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Abstract: This paper extends recent work by J. Sachs about the response of a two country plus OPEC neo-classical model to an oil shock with full inter-temporal optimization and perfect foresight. Here, the role of imperfectly flexible prices is studied under the assumption that firms are output constrained. The presence of expected inflation is shown to be pervasive. It affects the real interest rate term structure and therefore the valuation of all components of wealth, as well as the exchange rate and the attending distribution of world expenditures. Inflation also enters the wage adjustment mechanism and therefore the path of unemployment and capital accumulation.

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I - INTRODUCTION

As recently pointed out by Krugman (1980), the proper study of the effects of an oil shock on the exchange rate requires two essential features. First, because the exchange rates which are interesting are those linking the non-OPEC countries, the minimal set up consists of a model including two such countries and OPEC. The exchange rate then reflects how differently the two countries react to the shock.

Second, there are two aspects in which the countries reactions may differ: trade and finance. Depending upon OPEC's savings behavior, capital movements may be the driving force in the short run while, in the long run, trade considerations should eventually dominate.

These compelling remarks raise a host of difficulties. First, three country models are scarce and either very schematic or cumbersome to the point that they can become intractable. Second, to reduce the level of complexity, these models frequently come in linear form. Presumably, this is to be interpreted as an approximation around the equilibrium. But with such an occurence as a fourfold increase in oil prices, one cannot realistically appeal to the small disturbance assumption. This is more so when one of the crucial considerations concerns the issue of substituability among factors of production which requires nonlinear technologies. Finally, the literature on exchange rate determination has emphasized in the recent years the power of the rational expectation hypothesis.[1] But then, Krugman's dichotomy between financial effects in the short run and trade effects in the long run is open to the question that the long run effects should be anticipated and discounted back into the short run.

The basic ingredients of a description of the effect of an oil shock on the exchange rate might be as follows. Supply being a function of capital, labor and energy, there will be, in the long run, substitution away from energy into either capital, or labor, or both, depending upon the relevant substituabilities and complementarities. On the demand side, the shock implies a wealth transfer. If tastes differ across countries, this will force a change in the distribution of world demand for goods. Thus, the relative price of goods, i.e. the real exchange rate, will reflect these shifts in both supply and demand. It is important to realize that in a general equilibrium framework the change in the real exchange rate feeds back into the supply side as it affects the real cost of energy.

This long run view is needed for the understanding of the short run since, in a rational expectations world, asset prices instantaneously react to anticipated future developments. In addition, the paths of asset prices will be influenced by the dynamic characteristics of the economy such as the degree of wage indexation, price stickiness and asset substituabilities. Obviously, these considerations matter directly for the determination of the exchange rate.

These interconnections have been gradually uncovered one by one through various models specifically designed for each task.[2] Bringing them together would provide a convenient framework for empirical investigations but results in a model that cannot be solved analytically anymore. One solution consists in exploring through simulations the properties of such a model. This is the route followed in Sachs (1981).[3]

His model, indeed, contains most of the features discussed above. It can be considered as a neoclassical benchmark with fully optimizing producers and consummers in a perfect foresight world, with perfect asset substituability and where all markets clear continuously. This important step being achieved and the attendant computation problems having been solved, the next step is to extend the model incorporating more realistic features. The aim of the present paper is to explore the properties of the model when the price flexibility assumption is relaxed. The motivation is, of course, that real world prices do appear to be sticky.[4] It turns out that relaxing the assumption of goods market equilibrium has strong effects on the determination of the exchange rate. First directly, as it may, for example, provoke overshooting reactions (Dornbusch (1976)). Second indirectly, as it modifies the wage dynamics when there exists an indexing scheme, and therefore the whole adjustment path of the economy. The model presented here derives directly from the one built by Sachs. Beyond the behavior of prices a certain number of other technical modifications have been added and will be discussed in detail. One of them concerns the form of the production function and our attempt to mimic a putty-clay technology by using elasticities of substitution that increase over time. To introduce sticky prices, we follow the Keynesian tradition of a demand determined output. Following Blanchard (1980), this constraint is explicitly taken into account by the firms in their intertemporal optimizing program.

In the next section the model and its steady state properties are presented; the simulation technique is discussed in Section III. In Section IV we present the simulated effects of an unanticipated quadrupling of the price of energy. We first study the base case where the domestic economy is similar to the rest of the world in every respect except for the size. This experiment outlines the nontrivial role of sticky prices. In order to obtain meaningful changes in the exchange rate in the absence of policy interventions, we differentiate the two oil importing countries by changing some of the characteristics of their economies, such as the labor market or the production technology. Given the delicate stability conditions of the model (which are discussed in Section III), the first step is to explore the role of some key parameters, changing them one by one. This is done in the rest of Section IV. The last section is devoted to concluding remarks.

II - THE MODEL

There are two industrial countries in the model, plus OPEC. One of the two industrial countries is ten times smaller than the other, representing one OECD country versus the rest of OECD. Each of the two industrial countries produces one good: each good is used for private consumption at home and abroad, for domestic capital formation and domestic government consumption. In each country there are only two assets: money, which is non-traded, and equity claims on the domestic capital stock, which are traded, but only with OPEC. This assumption makes the treatment of the current account very simple, since OPEC acts as a clearing house to balance the current accounts of the two industrial countries.

Output in the two industrial countries is produced using three factors: capital, labor and oil. The technology - equations (8) and (9) in Table 1 - is embedded in a two-level CES production function with unit elasticity of substitution between labor and the capital-energy mix, itself characterized by a constant elasticity of substitution between capital and energy. Although we have no growth in the simulations, we try to capture in a simple, even if in an *ad hoc* fashion, the properties of a putty clay technology allowing for the elasticity of substitution between capital and energy to be variable over time.[5] All oil is imported from OPEC[6], and supply is perfectly elastic at the real price set by OPEC in terms of its consumption basket.

Nominal wages (21) are indexed to the consumption deflator (20) although the full response to a change in prices takes two periods. They also react to labor market conditions.[7] At each point in time, for a given stock of capital, the firm chooses its variable factors so as to satisfy its intertemporal profit maximizing conditions, but it is assumed that the firm is constrained to produce whatever the market requires (7), (7'). Thus the factor demand equation (10) differs from the unconstrained maximization case (24) and (25). The latter defines the potential output, (22) and (23), that it is optimal for the firm to produce given factor prices and given the stock of capital. The justification is the usual Keynesian one with output entirely demand determined at fixed price: presumably in case of excess supply firms cannot force consumers to buy more, while in case of excess demand they do not wish to harm their customer relationship. Here, however, prices are not entirely fixed but vary in proportion with the difference between actual and potential output (26)[8]. The reason for slow adjustment in prices is not irrational expectations, but inertia or the existence of predetermined contracts.

The investment function follows the cost of adjustment literature in assuming that total investment expenditures, I, exceed the value of actually installed capital, $\dot{K}$, by a given cost, here taken as a linear function of the rate of investment (12).[9] As shown by Hayashi (1981), when the firm is output constrained, the marginal value of capital in place (Tobin's q) differs from its average value observed on the stock market. The firm then equalizes the marginal cost of investment and Tobin's marginal q (11), while the valuation of the firm is determined by average q (see (1) or (28)). Further, it is assumed that all invest-

Table 1 : The Model

Whenever they are identical to the domestic ones, the foreign economy relationships (denoted by an astersk) are omitted.

Consumption and Saving

(1) $A = q^a(K - Z) + H + M/P$

(2) $\dot{H} = rH - (1 - \tau)wL$

(3) $C^T = \delta A$

(4) $C = C(\lambda, i, C^T)$

(5) $C_M = C_M(\lambda, i, C^T)$

(6) $M/P = m(\lambda, i, C^T)$

The consumption functions are derived from a nested CES utility function. Detailed formulations are provided in the appendix.

Production

(7) $Q = C + I + G + C_M^* + X$

(7') $Q^* = C^* + I^* + G^* + C_M + X^*$

(8) $Q = \bar{Q}V^aL^{1 - a}$

(9) $V^\rho = bK^\rho + (1 - b)N^\rho$

(10) $(\partial Q/\partial L) \ / \ (\partial Q/\partial N) = w/(P_N/P)$

(11) $\dot{K}/K = (q^m - 1) \ / \ \phi$

(12) $I = \dot{K}\ (1 + \frac{\phi}{2}\ \frac{\dot{K}}{K})$

(13) $D = Q - wL - (P_N \ / \ P)N - I + q^a\dot{K}$

The derivations of the constrained output problem are sketched in the appendix.

Asset Markets and Government Finance

(14) $\dot{q}^a/q^a = r - (Q - wL - (P_N/P)N - I + q^a\dot{K}) / q^aK = r - \dfrac{D}{q^aK}$

(15) $\dot{q}^m/q^m = r - (wL \dfrac{a}{1 - a} - (P_N/P)\ N - I + q^m\dot{K}) / q^mK$

(16) $\lambda = eP^* / P$

(17) $i = r + \dot{P} / P$

(18) $r = r^* + \dot{\lambda} / \lambda$

(19) $G = \tau wL$

Labor Market

(20) $P_c = P^{C/(C + \lambda C_M)}\ (eP^*)^{\lambda C_M/(C + \lambda C_M)}$

(21) $\dfrac{wP}{w_{-1}P_{-1}} = \left(\dfrac{P_c}{P_{c-1}}\right)^{\theta} \left(\dfrac{P_{c-1}}{P_{c-2}}\right)^{1-\theta} \left(\dfrac{L}{\bar{L}}\right)^{\gamma}$

Price Adjustment

(22) $Q_p = \bar{Q}\ V_p{}^a\ L_p{}^{(1 - a)}$

(23) $V_p{}^{\rho} = bK^{\rho} + (1 - b)\ N_p{}^{\rho}$

(24) $\partial Q_p/\partial L_p = w$

(25) $\partial Q_p/\partial N_p = P_N/P$

(26) $P_{+1}\ /P = (Q/Q_p)^{\varepsilon}$

OPEC and the Current Account

(27) $\dot{W}_N = \delta W_N - S(N + N^*)$

$$(28)\ W = W_N + S(P/P_N)\, q^a Z + S(P^*/P^*_N)\, q^{a^*} Z^*$$

$$(29)\ X^T = gX^T_{-1} + (1 - g)\, \delta W$$

$$(30)\ PX = \beta P^\beta\, (eP^*)^{(1-\beta)}\, X^T \qquad (30')\ eP^* X^* = (1 - \beta)\, P^\beta\, (eP^*)^{(1-\beta)} X^T$$

$$(31)\ q^a \dot{Z} = \lambda C_M + (P_N/P)\, N + DZ/K - C_M^* - X$$

$$(31')\ q^{a^*} \dot{Z}^* = \lambda^{-1} C_M^* + (P_N^*/P^*)\, N^* + D^* Z^*/K^* - C_M - X^*$$

$$(32)\ S = \frac{P_N}{P^\beta\, (eP^*)^{1-\beta}} \quad \text{and} \quad P_N = eP_N^*$$

(S is the real price of oil in terms of OPEC's consumption basket)

Note: The model is utilized in discrete time, so, e.g. $\dot{H} = H_{+1} - H$

Definition of Variables

(Foreign starred variables have identical definitions)

A : Total Wealth
C^T: Total spending (includes "consumption" on cash balances)
C : Spending on domestic goods (volume)
C_M: Spending on foreign goods (volume)
D : Dividends
G : Government expenditures (volume)
H : Human wealth
I : Cost of Investment
K : Capital Stock
L : Employment ($\bar{L}$: full employment level)
L_P: Potential (i.e. unconstrained optimal) demand for labor
M : Nominal Money Stock
N : Energy input
P : Domestic goods price
P_C: Domestic CPI
P_N: Real (product) price of energy
Q : Output ($\bar{Q}$: a scale constant)
Q_P: Potential output
S : Price of energy in units of OPEC's consumption bundle
V : Capital - Energy Mix
V_P: Potential Capital-Energy mix
W : OPEC's wealth in units of OPEC's consumption bundle
W_N: The oil component of OPEC's wealth
X^T: OPEC's total spending in units of OPEC's consumption bundle
X : OPEC's spending on domestic goods (volume)
Y : GNP
Z : OPEC's claims on the domestic capital stock
δ : rate of time discount
e : nominal exchange rate
i : nominal interest rate
λ : real exchange rate
q^a: Tobin's average q
q^m: Tobin's marginal q
r : real interest rate
τ : tax rate
w : product wage

ment is equity financed with no corporate savings, so that dividends include the proceeds of the issue of new stocks (13).

Consumers also fully optimize over time. In order to give a role to money we follow Sachs in bringing real cash balances into the utility function. For stability reasons to be discussed below, we introduce a nested CES utility function in logarithmic form so that total private consumption C_T, inclusive of expenditures on money (iM/P), is a constant share of total wealth, the constant being the rate of time discount (3).[10] Wealth is defined in (1) as the sum of the market value of domestically owned capital stock, money balances and human wealth. Human wealth in (2) is the present discounted value of labor income whose path, under perfect foresight, households fully anticipate.[11] Using the real interest rate to discount human wealth amounts to assuming that physical and human capital are perfect substitutes.

The revenue to the government arises only from taxation on labor income and government consumption always adjusts so as to maintain a balanced budget(19).

OPEC's desired consumption is a function of wealth. OPEC's wealth is the sum of oil wealth plus the market value of its holdings of equity claims on the two industrial countries' capital stocks (28). Following Sachs we assume away the problem of exhaustibility, introducing oil wealth in (27) as the present value of future revenues from oil exports. The flow of oil is determined by the derived demand of the two industrial countries given the price exogenously set by OPEC.

The pricing rule set in (32) is that OPEC pegs the price of oil in terms of its own consumption basket.[12] This price index reflects the simplifying assumption, (30) and (30'), that OPEC's expenditure shares on the goods produced by the two industrial countries are constant. The total consumption of OPEC, however, lags behind its desired consumption in (29), reflecting the fact that adjustment costs prevent sharp changes.

OPEC acquires stocks of both industrial countries through their current account deficts, (31) and (31'). The assumption that only OPEC holds foreign assets simplifies a great deal the accounting and plays no significant role as we assume perfect asset substituabilities so that stocks of both countries bear the same real return once we account for perfectly anticipated exchange rate changes (18).

Finally, in (17) we define the nominal interest rate (which is the cost of holding money) using Fisher's relation. Equation (14) simply defines average q as the present discounted value of future dividend payments.[13] Marginal q in (15) is the shadow real price of capital.

III - SOLUTION OF THE MODEL

1. Steady-state

Assuming away growth and depreciation, the steady state of the system is characterised by zero savings and investment, as well as by labour, goods and money market equilibrium. With Tobin's q equal to one, the wage rate clearing the labour market and the price level clearing the money market in each industrial country, the steady state is characterized by three independent equations: one good market equilibrium condition and two zero savings conditions. The three together imply current account equilibrium.

In each country saving is zero if the real interest rate is equal to the rate of time preference. These two steady state conditions therefore collapse into the condition $r = r^{*} = \delta$

We are left with one good market equilibrium condition and three variables to be determined, λ, Z and Z^{*} (supply, i.e. real wages, the capital stock and oil imports, being a function of the real interest rate and the real exchange rate). What is required for the system to be in a steady state is only that λ, Z and Z^{*} be such as to satisfy the goods market equilibrium condition[(14)]. The values actually obtained in the steady state, which in turn determine the values of domestic and foreign output, will depend on the particular adjustment path of the economy and therefore on the parameters characterising the adjustment process, such as the degree of labour and goods markets rigidity.

If the two countries were identical except for their size, an increase in the price of oil in terms of OPEC's consumption bundle would leave the real exchange rate unaffected. With λ constant, the increase in S is fully reflected in the price of energy in terms of home goods. In the new steady state, with $L = \bar{L}$, cost minimization implies a fall in output, in the real (product) wage, in energy demand and in the capital stock, the magnitude of which depends upon the value of σ, the elasticity of substitution between K and N. With the parameters of our model, a quadrupling in the ratio (P_N/P) implies the adjustments exhibited in Table 2, for two different values of σ.

Table 2

	Q	K	N	w
Initial Stationary State	100	500	500	1
New Stationary State with $\sigma = .4$	87.9	349.2	200.6	.879
New Stationary State with $\sigma = .8$	90.2	423.9	139.8	.902

The value of domestic and foreign wealth in the new steady state will depend on the values of Z and Z^*, which will change in the same proportion, and therefore on the particular adjustment path. The deeper the current account deficit cumulated along the path (when for example, the elasticity of substitution between K and N takes a long time to reach its long run value), the higher Z and Z^*, and the lower wealth and consumption in the new steady state. In this case money demand will also be lower, hence the price level higher.

If the two countries'structures differ, λ should not remain unchanged and the new steady state values of Q, K, w and N will now depend on the adjustment path. Figure 1 describes the steady state condition between λ, Z and Z^* for domestic (or equivalently foreign) good market equilibrium.It can be shown that under fairly general conditions for a given λ, Z and Z^* are postively related,and that for given Z^*, an increase in Z requires a higher λ.

Figure 1 here

For example, a transfer of wealth from the home country to OPEC (a raise in Z) will raise λ if a real depreciation raises world demand for domestic goods. This will always be the case if the positive substitution effect in world consumption is larger than the negative income effect at home, due to the higher oil bill. If the elasticity of substitution between goods and real money balances in the utility function is smaller than 1, the increase in λ will work in the same direction as the fall in wealth reducing money demand and therefore raising the price level. The real depreciation amplifies the effects of the oil shock, further reducing K and w and therefore wealth and consumption in the steady state.

2. Dynamics

With our assumption of perfect foresight, the model is driven by seventeen dynamic equations. Three of them characterize human wealth in the two industrial countries (equation (2) and its foreign counterpart) and OPEC's oil wealth (22). Five other equations depict the behavior of Tobin's q's (14) and (15) and that of the real exchange rate(18). All eight of these variables (H, H^*, q^a, q^{a*}, q^m, q^{m*}, λ, W_N) are "jumping" variables, i.e. they are not predetermined by past history and are free to react fully to unexpected contemporaneous or to newly expected future events. Technically, this means that these difference equations are to be integrated forward (between now and the infinite future) and that the solution is a function of present and future exogenous variables only.

The nine other variables (K, K^*, Z, Z^*, w, w^*, P, P^*, X^T) are predetermined variables. At any moment of time they are set by the history of events, both actual and as expected in the past. This means that their difference equations are integrated backward (between the infinite past and now) so that their solutions are functions of the past values of the exogenous variables.[14]

This separation of difference equations into two classes and the requirement that the predetermined variables assume some well defined initial values while the non-predetermined ones all satisfy a necessary boundary condition that excludes "explosion", poses the two-boundary conditions problem. The problem is solved with the technique of multiple shooting which searches for the convergent path between these two sets of initial and final conditions. This is described elsewhere and will not be discussed further here.[16] An important point though is the question of stability. Linear perfect foresight models can, at best, be saddle-point stable and the conditions for global stability can be easily derived. However, such conditions do not exist for large non-linear systems. In the absence of a formal proof of stability, the fact that the model, following a change in the value of an exogenous variable, converges to a new steady state along a path requiring an initial jump in the non-predetermined variables, is an ex post indication of saddle-point stability.[17]

Finding such a stable path has proved to be much more difficult when the flexible prices are replaced by the assumption of sticky prices and constrained output. To understand why, we consider Figure 2 below. The AA schedule simply translates the fact that total wealth A, through its components K and H is the discounted value of future income streams, here after tax output, so that an increase in the real interest rate lowers A. The MM schedule depicts the money market equilibrium condition as implied by equations (3), (6) and (17), for a given price level and for given inflationary expectations.

FIGURE 2 HERE

Now assume that demand exogenously increases: resulting excess demand in the goods market leads through (26) to higher expected inflation. Consequently the MM schedule shifts leftward by the amount of the increase in expected inflation. At E', total wealth has risen and this further increases excess demand, which in turn pushes up inflationary expectations, leading to another leftward shift in the MM schedule. This potentially disequilibrating mechanism is aggraved by our assumption that output is demand determined since an excess demand not only pushes up prices but leads to a higher output and therefore more wealth creation. This means that the AA schedule also shifts up: instead of moving from E to E', we move to F'. It appears clearly that the chances of instability are greatly enhanced.

This has lead us to specify the utility function in such a way that the drop in the real interest rate be as small as possible. This is achieved through a flat MM schedule, i.e. a low interest elasticity of the demand for money (6). On the other side, to fulfill the Marshall-Lerner stability conditions we need high elasticities between the two goods. The solution has been a two level CES utility function which is presented in the appendix. The simulations are performed starting from an initial steady state which was built using "reasonable" values for the parameters and variables involved. A brief justification for all this is given in Table 3.

The oil shock, a fourfold increase in the real price of oil (S in (32)) comes as a surprise, i.e. it is unanticipated. Although convergence to the new steady state is asymptotic only, the simulations require a finite time horizon to be chosen. The experiments cover 90 periods, yet this length proved in several instances to be insufficient.[18] As a result, the last periods exhibit a "squeezed-in" pattern as we force the variables to reach their terminal values too early. Because of computation costs we have not attempted to go further and report in the tables only the first 50 periods of simulation.

Table 3 : Initial Parameter and Steady State Values (unless otherwise specified, all OECD values are 10 times the domestic ones)

All value are in terms of the locally produced goods.

Consumption and Saving

$A = 1665$ $K = 500$ $Z = 20$ $H = 1125$ $M/P = 60$

$C = 44.45$ $C^M = 19.75$ $C^* = 622.25$ $C^*_M = 19.75$ $\delta = .04$

The interest elasticity of demand for money is .1.
The elasticity of substitution between C and C_M is 2. (For details see the appendix)

Production

$Q = 100$ $K = 500$ $L = 75$ $N = 500$ $I = 0$

$a = a^* = .25$ $b = b^* = .8$ $\tau = \tau^* = .4$ $\phi = \phi^* = 5$

$P = P^* = 1$ $P_N = P^*_N = .01$ $w = w^* = 1$ $\sigma = 1/(1 - \rho) = .4$

In the base case, σ and σ^* reach their long run value over 10 periods.

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$q^m = q^{m^*} = q^a = q^{a^*} = 1$ $r = r^* = .04 = i = i^*$ $G = 30$ $\tau = \tau^* = .4$ $\lambda = e = 1$

Wage Indexation

$P_c = P^*_c = 1$ $\gamma = \gamma^* = .1$ $\theta = \theta^* = .5$

A 1 percent rate of unemployment reduces nominal wages by .1% per period.
Half of price increase is passed through to nominal wages the first period the second half in the next period.

OPEC

$W = 1595$ $W^N = 1375$ $X^T = 63.8$ $X = 5.80$ $X^* = 58.0$

$S = .01$ $g = .8$ $\beta = 1/11$

Domestic goods capture 1/11th of OPEC's spendings
OPEC's total spending mean lag is 4 periods.

Price Adjustment

$\varepsilon = \varepsilon^* = .2$: demand 5 % below optimal supply leads to a drop of 1 % per period in goods prices.

IV - SIMULATION RESULTS

It is assumed that until period 0 the world was resting in a stationary state. The unanticipated oil shock comes in period 1: OPEC raises its terms of trade $S = P_N/(P^{\beta}(eP^{*})^{1-\beta})$ and thereafter pegs the price of oil (P_N in the domestic currency) to its own consumption price index. We assume all policy parameters, i.e. the nominal money supply M and the tax rate τ, to remain unchanged.

Obviously, one way of attempting to reduce the shock consists in lowering back P_N/P through increases in P. But, of course, if OPEC pegs S, this is not possible for the world as a whole. The only possibility then is for one country to improve its terms of trade vis à vis the rest of the world, thus reducing its own relative price of energy at the expense of the rest of the world.

The results of the various simulations are presented in Tables 4 to 7 for a selected subset of variables. We first briefly consider the long run effects in the base case, where the two countries are identical except for their sizes. We then describe the dynamics in this base case before discussing the effects of changing some of the model's parameters for the domestic economy, leaving the larger one unchanged.

1 - The Long Run Effects

With complete symmetry we expect the two countries to react identically to the oil shock, therefore with no change in the real and nominal exchange rate. The steady state results discussed in Section III are verified: total output falls by about 12 percent and this is matched by a drop in total domestic wealth slightly exceeding 20 percent, the gap being of course filled by OPEC's higher wealth. Human wealth falls by only 13 percent since there is a higher substitution from oil into labor than into capital, which drops by about 30 percent.

With less total wealth,demand for real money balances falls, and this is obtained through a 27 percent increase in the price level. Finally, the cumulated current account deficits in both oil importing countries lead in the long run to a fourfold increase in the amount of stocks held by OPEC.

2 - The Impact Effect

More interesting here are the shorter run effects of the oil shock. An implication of the sticky price assumption is that we now have expected inflation. In Sachs' (1981) model, prices, being non-predetermined variables, jump on impact and remain steady thereafter, ruling out inflation. This occurs because any expected price increase implies a loss on money balances and is therefore immediately discounted back to the present if there is no sluggishness. In our case, with prices reaching gradually their higher long run value, we observe a Mundell effect, whereby the nominal interest rate increases by less than the expected inflation rate, the implication being a drop in the real interest rate. This point had already been noted on Figure 2 as a source of instability. It also generates interesting dynamics which we discuss on Figure 3 below.

FIGURE 3 HERE

An oil shock unambiguously causes wealth to fall at a given real interest rate since it lowers the potential output to which the economy will ultimately converge. Thus the AA schedule shifts down.[19] What happens to the MM schedule essentially depends upon the expected inflation rate which, in turn, through (26), is determined by the ratio of demand to potential output. If we concentrate on period 1's impact effect, we have the two possibilities depicted on Figure 3. Starting out at point E, with an initial excess demand we have a leftward shift in MM leading to F_1, while an initial excess supply would bring us to F_2.

On impact, given the capital stock and real wages, an oil shock reduces potential output. If demand initially falls by more, we get to point F_2, but this is not the end of the story: with output reduced, demand for labor falls, bringing wages down and by reducing total factor costs, it compensates for the oil shock effect on potential output. But then, (Q/Q_p) drops even more pushing prices further down and shifting MM to the right again, thus amplifying the initial disequilibrium.

Clearly, whether at constant product wages we initially get an excess demand or supply, is crucial to the understanding of the early effects of an oil shock.

What then can explain such different responses? It cannot be consumption which depends upon wealth which, in turn, is a function of total output and the real interest rate, both of which move as a consequence of the early disequilibrium.[20] It cannot be OPEC's demand because its expenditures level react with considerable sluggishness.

Inspection of the behavior of Tobin's marginal q gives us the clue: it is investment which makes the difference on impact. While investment always falls, the magnitufe of this fall (on average 5 percent of GNP) can differ quite a lot and thus throw the economy into the amplifying mechanism described on Figure 3. It is clear that the fall in Tobin's marginal q is directly influenced by the ability of the firm to cushion the effect of the shock: anything that enhances its freedom to react will make for a smaller drop in q^m and consequently for a smaller reduction in investment. Thus, while the long run implications in terms of demand, potential output and prices are qualitatively the same in all cases, we may well observe impact responses which differ dramatically.

It is interesting to note that, as is usual in rational expectations models with sticky prices, we may obtain an overshooting reaction for some or all of the nonpredetermined variables. If we consider human wealth (not reported in the tables), it increases on impact, even when r increases in the early periods, for two reasons: first, r actually remains below its steady state value during most of the adjustment period and second, because with demand in excess of potential output and with energy now more expensive, labor is the factor of production the least hit by the oil shock. If firms were not output constrained we could equally well observe an increase in q^m on impact as the actually observed lower value of q^m results from a lower r pushing q^m up and from reduced profits as the firms are thrown out of their national supply curve, which pushes q^m down.

3 - <u>The Adjustment Period in the Base Case</u>

Having characterised the impact effect we now briefly describe the adjustment path in the base case. With OPEC gradually increasing its expenditure level to its newly acquired wealth, demand recovers and tilts the goods market into an excess demand situation, prices increase regularly lowering the real interest rate below its steady state level. As the capital stock is steadily reduced and with the ownership of domestic stocks by OPEC quickly building up, domestic wealth falls reducing expenditures and bringing the current account back into balance.

Table 4 : The Base Case (γ = .1, θ = .5, σ = .4)

Period	Q	L	Q_p	w	q^m	q^a	r	A	Z	λ	P
0	100.0	75.0	100.0	1.00	1.00	1.00	.040	1665	20.0	1.00	1.00
1	88.8	66.2	95.6	.99	.91	.88	.055	1667	20.0	1.00	1.00
5	98.0	76.6	88.9	.99	.96	.92	.021	1611	57.8	1.00	1.04
10	87.5	69.0	81.1	.97	.93	.92	.025	1451	79.9	1.00	1.15
15	86.5	69.7	86.2	.93	.94	.94	.039	1403	81.3	1.00	1.19
20	89.4	73.6	88.4	.91	.97	.96	.038	1396	81.5	1.00	1.19
30	88.8	74.0	87.9	.90	.98	.98	.038	1359	81.4	1.00	1.23
50	88.3	74.7	88.0	.89	.99	1.01	.039	1324	80.4	1.00	1.26

Table 5 : Complete Contemporary Wage Indexation (γ = .1, θ = 1, σ = .4)

Period	Q	L	Q_p	w	q^m	q^a	r	A	Z	λ	P
0	100.0	75.0	100.0	1.00	1.00	1.00	.040	1665	20.0	1.00	1.00
1	88.9	66.2	95.5	.99	.91	.88	.055	1667	20.0	1.00	1.00
5	98.0	76.5	85.6	1.00	.96	.93	.013	1607	57.9	1.00	1.04
10	86.8	68.4	81.7	.97	.93	.92	.028	1446	80.3	1.00	1.15
15	87.4	70.7	87.3	.93	.95	.94	.040	1407	81.8	1.00	1.19
20	89.6	73.8	88.4	.91	.97	.96	.037	1397	81.9	1.00	1.19
30	88.8	74.1	87.9	.90	.98	.98	.038	1359	81.9	1.00	1.23
50	88.3	74.7	88.0	.89	.99	1.01	.039	1324	81.2	1.00	1.26

TABLE 6 : Low Wage Responsiveness to Labor Market Conditions (γ = .01, θ = .5, σ = .4)

Periods	Q	L	Q_p	w	q^m	q^a	r	A	Z	λ	P
0	100.0	75.0	100.0	1.00	1.00	1.00	.040	1665	20.0	1.00	1.00
1	101.4	78.4	87.9	1.01	.95	.91	.009	1673	20.0	1.05	1.00
5	98.4	76.9	85.7	1.00	.97	.93	.011	1559	52.3	1.01	1.07
10	83.7	65.0	77.4	.98	.93	.92	.023	1380	68.4	.99	1.20
15	76.6	59.6	73.8	.97	.92	.92	.031	1289	64.9	.96	1.27
20	75.7	59.9	74.2	.95	.93	.95	.035	1250	62.0	.94	1.31
30	74.9	60.8	73.8	.93	.96	.99	.037	1195	59.3	.92	1.36
50	76.2	63.8	76.2	.90	.99	1.07	.040	1163	57.7	.92	1.40

TABLE 7 : Higher Long Run Elasticity of Substitution (γ = .1, θ = .5, σ = .8)

Period	Q	L	Q_p	w	q^m	q^a	r	A	Z	λ	P
0	100.0	75.0	100.0	1.00	1.00	1.00	.040	1665.0	20.0	1.00	1.00
1	83.2	60.7	103.9	.97	.93	.91	.087	1646.6	20.0	.93	1.00
5	99.6	78.0	92.5	.98	1.00	.98	.026	1628.6	66.9	.95	1.01
10	88.7	70.0	80.4	.97	.97	.97	.021	1477.1	95.3	.96	1.12
15	86.5	69.1	89.0	.93	.97	.98	.046	1439.2	98.6	.96	1.15
20	91.4	74.6	89.6	.92	.99	.98	.036	1449.8	100.6	.97	1.14
30	90.8	74.6	89.8	.92	.99	1.01	.038	1425.6	103.1	.98	1.16
50	90.5	74.7	90.3	.91	1.00	1.05	.039	1401.6	104.1	.99	1.19

Interestingly, there is a short spell of over-full-employment as firms try to substitute away from oil and are forced to do so into labor because of the temporarily low elasticity of substitution between capital and energy. This does not last long and the economy falls into unemployment (at 8 percent below the pre-shock "natural" rate) from which it recovers only slowly while product wages fall, thus bringing about a severe drop in human wealth.

The behavior of Z describes the response of the current account to the oil shock (see(31)). Until about the twentieth period, the oil importing countries run deficits for two reasons. First it takes time to substitute away from energy. Second OPEC adjusts its consumption slowly as it quickly builds up its asset holdings and adds interest payments to its oil revenus. Then, with consumption peaking at about twice its initial level and dwindling oil exports, OPEC's current account reverses and remains in deficit until it reaches its long run balance.

4 - The Role of Wage Indexation

In Table 5, we report the simulation performed with 100 percent immediate indexation of nominal wages at home($\theta = 1$ in (21)). The surprise is how little difference it makes: no change can be detected concerning prices, the exchange rate or Tobin's q. Real wages are temporarily slightly higher between periods 5 and 10 than they were in the base case as a rising inflation rate was then taking its toll on real wages. With product wages now higher, potential output is reduced as is the level of employment. Higher wages also reduce the substitution into a more labor intensive production mix so that the imports of oil remain higher, making for a modest increase in current account deficits. The absence of strong effects may appear to run counter to the view of Modigliani and Padoa-Schioppa (1978) who argue that less than full indexation is necessary to adjust to an oil shock. It must be noted, first, that we had full indexation in the base case and, second, that we retain the responsiveness of real wages to labor market pressures so that there is a mechanism still open to bring back real wages to their long run equilibrium value. It is true, however, that we now need a temporarily higher unemployment (between periods 5 and 10) as inflation is not contributing to the decrease in wages.

5 - Real Wages Response to Unemployment

In table 6, we take up the other parameter describing the functioning of labor markets: the elasticity of real wages to unemployment which is now reduced at home from $\gamma = .1$ to $\gamma = .01$ in (21). This turns out to play a major role, essentially because it makes it easier for firms to substitute away from energy into labor. Consequently, on impact, q^m falls less than in the base case and this is precisely one occurence where, as discussed in section 2, the drop in total demand is smaller, thus tilting the initial disturbance into an excess of demand over potential output, with an early, if short-lived, period of over-full-employment.

The dominant feature is that it now takes much more time for real wages to reach their lower long-run level. The implication is a more profound and long-lasting unemployment situation and a more depressed potential output level. With firms forced even further away from their optimum level of operation, total wealth stays at a lower level. This has several consequences. First total demand is lower. Second as total expenditures are reduced, the current account deficit is less than in the base case. Third, with a larger gap between demand and output, prices rise faster which, through the Mundell effect, makesfor a lower real interest rate. With $r < r^*$ we have the need for an expected appreciation. Consequently, the real exchange rate depreciates on impact (overshoots in the wrong direction) and slowly appreciates over the adjustment period. Indeed, in the long run, we end up with a real appreciation. To understand this unexpected implication of wage stickiness, we note that the lower cumulated current account deficits (Z) together with the "preferred habitat" assumption on spending results in a higher world demand for domestic goods (see figure 1).

It is natural, therefore, to ask whether real wage sluggishness can be beneficial in the long run. For example, while product wages end up similar to their base case level, their purchasing power falls only by 8 percent as compared to 11 percent (since $wP/P_c = w\lambda^{\sigma-1}$, where σ is the share of domestic goods in total consumption) suggesting a better situation. This, however, is misleading as, for example, the capital stock goes down by 37 percent in Period 50, with a drop of only 29 percent in the base case. Another check consists in measuring the value of the welfare function (which generates the consumer's behavior, see the appendix) toward its steady state level: by period 50 the reduction is 28 percent with sluggish wages and 21 percent in the base case.

6 - <u>Higher Long Run Elasticity of Substitution</u>

The last experiment reported in Table 7 corresponds to the case where the elasticity of substitution at home between capital and energy (equations (9) and (23)) $\sigma = 1/(1-\rho)$ increases over 10 periods from the same minimum value to a long run value of 0.8 as compared to an unchanged value of 0.4 in the larger country. In this experiment, it is important to note that we change the structure of the economy, not only its dynamic properties.

From Table 2, we know that the long run adverse effects on Q, w, and K are going to be reduced, while the demand for energy is going to be curtailed much more substantially. With total activity higher, total wealth, A, will hold up better and, consequently, the demand for money will fall by less, implying less inflation over the adjustment period.

The initial response can be decomposed into two stages. First, on impact, with our putty-clay model, the elasticity of substitution is as in the base case so that qualitatively the reaction is similar: we observe an excess supply in the goods market. But the numbers are quite different and show an interesting effect. We have seen in Figure 3 that with an initial excess supply we obtain a higher real interest rate through expected deflation. Now, with long run prospects being improved by the larger substitution possibilities, the downward move of the AA schedule is reduced, implying $r > r^x$. This in turn triggers a new mechanism: as is usual in the exchange rate overshooting literature (Dornsbusch (1976)), since (18) implies an expected depreciation, the real exchange appreciates thus alleviating the effect of the oil shock at home (and worsening it abroad). As a consequence, the potential output decreases by less, deepening the excess supply and expected deflation, and starting up the deviation-amplifying effect described in Section 2. The result is a sharp increase in r and a 7 percent real appreciation which more than offsets the oil shock since potential output actually increases.

The ensuing adjustment also differs significantly from the base case. As K is eventually reduced by 13 percent instead of 28 percent, the drop in investment and wealth is smaller, making for a larger absorption and a more pronounced current account deficit as evidenced by the behavior of Z. Also, a higher level of K and a reduced long run drop in potential output lead to a more sustained demand for labor and a more moderate reduction in the product wage throughout the adjustment period.

Finally, we note that in the long run, the real exchange rate appreciation is negligible. This is related to the higher cumulated current account deficits which means a larger transfer of domestic stocks to OPEC, thus reducing total world demand for domestic goods and forcing λ to increase from its initial lower level. With long run P much lower at home, though, we obtain a 6.4 percent appreciation in the nominal exchange rate.

V - CONCLUSIONS

This paper has extended Sachs' work who had investigated the response to an oil shock of a two countries plus OPEC neo-classical model with full intertemporal optimization and perfect foresight. Here, the role of imperfectly flexible prices has been studied under the assumption that firms are output constrained. The experiments confirm the presumption that such a modification results in significantly different responses because the role of expected inflation is pervasive. It affects the real interest rates and therefore the valuation of all components of wealth, as well as the exchange rate and the attending distribution of world expenditures. Inflation also enters the wage adjustment mechanism and therefore the path of unemployment and capital accumulation.

There could be other ways of introducting price stickiness in the model, for example, by assuming that the short end of the market dominates, following the disequilibrium literature. This poses the problem of treating rationing in the goods markets and does not necessarily fit reality better. We believe, however, that it would make the stability conditions of the model less stringent by eliminating the deviation-amplifying mechanism previously described.

Another extension has been the introduction of a time-varying elasticity of substitution as a simple way of capturing the embodiment of technology in capital vintages. This has been shown to play an important role in the early dynamics of the labor market.

As it is, the model can be used for policy experiments. Sachs has already noted that in this model with full labor indexation and flexible prices, monetary policy does not affect output while fiscal policy does, because it shifts demand between domestic and foreign goods. With sticky prices, though, the short run neutrality of money disappears and the fact that this is a two-country model makes it suitable to address the issue of policy coordination between countries with different structural characteristics.

Finally, this should be considered as a preliminary work with a new generation of models and their solution techniques, as pioneered by Sachs. Several extensions and improvements are on the agenda. Also, we feel quite unsatisfied with our treatment of the oil exhaustion issue: clearly we need a better treatment of OPEC's intertemporal optimization between oil wealth, other assets and consumption, but this seems not yet to be within reach. Equally desirable would be the introduction of risk and imperfect asset substituability.

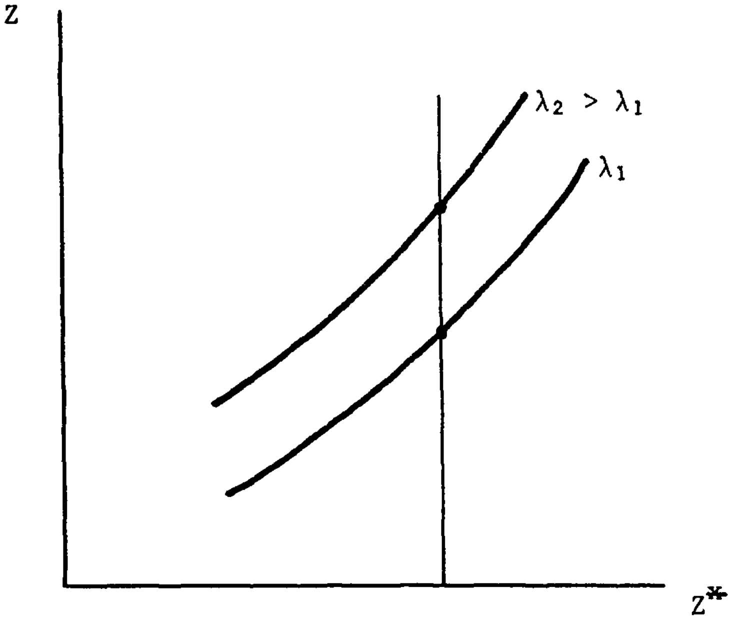

Figure 1

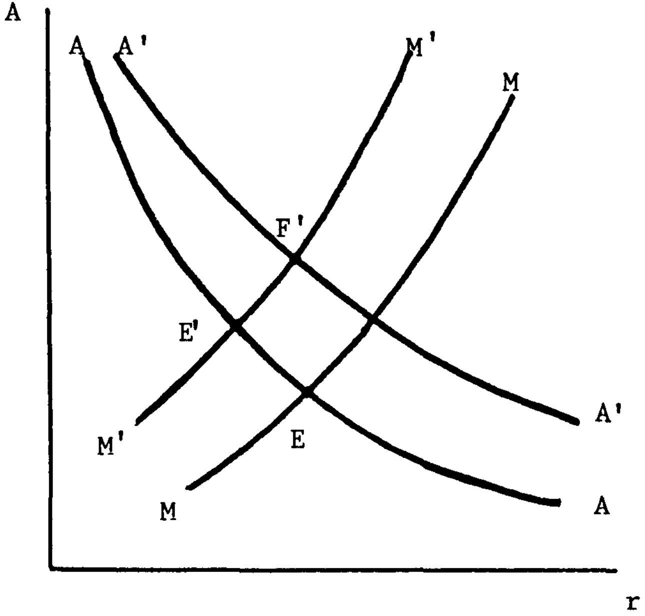

Figure 2

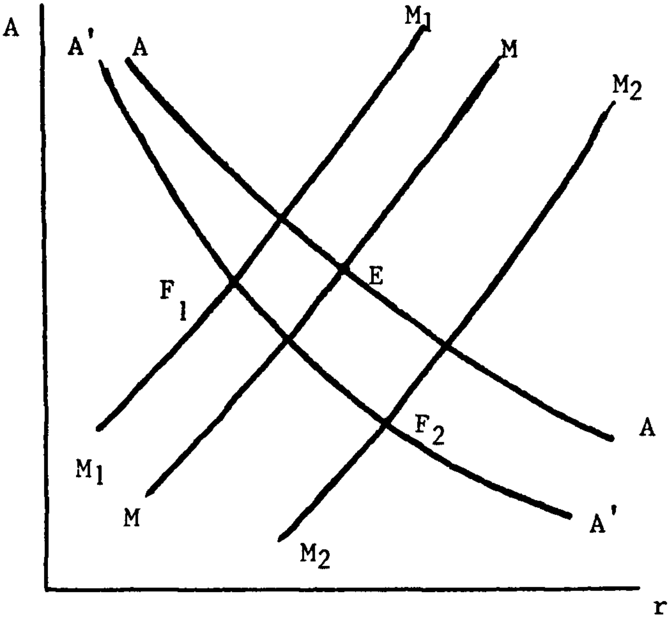

Figure 3

APPENDIX

1. The Consumption Functions

We wish to maximize $\int_0^\infty e^{-\delta t} \ln U(t)dt$ where $U^{\rho_1} = cV^{\rho_1} + (1-c)m^{\rho_1}$, $V^\rho = \alpha C^\rho + (1-\alpha) C_M^\rho$, under the constraint that $\dot{A} = rA - C_T$ with $C_T = C + \lambda C_M + im$.

The first order conditions are :

(A1) $\frac{1}{U}\frac{\partial U}{\partial C} = \phi$, $\frac{1}{U}\frac{\partial U}{\partial CM} = \phi\lambda$, $\frac{1}{U}\frac{\partial U}{\partial m} = \phi i$ where ϕ is the Lagrangian multiplier. We also have as first order condition :

(A2) $\dot{\phi} = (\delta - r)\phi$

Together with the constraint, (A2) leads to :

$(\dot{A/C_T}) = \delta(A/C_T) - 1$

Integrating forward we get $\frac{A}{C_T} = \int_0^\infty e^{-\delta t}dt = \frac{1}{\delta}$, so $C_T = \delta A$.

This covers all of the dynamic problem. As is clear from (A1), the remaining task is the more familiar one of static optimization. It is readily verified that the logarithm part plays no role. The solution to (A1) is made easier by defining

$C_N = C + \lambda C_M$, i.e. total expenditures on goods

$C_T = P_u U$ and $C_N = P_v V$, P_u and P_v being two price indices.

The solution is then :

$$C = \alpha^\sigma P_v^{\sigma-1} C_N \; ; \; C_M = (1-\alpha)^\sigma \lambda^{-\sigma} P_v^{\sigma-1} C_N \; ; \; m = (1-c)^{\sigma_1} i^{-\sigma_1} P_u^{\sigma_1-1} C_T$$

with $C_N = c^{\sigma_1} P_v^{1-\sigma_1} P_u^{\sigma_1-1} C_\alpha$; $P_v^{1-\sigma} = \alpha^\sigma + (1-\alpha)^\sigma \lambda^{1-\sigma}$;

$$P_u^{1-\sigma_1} = c^{\sigma_1} P_v^{1-\sigma_1} + (1-c)^{\sigma_1} i^{1-\sigma_1}$$

In the numerical simulations the following consistent values have been used:

$\alpha = .6$, $\alpha^* = .151$, $c = .12$, $c^* = .773$, $\sigma = \sigma^* = 2$, $\sigma_1 = \sigma_1^* = .1$

2. The Constrained Output Case

The derivation follows Blanchard (1980). The firm's problem is to maximize its present value $B = \int_0^\infty [y - wL - \pi N - I]\, e^{-rt} dt$

under the two constraints :

$$y(K, L, N) = Q \quad \text{and} \quad I = \dot{K}\left[1 + \psi(\tfrac{\dot{K}}{K})\right], \; \psi'>0, \; \psi''\geq 0$$

Introducing the notation $J = \dot{K}$ and inverting the output constraint condition to obtain $L = L(Q, K, N)$ we have the Hamiltonian :

$$H = \left[Q - WL(Q, K, N) - \pi N - J\,[1 + \psi(\tfrac{J}{K})] + q^m J\right] e^{-rt}$$

where q^m is the shadow price of investment, i.e. Tobin's marginal q.

The first order conditions are :

(B1) $\partial H/\partial N = 0$, so $w/\pi = - L_N = (\partial y/\partial L)/(\partial y/\partial N)$

(B2) $\partial H/\partial J = 0$, so $q^m = 1 + \psi(J/K) + (J/K).\psi'(J/K)$

(B3) $-\partial H/\partial K = e^{-rt}(\dot{q}^m - rq^m)$, so $\dot{q}^m = rq^m + wL_k - (J/K)^2\psi^1$

(B1) gives (10) in the text, while (B2) with $\psi(\frac{J}{K}) = \frac{\phi}{2}\ \frac{J}{K}$ gives (11) and (12). After same manipulation and using the linear homogeneity assumption for y(K,L,N) it is easy to derive (15) from (B3).

Tobin's average q follows from the definition : $q^a = B/K$, where B is the market value of the firm defined above. This gives (14).

FOOTNOTES

* An earlier version of this paper was presented at the International Seminar in Macroeconomics, Paris, June 17-18, 1981.

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1 - See, for example, Dornbusch (1976), Kouri (1976) and Mussa (1979).

2 - For reference on the supply side, see Bruno and Sachs (1979). For the role of future disturbances on the exchange rate, see Dornbusch and Fischer (1980) and Rodriguez (1980). A large number of papers have explored the effect of future wealth effects in a closed economy setting (for example Blanchard (1980, 1981). An extension to the open economy case can be found in Sachs (1981).

3 - For a closed economy linear model simulated under rational expectations, see Blanchard (1980). Because his model is linear, the solution technique is considerably simpler.

4 - An overview of theoretical developments and empirical work is in Gordon (1981).

5 - The slowly increasing elasticity of substitution produces effects similar to those obtained by Nordhaus (1980) with a vintage production function. His derivation is of course more rigorous. Here it takes 10 periods for σ to grow from as low a value as possible (.08) to its long run level (.4), so that early on there is little scope for substituting capital to energy.

6 - The extension to allow for domestic production of oil is straightforward, provided domestic oil is of the "gold under the pillow" type. This is also in Sachs.

7 - Assuming inelastic labor supply, the wage equation should be interpreted as describing labor market disequilibrium and involontary unemployment.

8 - As surveyed by Gordon (1981), there is considerable evidence that prices move as a mark-up over costs with a role for excess demand. Equation (26) does not violate this evidence since potential output Q_p is directly a function of factor costs. For the simplest case of a Cobb-Douglas technology, $Q = K^a L^{1-a}$, it is readily verified that (26) becomes $P_{+1}/P = kK^{-\varepsilon}Q^{\varepsilon}w^{\varepsilon(1-a)/a}$ (with k a constant) so that both actual demand (Q) and factor costs (w) enter the relation.

9 - For the properties of this investment function, see Abel (1978). For applications see Blanchard (1980), Sachs (1980).

10 - The simple form $C^T = \delta A$ is a consequence of using a logarithmic transformation of the instantaneous utility function which implies that utility is Cobb-Douglas over time.

11 - Variables such as H can be described either as the present discounted value of the future stream of income - in this case of labor income - or, as in (2) by a dynamic equation plus a transversality condition. We have not included the transversality conditions in Table 1, but we shall return to their role in driving the system from one steady state to another.

12 - If oil were correctly treated as an exhaustible resource, OPEC should not set the real price of oil exogenously, but should set the rate of increase of the real price of oil equal to the rate of return on the alternative asset (see for example, Dasgupta, Eastwood and Heal (1978)). In this case however the steady state price of oil is infinite, oil consumption goes to zero and in order for the technology to be consistent we should allow for subsituability between oil and an alternative source of energy. Another possibility would be the introduction of a backstop technology as in Nordhaus (1973).

13 - As already noted in footnote 11, together with the transversality condition $\lim_{T\to\infty} q^a(T)e^{-\int_t^T r(s)ds} = 0$, equation (14) implies

$$q^a(t) = \int_t^\infty e^{-\int_t^s r(v)dv} \left[D(s)/q^a(s)K(s)\right] ds,$$

or, equivalently, the present value of the firm :

$$q^a(t)K(t) = \int_t^\infty e^{-\int_t^s r(v)dv} \left[Q - (P_N/P)N - wL - I\right]ds$$

14 - Technically this means that one of the boundary conditions of the dynamic problem consists of a relation between three state variables, rather than a given value, as in the case of r and r^*. Assuming that claims on K and K^* are imperfect sybstitutes in the portfolio of OPEC would add one steady state condition - OPEC's portfolio balance equation - but would still be insufficient to uniquely determine the steady state.

15 - For a detailed characterization and the formal derivation of the solution in the case of a linear model, see Blanchard and Kahn (1980).

16 - For a general statement of the problem and economic examples, see Buiter (1981). For a previous application to this model and a more detailed discussion, see Sachs (1980). A detailed presentation of the technique of multiple shooting is in Lipton, Poterba, Sachs and Summers (1980).

17 - In principle one could search for a Lyapunov function. Another possibility consists in linearizing the model along its solution path and in checking that, at each point, the transition matrix has 8 eigenvalues outside and 9 eigenvalues inside the unit circle. Given both the size of the model and the length of the simulation period we have decided to rely on theis <u>ex post</u> indication of saddle-point stability.

18 - This is particularly the case when prices are very sluggish, the response of real wages slow or when the elasticity of substitution between capital and energy takes a long time to reach its long run value.

19 - This is not quite true. A is the present value of all future incomes discounted with the actual rates over each period, so with contemporaneous r unchanged, the schedule AA can shift to reflect the whole term structure of interest rate. In Table 4 we have an increase in both A and r in period 1, while future interest rates all lie below their long run value.

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