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A Simulation Of The Energy Crisis And Economic Development

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Introduction

The sudden termination of the period of cheap and abundant oil and natural gas in late 1973 has caused severe difficulties in most of the less-developed countries. The most critical problem has been acquiring the additional foreign exchange necessary to purchase the oil imports that are so critical for maintaining economic growth and development. Most LDC's have few exploitable energy resources and consequently depend totally on this imported oil. In response to this problem, the macroeconomic simulation model presented here has been developed to investigate various policy measures that might be attempted to code with this foreign exchange shortage. For the purpose of this paper, the model is calibrated to a hypothetical but representative developing country.

Overview Of The Model

The economy of a nation can be described as a system of interrelated processes such as production, investment, and factor allocation. In modeling the economy, these processes can be represented by submodels linked together with a system of resource and information flows that parallels the corresponding pattern of interrelationships between processes in the economy. The advantage of such a model is its easy adjustability for changes in the assumptions of one or more of its internal processes. That is, the required modifications normally can be made within the corresponding submodel (s) without altering the rest of the system. This makes the model useful in the study of a broad range of problems and allows substantial flexibility in exploring the implications of alternative policies and assumptions.

Moreover, the model differs from conventional develepoment models

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by considering multiple factors of production rather than the single factor of capital as in the Harrod–Domar approach; and the overall perspective is provided by a disaggregated cohort survival demographic submodel in connection with an exponential production function of the Cobb-Douglas type.

The model consists of eleven closely linked submodels. The first and most central is the Cobb-Douglas production function, which describes the level of output of an economy that can be achieved with a particular set of technical retationships and specified inputs. The second, a resource allocation or market mechanism, determines the size and composition of the inputs flowing to production function. The third submodel fixes the supply of capital, the fourth determines the level and type of technology and socioeconomic organization in the economy, and the fifth represents the supply of land and other fixed resources. The policy decision submodel is the sixth, and the seventh is by the labor submodel, the heart of which is a Markov process that specifies the maximum possible supply of each type of labor that will be available for allocation to production. Submodel eight determines the amount of energy demanded by the economy (postulated to follow closely changes in GNP) to maintain its level of production. Submodel nine concerns external demand for foreign exchange generating exports of the developing country, and the tenth submodel, that of foreign exchange,determines the actual rate of expenditure of foreign exchange for oil imports. Finally, the intersectoral resource mobility submodel follows shifts in the economy's productive factors to produce additional foreign exchange to purchase oil imports during an oil-price-generated foreign exchange crisis.[1]

Model Operation

Briefly, the entire economy operates on a 15-year planning cycle with policy decisions taken only at the start of the period. The overall system is driven by its demographic model. On the basis of a set of

1. This presentation of the theoritical model and its operation is considerably abridged due to space limitations and a desire to attract a broad audience. Consequently, no equations or their explanations appear in the text. The interested technically oriented reader is directed to David J. Edelman, **The Energy Crisis and the Development Prospects of Low-Income Gountries: A Macroeconomic Simulation,** (Ithaca, Cornell Dissertations in Planning, January 1978).

of policy decisions, the model calculates the expected demographic situation of the nation in 15 years. It then compares that situation to the one at the beginning of the planning period and calculates the annual rates of change for each subgroup of the population Equipped with this annualized information, the model then moves through an iterative process of calculating all the relevant variables for each year from the beginning to the end of the 15 year planning cycle. At the end of the cycle, policy decisions are again read in, and the model undergoes the entire process again. The model provides for four consecutive policy periods.

Within each cycle, the intersectoral resource mobility submodel operates after receiving certain information in sequence. Model operation follows reality in that current action is based on information generated in the previous year. Gross Sectoral and Gross National Products are determined in the production function, and equilibrium levels of demand for the factors of production of the economy as a whole are computed in the market submodel. Then, the capital supply submodel determines investment and hence the capital employed in the economy. Next, the foreign exchange submodel develops the amount of foreign exchange necessary to purchase the required quantity of energy imports as specified by the energy demand submodel to maintain the level of production. However, if the requisite foreign exchange does not accrue to the economy in the external demand submodel, the intersectoral resource mobility submodel is activated.

Intersectoral movement of the factors of production is considered to depend on their marginal productivities. Those factors that are considered to be mobile are capital and high-and low-productivity labor. The marginal productivities are determined in the production function. The factor with the highest marginal productivity is sonsidered the leading factor of the shift. For example, if the marginal productivity of capital is greater than that of high-and low-prductivity labor, a unity of capital will shift and will be accompanied by the shifts in high-and low-productivity labor necessary to support the increase in output initiated by the additional unit of capital. The relative magnitude of such shifts is easily computed because of the properties in a Cobb-Douglas production function.

Policy Analysis

Two types of policy analysis may be attempted with this simulation model of a developing economy. The first explores the long term (60 years) implications of pursuing alternative investment policies in health, education, capital and energy efficient technology; the second considers the immediate policy decisions necessary to cope with the short term foreign exchange shortage caused by the sharp increases in the world market price of oil.

London-Term Investment Analysis

The purpose here is to determine whether the emerging economy can become more energy efficient without undergoing a fundamental change in its structure or in its anticipated growth path of production and development. Consequently, the two policies of continuing the government's current investment practices and of cocentrating on developing and implementing a more energy efficient technology are discussed below

Policy Comparison

The results of comparing policies are striking. They suggest that a government committed to energy efficiency can conserve both oil and the foreign exchange needed to buy it while simultaneously improving the quality of life of its citizens and accelerating the development process. Although this analysis is marginal because it assumes no basic change in either the strategy of development or the mode or production, the results suggest that even the governments of the least flexible LDC's can retard the growth oil imports (relative to the growth of production). Through thoughtful policy-making, they could conserve crucial foreign exchange for other uses (such as purchasing more oil and capital equipment to expand domestic production) while the wholly new energy technologies that will eventually replace oil and natural gas are developed, tested, and installed.

As even a glance at the following tables will reveal, the policy emphasizing energy efficiency performs as well as or better than the policy maintaining the status quo on almost all indicators of development Of the **annual indicators** (see Table 1), the interest rate, the high-productivity unemployment rate, and the capital formation rate show no differences due to the pursuit of a policy of enrgy efficiency. They vary over time in precisely the same way as under the policy of maintaining current investments. There are several reasons for this. First, the high-productivity unemployment rate remains zero under a policy of energy efficiency because the demand for productive factors in the economy (other than oil) is in no way diminished. While the same level of production can be attained under a policy of energy efficiency despite using less oil, the same level of other factors of production must be maintained. Full employment of skilled labor continues. Similarly, the interest rate and the capital formation rate are the same under both policies because both depend on the level of production, which does not vary. However, if production were to change (rise or fall) under energy efficiency, both rates would be influenced and would rise or fall accordingly.

TABLE 1.

Summary of the long term policy comparison between maintaining the status quo and emphasizing energy efficincy—annual indicators

	1988	2003	2018	2033
GNP per capita				
Status quo	217.13	284.45	383.75	577.07
Energy efficiency	217.17	284.58	384.29	527.76
Interest rate				
Status quo	.1462	.1479	.1485	.1483
Energy efficiency	.1462	.1480	.1485	.1483
High productivity wage rate				
Status quo	1,377.06	1,620.73	1,923.17	2,311.84
Energy efficiency	1,377.19	1,621.26	1,924.29	2,313.84
High productivity unemployment rate				
Status quo	0.0	0.0	0.0	0.0
Energy efficicency	0.0	0.0	0.0	0.0
Low productivity unemployment rate				
Status quo	.2234	.1788	.1269	.0659
Energy efficiency	.2233	.1787	.1266	.0655
Capital formation rate				
Status quo	.0809	.0823	.0827	.0823
Energy efficiency	.0809	.0823	.0827	.0823
Energy imports (barrels)				
Status quo	5,807,075	10,014,206	17,865,690	32,049,993
Energy efficiency	5,749,183	9,727,332	17,406,383	31,270,953

On the other hand, both high-and low-productivity wage rates as well as GNP per capita rise while the low-pıoductivity unemployment rate falls. These phenomena demonstrate possible direct finanacial benefits to labor due to a policy of energy efficiency. Through reductions in energy expenditures, government and industry are able to raise wages somewhat, while employing more unskilled and semiskilled labor. Hence, when these changes are coupled with a declining birth rate (see Table 2), GNP per capita also rises. These developments improve the living standard of labor and simultaneously reap savings in foreign exchange for goverment and industry.

The magnitude of benefits to government and industry is illustrated by the decline of the final indicator-energy imports. **Total** GNP is the same under both investment strategies, whereas oil imports are somewhat lower under the policy of energy efficiency, which releases critical foreign exchange for additional investments. Energy imports (relative to the policy emphasizing the status quo) are reduced by 36,228 barrels in 1974, the first year of energy efficiency, and by 250,092 barrels in 1988, they continue to decline until 2033 when they are reduced by 752,606 barrels. Thus, by 2033 the annual saving in foreign exchange are $ 1,505,212 under the old market price of $ 2 per barrel, or $ 7,526,060 under the new (post-Octoder 1973) price of $ 10 per barrel.

The demographic and social indicators (see Table 2) remain virtually unchanged when an investment policy program emphasizing an energy-efficient technology is substituted for one emphasizing the status quo, although under the former they exhibit a slightly improved overall performance by 2033. This is likely to be related to the rising income and decreasing unemployment noted above. It is well established in the literature that a declining birth rate and improved health and education levels are related to increasing per capita income. The very modest and late improvements here probably reflect the rather slight rise in per capita GNP noted above. Nevertheless, the suggestion is that energy efficiency, by releasing financial resources for other purposes, does not harm and probably aids in promoting the social well-being of the population.

The resource supplies situation (see Table 3) is also better overall under energy efficiency than under the status quo. By 2004 the supplies of labour and capital are somewhat greater under energy efficiency, whereas the levels of foreign exchange reserves and export sales are both somewhat lower. The implications here are important. It appears that under a policy of energy efficiency, domestic production can be expanded relative to export production. If sustained, such a change is a critical indicator of development. The higher levels of labor and domestic capital show that additional purchases of oil and capital equipment from abroad to expand domestic output are justified in terms of the available supply of required domestic resources. Furthermore, the decline in the levels of exports (by $824,779 in 2004 and $915,571 in 2019) and foreign exchange reserves (by $288,042 in 2004 and $622 in 2019) is kept to a moderate level by the savings in foreign exchange to reduced oil imports. Energy savings in 2004 and 2019 amount of 286,872 barrels $573,748 at the $2 per barrel market price) and 409,307 barrels ($918,614 at the $2 price), respectively. Consequently, a large part of the increased foreign exchange expenditures for inputs to domestic production is derived from the foreign exchange savings due to the policy of energy efficiency.

In addition, Table 1 and 2 demonstrate that domestic demand is higher under energy efficiency than under the status quo. Increased per capita income, higher wages to both labor productivity types, reduced low-productivity unemployment, and higher levels of health and education in the population all contribute to rising demand within an expanding domestic market.

TABLE 2

Summary of the long term policy comparison between maintaining the status quo and emphasizing energy efficiency-demographic and social indicators

	1988	2003	2018	2033
Birth rate (per 1,000)				
Status quo	37.43	36.05	33.94	32.53
Energy efficiency	37.43	36.05	33.94	32.52
Death rate (per 1,000)				
Status quo	10.14	9.78	9.31	8.96
Energy efficiency	10.14	9.78	9.31	8.96
Population growth rate (%)				
Status quo	2.73	2.63	2.46	2.36
Energy efficiency	2.73	2.63	2.46	2.36
% of population well educated				
Status quo	4.091	4.601	5.350	6.279
Energy efficiency	4.091	4.601	5.351	6.281
% of population in good health				
Status quo	64.583	67.163	70.328	73.894
Energy efficiency	64.583	67.164	70.333	73.904

Finally, it should be recognized that most of the differences that result from pursuing a policy of energy efficiency rather than one of maintaining the status quo are rather small in absolute terms. Although these seem more significant when marginal changes are emphasized, it is clear that there are real limitations on the effectiveness of policy. Nevertheless, it appears that the governments of energy-poor LDC's have some capacity to conserve oil through policies that seek to make production technologies more energy efficient without at the same time curtailing economic growth and development. Rather, the opposite seems to be the case. Improvements in the economy and the population's standard of living are likely to accompany an energy efficiency program.

TABLE 3

Summary of the long term policy comparison between maintaining the status quo and emphasizing energy efficiency-resource supply

	1974	1989	2004	2019
Capital supply				
Status quo	492,852,042	910,567,262	1,747,687,303	3,393,708,692
Energy efficiency	492,852,042	910,630,705	1,748,234,095	3,396,012,132
Low productivity labor supply				
Status quo	407,251	644,431	996,013	1,518,925
Energy efficiency	407,251	644,444	996,077	1,519,089
High productivity labor supply				
Status quo	39,741	67,424	113,013	190,756
Energy efficiency	39,741	67,424	113,016	190,778
Foreign exchange reserve ($)				
Status quo	20,386,137	35,260,465	68,916,783	113,555,130
Energy efficiency	20,386,137	35,261,600	68,628,741	112,932,522
Exports ($)				
Status qno	27,606,726	49,051,972	106,047,296	160.598,500
Energy efficiency	27,606,726	49,053,788	105,222,517	159,682,929

Short-Term Analysis of the Foreign Exchange Implications of the Energy Crisis

This type of analysis considers the immediate policy alternatives that the government of a developing country might consider as a means of coping with its short-term foreign exchange shortage due to the sharply increased world market price of oil. In late 1973 and early 1974, the Organization of Petroleum Exporting Countries (OPEC) increased the average price of a barrel of oil by a factor of five. This change is accomplished in the model by raising the world oil market price from $2.00 per barrel to $10.00 per barrel after 1973. The result is a foreign exchange shortfall for imported oil $16,401, 756. In other words, to maintain production in the economy and prevent a decline in GNP, more than $16 million must be acquired to purchase essential oil.

Although foreign exchange reserves total just over $20 million dollars, spending more than 80% of reserves for this purpose would destory the country's credit rating and leave it dangerously unprotected in the event of any other crisis. An attempt to acquire the entire sum through foreign aid alone is inconceivable due to the similar plight of many other LDC's and the serious problems facing the donor countries themselves. They are unlikely to be free with their aid without the support of the developing countries.

There are seven policy alternatives that this hypothetical developing country might consider to alleviate its foreign exchange problem. These alternatives are: (1) cutbacks in energy use; (2) mild austerity; (3) moderate austerity; (4) moderate austerity plus cutbacks in energy use; (5) severe austerity plus cutbacks in energy use; (6) moderate austerity, additional foreign exchange controls, plus a comprehensive foreign aid package; and (7) moderate austerity and comprehensive foreign aid package. The following paragraphs explore the possibilities of employing these policy alternatives:

Policy 1: Cutbacks in Energy Use

The computer printout of the results of the price rise in oil shows not only a foreign exchange shortage oil of $16,401,756 but also the message "skilled labor shortage." This indicates that the intersectoral movement of resources in the economy that might produce more foreign exchange through increased production in the export sectors has already reached its limit due to a shortage of high-productivity labor. Thus, mere shifting of resources is ineffectual in coping with the crisis and the government must consider more drastic policy measures.

The first of these is simply to reduce energy consumption and hence energy imports. Yet even a policy with a 20% reduction in energy use for domestic sectors of the economy and a 10% reduction for export sectors (relatively drastic cuts) is unable to alleviate the foreign exchange problem. In fact, the shortage is merely reduced to $10,452,990 while new and potentially explosive social and economic problems are created.

First, the minimum oil requirements that must be met to maintain over all production in the economy are not attained. Only 3,088,902 of the 3,580,466 barrels required are actually imported. Domestic production is affected more acutely because cuts are greater in the domestic than the export sectors. Moreover, with a more labor-intensive technology than the export sectors, unemployment in the domestic sectors is liable to become serious with the layoffs that must inevitably accompany reduced production. Finally, with increased unemployment local purchasing power will also decline and the country could face a period of recession and social unrest. Clearly, such a policy is undesirable.

Policy 2: Mild Austerity

The second policy alternative is to embark on a program of mild austerity, which in this case refers to an 8% reduction in all imports other than oil. This is accomplished by instituting stronger import controls to stem the outflow of foreign exchange. The computer output shows such a policy to be virtually ineffectual; the foreign exchange shortage for oil is reduced only slightly to $14,537,919.

Policy 3: Moderate Austerity

In this alternative, an attempt is made to stiffen austerity somewhat. This action has almost no further effect on the economy's foreign exchange problem, and the shortage is reduced further by only a few thousand dollars to $14,483,657. Thus, austerity measures alone seem rather weak.

Policy 4: Moderate Austerity Plus Cutbacks in Energy Use

With austerity by itself so ineffectual, a policy that combines reductions in energy consumption (Policy 1) with it might be thought to be an improvement over either alone. The computer printout indicates that this is true; however, fully 50% of the foreign exchange shortage for oil is still not covered and all the aforementioned social and economic problems associated with energy cutbacks remain.

Policy 5: Severe Austerity Plus Cutbacks in Energy Use

A government that is truly desperate and is tightly in control of its people through repressive means might consider this Draconian policy. In this senario, imports other than oil are curtailed by 15% in addition to the energy cuts outlined previously. Yet the shortage of foreign exchange remains; it is merely reduced to $7,044,859.

The crucial lesson to be learned from the analysis of the first five policies is that energy poor developing countries cannot cope unassisted with the short-run foreign exchange problems of higher energy prices. Even a policy of severe austerity and reductions in energy consumption (with its accociated production and economic development setbacks) is insufficient, despite the fact that at this point the poorest countries would be reducing imports of such essentials as food and fertilizer. Consequently, a number of policies incorporating foreign aid elements must be considered. The two that are discussed below are both capable of eliminating the hypothetical country oil-related foreign exchange shortage in 1974.

Policy 6: Moderate Austerity, Additional Foreign Exchange Controls and Comprehensive Foreign Aid Package

The policy cuts imports other than oil by 8% and imposes a tax on the repatriation of profits of 10%. The foreign aid elements include a suspension of interest payments on foreign debts, a 25% reduction in the repayment of the principal due on loans (perhaps by extending the repayment period), a 20% increase in foreign investment, and a 25% increase in new foreign aid grants and loans.

The drawback of this policy is that it may be rather difficult to attract new foreign investment at a time of worldwide economic gloom while instituting new limitations on profits. The government of the LDC might point out that the new investment to be allowed is greater than would be the case without the tax; nevertheless, the potential investors could prefer to invest in another, more attractive LDC, or they could choose not to expand investment at all under conditions of uncertainty.

Policy 7: Moderate Austerity Comprehensive Foreign Aid Package

This policy may represent a more attractive alternative to the donar nation (s). The 8% import reduction, the 25% reduction on repayment of the principal on loans outstanding, and the waiving of interest of these loans are all retained as elements of Policy 7. However, the tax on repatriated profits is eliminated, the amount of new foreign investment is reduced from a 20% increase to a 15% increase, and new foreign aid grants and loans are increased by 30% rather than 25%. This increases the burden of foreign aid borne by the industrial countries and the international lending institutions they dominate (and also, to a limited extent, by the newly rich, sparsely populated Arab states). Although the amount of new foreign investment allowed is reduced, the new figure may be a more realistic one. At any rate, by eliminating the new tax on repatriated profits, the LDC's investment climate is likely to appear far more attractive to international firms.

Final Note

Looking beyond the conclusions of the above analysis, the fundamental significance of the study is methodological. With the growing awareness of the complex nature of developments problems and of the desirability of planning to deal with them in a more comprehensive manner, there is an increasing need for models that help both planners and policy-makers to comprehend the nature of the system with which they are faced. The microeconomic simulation model to this study is designed to help meet this need in the areas of energy policy. The flexibility of its system dynamics structure allows it to be adapted to various assumptions. It can be used to anticipate the dynamic impact of a proposed development program or to explore the trade--offs among a number of alternative programs.. It can also be used to investigate the quantitative implications of some untested assertions in the literature of development Many of these qualitative arguments can now be studied systematically and quantiatively within the frame of reference of general equilibrium theory. The model, then, has both policy and research applications and is potentially useful for government agencies, multinational institutions, universities, and other research organizations.