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ENERGY PRICES, INFLATION, AND RECESSION, 1974-1975

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ABSTRACT

The energy price shock depressed real output by two percent in 1974 and by five percent in 1975, according to our results. Prices rose by four percent in 1974 and by another two percent in 1975. These conclusions are derived from an aggregate model of the U.S. economy with an explicit role of energy in production. The distinction between expected and unexpected shocks is an important part of the model. We also examine monetary and fiscal policies that might have offset the energy shock.

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I. INTRODUCTION

The rapid escalation of energy prices in late 1973 and early 1974 has a dominant role in most accounts of the deep recession and high inflation of the mid-1970s. This paper presents a quantitative appraisal of the response of real output, prices, and employment to the energy price shock. It considers both the substitution away from energy as an input to production that occurred because of the shock and also traces the monetary and general macroeconomic effects. Two of the most important mechanisms considered are the adverse impact of higher energy prices on the permanent incomes of consumers and the reduction in investment brought about by higher interest rates. The analysis of these and other channels of influence of energy prices is carried out within a compact macroeconomic model of the U.S. economy with an explicit treatment of energy.

Our findings suggest that the energy price shock depressed real output by two percent in 1974 and by five percent in 1975, and so accounts for at least two-thirds of the total decline in real output from trend that occurred in those years. Consumption declined permanently by about three percent in response to the decline in real incomes associated with the increase in price of a product which the nation imports, on net. Investment fell temporarily but by a much larger percent. Prices rose by four percent in 1974 because of the energy shock, and inflation worsened by another two percent in 1975. Together with the impact of the termination of price controls, energy prices can account for all of the enormous acceleration of inflation observed in 1974, but falls short of explaining the continued inflation in 1975. The deep recession of 1974-75 could have been offset or moderated by suitable policies. In particular, the announcement in 1974 of a monetary expansion to take place in 1975 could have postponed the inflation until 1975 and eliminated the recession. This conclusion demonstrates our model's ability to handle the expectational issues that are now recognized to be so important in studying the influence of aggregate policy, but, of course, the conclusion rests on the stark assumption that the public would believe an announcement of future policy. A fiscal expansion could also have moderated the recession, but at the cost of inflation of almost 20 percent in 1974. The bias in our model toward a monetary rather than a fiscal offset comes from its incorporation of a full treatment of the adverse effect of expansionary fiscal policy on aggregate supply. We also look at the possible success of policies to counteract the inflationary impetus from the energy shock. We conclude that contractionary money policy would probably not have been capable of fully offsetting energy inflation, and only an impracticably large fiscal contraction would have done the job.

Our work follows in the footsteps of a number of innovative earlier studies. One of the first to predict the recession as a result of the energy shock seems to have been Robert Gordon (1974). A number of later studies have followed. Some of these have made important theoretical contributions, like Gordon (1975a), E. Phelps (1978), Solow (1978), and Findlay and Roderigues (1977). Others have employed quantitative models to simulate the 1974-75 experience. These include Pierce and Enzler (1974), Berner et al. (1975), Perry (1975a, b), Eckstein (1978), Fair (1978), Klein (1978), and from a slightly different perspective Hudson and Jorgenson (1978). Contributions of the more informal type include Haberler (1976), Serot (1978), and Okun (1975). The present paper is, to our knowledge, the first attempt to give a unified treatment of the issues associated with factor substitution on the one hand and monetary and general macroeconomic aspects on the other. We have done this by constructing a medium-sized macroeconomic model of the U.S. with an explicit treatment of energy. The modeling of energy demand is similar to the various general equilibrium energy-economy models (cf. e.g. Hudson and Jorgenson (1977) except that our model has a simpler, one-sector structure. The price of energy is taken as exogenous, which is convenient for studying the macroeconomic effects.

The macroeconomic structure of our model includes a financial system, which enables us to study various aspects of inflation and monetary policy. The model incorporates the hypothesis of rational expectations, but it is also somewhat Keynesian in treating money wages as predetermined in the short run. In a purely classical economy where wages clear the labor market instantaneously, an unexpected energy price increase would reduce the level of output as a way of substituting away from energy. Because of an accelerator effect on investment, this impact would be larger in the short than in the long run. However, there would be no effect on employment or prices. When the price of one factor, energy, increases, the price of other factors, especially the wage, would fall to offset it. Full employment should always prevail, and the price level should be linked directly to the money stock. In our model, on the contrary, wages respond slowly to unexpected changes in energy prices (and to all other surprises in the economy). During the period following an energy price increase but before the accommodating change in the wage, labor is priced too high for full employment. Furthermore, with wages sticky, an energy price increase increases the price level, so that the real money supply is lowered, which has an additional contractionary effect on the economy. Our model deals explicitly with these aspects of the effect of an energy price shock; investment and interest rates play an important role in the relation between the sticky wage rate and the resulting levels of prices, output, and employment.

When energy is partly imported, as in the U.S. of the 1970s, another consideration links output and employment to an unexpected increase in energy prices -- higher prices make the U.S. poorer and so reduce the level of consumption in real terms. Often this is compared to the imposition of a tax on U.S. consumers with the proceeds going to foreigners. As the U.S. is made poorer, energy-supplying nations become richer. They acquire claims upon the U.S. and face the choice of accumulating the claims (as government or corporate bonds, stocks, direct investments and so on) or cashing them in for goods produced in the U.S. Our model does not attempt to explain the choices of oil producers in this regard, but uses a guess that oil producers spend a relatively small fraction of their new income on U.S. goods. This seems consistent with observations on actual behavior in recent years.

II. The Model

The results of this paper are obtained by simulation of a macro model of the U.S. economy with explicit treatment of energy. The model was constructed on the basis of the one used by Hall (1978a), but contains some important extensions and revisions. The present model treats the economy as having two sectors, goods and energy. Only the goods sector is fully represented in the model. Energy is used as an input to the goods sector and is thought of as primary energy, such as crude oil, natural gas at the wellhead, and coal at the minemouth. For simplicity, there is a single price of energy, though it should be recognized that this is only a rough approximation. The price of energy is viewed as exogenous, and what cannot be supplied by the domestic energy sector is imported. The price elasticity of domestic energy supply is not considered here.

The goods sector combines labor, capital, and energy to produce goods. The term "goods" covers all sorts of goods and services and includes finished energy products such as gasoline and electricity. Total goods production is allocated among consumption, investment in the goods sector, government expenditures, net export of goods, and deliveries to the energy sector. It differs from real GNP by the amount of the last item, which is small, and net energy imports.

Within this sector, the critical elements of the model are the technology constraint, the price equation, the specifications of the investment process and wage determination, including lags; the consumption function; and the demand function for money.

The technology constraint is represented in the form of a unit cost function

$$\phi(e^{-\mu_1 t} w,\ P_E,\ P_K), \tag{1}$$

where w is the aggregate wage rate, P_E the price of energy, and P_K the nominal rental price of capital. ϕ is specified as a translog function and has the following properties. The own price elasticity of energy demand is about -0.3, and the partial elasticities of substitution are about zero for capital and energy, unity for capital and labor, and around one half for energy and labor. These are long-run elasticities; short-run behavior is modeled by specifying P_K as the shadow price of existing capital. The low value for the own elasticity of energy in the aggregate is supported by evidence by Mork (1978a) and by casual reading of post-1973 data. The unitary elasticity of substitution between capital and labor is strongly supported by the evidence of Berndt (1976) and many other authors. For the corresponding elasticity between capital and energy, strikingly different estimates can be found in various parts of the literature.[1] Despite new insights and attempted reconciliations,[2] the issue seems to remain a subject of controversy. Our choice of a zero elasticity is partly based on the evidence of Hudson and Jorgenson (1978). Although their model has capital-energy complementarity for the manufacturing sector, substitutability in service industries and interindustry shifts in final demand gives a net effect on capital intensity of the 1973-74 energy price increase that is very close to zero. We hope to pursue this issue at a later stage.

The overall price leve, defined as the money price of goods, is determined as standard unit cost, described by the price equation

$$(1 - \tau)P = (e^{-\mu_1 t} w^o, P_E, P\overline{v}) \qquad (2)$$

where τ is a tax parameter for indirect taxes. The function ϕ is the same as

[1] Cf. e.g., Berndt and Wood (1975) and Griffin and Gregory (1976).

[2] Cf. Berndt and Wood (1979) and Field and Gribenstein (1977, 1978).

in (1), but the arguments are slightly different. First, fluctuations in the efficiency wage due to cyclical variations in productivity, are excluded from the price equation (2) where as the technology constraint (1) includes them. Secondly, the capital price used in the price equation is a long-run average of the real rental price times the price level rather than the actual nominal price as in (1). This formulation corresponds with the following important findings of the price equation literature: (1) Apart from the effect via wages, fluctuations in demand have little or no effect on the price level;[1] (2) prices show no sensitivity to cyclical fluctuations in productivity;[2] and (3) transitory fluctuations in interest rates do not affect prices.[3] In addition, this specification seems to give a sensible estimate of the partial impact on the price level of an energy price increase, namely the share of energy in variable cost.

Investment demand is derived from the demand for capital. However, in the short run, the model assumes that the economy's ability to adjust the capital stock is limited. Part of the investment in the next few years is already committed today and cannot be adjusted in response to new information. Specifically, this is modeled by treating capital as an aggregate of m categories, such that the quantity of category j needs to be determined j - 1 years in advance. Each category enters symmetrically in the technology model; but the categories are imperfect substitutes in production, since otherwise all investment would be concentrated in the category with the shortest lead time. In the year of the energy shock, investment in m - 1 categories is committed already, whereas investment in the last category is

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[1] Cf. Gordon (1970, 1971, 1977), Nordhaus (1972), Hall (1979).

[2] For an alternative interpretation of this observation, see Mork (1978b).

[3] Cf. e.g. Gordon (1975b), pp. 643-44.

determined by the demand for capital of that category as determined by present and expected future prices and demand. The next year, another category becomes "flexible" until all capital and investment is determined by post-energy shock forces after four years. This formulation, which is adapted from Hall (1978a), does justice to the physical lags in the investment process without introducing arbitrary lags for expectation formulation.[1]

The lag in wage determination is incorporated in a similar way, except that it is the nominal wage, not the quantity of labor services, that is committed in advance. When wages are set, they clear the labor market, or come as close as they can given current information about future demand for labor. When unexpected events occur, such as the doubling of the price of energy considered here, the demand function for labor determines the level of employment, which may then be well below the supply of labor. This can be interpreted as a characterization of the Keynesian hypothesis of wage rigidity and is an attempt to embody the view that the labor market achieves equality of supply and demand in the long run but that the process takes time. It implies a kind of Phillips curve for the economy. However, in place of the expected inflation term that has been the source of so much instability and conceptual ambiguity in the literature on the Phillips curve, expectations of future labor demand are formed using the model itself. In particular, feedback from prices to wages occurs in the model to the extent that price increases signal current or future increases in the demand for labor (as they typically do).

This formulation, set forth by Hall (1978a), has been extended in two

[1] The length and shape of the investment lag is exogenous in our model. An endogenous speed of adjustment, as in Lucas (1967) might have been more appropriate.

directions. First, a cost of living increase has been added to the precommitted wage rate. Specifically, for each percentage point of unexpected price inflation, the committed wage rate is raised by 0.25 percent in the same year and another 0.25 percent in the year after. Roughly, this corresponds to a 50 percent escalation clause with a six month lag, assumed to reflect the time needed for data collection. The inclusion of this feature is justified by the widespread occurrence of such clauses in the U.S. labor contracts (cf. Mitchell (1978)) as well as the theoretical argument by Hall and Lilien (1979) that efficient labor contracts will have this feature. Furthermore, it allows for a positive feedback from energy prices to wages in the short run. Since it turns out that an energy price increase lowers the demand for labor permanently, however, this positive feedback is counteracted by a tendency towards lower wages in the longer run.

The other extension is an adjustment in the committed wage rate to incorporate cyclical movements in labor productivity. This feature makes the model obey Okun's law but has few other implications and thus will not be discussed in detail here.

Consumption in the model is determined by permanent income. Consumers are viewed as looking into the future to evaluate their future incomes, and then choosing a growth path of consumption that is the highest feasible given expected future income. The behavior of consumption has the character described by Hall (1978b) -- consumers always plan a constant growth rate for consumption. When new information arrives, they make an immediate once-and-for-all adjustment to the level of consumption. We assume that consumption is unaffected by real interest rates, in the sense that the rate of growth of planned consumption does not depend on the interest rate. Note that the assumption in Hall (1978a) that consumption is unresponsive to all economic events is replaced by an explicit dependence on permanent income.

Government expenditure and net export of goods are taken to be exogenous. Among other things this means that, rather than modeling the behavior of petroleum exporting countries, we use an outside estimate of their demand for U.S. goods.

In the money demand function, the major issue is the specification of the variable that measures the dollar volume of transactions. The use of nominal gross national product for this purpose is one of the many reasons that macroeconomic models in existence in 1973 were unable to deal effectively with the energy price shock (cf. the remarks by Pierce and Enzler, op. cit., p. 16) -- nominal GNP subtracts imports and so cancels out much of the effect of higher energy prices. We use the dollar volume of output from the goods sector as a proxy for transactions. This variable makes sense in view of the fact that much of the money stock is in the hands of consumers, not businesses. We neglect the small contribution to the demand for money that might come from the energy sector (recall that all energy passes through the goods sector on its way to final demand).

A technical presentation of the model is given in the Appendix.

III. Actual Performance of the U.S. Economy, 1973-77

The upper panel of Table 1 summarizes the actual performance of the U.S. economy over the last five years. The data have been recast so as to fit into the sectoral and conceptual framework of our model. Gross output is defined as total GNP minus GNP originated in the energy sector (defined as coal mining and oil and gas extraction), plus the value of primary energy input to the goods sector.[1] Investment is defined as gross private domestic investment except structures for mining exploration, shafts, and wells, and mining and oilfield machinery. Rather than following the practice of double deflation, which can be misleading over a period with changing relative prices, all nominal figures were deflated by a common price index. We used the Consumer Price Index for this purpose and for general description of the price level over the period. We preferred the CPI to the GNP deflator because it corresponds better to our definition of gross output.[2,3]

In spite of the differences in definition, the numbers of Table 1 are very close to the standard macroeconomic variables. This similarity is, however, the result of several factors working in different directions. Thus, the decline in gross output is made larger than the fall in GNP by the exclusion of the domestic energy sector, whereas the increased value of energy imports worked in the opposite direction. Furthermore, deflation by

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[1] The value of primary energy and GNP in the energy sector were taken from Mork's data base (cf. Mork et. al. (1978)). Some extrapolation was necessary for 1976 and 1977; the possible extrapolation errors are not likely to have been important.

[2] As noted by Pierce and Enzler (op. cit.), import price increases affect the GNP deflator only through the increases in the prices of domestically produced substitutes. There is no direct effect because imports are substracted off in the computation of GNP from gross output data.

[3] We recognize the limitation of the CPI in that it covers consumer goods only.

Table 1

Actual performance
of the U.S. economy 1973-77

Levels

	Real Gross Output (bill. of 1972 $)	Real Growth	Price Level (CPI)	Rate of Inflation	Investment (bill. of 1972 $)	Consumption (bill. of 1972 $)	Net Export of Goods and Government Expenditure	Unemployment Rate	Value of energy imports (bill. $)
1972	1186.1	6.5	1.000	3.3	184.3	733.0	268.8	5.6	4.8
1973	1248.8	5.3	1.062	6.2	203.0	762.6	283.2	4.9	8.2
1974	1229.9	-1.5	1.179	11.0	176.8	754.5	298.7	5.6	25.5
1975	1219.8	-0.8	1.287	9.1	140.4	761.8	317.6	8.5	26.5
1976	1287.7	5.6	1.361	5.8	171.7	803.8	312.1	7.7	34.0
1977	1340.6	4.1	1.449	6.5	195.7	835.9	309.0	7.0	44.5

Deviations from base case forecast

	Real Gross Output					Investment		Consumption		Net Export of Goods and Government Expenditure	
	Abs. diff.	% diff.	Real Growth diff. in % points	Price Level % diff.	Rate of Inflation, diff. in % points	Abs. diff.	% diff.	Abs. diff.	% diff.	Abs. diff.	% diff.
1972	-	-	-	-	-	-	-	-	-	-	-
1973	-	-	-	-	-	-	-	-	-	-	-
1974	-41.1	-3.2	-3.3	4.8	5.0	-17.6	-9.0	-30.5	-3.9	7.2	2.5
1975	-88.7	-6.8	-3.8	7.9	3.1	-59.8	-29.8	-46.3	-5.7	17.5	5.5
1976	-58.5	-4.3	2.7	7.7	-0.2	-33.7	-16.4	-28.1	-3.4	3.2	1.0
1977	-45.5	-3.3	1.1	8.1	0.5	-16.0	-7.6	-20.5	-2.4	-9.0	-2.8

the CPI made for a somewhat larger decline in real output in 1974.

The largest decline in real output took place from 1973 to 1974 with a growth rate of -1.5 percent. The depth of the recession was, however, reached in 1975 with real production 2.3 percent below its 1973 level. This was also the year of record high unemployment rates. As for the components of output, the decline in investment in 1974-75 was most spectacular, as was its rapid rebound during the recovery. However, the stagnation of consumption was equally significant. Net exports of goods increased substantially in 1974 and 1975 but declined in 1976 and 1977, apparently as a result of the worldwide recession.

The price level movements over this period are well known. The first jump came with higher food prices in 1973 with another jump, twice as large, partly caused by higher energy prices, following in 1974. Although inflation slowed down somewhat after these jumps, prices continued to rise at high rates in 1975 and the following years. The development of the value of energy imports from 1972 to 1974 illustrates the transfer of wealth from the U.S. to oil-exporting countries. Part of the increase is due to an increase in quantity. This accounts for about half of the increase from 1972 to 1973. For the following year, however, the quantity increase was minimal. Thus, the wealth transfer may be roughly approximated as a $19 billion annual transfer of income.

IV. Estimates of the Energy Price Shock

Our first step was to prepare a base case describing the possible evolution of the economy from 1973 in the absence of the abrupt increase in the price of energy. Table 2 shows the assumptions in the base case and the model's corresponding projections. The nominal price of energy was assumed to increase at the same rate as the general price level. For all years except 1974 this was assumed to be 5 percent, which is the natural rate of inflation of the model. For 1974 an additional 2 percent inflation was projected as a result of the removal of general wage and price controls. The committed wage rate and the money stock were assumed to grow at 6.3 percent and 6 percent per year respectively. Investment commitments for 1974 were assumed to be somewhat lower than investment in the mini-boom of 1973 and to grow smoothly from then on. The labor force, expressed as the natural rate of employment, was assumed to grow at about 1.7 percent per year, which is about the same as population growth in recent years.[1] When combined with a labor productivity growth rate of 1.2 percent, this gives a total natural growth rate of slightly below 3 percent. This is lower than the postwar average but seems well in accordance with recent experience.

The model's projections are based on the absence of any surprises or shocks. The employment rate is the natural or equilibrium rate, which is 6 percent in our model. The wages actually set (the "flexible wage rate") equal the committed levels; roughly the same is true for investment. Real output grows smoothly and inflation proceeds at 5 percent.

Table 3 presents the model's estimates of the effects of an unexpected increase in the price of energy starting in 1974. Here the price of energy

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[1] We do not discuss changes in labor force participation.

Table 2

Base Case Projections

	Real Gross Output	Real Growth	Price Level	Rate of Inflation	Investment	Consumption	Employment	Unemployment rate	Wage Rate (1000 $)
1974	1270.5	1.7	1.136	7.0	193.9	785.0	86.4	6.0	10.4
1975	1308.2	3.0	1.193	5.0	199.9	808.1	87.9	6.0	11.0
1976	1346.4	2.9	1.253	5.0	205.6	831.9	89.4	6.0	11.7
1977	1386.5	3.0	1.315	5.0	212.0	856.4	91.0	6.0	12.5
1978	1426.8	2.9	1.381	5.0	217.9	881.6	92.5	6.0	13.3

Assumptions

	Money Stock	Committed Wage Rate (1000 $)	Investment Commitment	Net Export of Goods and Government Expenditure	Natural Level of Employment	Price of Energy
1974	280.1	10.4	193.9	291.5	86.4	1.241
1975	296.9	11.0	199.8	300.1	87.9	1.303
1976	314.7	11.7	205.7	308.9	89.4	1.368
1977	333.6	12.5	-	318.0	91.0	1.437
1978	353.6	13.3	-	327.4	92.5	1.509

Table 3

Estimated Impact of the Energy Price Shock

	Real Gross Output		Real Growth	Price Level	Rate of Inflation - diff.	Investment		Consumption	
	Absol. diff.	% diff.	diff. in % points	% diff.	in % points	Absol. diff.	% diff.	Absol. diff.	% diff.
1974	-25.8	-2.0	-2.1	4.0	4.2	-7.1	-3.7	-25.8	-3.3
1975	-62.8	-4.8	-2.9	5.7	1.8	-53.7	-26.9	-26.5	-3.3
1976	-54.3	-4.0	0.8	6.1	0.3	-30.1	-14.6	-27.3	-3.3
1977	-50.0	-3.6	0.5	5.9	-0.3	-25.0	-11.8	-28.1	-3.3
1978	-45.1	-3.2	0.5	5.8	-0.1	-19.5	-8.9	-29.0	-3.3

	Employment		Unemployment Rate		Wage Rate	Assumptions*: Price of Energy		Assumptions*: Net Export of Goods and Government Expenditure	
	Abs. diff.	% diff.	Level	diff. in % points	% diff.	Level	% Diff.	Absol. diff.	% Diff.
1974	-1.0	-1.1	6.9	0.9	0.7	2.089	68.3	7.2	2.5
1975	-2.1	-2.4	7.7	1.7	1.2	2.676	105.4	17.5	5.8
1976	-1.2	-1.3	7.0	1.0	1.5	2.818	106.0	3.2	1.0
1977	-0.8	-0.9	6.6	0.6	1.4	2.952	105.4	3.3	1.0
1978	-0.3	-0.3	6.2	0.2	1.2	3.098	105.3	3.3	1.0

*A permanent downward shift in money demand of 2% from 1976 is also assumed.

takes an unexpected jump of 68 percent in 1974 relative to its value in the base case. There is an additional but smaller surprise in 1975, so in that year the price of energy is 105 percent higher than in the base case. In all subsequent years the real price of energy is the same as in 1975. These figures were chosen to approximate the actual events of 1973-75 and are discussed in more detail below. Note that the increases are in addition to the projected increases of 7 and 5 percent respectively in each of the two years.

Monetary policy is assumed unchanged from the base case, but the simulation run underlying Table 3 assumes a permanent downward shift in money demand of 2 percent starting in 1976 in accordance with recent observations.[1] Net exports of goods are assumed to increase but only by a fraction of the transfer of income from the U.S. to foreigners following the oil price increase (cf. Table 1). Specifically, the sum of net exports of goods and government expenditures is assumed to follow its actual path for 1974-76 and to grow at a constant rate after that.

Overall Impact

The energy price shock generates a sizeable recession in the model. The energy price increase affects the economy via two principal channels. The first is a permanent lowering of the growth path of the economy as a result of labor-energy substitution. The higher energy prices induce more labor-intensive methods of production, but since the supply of labor is fixed in the long run, this can be done only by lowering output. The reduction in output carries with it an accelerator-effect on investment. Consumption is also affected since real income to domestic consumers is reduced by the amount of increase of the real value of energy imports. This effect is,

[1] Cf. Goldfeld (1976).

however, mitigated, first by the substitution away from energy, and secondly by the fact that some of the energy imports are financed by accumulating claims rather than export of goods. For the same reason, exports of goods is increased, but by less than the increase in energy imports. All these effects concern only the real part of the economy; the story told above is essentially a one-sector version of Hudson and Jorgenson's multisectoral studies,[1] except that our model does not assume that the labor market clears. More than half of the recession in the model seems explainable this way.

The other channel is related specifically to the financial sector of the economy. As wages are largely predetermined when the shock occurs, the sharp energy price increase causes a jump in the price level. Consequently, the transactions demand for money increases; stated equivalently, the real money supply declines, so that, in Keynesian terms, the LM-curve shifts to the left. The financial tightening drives up interest rates, thus discouraging investment. The resulting loss in real wealth depresses consumption as well. The fall in real money supply is furthermore increased by additional increases in the price level triggered by cost of living escalators in wage contracts, and by a permanent increase in the real interest rate of 0.35 percentage points.

The net result of all these forces and their interactions is an extraordinarily high inflation rate combined with a severe recession. For 1974, the model estimates that the total impact on real output was a reduction of 26 billion dollars, or about 2 percent. This is almost exactly the same amount as the reduction in consumption, whereas investment decreased by 7 billion and net exports of goods and government expenditure increased by the same amount. The effect on output is largest in the second and third

[1] Op. cit.

years after the shock, in 1975-76, when real output is down by 63 and 54 billion 1972 dollars, respectively. The bulk of this is decreased investment, especially in 1975; but the 3.3 percent permanent drop in consumption is sizeable enough. The fall in real output is accompanied by a decline in employment of 2 million workers in 1975 and a corresponding increase in the unemployment rate of 1.7 percentage points.

The predicted effect on the price level is substantial in the first two years. The monetary expansion implicit in the shift in money demand from 1976 maintains the effect and increases it slightly. In terms of rates of inflation, the effect is by far largest in 1974 with 4 percentage points added to the inflation rate. It tapers off thereafter and becomes slightly negative in 1977. The model offers a complete explanation of inflation in 1974, but cannot explain completely the continued high inflation in 1975 and the following years.

Comparing Table 3 with the lower panel of Table 1, the energy price shock appears to explain about two thirds of the recession in terms of decline in real output in 1974 and 1975, and practically all its shortfall thereafter. As will be shown below, however, a part of the remaining one third for the first two years can be explained as a decline in the demand for consumer durables, which is not treated explicitly by our model. This may increase the 1974-75 figures from two thirds to about four fifths. The magnitude of these ratios depend, however, crucially on how large the total recession is thought to be, in other words, what the base case should be like. Thus, our base case incorporates a 9 billion drop in investment from 1973-74. Also, the natural growth rate in our model is lower than the postwar average, but close to the average of the early seventies. We find it difficult to draw firm conclusions about the total magnitude of the recession. It seems clear, however, that the energy price shock was its largest single cause; and that, given the assumptions used here, very little of the behavior of real output is left unexplained.

Consumption

Consumption is determined by permanent income in our model. This, in turn, is affected mainly by three factors associated with the energy price increase. The largest, and perhaps most obvious effect comes from the transfer of income resulting from the increased value of energy imports. The magnitude of the transfer is reduced somewhat by substitution away from energy; but the 19 billion figure derived in section III may serve as a good approximation.

The second factor affecting permanent income is the recession itself. The decline in investment induced by the financial tightening represented a permanent loss of productive capacity and hence income. The third factor goes the other way and follows from the fact that oil-exporting countries accumulate part of their new wealth as claims on the U.S. economy rather than spending it. Since this accumulation is in fact saving, the productive capacity of the U.S. economy is increased, and hence permanent income.[1]

The simulated consumption path tracks actual consumption quite well. The exception occurs mainly in 1975, when actual decline was much larger; and a similar, but much smaller discrepancy is found for 1974. The main reason for this discrepancy is probably the failure of our model to account

[1] This result depends crucially on the assumption that oil exporters will not attempt to exchange their claims for U.S. goods in the foreseeable future. If this were expected, the model should have assumed a future increase in the net export of goods. This would have reduced permanent income for domestic consumers.

explicitly for the special behavior of expenditures for consumer durables.[1] As is well known, a decline in permanent income has an accelerator-like effect on the spending on durables. For the present drop in permanent income, the resulting one-time drop in spending can be estimated roughly as 15 billions. If it is assumed that one third of this took place in 1974 and the rest in 1975, the consumption level of 1974 is explained fully, and half of the gap is closed for 1975.[2] The authors hope to return to this issue in future work with the model.

Investment

Since investment demand is derived from the demand for capital as an input to production, the magnitude of the decline in investment in the model depends on the elasticity of substitution between capital and energy, which we have assumed to be practically zero. The drop in investment would have been larger with capital-energy complementarity and lower if the two inputs are substitutes in production. Although our choice of a zero elasticity is open for attack from both sides, it does give a good tracking of the actual investment data. We hope to investigate this aspect more carefully at a later stage.

Price Level

Our model indicates that the effect of the energy price shock on the

[1] The main reason why we did not include this in the model is technical. Adding consumer durables as a third asset in addition to money and capital would have added considerably to the complexity of the model because of its rational expectations property, so that the solution method presently used would have been highly inadequate.

[2] The discussion of this aspect in the literature (cf. Eckstein (1978), Perry (1975a), Okun (1975)) has concentrated on automobile sales, which dropped substantially in 1974. One has to be cautious, however, so as not to confuse income and substitution effects in automobile demand, since a good deal of the change that took place was from larger to smaller cars, and possibly from automobiles to other, less energy-intensive consumer goods.

general price level was quite substantial. In fact, it can be claimed that the extraordinary inflation in 1974 can be explained completely by this event and the removal of general price controls. Table 4 shows a decomposition of inflation in 1974 and 75. Out of the 11 percent inflation in 1974, the model attributes 2.8 percentage points, or about one fourth of the total, to the direct impact of higher energy prices. Another 0.7 percentage points are attributed to the permanent increase in the real cost of capital,[1] and a similar contribution comes from wage increases. The wage increase itself is a weighted average of the increase due to cost of living clauses and the decrease in the market-clearing wage. This decrease is somewhat lower than it would have been if the monetary expansion implicit in the shift in money demand had not been assumed.[2] Adding all these effects gives a total contribution to inflation of about 4 percentage points. Together with the effect of price decontrol and natural inflation in the model, this gives an inflation rate in 1974 that is very close to the observed increase in the consumer price index.

The 1975 inflationary experience is not so easily explained by our model. There was another direct impact of energy price increase about half as much as in 1974, and wages continued to increase somewhat in the model. There is, however, a gap of 2 percentage points of inflation for 1975 that we are unable to explain as a result of the energy price shock.

The impact on the price level depends of course crucially on the measurement of the energy price increase itself. It is worthwhile to consider this problem in a little more detail. The price of energy covers all forms of

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[1] We are aware that previous attempts to find an interest rate effect in the price equation have not been very successful (cf. section II above). Our price equation reflects this finding by excluding the current real interest rate and using a long-run average instead. Failure to include this long-run average would have produced a serious logical inconsistency in our model by forcing firms to run permanent deficits.

[2] On the other hand, this shift also gives a slight permanent reduction in the real interest rate, which tends to reduce the price level.

Table 4

Decomposition of Inflation 1974-75

	1974	1975
Total increase in inflation explained by the model	4.2	1.8
Direct impact of energy price increase	2.8	1.4
Effect via increased long-run cost of capital	0.7	0.0
Effect of wage changes	0.8	0.4
Cost of living increases	0.8	0.7
Reduction in equilibrium wage	-0.1	-0.3
Removal of price controls	2.0	0.0
"Natural" inflation	5.0	5.0
Total inflation of the CPI	11.0	9.1
Residual	-0.2	2.3

primary energy: crude oil (and imported petroleum products), natural gas, coal, and hydroelectric and nuclear power. The observed crude oil prices for this period were affected by the price equalization program. It has been argued, however, that this program was not fully effective in regulating the price of oil to final users because the prices of petroleum products are largely determined by the world market.[1] Rather than taking sides in this discussion, we looked at the published prices of petroleum products, calculated backwards what the increase in crude prices would have been to give the observed product price increase, and termed this the effective increase in crude oil prices. This was 110 percent from 1973 to 1974 and 16 percent the following year. For coal, the wholesale price index was assumed satisfactory, which gave 52 and 16 percent increases for the two years, respectively. Hydro and nuclear electricity were evaluated as the fossil fuel cost it replaces, and their prices were assumed to follow that of coal. The most serious problem existed for natural gas because the observed prices obviously did not clear the market in the relevant period. At this point we made the assumption that the effective price of gas followed that of crude oil. We then computed a preliminary energy price index as a Divisia index of the coal and oil prices. This gave an increase in the price of primary energy of 99 percent in 1974 and 16 percent in 1975. We recognize, however, that, because of regulations and controls, only a part of the 1974 increase reached the final users in that year. This is particularly true for fuel used for electricity and utility gas, because energy deliveries from utilities typically cannot be resold in the open market. Consequently, we assumed that the effective real increase in the price of energy in 1974 was only 80 percent of what our preliminary index indicated, but that our energy price level for 1975 was fully effective. This gave the energy price numbers in Table 3.

[1] Cf. C. Phelps and Smith (1977).

V. Comparison of Models

Table 5 presents the estimates of six different models of the impact of the energy price shock on inflation, aggregate output, investment, and consumption. For results other than our own in Table 3, the sources are Eckstein (1978) for the DRI model, Perry (1975b) for the FRB and University of Michigan models, Pierce and Enzler (1974) for the MPS model, and Fair (1978) for Fair's model. Making the estimates comparable offered some problems. First, inflation is measured by different indices in the various models. This is discussed further below. Secondly, the sector division of our model is somewhat different from the rest. We assume, though, that relative changes in GNP and gross output of our model are roughly comparable, and that the same is true for investment in the goods sector as against overall investment. Thirdly, since the models have different baseline projections, deviations for the real variables are presented as percentages of the actual levels. A special problem was encountered for the MPS model, which was simulated from 1967 rather than 1974. For this model, deviations for the real variables were computed in percent of the actual levels of 1967 etc., but presented as results for 1974 and the following years. Finally, different deflators had been used, resulting in real figures in 1958 and 1972 as well as 1973 dollars. Using the 1972 deflators of the three years, these were all converted to 1972 dollars.

Because of the different measures used, it is difficult to compare the estimates of the inflationary impact of the energy price increase. As discussed above in section II, the GNP deflator tends to give a lower estimate than measures of consumer prices, because imports are subtracted off in the construction of the GNP deflator. This difference becomes apparent in Eckstein's figures, who presents estimates for both the GNP deflator and the

Table 5

Effects of the energy price shock as estimated by various different models

Differentials in percent of actual levels.

	Eckstein DRI		Perry FRB	Perry Michigan	Pierce and Enzler[1] MPS	Fair	This Paper
Inflation	(GNP def.)	(CPI)	(GNP def.)	(GNP def.)	(Consumption price def.)	(GNP def.)	(Price of gross output)
1973	0.4	0.3	-	-	-	2.5	-
1974	1.6	2.5	1.3	1.8	2.6	8.3	4.2
1975	2.0	1.7	0.8	2.3	-0.0	4.5	1.8
1976	-	-	1.1	1.2	-0.4	-	0.3
1977	-	-	1.1	0.0	-0.8	-	-0.3
GNP/Gross Output							
1973		-0.4	-	-	-	-0.2	-
1974		-3.1	-2.0	-1.5	-1.1	-1.4	-2.1
1975		-5.2	-3.0	-4.0	-2.7	-5.3	-5.1
1976		-	-2.9	-5.0	-2.4[2]	-	-4.2
1977		-	-3.1	-4.4	-2.1[2]	-	-3.7
Investment:							
1973		1.0	-	-	-	-	-
1974		-7.2	-3.8	-2.3	-	-	-4.0
1975		-12.8	-7.4	-10.7	-	-	-38.2
1976		-	-3.8	-12.4	-	-	-17.5
1977		-	-2.7	-8.6	-	-	-12.8
Consumption:							
1973		-0.4	-	-	-	-	-
1974		-3.7	-2.6	-2.3	-1.9	-	-3.4
1975		-5.0	-3.7	-4.4	-4.4	-	-3.5
1976		-	-4.6	-5.6	-3.4	-	-3.4
1977		-	-5.1	-5.6	-3.1	-	-3.4

[1] Simulation actually starting in 1967.

[2] Figures for fourth quarters.

Consumer Price Index as well. Furthermore, Fair's estimate is based on a slightly different definition of the shock in that he compares actual inflation to predicted inflation with all import prices growing at 6 percent per year. However, even accounting for this difference, Fair's estimates seem unreasonably high, implying that import prices were responsible for three quarters of all inflation in 1974. Comparing our model to the remaining ones we find that, even after accounting for the conceptual differences, our estimate of the inflationary impact is substantially higher, whereas the other models agree fairly well among themselves.

Given the disagreement about the effect on inflation, the estimates of the real effects are remarkably close. All models predict a significant recession as a result of the energy price shock, but no model depicts this shock as its single cause. It may also be noted that the more recently published results, whose authors benefited from hindsight, indicate a deeper recession. Hopefully, this means that economists have learned some lessons over the past few years.

The real effect of the energy price shock is different in our model not so much in magnitude as in structure. With a slightly unconventional formulation of money demand[1] and a relatively high interest elasticity of investment demand, the drop in investment becomes the most significant feature of the recession in our model. Indeed, our model predicts a drop in investment for 1975 that is three times as large as in the DRI model and very close to what actually happened. The Michigan model has figures similar to the DRI model for investment, and the FRB model somewhat less. Pierce and Enzler do not report results for investment separately; but judging from the changes in

[1] Pierce and Enzler have a similar formulation but apparently did not get the same results.

consumption and GNP in their paper, the effect on investment cannot have been large. Fair does not report any results on GNP components.

All models predict significant effects on consumption.[1] It is interesting to note that models with more or less Keynesian consumption functions give results that are very similar to our permanent income formulation with rational expectations. It is clearly suggested by the numbers of Table 5 that the assessment of the real effects of energy price changes is quite robust with respect to many basic model assumptions.

[1]Eckstein's effect on consumption is based on comparison with unrevised actual figures published at an early date. If we compare with the revised figures, his numbers for consumption would decrease to -1.4 percent in both 1974 and 1975. This is the result of the fact that, from March to July 1976, actual growth in consumption for 1975 was revised upwards from 0.9 to 1.9 percent. As Eckstein pointed out to us in private conversation, this means that data revisions were almost as large as the effect of the energy price shock.

VI. Policies to Offset the Macroeconomic Impacts of the Energy Shock

The effects of the energy price shock on output, employment, and prices could have been altered by manipulation of macroeconomic policy instruments. For example, with monetary or fiscal expansion, the effects on output and employment could have been attenuated or even eliminated. Table 6 shows the results of two such policies, both aimed at stabilizing employment at around 6 percent in all years.

The two policies are expansion of the money supply and a government spending program. The monetary expansion alternative seems by far the most attractive of the two. It gives higher real growth and much lower inflationary response than the fiscal expansion. The necessary monetary expansion has a somewhat curious form: no extraordinary money growth is needed in the year of the shock, if an announcement is made that money supply will grow by an extra 2.4 percentage points the year after, 1.2 percentage points in the third year, and then return to its normal growth rate. The inflationary response of this policy is also somewhat surprising, in that inflation is predicted to go down rather than up in the year of the shock. The explanation for this is that monetary expansion lowers the real interest rate permanently and that this effect dominates the Phillips curve effect for this year. Obviously, this response is a conjecture and has not been inferred directly from the data.

Fiscal expansion can also stabilize the unemployment rate. However, a significant part of the employment effect in this case is a substitution effect as fiscal expansion increases the real interest rate substantially. Real growth suffers. Furthermore, the resulting inflation rates are forbidding. The same timing problem as above between the first and the

Table 6

Effect of Monetary and Fiscal Responses to the Energy Shock Aimed at Stabilizing Employment

	Rate of Money Growth			Extra Expenditures for Fiscal Response (billions of 1972 dollars)	Rate of Price Inflation				Rate of Growth of Output			
	Base	Energy shock	Energy shock & monetary response		Base	Energy shock	Energy shock & monetary response	Energy shock & fiscal response	Base	Energy shock	Energy shock & monetary response	Energy shock & fiscal response
1974	6.0	6.0	6.0	68	7.0	11.2	9.3	19.5	1.7	-0.3	1.8	0.7
1975	6.0	6.0	8.4	130	5.0	6,8	7.2	10.5	3.0	0.1	1.5	-0.5
1976	6.0	6.0	7.2	115	5.0	5.3	6.0	6.9	2.9	3.8	3.3	-0.2
1977	6.0	6.0	6.0	-	5.0	4.8	5.0	3.7	3.0	3.4	2.8	2.1
1978	6.0	6.0	6.0	-	5.0	5.0	5.0	5.0	2.9	3.4	3,0	3.4

second year occurs with the opposite sign, but this does not change the overall picture very much. Finally, there is a problem of how to carry out this policy. As a pure spending program it could be done as shown in Table 6, but it is clear that the amounts of extra spending needed are extremely large. In practice, tax cuts have been more popular among political decision makers; but there seems no simple answer to how an increase in spending equivalent to the one in Table 6 could have been obtained within a framework of permanent income consumption.

The other possible policy goal is of course to stabilize inflation. On the surface, monetary restraint seems the most obvious candidate for this purpose. However, although monetary policy is the perfect instrument for affecting the price level in the long run in our model, the short run is not so simple. It turns out that the monetary contraction needed to depress wages sufficiently in our model also pressures the real interest rate upward permanently, so that the negative effect on prices is offset. We were able to simulate a monetary response that brought inflation rates for the first two years back to their base case levels only by introducing a monetary expansion in the third year that would be even more extreme than the contraction needed in the first two. Although this did the trick of keeping down the real interest rate, we do not find this alternative credible for actual policy-making. Hence, we conclude that eliminating the energy-induced inflation in 1974-75 by monetary policy would not have been practically feasible.

Since fiscal policy has the opposite effect on interest rates, it seems more attractive for this purpose. Table 7 shows the results of such a simulation. However, the necessary policy response is unrealistically large; indeed, a near 35 percent surplus in the federal budget would have been needed in 1975. We conclude that any attempt to eliminate the increased inflation in this period completely would have been futile.

Table 7

Effect of a Response of Public Expenditure to the Energy Shock Aimed at Stabilizing Inflation

		Rate of price inflation			Rate of growth of output		
	Extra Expenditures (billions of 1972 dollars)	Base	Energy Shock	Energy shock and expenditure response	Base	Energy Shock	Energy shock and expenditure response
1974	-58	7.0	11.2	7.0	1.7	-0.3	-2.1
1975	-93	5.0	6.8	5.0	3.0	0.1	1.5
1976	-47	5.0	5.3	5.0	2.9	3.8	6.0
1977		5.0	4.8	5.1	3.0	3.4	4.0
1978		5.0	5.0	4.9	2.9	3.4	3.4

VII. Summary and Conclusions

We have constructed and simulated a relatively small macroeconomic model of the United States with energy. The important features of the model are a technology constraint with the three inputs capital, labor, and energy and with a flexible functional form; a money demand function with gross output as the transaction variable; a permanent income consumption function; rational expectations; and some important short run rigidities, notably in wage and price determination and in the investment process.

Large and unanticipated changes in the price of energy are found to have substantial disruptive effects on the economy. We have simulated the 1973-74 energy price increase and found the following effects: the rate of inflation was increased by four percentage points in 1974 and near two percentage points in 1975. Real output was decreased by 26 billion dollars (1972) in 1974, 63 billion in 1975, and around 50 billion in each of the following three years. For 1975, the relative decline was near 5 percent. The effect was found to have been largest for investment, but consumption decreased by a significant 3.3 percent in each year. The effects on employment can be expressed as an increase in the unemployment rate of near one percentage point in 1974, rising to 1.7 percentage points in 1974, and tapering off thereafter. The energy price shock was clearly a major cause of the 1974-75 recession and inflation. Other forces were present, however, such as the removal of the last price controls of the Economic Stabilization Program, and the slowdown of investment activity after the preceding miniboom. The collective effect of these and other possible factors seem, though, to have been substantially less than that of the energy price shock.

Our findings carry obvious implications for the expected effects of current events in the world market for oil. At the time of this writing it is not entirely clear how large the price increase is going to be and how much of it will be unanticipated. It seems likely that the oil price increase will be substantially smaller than in 1974; however, the aggregate cost share of energy is larger in the U.S. today than it was five years ago, which suggests a larger effect per percentage point of energy price increase. The authors plan to follow up the present paper with a study of these events.

Appendix: Technical Presentation of the Model

The model is a monetary growth model of a type similar to that of Sidrauski (1967), but with energy as a third factor, rigidities in the short run, and rational expectations. The static part of the model is made up of five markets:

- Input markets:
    - Labor
    - Capital
    - Energy
- The market for goods
- Money market

The money market and the market for energy clear in each period; the three other markets may or may not clear, depending on rigidities.

The rigidities are of three kinds. First, for the goods market, a standard unit cost pricing rule is assumed rather than marginal cost pricing in the short run. Secondly, only a fraction of the capital stock can be adjusted in the short run; and the adjustable part is assumed an imperfect substitute to the unadjustable part. Thirdly, wages are downward rigid.

The dynamic part of the model is made up by capital accumulation and permanent-income consumption on the one hand and by rational expectations price dynamics on the other. The latter is derived from the assumed equality of the real return to capital and the real interest rate.

Technology Model and Factor Markets

The technology constraint for the goods sector has the form of a unit cost function

$$\phi = \phi(e^{-\mu_1 t} w, P_E, P_K) \qquad (A.1)$$

w and P_K are aggregates to be defined below. ϕ is taken to have the following translog form:

$$\begin{aligned}\phi = a_0 &+ a_L(\ell n\ w - \mu_1 t) + a_K\ \ell n\ P_K + a_E\ \ell n\ P_E \\ &+ \frac{1}{2}\, b_{LL}(\ell n\ w - \mu_1 t)^2 + b_{LK}(\ell n\ w - \mu_1 t)\ell n\ P_K \\ &+ b_{LE}(\ell n\ w - \mu_1 t)\ell n\ P_E + \frac{1}{2}\, b_{KK}(\ell n\ P_K)^2 \\ &+ b_{KE}\ \ell n\ P_K\ \ell n\ P_E + \frac{1}{2}\, b_{EE}(\ell n\ P_E)^2\end{aligned}$$

where

$\mu_1 = 0.012$	$b_{LK} = 0.0$
$a_L = 0.6334$	$b_{LE} = -0.0150$
$a_K = 0.3233$	$b_{KK} = 0.0110$
$a_E = 0.0433$	$b_{KE} = -0.0110$
$b_{LL} = 0.0150$	$b_{EE} = 0.0260$

Cost shares and demand elasticities are variable. Computing cost shares for 1975 using base case and energy shock case prices, and taking means, the following values of cost shares and demand elasticities are obtained:

$S_L = 0.660$	$\varepsilon_{KE} = 0.002$
$S_K = 0.303$	$\varepsilon_{EL} = 0.264$
$S_E = 0.038$	$\varepsilon_{EK} = 0.012$
$\varepsilon_{LL} = -0.318$	$\varepsilon_{EE} = -0.276$
$\varepsilon_{LK} = 0.303$	$\sigma_{LK} = 1.0$
$\varepsilon_{LE} = 0.021$	$\sigma_{LE} = 0.400$
$\varepsilon_{KL} = 0.660$	$\sigma_{KE} = 0.041$
$\varepsilon_{KK} = -0.661$	

Factor demand under cost minimization is determined by Shephard's lemma:

$$x_i^D = \frac{\partial\phi}{\partial P_i}, \quad i = L, K, E$$

The supply of energy is assumed to be infinitely elastic at the exogenously given price. Rigidities in the investment process are modeled in the following way. There are m categories of capital; the quantity of category j is determined j - 1 years in advance. The various categories enter symmetrically in the technology model but are imperfect substitutes, or else all investment would be concentrated in the category with the shortest lead time. A simple Cobb-Douglas form is chosen for the capital submodel:

$$K = K_1^{1/m} \ldots K_m^{1/m} \quad (m = 4) \tag{A.3}$$

In the year of the shock, the quantities of the m - 1 last categories are predetermined; by symmetry, they all have the level $\overline{K}_1$, whereas the first category has the level $\hat{K}_1$. The year after, m - 2 categories have the level $\overline{K}_2$ and two have $\hat{K}_2$, etc. Defining b_t as the fraction of categories having their level determined by post-shock conditions ("flexible" capital), (A.3) can be replaced by

$$K_t = \hat{K}_t^{b_t} \, \overline{K}_t^{1-b_t} \tag{A.4}$$

The aggregate price of capital is determined by the dual of this function, i.e.,

$$P_{Kt} = \hat{P}_{Kt}^{b_t} \, \overline{P}_{Kt}^{1-b_t} \tag{A.5}$$

The quantity of flexible capital is determined by the demand equation

$$\hat{K}_t = (P_{Kt}/\hat{P}_{Kt}) \ \phi_K(e^{-\mu_1 t} w_t, P_{Et}, P_{Kt})Y_t \qquad (A.6)$$

where Y_t is output.

Since the quantity $\overline{K}_t$ ("rigid" capital) is predetermined, its price is determined by the equation

$$\overline{K}_t = (P_{Kt}/\overline{P}_{Kt}) \ \phi_K(e^{-\mu_1 t} w_t, P_{Et}, P_{Kt})Y_t \qquad (A.7)$$

Investment in rigid capital is derived simply from capital accumulation:

$$\overline{I}_t = \overline{K}_t - (1 - \delta)\overline{K}_{t-1} \quad (\delta = 0.1) \qquad (A.8)$$

The average amount of flexible capital in the absence of any investment is

$$[b_{t-1} \hat{K}_{t-1} + (b_t - b_{t-1})\overline{K}_{t-1}]/b_t$$

where the second term comes from the last category that just became flexible. Thus,

$$\hat{I}_t = \hat{K}_t - (1 - \delta)[\frac{b_{t-1}}{b_t} \hat{K}_{t-1} + \frac{b_t - b_{t-1}}{b_t} \overline{K}_{t-1}] \qquad (A.9)$$

and total investment is

$$I_t = b_t \hat{I}_t + (1 - b_t)\overline{I}_t \qquad (A.10)$$

Wage rigidity is modeled analogously except that here it is price, not quantity, that is predetermined. A similar subfunction is postulated,

$$L = L_1^{1/n} \ . \ . \ . \ L_n^{1/n} \quad (n = 6) \qquad (A.11)$$

Wages are thought of as determined by contracts. All contracts last n years, and contracts are renegotiated by one category each year. Wages are negotiated so as to clear the market in expectation. The market-clearing wage renegotiated after the shock is denoted $\hat{w}_t$, and full employment is given as the exogenously given natural level of employment $\hat{L}_t$.

Contracts negotiated before the shock set a starting wage level of $\overline{w}_t$ to be paid in the absence of unanticipated inflation. If unanticipated inflation occurs, a cost of living adjustment is made of the form

$$w_t^* = (1 + \gamma D_t)\overline{w}_t, \ \gamma = 0.5, \tag{A.12}$$

where

$$D_t = \begin{cases} (P_t - \overline{P}_t)/\overline{P}_t \text{ in the year of the shock, and} \\ (1/2)(P_t - \overline{P}_t)/\overline{P}_t + (1/2)(P_{t-1} - \overline{P}_{t-1})/\overline{P}_{t-1} \text{ thereafter.} \end{cases}$$

$\overline{P}_t$ is the expected price level, specified as the base case forecast. Thus, defining f_t as the fraction of categories with wages renegotiated after the shock, the average wage per worker is

$$w_t^0 = \hat{w}_t^{f_t} \, w_t^{*1-f_t} \;{}^1 \tag{A.13}$$

The efficiency wage over the cycle differs from w_t^0 because of cyclical fluctuations in labor productivity. This component of productivity is approximated by the following formulation. Consider the market for a category of labor whose contract has not been renegotiated. Disequilibrium in this market can be measured by the relative difference between the actual and the market-clearing wage, i.e., by the ratio

$$w_t^*/\hat{w}_t$$

The tightness in the labor market as a whole depends also on how many categories have had their wages renegotiated. The following measure is proposed:

$$(w_t^*/\hat{w}_t)^{1-f_t}.$$

[1] This formula and (A.11) should not be thought of as strictly technological relationships, but rather as a convenient way of modeling wage rigidity.

Thus, the average wage rate per efficiency unit is defined as

$$w_t = w_t^0(w_t^*/\hat{w}_t)^{h(1-f_t)}, \quad h = 0.8 \tag{A.14}$$

This is the wage rate that enters in the factor demand equations, whereas w_t^0 is used in the price equation (cf. below).

This gives the following demand functions for labor.

$$\hat{L}_t = e^{-\mu_1 t}(w_t^0/\hat{w}_t)\phi_L(e^{-\mu_1 t}\ w_t,\ P_{Et},\ P_{Kt})Y_t \tag{A.15}$$

$$\overline{L}_t = e^{-\mu_1 t}(w_t^0/w_t^*)\phi_L(e^{-\mu_1 t}\ w_t,\ P_{Et},\ P_{Kt})Y_t \tag{A.16}$$

and total employment is

$$L_t = f_t\hat{L}_t + (1 - f_t)\overline{L}_t \tag{A.17}$$

Clearly, when $f_t < 1$, the labor market will clear only if $w^* = \hat{w}_t$.

The Goods Market

The demand for goods consists of consumption, investment, net exports of goods, and government expenditures. The latter two are considered exogenous, and investment demand is discussed above. Consumption follows the permanent income hypothesis. This is modeled as

$$C_t = C_0e^{gt},$$

where g = 0.029 is the sum of the rate of growth of the labor force and the rate of labor productivity growth. C_0 is determined endogenously as described below.

Goods are produced by capital, labor, and energy subject to the production possibility constraint (A.1). After a shock occurs, some categories of capital have predetermined levels so that the firms' marginal cost schedule is upward sloping in the short run. Rather than treating this as the supply schedule for goods, however, the model specifies a standard unit cost pricing rule and assumes that firms passively supply any amount of goods demanded at that price. The pricing rule takes the form of the price equation

$$(1 - \tau)P = \phi(e^{-\mu_1 t}w^0, P_E, P\bar{v}), \quad \tau = 0.065 \qquad (A.18)$$

where $\bar{v}$ is a long-run average of the real rental price of capital, P is the price of goods, and τ a tax parameter accounting for indirect taxes. ϕ is the same function as in (A.1), but its first and third arguments are w^0 and $P\bar{v}$ rather than w and P_K. Since P_K is a market-clearing price for a (partially) fixed factor, it fluctuates procyclically whereas $P\bar{v}$ does not. Thus, there is no demand effect in the price equation.

The Market for Money

The financial sector of the economy is compressed into one equation of our model, namely the money demand equation. Its form is

$$\ell n(PY/M) = \psi_0 + \psi_1 r + \mu_2 t, \quad \psi_1 = 2.0, \; \mu_2 = 0.019 \qquad (A.19)$$

Money supply, M, is thought of as supplied exogenously by the monetary authority and, in the absence of specific policy actions, to grow at a constant exponential rate. Money and capital are considered perfect substitutes so that arbitrage gives

$$r_t = v_t/(1 - d_t) - \delta - \theta + \ell n((1 - d_{t+1})P_{t+1}) - \ell n((1 - d_t)P_t), \quad d_t = 0.036 \text{ (all t)}; \; \theta = 0.13 \qquad (A.20)$$

Here $v_t = \hat{P}_{Kt}/P_t$ is the real rental price of capital, d_t is the investment tax credit, and θ is the rate of tax on capital as a fraction of its value.

Compact Mathematical Statement of the Model

Capital Accumulation:

$$\hat{K}_t = \hat{I}_t + (1 - \delta)[(b_{t-1}/b_t)\hat{K}_{t-1} + ((b_t - b_{t-1})/b_t)\overline{K}_{t-1}], \quad (M.1)$$

$$\overline{K}_t = \overline{I}_t + (1 - \delta)\overline{K}_{t-1} \quad (M.2)$$

Demand for Capital:

$$\hat{K}_t = (P_{Kt}/\hat{P}_{Kt})\ \phi_K(e^{-\mu_1 t}\ w_t,\ P_{Et},\ P_{Kt})Y_t \quad (M.3)$$

$$\overline{K}_t = (P_{Kt}/\overline{P}_{Kt})\ \phi_K(e^{-\mu_1 t}\ w_t,\ P_{Et},\ P_{Kt})Y_t \quad (M.4)$$

$$P_{Kt} = \hat{P}_{Kt}^{\ b_t}\ \overline{P}_{Kt}^{\ 1-b_t} \quad (M.5)$$

Demand for Labor:

$$\hat{L}_t = (w_t/\hat{w}_t)e^{-\mu_1 t}\ \phi_L(e^{-\mu_1 t}\ w_t,\ P_{Et},\ P_{Kt})Y_t, \quad (M.6)$$

$$\overline{L}_t = (w_t/w_t^*)\ e^{-\mu_1 t}\ \phi_L(e^{-\mu_1 t}\ w_t,\ P_{Et},\ P_{Kt})Y_t \quad (M.7)$$

$$w_t^0 = \hat{w}_t^{\ f_t}\ w_t^{*\ 1-f_t} \quad (M.8)$$

$$w_t = w_t^0(w_t^*/\hat{w}_t)^{h(1-f_t)} \quad (M.9)$$

$$w_t^* = [1 + \gamma(\frac{1}{2}\ \frac{P_t - \overline{P}_t}{\overline{P}_t} + \frac{1}{2}\ \frac{P_{t-1} - \overline{P}_{t-1}}{\overline{P}_{t-1}}\ )]\overline{w}_t \quad (M.10)$$

Supply of Labor:

$$\hat{L}_t = \hat{L}_0 e^{nt}\ , \quad n = 0.017 \quad (M.11)$$

Demand for Energy:

$$E_t = \phi_E(e^{-\mu_1 t}\ w_t,\ P_{Et},\ P_{Kt})Y_t \quad (M.12)$$

Supply of Energy:

P_{Et} exogenous (M.13)

Consumption Function:

$$C_t = C_0 e^{gt}\ ,\ g = n + \mu_1,\ C_0 \text{ chosen so as to attain steady state for real economy in the long run} \quad \text{(M.14)}$$

Distribution of Output in goods market:

$$Y_t = C_t + b_t \hat{I}_t + (1 - b_t)\bar{I}_t + X_t + G_t \quad \text{(M.15)}$$

X_t, G_t exogenous

Price Equation:

$$(1 - \tau)P_t = \phi(e^{-\mu_I t}\, w_t^o,\ P_{Et},\ P\bar{v}), \quad \text{(M.16)}$$

$\bar{v}$ long run average of P_{Kt}/P_t

Money Market Equilibrium:

$$\ell n(P_t Y_t/M_t) = \psi_0 + \psi_1 t_t + \mu_2 t,\quad M_t = M_0 e^{mt},\ m = 0.058 \quad \text{(M.17)}$$

Equality of Nominal Return to Capital and Nominal Interest Rate:

$$r_t = v_t/(1 - d_t) - \delta - \theta + \ell n((1 - d_{t+1})P_{t+1}) - \ell n((1 - d_t)P_t),$$

$$v_t = \hat{P}_{Kt}/P_t \quad \text{(M.18)}$$

Dynamic Solution of the Model

The solution algorithm assumes initial guesses for the initial levels of consumption and price level and for the long run average of the real cost of capital $\overline{v}$, The initial level of $\overline{K}$ is given historically. The model can then be solved period by period, and (M.1), (M.2), (M.14) and (M.18) give the dynamic links between periods.

Since it turns out that the roots of this system are unstable, the solution based on initial guesses will give a finite path of price level and capital stock only by chance. The model therefore searches over several values of initial price and consumption levels until it finds a pair that gives a finite solution. This process limits the initial price level to a very tight interval and determines the permanent income level of consumption. A final set of iterations makes the value of $\overline{v}$ consistent with the steady-state value of v.

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