7	2.7	4.3	0.2

[a] Average growth rate, 1982-1990.

[b] Average deviation from target, 1982-1990, billions of $US.

Figure 10

SENSITIVITY OF WELFARE LOSSES TO CHANGES IN INSTRUMENT WEIGHTS CASE III

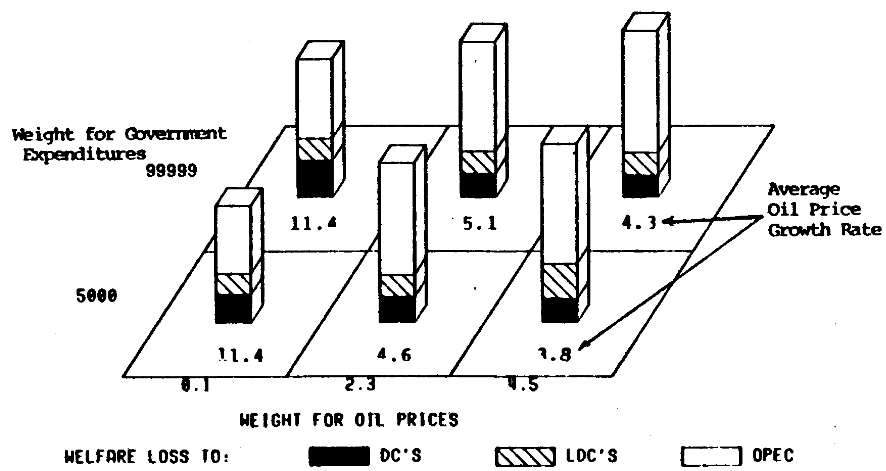
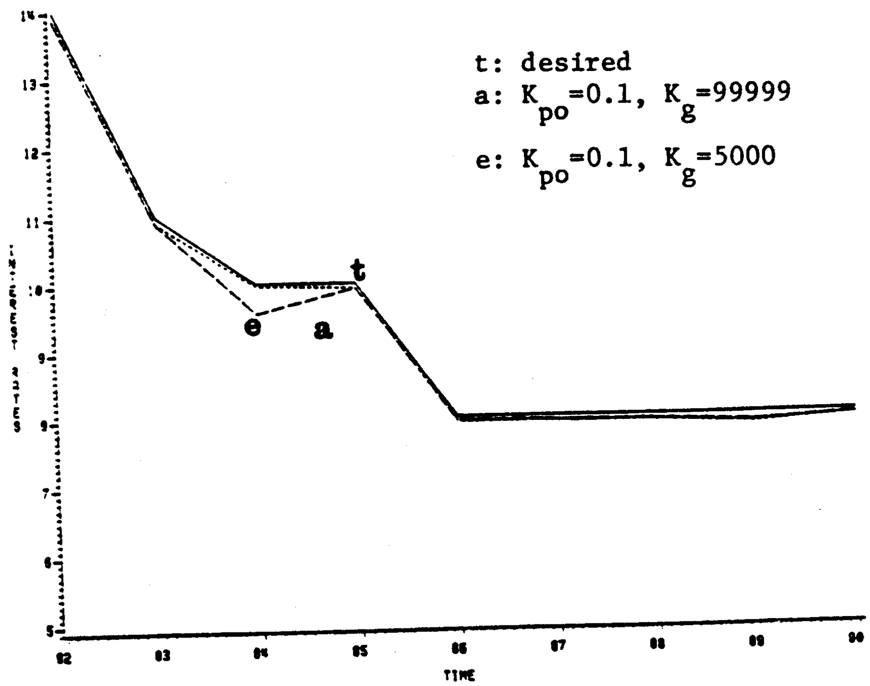


Figure 11

Mean Fitted Values for Instruments: Case III



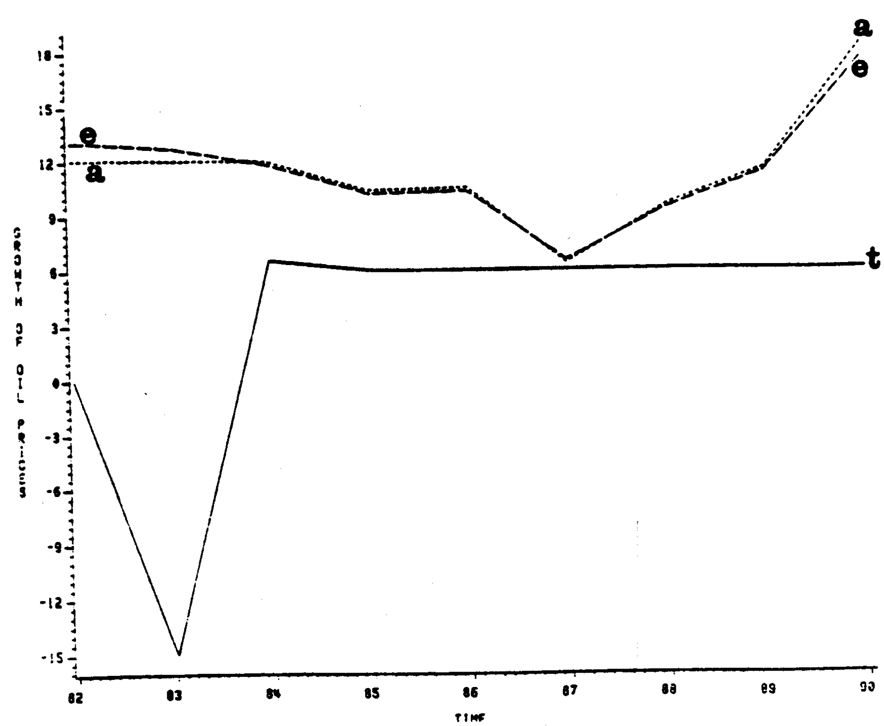


Figure 11

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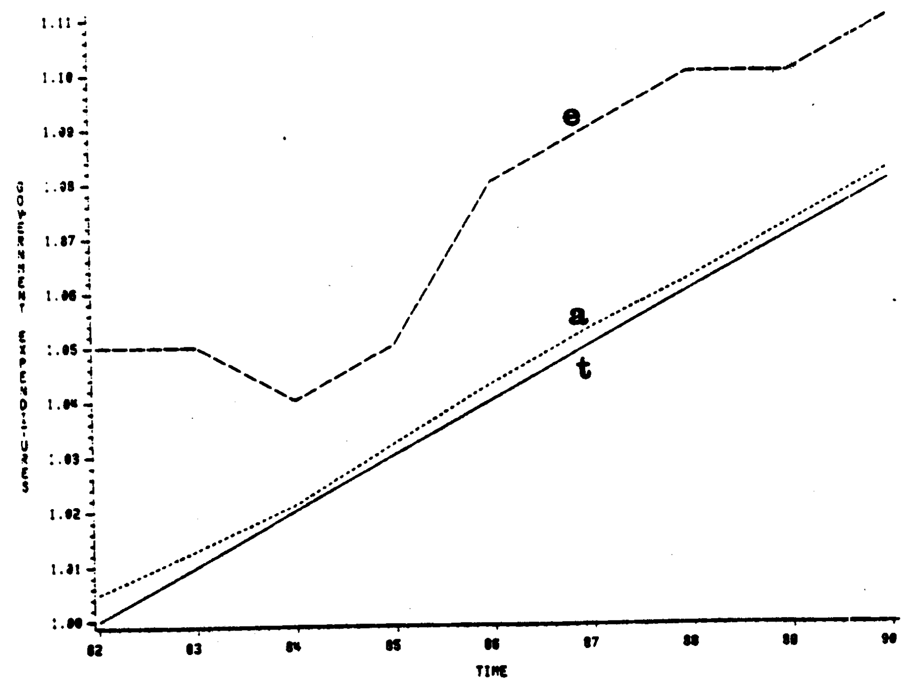

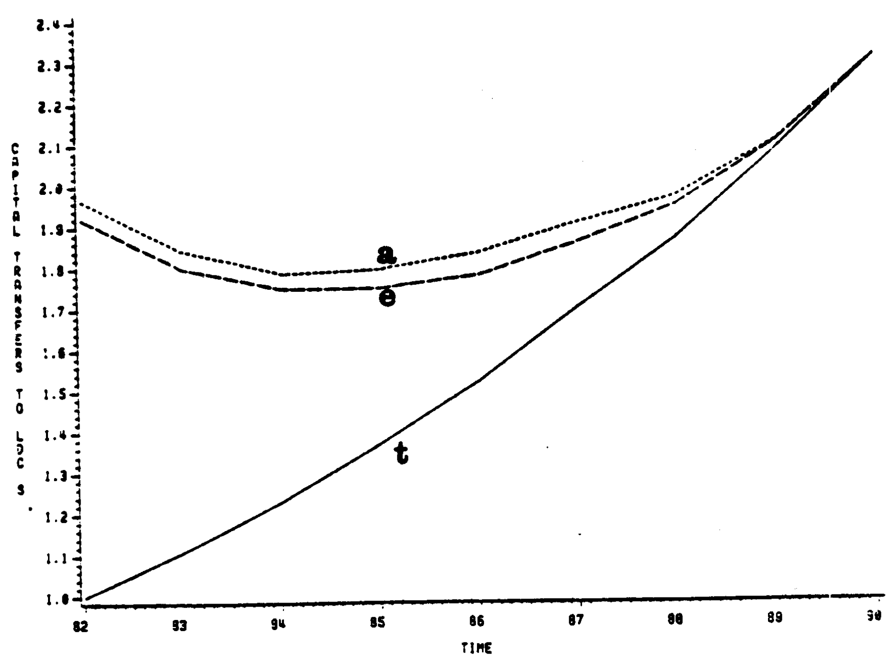

Figure 12

Mean Fitted Values for Targets: Case III

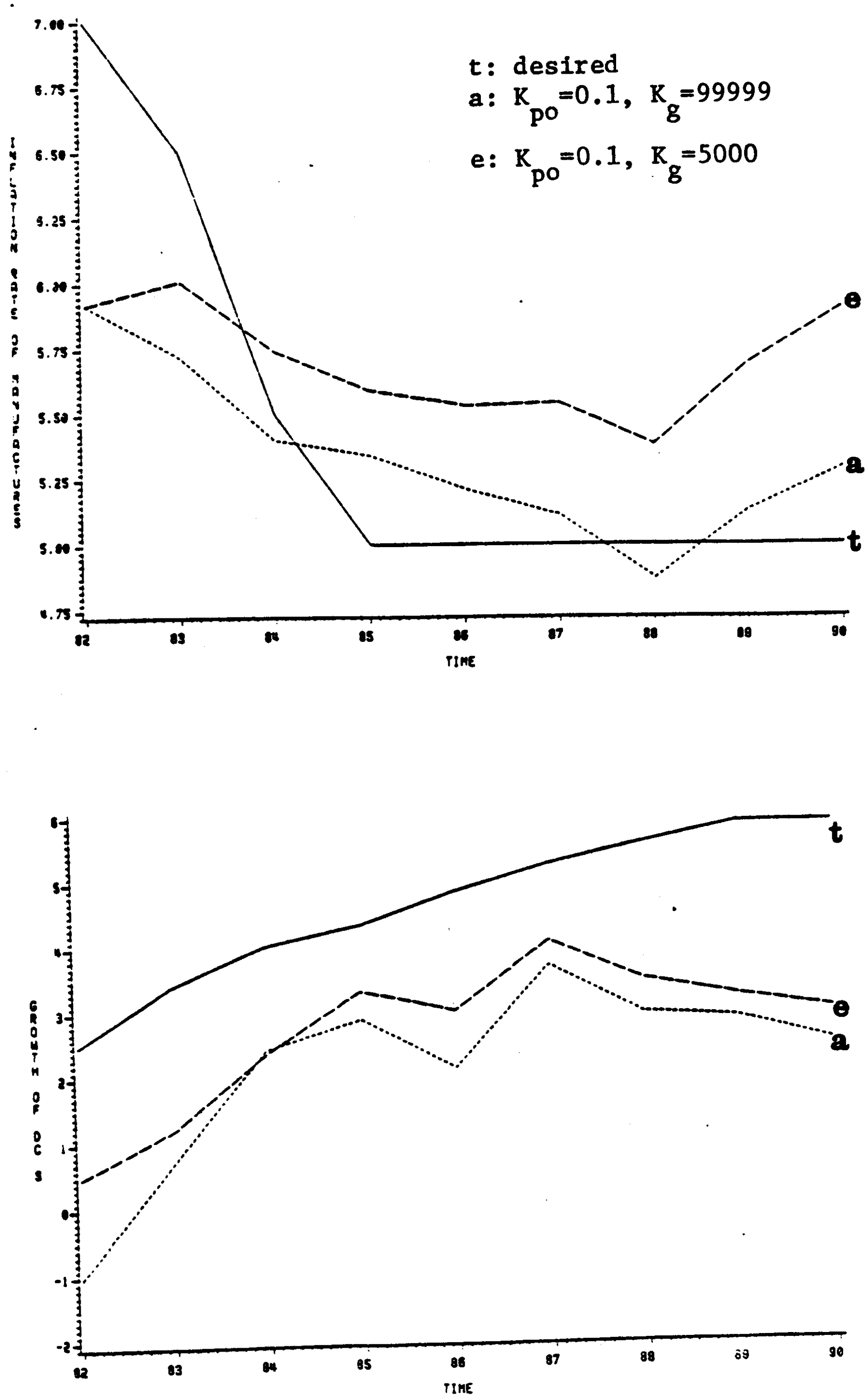

Figure 12

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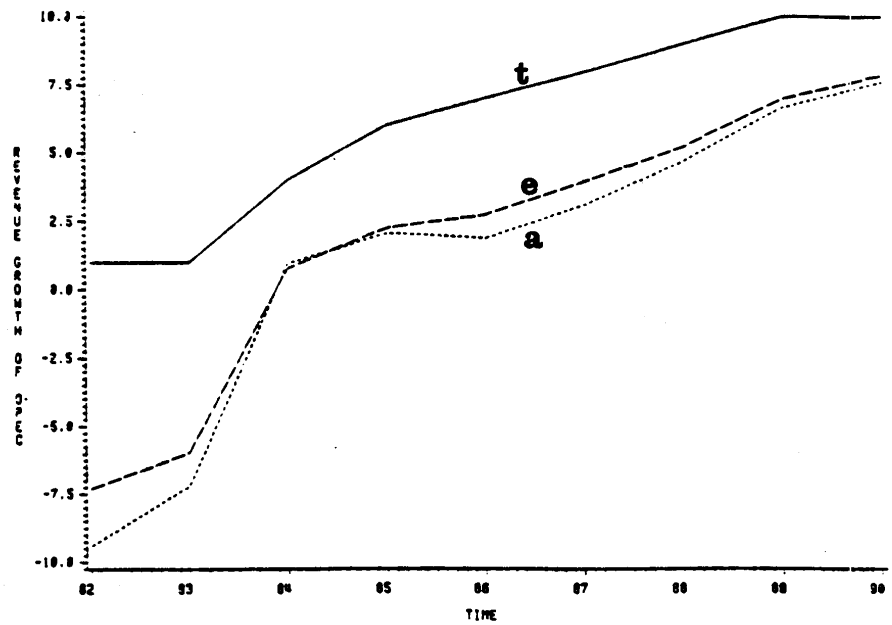

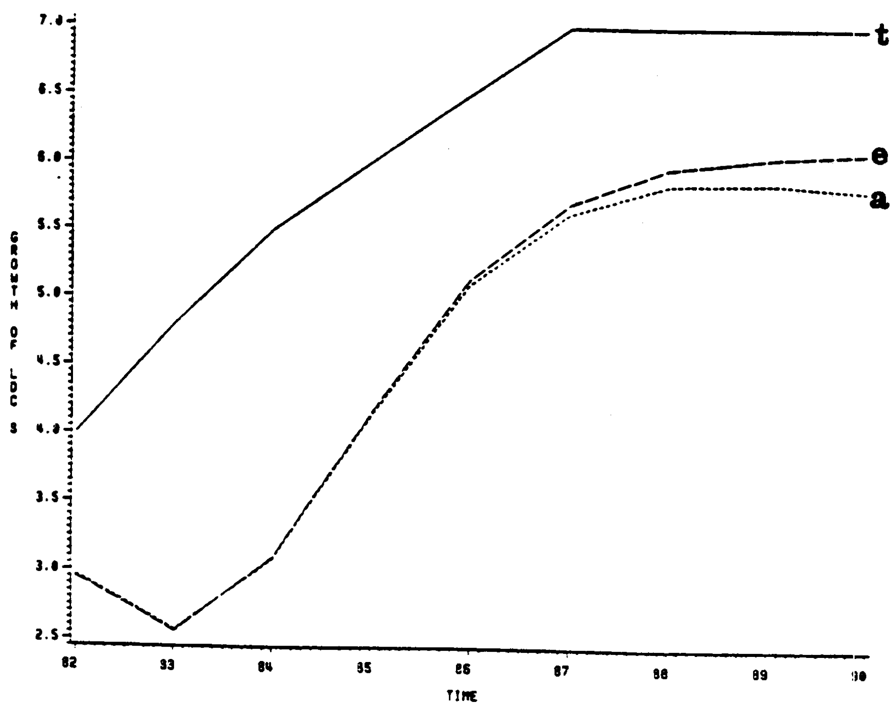

on DCs and OPEC. We also notice that, despite the decline in the average growth rate of oil prices, there is an increase in the amount of capital transfers to LDCs. This increase is necessary to offset the impact that lower growth in DCs has on the LDCs, since the beneficial aspects of lower oil prices are being offset by the reduction in growth of DCs.

In contrast to the previous situation, a reduction in the weight of oil prices to 0.1 means that oil prices can deviate more freely from their target path. As a result, a reduction in the cost of fluctuations in government expenditures from 99999 to 5000 marginally reduces welfare losses of LDCs and significantly reduces the welfare losses of both DCs and OPEC. In addition, we notice that it is possible to have a decline in average capital transfers to LDCs since DCs' government expenditures are now higher, which increases imports from LDCs and enlarges their foreign exchange receipts.

Evaluation of Sensitivity Analysis Results

Several interesting results emerge from the extensive sensitivity analysis performed so far. First, although instrument instability did not materialize for the weights we have used, there are cases where small weight values result in paths for instruments that are not entirely consistent with the policy environment where these instruments are determined. In other words, even though a policy mix might be efficient, it may lack credibility when compared to historical standards. To be specific, we find that in order to accelerate economic growth in Non-OPEC LDCs, capital transfers would have to exceed the (already high) targets by an annual average of $US 20 billion in some cases, and in no case is this excess below an annual average of $US 12 billion. Given today's current financial situation for some developing countries, it seems unlikely that such large transfers will take place.[13]

Second, we find that the oil price path consistent with OPEC's best interests is higher than the oil price path consistent with either DCs or Non-OPEC LDCs' best interests. This result is robust with respect to the different combinations of weights considered here, as can be seen from Figures 4, 7, and 10 by comparing the average growth rate for oil prices for each of the weighting schemes we have considered. This finding clearly indicates the existence of conflicting interests among the three blocks of countries included in our model, and calls for an extension of our analysis to allow for non-cooperative policy design.

V. CONCLUSIONS

Our first purpose in this paper has been to study the international transmission of oil price effects <u>and</u> the determination of optimal oil price paths, not as separate problems but rather as one problem by recognizing that economic activity and oil prices are jointly determined. We then study the set of efficient policy paths for oil prices, government expenditures, and capital transfers to LDCs consistent with a non-inflationary reactivation of the world economy. The effects of changing the weights of the welfare function on the income tradeoffs among different regions and on the optimal policy mix are also examined.

We start our analysis by developing a nonlinear stochastic dynamic econometric model for a three region world economy that highlights the channels of international transmission of oil price effects and the feedback effects of oil price changes on the demand for oil. The simultaneous relation between oil prices and real income is obtained by minimizing a quadratic welfare function subject to the econometric model. We apply optimal control to an estimated version of this model and we find that if (1) oil prices grow at six percent per year, (2) government expenditures grow at 0.9 percent per year, and (3) capital transfers to developing countries grow at 9 percent per year, then it is feasible to achieve a non-inflationary recovery of the world economy.

Given the structure of the model, its estimated parameters, the optimizing horizon, and the optimization algorithm we find that:(1) the growth rate of oil prices taking into account income feedback effects is smaller than the growth rate of oil prices when these feedback effects are not taken into account; (2) real oil revenues of OPEC grow at a faster rate when income feedback effects are allowed in the determination of oil prices than in the case where these income effects are not allowed; (3) there is a positive relationship between the optimal response of government expenditures and optimal oil price changes; (4) low oil prices and expansionary fiscal policy in DCs serve as substitute instruments for net capital transfers to developing countries; (5) there exists a conflict of interests between oil importers and oil exporters since the oil price path that reduces OPEC's welfare losses is higher than the oil price path required to reduce welfare losses for both DCs and LDCs.

ENDNOTES

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1 See Hamilton (1983), Marion and Svensson (1982), Bruno and Sachs (1979), Findlay and Rodriguez (1977), and Schmid (1976).

2 See Hotelling (1931), Solow (1974), Cremer and Weitzman (1976), Pindyck (1978), and Salant (1982).

3 See Niehans (1968), Hamada (1979), Johansen (1982), Canzoneri and Gray (1983), and Oudiz and Sachs (1984).

4 In order to be fair, we should point out that optimal control applications are not problem free. In particular, Kydland and Prescott (1977) argue that policies derived using optimal control need not be optimal if agents have rational expectations. The main problem is, as they indicate, the absence of a mechanism inducing future policymakers to take into account the effects of their

policies on today's agents decisions. However, the issue is far from resolved since Chow (1981) shows how to apply optimal control theory allowing for rational expectations.

5 Capital transfers to Non-OPEC LDCs can hardly be considered a variable under their control. A more reasonable interpretation in our context would be to treat them as transfers required from international cooperation.

6 Capital transfers here are net of amortization and interest payments, and thus they represent "new money".

7 A similar target growth rate is found in the United Nations Development Report (United Nations 1982).

8 This growth rate is similar to that of the "high-transfer scenario" of the World Bank Report for 1982 (World Bank 1982).

9 The optimal control solutions converged in three iterations.

10 This growth rate is higher than the "high scenario" target growth rate for developing economies (3.3%) of the 1982 report of the World Bank (World Bank 1982:37).

11 It might be possible to argue that the higher revenue growth derived using optimal control solutions is not due to income feedback effects, but rather due to the response of some other instrument such as

government expenditures, which stimulates DC's real income and thus OPEC's revenue growth. To make sure that an instruments' responses, other than oil prices, are not responsible for the rapid growth in OPEC's revenue, we have given a rather high weight (99999) to government expenditures. We find that the average deviation of government expenditures from their target is, in absolute value, equal to 0.9 percent, which can hardly be considered as a reason for the increase in OPEC's revenue growth.

[12] One way of relaxing the assumption of cooperation is, for instance, to include in the welfare function only OPEC's targets and instruments and have reaction functions for DCs and LDCs. A second approach is to have a welfare function for each of the players who have conflicting objectives (Pindyck 1977).

[13] Another instance is the case of greater weight to OPEC's growth target using a low weight for government expenditures. These expenditures exceed their targeted values by an annual average of $55 billion in real terms. Again, given today's concern with government budget deficits, it seems unlikely that such an expansion of government expenditure will materialize.

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