MODELING FUEL PRICING POLICY AND CONSUMPTION PATTERNS

by

M.T. Tabucanon, K. Saeed and Q. Suhail
Division of Industrial Engineering and Management
Asian Institute of Technology
P.O. Box 2754, Bangkok 10501, Thailand

Abstract. This paper examines the domestic energy consumption in Pakistan in the backdrop of the government's pricing policies using a system dynamics model as an explanatory tool. In the context of policy analysis, the simulated behavior of the system are tested based on various pricing schemes of the competing fuels. The simulation experiments reveal, among others, that Pakistan's energy system structure is such that any policy involving government control over the prices will eventually result in an increase in burden on family income of rural and urban poor classes mainly and urban middle class partially. It seems that the only way to redistribute the burden on family income, minimize the burden on national economy, and also achieve conservation of fuels, is by allowing the price of fuels to be determined by the supply-demand conditions of the market.

I INTRODUCTION

In energy planning and policy making it is imperative to understand the underlying causes and effects of future demands for energy, prices of competing fuels, supply of various energy sources, and even opportunities for conservation, among other things. Any comprehensive analysis of the energy sector of a country must clearly comprehend this complex interacting network. There are times when planning and policy making focus on a subsector of the energy system, but yet this telescopic view cannot be clearly visualized without also considering the interrelated forces that drive the energy system as a whole.

The case in question in this paper is the residential sector of Pakistan as a consumer of energy for cooking purposes. There are two broad classes of fuels being consumed by the households: (1) Regulated fuels whose prices are controlled by the government. These include kerosene, natural gas, LPG, and electricity. (2) Nonregulated fuels whose prices are not controlled by the government. These include firewood and coal. There is also a third "fall back" category consisting of rice husk, baggasse, cowdung, etc., which do not have a commercial value but only require family labor for collection and consolidation. These have not been included in the analysis.

Tables 1 & 2 show current family expenditure on fuel and the types of fuels used in each social class. It can be observed that, in terms of average cost per family per year, coal and firewood are the most costly fuels followed by kerosene, electricity, LPG, and natural gas, in that order (Ahmed, 1980). Also, the higher cost fuels are being used by the lower income groups while higher income groups consume cheaper fuels. It seems that cost of fuels have little or no influence at all on their consumption. This also suggests that there may be other strong factors which influence the patterns of consumption observed. This paper attempts to identify such factors and evaluate the government's fuel pricing policies keeping these in view.

TABLE 1. Household Energy Burden

User Population	Number	Percent (%)	% Income Spent on Fuel
Urban Rich	152,827	1.2	1
Rural Rich	117,435	0.9	1.5
Urban Middle Class	977,398	7.8	3
Urban Poor	2,423,946	19.3	11
Rural Poor	8,916,040	70.8	11
Total	12,587,648	100%	

TABLE 2. Household Fuel Use: Percent of Population in Social Class

Fuel / User	Urban Rich	Rural Rich	Urban Middle	Urban Poor	Rural Poor
Wood	0.79	77.36	32.24	69.95	74.04
Cowdung	0.05	4.27	1.83	9.91	20.15
Other Noncommercial	0.03	1.3	.93	1.25	4.59
Kerosene	1.07	12.7	54.76	16.12	0.76
Coal	0.46	1.27	2.60	1.04	0.28
Electricity	0.09	0.62	0.32	0.13	0.12
Natural Gas	97.51	2.48	7.32	1.7	0.06

II MODEL DEVELOPMENT

The purpose of the model developed here is, firstly, to gain a general understanding of the causes and consequences of the problem of high cost fuels being used by lower income groups, and vice versa; and, secondly, to suggest some policy prescriptions to alleviate this problem.

The pertinent variables lying inside the system boundary are as follows:

1. Supply/production, prices, and inventories capacities of the six fuels under consideration - firewood, coal, kerosene, electricity, LPG, and natural gas.

2. Consumer population of different fuels and different income groups - rural poor, urban poor, urban middle, rural rich, and urban rich.

3. Consumption per household of different fuels by different income groups.

Fig. 1 illustrates the causal structure of the fuel production, consumption, and pricing system. An increase in price of fuel above its shadow price will increase the production of that fuel by increasing the supply capacity. The opposite is true in the case of a decrease in price below the shadow price. For the nonregulated fuels, the shadow price is the actual market price. For regulated fuels, however, it represents the price that would have been attained had the fuel been left open to determine its own price according to the supply-demand conditions of the market. Apart from price, the supply capacity is negatively affected by the inventory

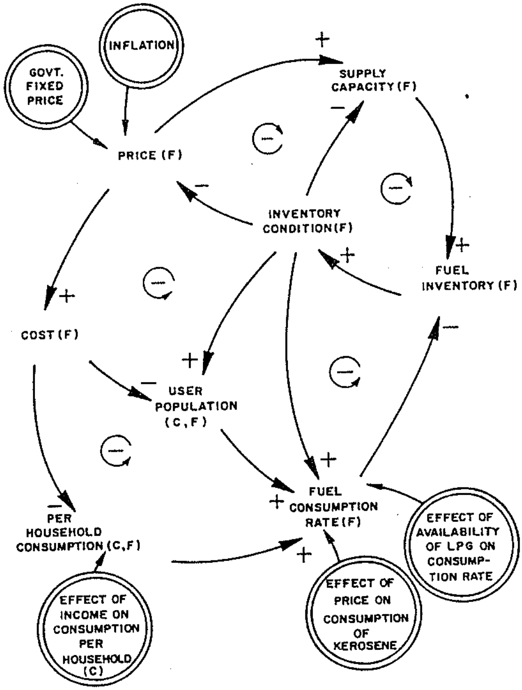

Fig. 1 Causal Structure of Fuel Consumption, Supply and Pricing System (Endogenous and Exogenous Inputs)

condition. Even if the prices may be equal to the shadow prices, the producers will be compelled to increase their supply capacities if the inventories are undesirably low. The increase in supply capacity is however restricted by the supply constraints, and the time required for this increase varies according to the fuel type. Fuel inventory is positively affected by supply capacity. An increasing fuel capacity builds up fuel inventory, which in turn depresses prices. These negative feedback loops regulate production, although capacity expansion takes considerable time.

The variable termed as "inventory condition" is the indicator of the level of inventory compared with a desirable level. The price of fuel is negatively related to its inventory condition, whereas the user population for this fuel is positively influenced by its inventory condition. As such, when the inventory of fuel is less than desired, on one hand, it goes to decrease the user population which shifts its consumption to other types of fuel in view of the nonavailability of the first fuel. On the other hand, the price of that fuel goes up. The increased price of this fuel again diverts some consumers to other fuels. The shifting time, of course, is different for various income groups and depends on their individual ability to acquire the necessary equipment suitable for the fuel adopted for use. Thus, the rich can shift to a different fuel quite fast while the poor may take considerable time. The decrease in consumer population reduces the rate of consumption of a fuel, which further builds up its inventory and reduces its price.

The aforementioned feedback loops affecting consumer population (one through price and the other through inventory condition) appear to dominate in determining the behavior of the system. The most immediate effect of the increase in prices of fuels is a decrease in consumption per household; but various income classes are affected differently.

A decrease in supply restricts fuel consumption rate due to the nonavailability of fuel to consumers. This builds up inventory and restores supply. This feedback loop, however, remains inactive as long as supply is equal to or more than demand.

The growth in user population constantly disturbs the system and is a catalyst in activating interactions among various variables in the system.

The key limiting assumptions in the model are that the fraction growth rate in population is 3 per cent per year (Federal Bureau of Statistics, 1979 & Pakistan Government Report, 1983), that no change in the proportion of income groups occurs over the period of analysis, that consumers use only one fuel for cooking, and that income of households is exogenously determined.

The effect of cost on user population is modeled as a nonlinear function of the ratio of cost of a specific fuel to the average cost of all fuels (see Figs. 2 & 3). It is assumed that the rural poor and urban poor classes behave relatively slower as regards shifting to other fuels. For these classes, one type of nonlinear function is used (Fig. 2). When the cost is equal to the average cost, there is no effect of cost on the user. When the fuel cost exceeds or falls below the average cost, population changes occur. The rate of these changes varies asymptotically as the difference between the two costs increases. This occurs because of physical limitations to change and because of the psychological experience gained in coping with abnormal prices. For urban middle, rural rich, and urban rich groups, the function illustrated in Fig. 3 is used. Compared to the poor classes, the more affluent classes have faster and more pronounced fuel switching behavior.

It is assumed that the effect of inventory condition on user population is similar for rural poor, urban poor, and urban middle classes (Fig. 4). At zero inventory condition, the user population is zero. When the inventory condition is 1, the 'months of inventory' is equal to the desired 'months of inventory', and there is no effect of inventory on user population. When the inventory condition is above or below 1, fuel switching is rather fast. For the rural rich and urban rich groups, the fuel switching pattern is rather slow (Fig. 5). This behavior could be attributable to the fact that the more affluent population are less affected by shortages of fuel; they, through their contacts, are able to procure their desired fuel.

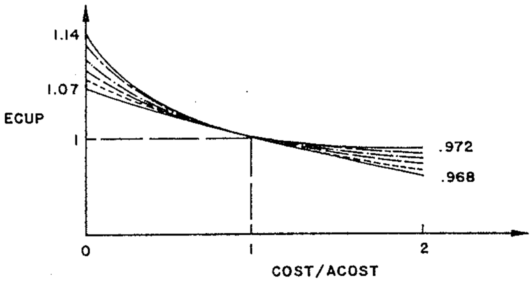

Fig. 2 Effect of Cost on User Population (ECUP): rural poor, urban poor class

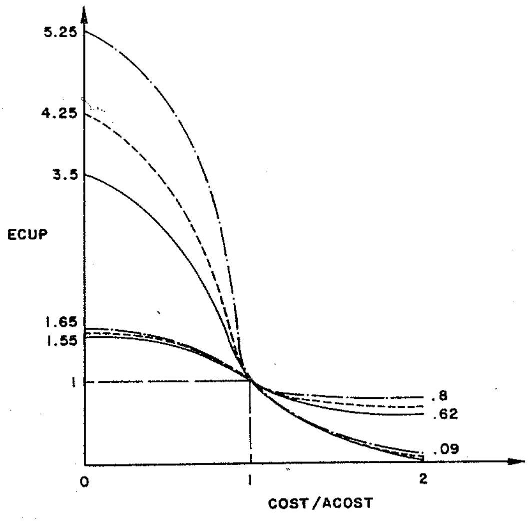

Fig. 3 Effect of Cost on User Population (ECUP): rural rich, urban rich & urban middle class

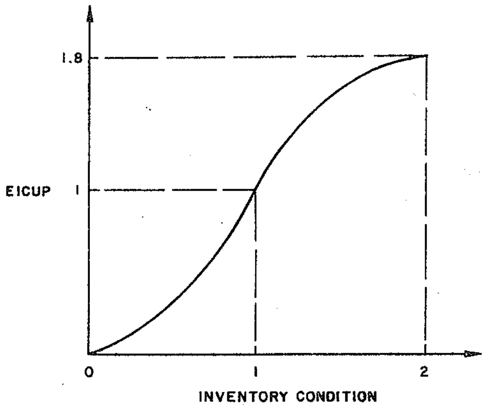

Figure 4 Effect of Inventory Condition on User Population (EICUP) : rural poor, urban poor & urban middle class

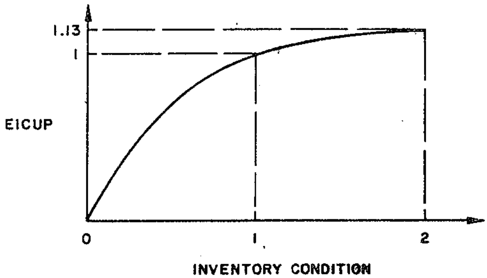

Figure 5 Effect of Inventory Condition on User Population (EICUP) : rural rich & urban rich class

The effect of cost on consumption per household is modeled as a nonlinear function of the ratio of cost of a specific fuel to the average cost of all fuels. It is assumed that the consumption of the poorer classes is quite elastic to costs while that of richer classes is relatively inelastic (Figs. 6 & 7).

The effect of income on fuel consumption per household is modeled as a nonlinear function of the ratio of actual income of household over the "normal" income of the urban or rural category whichever the user belongs to. As far as "normal" income is concerned, the concept of "poverty line" as used by various international agencies, is introduced. According to this concept, there exists a certain level of income sufficient to meet the basic needs of individuals and allows about 10 per cent monthly savings. This level of income can be defined on a

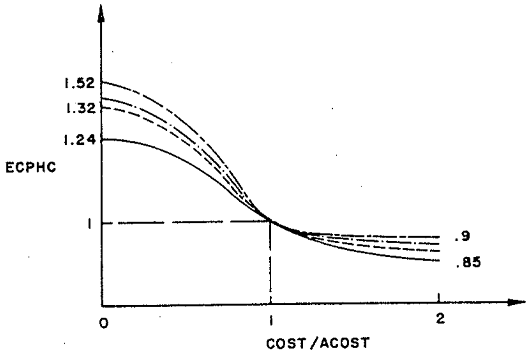

Figure 6 Effect of Cost on Per Household Consumption (ECPHC) : rural poor , urban poor & urban middle class

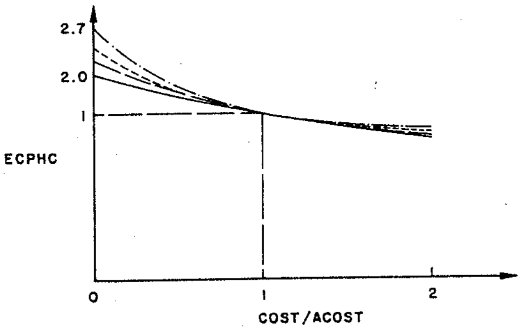

Figure 7 Effect of Cost on Per Household Consumption (ECPHC): rural rich & urban rich class

spatial/sectoral basis. Since urban and rural sectors of Pakistan vary significantly according to their energy requirements and needs, a distinction is made between these two sectors with respect to the so-called normal income. These are derived from the historical time series data of the various sectoral groups. As depicted in Figs. 8 & 9, the poor and middle income groups are relatively more sensitive to income and vary their consumption accordingly quite fast. The rich groups are relatively less sensitive to changing income due to the fact that the consumption of fuels by these groups represents only a small percentage of their income (see Table 1). Further details of the model are given in Suhail (1983). A machine readable listing of the model can be obtained from the authors on request.

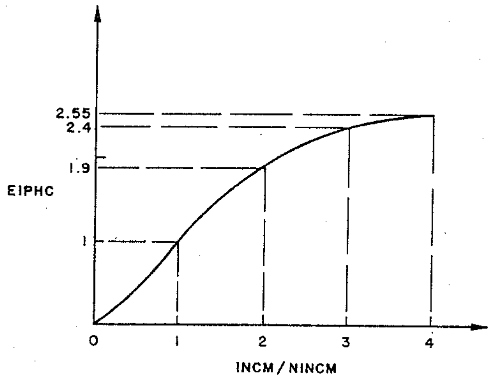

Figure 8 Effect of Income on Per Household Consumption (EIPHC) : rural poor, urban poor & Urban middle class

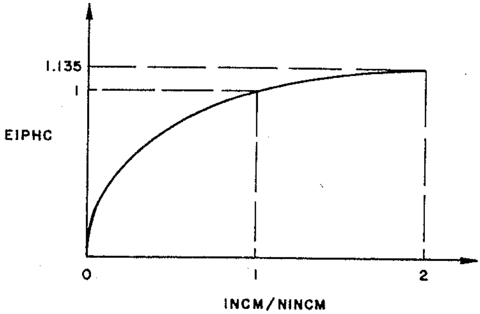

Figure 9 Effect of Income on Per Household Consumption (EIPHC) : rural rich & urban rich class

III SIMULATION RUNS

The computer simulations are focussed on achieving a valid correspondence between the model structure, its simulated behavior and the empirical observation portrayed in the reference mode, as well as on testing the robustness of the model in the light of exogenous policy interventions. The following set of simulation experiments are performed for model validation:

(1) The first experiment is aimed at generating the historical behavior of fuel consumption patterns in response to the different pricing policies launched over a certain period of time. The model results when observed in the light of the historical evidence seem to have close resemblance with past reality - which creates some degree of confidence in the model.

(2) In the second experiment, a 'step' change in the 'per household consumption' of all the fuels is made, and the resulting model behavior is analyzed to see whether the decision rules contained in the information structure of the model give a logical and reasonable explanation of the sequence of events which follow thereon. The model behavior in response to this set of excitations is undoubtedly in accordance with the empirical evidence gathered according to which, at new equilibrium the following conditions can be observed: (a) Regulated fuels have low inventory (or low availability and low price); (b) Nonregulated fuels have comparatively higher inventories and higher price; (c) Richer groups are more concentrated towards lower cost regulated fuels and hence the burden on these groups, as a whole, is further decreased; and (d) The poor groups are concentrated towards higher cost nonregulated fuels and hence burden on these groups is further increased. The results of these experiments further enhance confidence in the model.

(3) The third set of simulation experiments is conducted to check the parameter sensitivity of the model. The slopes of the various nonlinear relationships are varied; some model constants changed; and the resultant model behavior analyzed to see if there are any differences in the newly generated system's behavior. Consequently, the behavior of the model is found to be quite similar to the behavior outlined in the reference mode. The model is therefore quite parameter-insensitive.

After having tested the model for validity of its system structure, it is then used to formulate general suggestions towards improvement of the existing system. Among the policy questions considered in the simulation are increases in prices of various fuels, improvement of efficiency of firewood stoves in particular, and deregulation of fuel prices. These policies and their respective effects on user populations are summarized in Table 3.

When the price of natural gas is set to be the highest, the burden on the family income of the poorer groups increases since they are pushed out of using current relatively cheaper fuels by the richer groups who substitute gas consumption with these. The richer groups are affected only slightly and momentarily. There is no significant decrease in the burden on national income. The consumption rates of firewood and electricity increase quite fast and this behavior is undesirable. There is a temporary decrease in the consumption rate of natural gas but after about two years of the policy's introduction it starts to gain ground once again. The overall behavior of the system seems to indicate that this particular policy is not attractive.

The policy of setting the price of kerosene to be the highest does not appear reasonable either. The outcome is that the burden on family income of the poorer groups increases; the rural rich are affected very slightly; and the urban rich are not affected at all. The burden on the national income is somewhat more as compared to the corresponding effect of the natural gas price escalation policy. The consumption rates of firewood, electricity, and natural gas are also increased.

TABLE 3. Policy Effects on User Populations

Policy	Outcomes
Increase Price of Natural Gas	- Consumption of kerosene rises - Poor groups crowded out to use more expensive fuels - Gas becomes price leader - Fuel burden of all groups increases - National burden rises - Rapid increase in consumption of wood and electricity
Increase Price of Kerosene	- Middle income groups worst hit - Consumption of wood rises, capacities of other fuels being limited - Poor groups shift to more expensive fuels whose prices rise further - Burden of poorer groups rises - Burden of national income slightly higher
Increase Price of Electricity	- Similar to increasing price of gas but weaker effect
Increase Price of all Clean Fuels	- Similar to increasing price of gas but stronger effect
Improve Efficiency of Firewood Stoves	- Positive effect in the beginning but after firewood reserves are devastated, all burdens rise
Deregulation of Fuel Prices	- Prices of convenient but cheap fuels rise - Rich have higher burden - Consumption per household is restricted - Coal consumption rises - Burden on firewood decreases - Cumulative burden on national income lower - Kerosene use fluctuates

The effect of the policy of setting the price of electricity to be the highest is similar to that of the natural gas price escalation policy. In magnitude, however, this effect is much smaller because the population consuming electricity for cooking purposes is also very small.

The model when subjected to the policy of setting prices of clean fuels (LPG, natural gas, and electricity) to be the highest, displays an effect similar to, albeit stronger than, that of the policy of increasing the price of natural gas.

On the whole, the situation appears to be more attractive when the system is subjected to the policy of improving the efficiency of firewood stoves. It leads to a considerable reduction in the burden on family income of the poorer classes. The rate of increase of burden on the urban middle class is also reduced. The burden on national income in terms of foreign exchange is lowered considerably. The increase in consumption rate of electricity and natural gas is also checked. All of the aforementioned positive effects are, however, only temporary since after firewood reserves are devastated (in about five years), all burdens rise again.

Finally, the policy of deregulating fuel prices seems to be the most attractive of all policies considered. It leads to a better distribution of burden on family incomes of the various social classes. Prices of fuels previously used by lower income groups do not increase, whereas prices of fuels used by richer groups which were substantially lower previously, increase. The burden on national income is among the lowest for all policies tested. With the increase in prices of natural gas and electricity, the richer groups who are the major users of these fuels, are bound to conserve these fuels unlike previous practises. With this policy, the pressure on regulated fuels increases (although accompanied by a decrease in consumption per household), and the pressure on firewood is somewhat relieved. Furthermore, unlike other policies, the demand for coal increases. This is undoubtedly a healthy sign since it would result in substitution of coal for other fuels having severe capacity constraints. Coal reserves, as widely known, are in abundance.

IV CONCLUSIONS

The simulation experiments are significant for some particular results. Firstly, the model generates a behavior that is qualitatively similar to the real world observations. This behavior results from the internal feedback structure of the model and the integration process incorporated in it. Secondly, the validity of the model seems to be justifiable as the model not only appears to be insensitive to any parametric changes, but also is able to give a logical and reasonable explanation of external disturbances applied to it.

The analyses of the simulated behavior shows that the structure of the domestic energy system of Pakistan is such that any policy involving government control over the prices will eventually result in an increase in burden on family income of rural and urban poor classes. It seems that the only way to redistribute the burden on family income of various population groups, minimize the burden on the national economy, and also achieve conservation of fuels (all except, perhaps, coal) is by allowing the price of fuels to be determined by the demand-supply conditions of the market. Some nonprice-related policies tested include increased efficiency of stoves and increased supply capacity of LPG, both of which are found to be effective only in the short-run while they devastate supplies of these fuels in the long-run.

REFERENCES

Ahmed, I. (1980). Conservation Plan in the Domestic Sector. Proceedings of the National Symposium on Energy Conservatione. Islamabad, Pakistan, February.

Federal Bureau of Statistics (1983). 1979 Household Income and Expenditure Survey. Karachi, Pakistan.

Forrester, J.W. (1977). Two Views on Validation of System Dynamics Models. D-2690, SDG, MIT.

Planning and Development Division (1983). Report on Energy Pricing and Policy. Government of Pakistan, Islamabad.

Suhail, Q. (1983). Fuel Pricing Policy and Consumption Patterns in the Residential Sector of Pakistan: The Case of Cooking Fuels. Master's Thesis, IE-83-4. Asian Institute of Technology, Bangkok, Thailand.