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MODELLING ENERGY-ECONOMY INTERACTIONS IN SMALL DEVELOPING COUNTRIES: A CASE STUDY OF SRI LANKA*

by

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I. Introduction

In this paper, we report on the results of a research project addressed at modelling energy-economy interactions in small developing countries.[1] The overall objectives of the research were to learn more about how energy-economy interactions can be usefully modelled for policy purposes, to compare the pros and cons of alternative methods which have been used previously, and to test the feasibility of utilizing simple general equilibrium models by constructing an illustrative model for Sri Lanka. The focus of the project was largely on methodology.

Most previous studies of energy demand in developing countries have used partial equilibrium methods.[2] That is, energy demands are projected on the basis of exogenously forecast sectoral or macroeconomic growth, with or without sensitivity to variations in energy prices. The problem with this approach is that for many developing countries, the level of energy demand and the associated costs of meeting these demands is likely to have a significant impact on the macroeconomic variables and sectoral growth, which have been projected independently of the energy situation. It is this feedback of energy costs and demands on the rest of the economy--including aggregate growth, the balance of payments situation, and the sectoral pattern of growth--that we have in mind when referring to "energy-economy" interactions.

These interactions probably are more significant for developing than developed countries because the former are more dependent on imported oil than most OECD countries, and financially they they are in a weaker position to cushion any oil price shocks. At the same time, their economies are changing at a more rapid rate, generally characterized by increased industrial production and urbanization, both of which tend to be energy-intensive.

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[1] This project was sponsored by the Office of Energy of the Agency for International Development.

[2] For example, see Choe (1978), Dunkerley (1982), and Wolf et al. (1981).

As described in the next section, there are several methods available for modelling these kinds of two-way feedbacks. The alternatives vary with respect to: data requirements, the economic or policy issues which are given special attention, and the economic behavior underlying the models. Which method is "best" depends in large measure on the scope and intensity of the energy-economy interactions. More complicated methods would be appropriate for, say Mexico, with its large petroleum and industrial sectors, than for say Kenya, even if they had similar data bases.

Here, we are specifically concerned with the smaller, less industrialized developing countries. We refer to countries with populations less than 20 million or so and where neither the industrial or energy sectors are dominant. This set would include a number of countries in South and East Asia, sub-Saharan Africa, and the island economies. In designing an appropriate methodology, we also have tried to take into account typical data limitations and the limitations on the amount of real resources (manpower, computer costs, etc.) available to undertake this type of policy modelling.

After reviewing various alternative, we reached several general conclusions about what types of models are most appropriate. For the type of country we have in mind, the model should be focused specifically on the key energy-economy interactions, rather than address all interesting macroeconomic and planning issues. In most situations, we would recommend using rather simple general equilibrium models for this purpose. These have a number of advantages. They embody the interdependence among the sectors and between the foreign trade situation and macroeconomic variables. Their structure not only insures full multisectoral consistency, but builds in conventional microeconomic behavior by private consumers and producers.

A multisectoral approach, even if only a small number of sectors are distinguished, is extremely useful as a way of capturing the sensitivity of energy demand growth to structural change and the sensitivity of structural change to changes in the energy situation. The models should allow for the feedback of energy prices on the household consumption and production demands for energy. This, too, is something for which general equilibrium models are well-suited.

Although it would be, in principle, desirable to have a model which determines the optimal or efficient level and composition of investment, that is too ambitious for most countries. On the other hand, an energy-economy model should be capable of making at least medium term projections. This is important because many of the adjustments to changes in energy costs or energy supply policy occur with quite long lags.

We have used Sri Lanka as a test case to illustrate how such a model can be built rather quickly in a situation with severe data limitations. The Sri Lanka model was constructed in less than a month, and initially tested and implemented during a visit of only several weeks to Colombo in the summer of 1984. The data come from existing sources (mainly from the Statistical Office, the Central Bank, and the Energy Ministry), supplemented by some minimal econometric estimation. The model has nine sectors (including three energy sectors), eleven goods and services, two consuming groups, and a partial set of government flow accounts. It was designed to run on a personal computer.

The next section summarizes our review of alternative methods for investigating energy-economy interactions. Six general approaches are discussed and then compared. This section also contains a discussion of the use of simple general equilibrium models in small countries. Section III

presents the formulation of the specific model for Sri Lanka. Here we emphasize the reasons why certain aspects of the economy where given more attention and others less. Section IV is a discussion of the initial results of the model. In additional to a Base case, we explore some of the implications of possible changes in world or domestic oil prices. Finally, there is a brief concluding section.

II. Assessment of Alternative Approaches to Energy Policy Models

A survey undertaken by this project of alternative energy policy methodologies, "Models of Energy-Economy Interactions for Developing Countries: A Survey," by Sunwoong Kim revealed a number of different approaches.[3] These reflect the different countries and problems for which they were intended as well as the different analytical techniques which were applied. As experience with the analysis of energy-economic issues has expanded, a better realization of the essential nature of the issues has been achieved and more powerful tools have been developed. To some extent, early methods have been superseded, but some remain useful in particular circumstances. As an introduction to the presentation of the model developed for Sri Lanka, alternative methodologies for energy-economy policy analysis will be examined, relying on the survey by Kim, in order to place in context the approach which was adopted in this project for Sri Lanka.

In this section, we first review alternative methodologies for energy policy modelling, then provide a brief appraisal of their usefulness, and close with a discussion the use of simple general equilibrium model for small, less industrialized developing countries.

Project Evaluation

In some ways the most basic policy problem is that of deciding whether to devote resources to a particular energy project. The standard way of dealing with this is a project evaluation and standard programs are available to do this.[4] There are several drawbacks to the standard programs. They do not deal with the difficult, but often central, problems of determining the correct shadow prices, including the shadow discount rate, which will

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[3] See Kim (1984).
[4] Project models such as Envest are discussed in Kim (1984).

correctly evaluate the real social costs of the resources to be used and the outputs. This is because the methods are essentially myopic with respect to the rest of the economy, with respect to intertemporal decisions and concentrate only on the particular project. Another aspect of the myopia is that the calculations do not take into account the overall riskiness of the "portfolio" of projects in the energy area and the evaluation is carried out independently of other projects which may be under consideration.[5] To become more useful, the project evaluation techniques must include a methodology for estimating shadow prices, which is an undertaking of a different type.

Technology Assessment

Technology assessment or energy sector optimization is another modelling approach. It starts from a given energy demand forecast, whose origins are not of concern to the model itself, and finds the "optimum" mix of energy energy projects which will satisfy these demands. The criterion function which is minimized is usually total cost in the entire energy sector, and only in the energy sector. The technological possibilities are represented by linear functions in some cases as if there were no committed capital equipment in place. This type of model allocates resources and makes technological choices as if starting from a clean slate, which must obviously overstate the potential rearrangements which are desirable, as well as the desirability of some new projects. Since most such models use the "energy reference system" developed in the Brookhaven National Laboratory, there is some questions as to the currency and relevance to particular developing countries of the technologies and associated costs.[6]

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[5] For examples related to oil exploration, see Blitzer, Cavoulacos, Lessard, and Paddock (1983).

[6] See Kydes, Cherniavsky, and Babinowitz (1976).

Energy Sector Assessments

Many energy sector assessments are carried out which do not rely on an explicit modelling analysis. The studies typically include detailed investigations of particular features of the energy producing sectors and particular areas of demand as well as analyses of policy approaches to specific problems. They often contain insightful information which, however, will be at different levels of detail. The pattern of development ascribed to the economy being studied is typically based on some other sources. The implicit or explicit demand and supply elasticities which are employed in these reports are also usually taken from other sources for the particular country or the report may rely on estimates made for another country which is assumed to be similar.

The World Bank, the U.S. Agency for International Development and other international and national agencies frequently commission such studies. Groups of experts with previous country and energy sector experience are assembled for the purpose.

This approach typically suffers from three types of deficiencies. First, it will not be comprehensive. It is frequently true, for example, that energy demands and supplies in the agricultural sector are not investigated, although the characteristics of the "traditional" energy sectors, may be studied. Secondly, the analyses and recommendations of the various parts of the report will not necessarily be consistent. That is because, there is no overall framework which is imposed on each sector and on demand and supply conditions, and, thus, there is no way of insuring consistency. Finally, and, perhaps, as an aspect of the former point, this type of study cannot take into account the interactions between the energy sector and the rest of the economy. As a result, the studies cannot reveal the full effects on either

the energy sector or the rest of the economy of changes which might be proposed or might take place.

Macro Simulation Models

This category covers several different types of models which have in common the feature that they cover the entire economy and generate forecasts of aggregate variables as well as energy sector variables. The models will typically distinguish from a few to a substantial number of sectors and may embody a set of input-output coefficients for estimation of intermediate demands. There will, as well, be a set of macroeconomic relations which generate the projections of the aggregate variables.

It would appear that this methodology might solve the problem of achieving consistent energy-economy interactions. This is not the case because the causal relations between the energy sectors and the economy as a whole go in only one direction in the calculations for a particular period. Aggregate economic variables are used to calculate energy demands. Energy supplies and prices also will be calculated, or will be assumed. These results will be used in projecting aggregate aggregate variables in a subsequent period.

The dynamic relations embodied in such models are typically relatively simple with each period's economic activity building on the period before and affecting only the next period. There is no foresight and the intertemporal interactions are highly simplified.

There are, however, many differences among the models of this general type. In some cases, the energy sector is treated in a sophisticated manner being represented by an optimizing process intended to reflect the outcome of myopic, but otherwise perfect market processes or skilled planning.[7] There is

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[7] Examples include Blitzer (1985), Hill (1983), Hoffman and Jarass (1982), Modiano (1983), Mukherjee and Rahman (1982).

also a danger of instability in such models, if the sectoral balance equations for several sectors, such as the investment supplying sectors or the energy supplying sectors take the form of difference equations.

Economy-Wide Optimization Models

Models of this type achieve the goal of embodying the mutual interactions between the energy sectors and the rest of the economy instead of having only one way causal relations. They also avoid the instability properties of multisector difference equations models and find a unique solution which is optimal in terms of the criterion function which is being maximized or minimized.[8] There will be one or more energy producing sectors and the energy demands for consumption and production purposes will be described separately.

These models typically cover a number of time periods. They also have an number of sectors, one or more of which is an energy producing sector, which respond to the demands on them for intermediate and final products. The intermediate demands are nearly always determined by an input-output matrix with fixed coefficients, although in a recent model these fixed energy coefficients are replaced with a set of alternative input requirements.[9] The demands for personal consumption by sector may be determined simply as shares of total consumption which is being maximized or, in a much more satisfactory manner, by their contribution to total utility which is maximized. The latter method makes it possible to introduce explicitly the energy demand functions of consumers.[10]

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[8] For a comprehensive discussion of early examples of such models see Blitzer, Clark, and Taylor (1975). More recent models of this type include Blitzer and Eckaus (1983) and Tourinho (1985).
[9] See Blitzer and Eckaus (1983).
[10] For examples of alternative ways this can be done, see Goreux (1975), Blitzer and Eckaus (1983), and Tourinho (1985).

Government and export demands are usually specified exogenously, though the latter can be determined endogenously in response to export demand functions. Investment demands are determined by the maximization process but consistently with specified inputs requirements for the components of capital. As was done in a recent model, it is possible to specify alternative capital, energy, labor input activities, one of which is chosen in each period for whatever new investment is carried out in each sector. Imports by sector type can also be determined by simple fixed coefficient relations to output, or considered as a residual supply or deduced as part of the maximizing process which finds the "cheapest" way of producing the output desired, consistent with the constraints imposed. Internationally traded energy imports can be handled in this manner, with non-traded energy inputs, which cannot move in international trade being generated by domestic production.

The constraints embodied in such models are the usual sectoral balance and foreign exchange balance conditions as well as the production conditions which, for investment, determine the time required to produce new investment goods. There may be other constraints which relate, for example, the cost of foreign borrowing to the amount of borrowing and the rate of drawdown of oil reserves to the rate of exploitation of the reserves. It is possible to approximate non-linear relations in a satisfactory manner except for increasing returns to scale types of production. The latter can be handled only if it occurs infrequently in a model.[11]

The advantages and disadvantages of economy-wide optimizing models depend, of course, on the particular formulations of its various components.

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[11] Blitzer and Eckaus (1983) use linear approximations to solve such "non-linear" formulations using linear programming methods. Illustrating the rapid improvements in available software, Tourinho (1985) handles non-linearities directly using a non-linear programming algorithm.

The models, in any case, are sectorally and intertemporally comprehensive and internally consistent. The intertemporal decisions are made taking into account the entire relevant planning period, as would be desired in a policymaking process. In their simpler, completely linear forms the models suffer from intertemporal "flip-flop", tending to concentrate all the maximized consumption at the beginning or, more usually, at the end of the planning period. When convexities are added in the consumption-utility functions, the production functions, the foreign borrowing and oil reserves-depletion relations and in absorptive capacity constraints, the flip-flop problem is eliminated.

While such models have many advantages as compared to those described previously, they also have some drawbacks. The economy which the models simulate is one with perfect markets and perfect foresight. Thus the models are normative and the adjustment of their projections to real conditions requires careful judgment. One aspect of this limitation is that it is difficult to specify price policies and constraints which may prevail in reality, for example in fixed wage levels in some sectors, or which might be considered as a matter of policy, for example, taxes and subsidies.

General Equilibrium Models

Although the previous models are a type of computable general equilibrium model, the latter term is generally used to refer to static models of a perfectly competitive economy for which solutions are calculated.[12] The models have many of the features of optimizing models and also capture the interactions between the energy sectors and energy policy and the rest of the economy. The models contain a number of sectors, including one or more energy

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12 For a discussion focussing on developing country applications, see Dervis, de Melo, and Robinson (1982).

sectors. There may also be a number of time periods but, whereas in the multiperiod optimization models the results for each year take all the periods covered by the model into account, the intertemporal effects in the general equilibrium models are myopic. The time structure of the models is recursive and each period builds on the previous period but is not affected by the next period.

The production technologies embodied in these models can be linear and/or non-linear, depending on the sector and the factors, so that capital-labor-energy substitutability or complementarity can be reflected. Increasing returns to scale relations are completely ruled out in this methodology as in most others. Typically, intermediate requirements are determined by an input-output coefficients table and primary inputs are determined by production functions which embody substitution possibilities, either in a Cobb-Douglas or a CES form. In some recent models, intermediate energy inputs are removed from the input-output table and treated as if they were a primary factor so that the possibilities of substituting for or against energy can be included in the model.[13]

Consumption demands for energy and other goods can be determined by the specification of consumer utility functions or the demand equations which they imply. Export demands are usually specified exogenously, although they can be made a function of the domestic prices which are generated. Imports can be determined either by fixed coefficients or, again, related to foreign prices which have to be exogenous to the model and endogenously determined domestic prices.

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[13] For an example applied to Mexico, see Blitzer and Eckaus (1983).

Investment is either exogenous or determined endogenously, in total, by the level of savings and allocated among sectors according to the relative shadow prices on capital stock in each sector. Since these relative shadow prices reflect only current conditions and not the future demands for investment, savings and capital stocks, the models are, as noted above, myopic.

Government taxes and subsidies on goods and resources can be specified explicitly sector by sector and according to the use of the goods and resources. Functional incomes are determined and the distribution of personal incomes can be derived by allocating shares of ownership of factors to different income classes. Taxes and subsidies can be specified on particular goods and factors and by income class.

As can be inferred, the particular advantage of this type of model is in the ability to analyze the implications of price policies for petroleum and other energy sources, for example. In addition, the effects of alternative price interventions on energy and other inputs and outputs, through taxes and subsidies can be analyzed. These effects may operate on private domestic consumption, production and imports. Although most models of this type assume market clearing prices, it is possible to specify, exogenously, fixed prices for goods or services which do not clear the markets. The effects on the distribution of income of changes in energy and other prices and the feedback effects on demands can be investigated.

The disadvantages of such general equilibrium models are in their limited and myopic dynamics and, also, in their commitment to a competitive structure, except where prices are fixed exogenously.

Appraisal of Alternative Energy-Policy Modelling Methodologies

The "best" choice among the alternative approaches to energy policy modelling depends on the issues to be analyzed in the particular country and the time and resources which can be employed. Yet, although the techniques which are conceptually the most satisfactory require more time and resources than the least satisfactory, it is often the case that improvements can be achieved with relatively little cost. Both the objectives of the analysis and time and resource constraints will be kept in mind in appraising the alternatives.

The objectives of energy policy modelling in developing countries vary from the design of an integrated energy and overall economic development policy to the appraisal of a single small project. There are, typically, intricate interactions between energy policy and overall economic performance. Thus, unless the project is small relative to the economy and the energy sectors as a whole, even a single undertaking should be appraised taking into account its overall consequences. Most of the approaches to energy policy modelling are intended to do this, but with different degrees of ambition and success.

Project evaluation, focussing on individual undertakings, might appear to be completely unable to take into account overall energy-economy interactions. Yet, the use of shadow prices in evaluating inputs and outputs ties the individual project evaluation to the entire economy. The shadow prices are intended to reflect for the economy as a whole the marginal costs of the resources employed and the marginal benefits of the outputs achieved. The methods of project evaluation, however, are intended to finesse the overall analysis through shadow prices which make the correct linkage between the individual undertaking and overall development. If the intention is achieved, therefore, project evaluation is carried out as if it were embedded in an overall energy-economy analysis.

That is a goal which cannot ever be attained fully but can be approximated in certain circumstances in which shadow prices can be estimated without a comprehensive analysis. One condition is that the project must be relatively small and not set off a chain of events which change the character of an important part of the economy within several years or or so after its completion. Another condition is that the current prices in the economy must not be completely unrepresentative of real relative scarcities or that international prices can be used to evaluate most of the inputs and outputs. Then current relative prices, with some critical adjustments, can be used to calculate shadow prices.

These conditions will hold to a reasonable degree in many countries for many undertakings, so that project evaluation techniques are, and will be, an important tool. It is clear that the techniques are simply not useful for the sectoral investment decisions and other policies, such as those on pricing, which affect the entire economy.

The conditions under which <u>technology assessment</u> methods will be satisfactory are much like the conditions under which project evaluation methods succeed. The starting point for the technological assessment must not be too far away from the actual current conditions since the technological choices in the energy sectors are explicitly assumed not to feed back into overall development of the economy. If that is not so, the final results of the technological assessments will be different from the economic assumptions on which those assessments were based. Unfortunately there is no reason to believe that successive iterations will resolve the inconsistencies. However, in countries which have been relatively open to energy price changes and in which markets have operated with relative effe-tiveness, the technology assessment techniques may, themselves, give useful details. To state the

conditions, however, is to make apparent the limited scope of such techniques, when used by themselves.

That does not mean that technological assessments are without value. If, when such an assessment is carried out, the types of technologies which are chosen are substantially different from those which are in place, that would be a strong indication that further studies are highly desirable. At the end of a study which does take energy-economy interactions into account, a technology assessment can be used to check specific aspects of the results and to provide more technological detail. It would, of course, be absolutely essential that the technological data and cost information included in the assessment be up-to-date.

Overall energy assessments, can provide a background information as well as some detailed evaluations of particular energy demands and supplies and other related policies. They cannot provide a comprehensive basis for policy but they can be quite useful when there are strong reasons to believe that the major energy problems and their solutions are readily identifiable. This can be the case in economies with a relatively simple economic and/or energy structure, for example an economy in which agriculture accounts for, say, 75 per cent or more of the gross national product and the only nontraditional energy source is, and will be, imported petroleum. In such cases energy demands can be readily identified and energy policy formation, at least with respect to imports and their domestic use will be straightforward.

That is not to say the problems will actually be easy ones to resolve. The energy supplies to the agricultural sector may be quite difficult, for example, if local fuel wood is being depleted. The problems can be isolated, however, and do not require overall modelling for successful analysis. It may be necessary to carry out sophisticated forestry and transportation studies but those can be expected to be different for each country.

It is as much of a mistake to be analytically more sophisticated than a problem requires as it is to be less sophisticated than necessary. Overall energy sector assessments can embody general collections of data, identify problems and develop special purpose analyses, all of which can be quite useful in particular circumstances. The approach cannot deal with interacting energy-economy policy issues in even a moderately sophisticated economy and should not be expected to do so.

Macrosimulation models, as noted, are formulated in a number of different ways in covering an entire economy. In general such models generate for one period, or for several periods, not only aggregate economic variables, but sectoral detail. Their structure is such that this detail is produced in a rather mechanical way, either without interactions between the energy sectors and the economy as a whole or with only one way interactions. It is as if an economy and the energy parts of it were a wind-up toy that will climb steps when set off on its own. Such models do not have built into them procedures for choices among alternatives and for adjustment of their paths depending on such choices, except, in some cases, where energy technology choices are made in one period which affect output levels in the next period.

The intent of the macrosimulation models, to have a comprehensive approach to energy policy formulation, is praiseworthy and, as such, it represents, in some ways, an advance over the previously discussed methods. The fatal disadvantage is their mechanistic structure. This not only makes it impossible for them to deal with such important issues as price policy, but can even lead to serious errors when the fixed consumption, input and output patterns are projected into the future. Finally, the data base necessary for the construction of macrosimulation models needs only modest amplification to serve in the formulation of the more satisfactory economy-wide optimization and general equilibrium models.

The economy-wide optimization models and the computable general equilibrium models each have some of the features most desired for energy policy analysis. These models can take into account interactions between the energy sector and energy policy and developments in other sectors and the economy as a whole. Although they could be disaggregated to include specific large projects, they are typically formulated with relatively few sectors. Thus they are not as versatile and convenient as project evaluation techniques for the assessment of small projects. Nor do such models provide much technological detail. On the other hand, the optimization and computable general equilibrium models do everything that macrosimulation models can do, do it in a more satisfactory manner and utilize the data assembled more effectively.

The choice between economy-wide intertemporal optimization models and computable general equilibrium models depends on the nature of the policy issues to be addressed. Both models take intersectoral interactions into account. Both allow for technological choices in the energy sector which reflect the relative demands and supplies of energy sources of various types and uses in the different consuming sectors. Both generate shadow prices which reflect the real relative scarcities of energy and other productive resources and other inputs and outputs in the economy. The differences between these two broad types of models are mainly in the effectiveness with which they deal intertemporal issues and the convenience with which alternative types of policy issues can be studied.

If the central policy issues at a particular moment are decisions about major sectoral investment programs and other intertemporal policies with respect to the overall patterns of energy sector development in relation to the economy as a whole, then the intertemporal optimization models almost

certainly dominate. As noted above, the computable general equilibrium models treat intertemporal questions in a rudimentary and myopic manner. By comparison in the optimization models it is possible to make policies over a long planning horizon which are consistent and even optimal with respect to a specific criterion function.

On the other hand, the important sectoral development programs may be deducible without sophisticated techniques because of the clear dominance of some programs or they may have been decided for the near future. In this case the current issues will be the implementation of the programs via price policies and the consequences of alternative policies. Then the computable general equilibrium models have distinct advantage. In these models it is easier to impose and find the static consequences of alternative tax and subsidy policies which effect prices. It also possible to develop some approximations as to the income distribution effects of the alternatives as well as the macroeconomic effects.

Simple General Equilibrium Models for Small,Less Industrialized Developing Countries

The situations of small developing countries will often fit the circumstances in which general equilibrium models will be the most effective tool for analysis of energy policy issues. In these countries, the major source of energy for urban consumers and industry typically will be petroleum imports and, possibly, electricity from hydro projects. The major intertemporal decisions with respect to the sectoral allocation of investment will often be relatively straightforward and not require the sophisticated techniques of economy-wide optimization models. For example, the countries are often predominantly agricultural with a clear advantage in a few particular crops. Or the countries may have a major mineral resource whose

exploitation must provide most foreign exchange earnings. In these circumstances an economy-wide intertemporal optimization model is not likely to provide better first approximations than are already available unless substantial effort is put into the generation of detailed data for such a model. Likewise, if it is necessary to develop a mix of light industries to supplement the agricultural sectors, optimization models are also not likely to be helpful. The highly disaggregated data necessary to include a number of different small sectors in an optimization model are not likely to be available.

By comparison, even when the major lines of investment and sectoral development are relatively clear, the policies which will implement these energy programs and the consequences of alternative policies for government finance will not be obvious and will have to be worked out in detail. The computable general equilibrium models will be most effective for these purposes.

Both because of data limitations and because the types of policies to be developed are quite general in nature, the general equilibrium models will have to be and can be relatively simple. With respect to sectoral detail, it will be desirable to distinguish several energy sectors and sources and the major agricultural and, perhaps, mineral products. It will generally not be necessary to have many separate industrial and service sectors. Information on sectoral consumer demands and investment programs will have to be added and major tax and subsidy programs will need to be taken into account.

It will always be necessary to be alert to the need to use the analytical tools most suited to the particular situation. However, simple general equilibrium models for the analysis of energy policy in the context of general economic development will have the highest priority for a substantial class of countries.

III. Formulation and Description of the Sri Lanka Model

There are numerous aspects of energy-economy interactions which could be considered, since energy is an important input throughout the Sri Lankan economy. Among the most important questions which might be considered are: (1) the impact of energy costs and prices on aggregate growth and its sectoral composition; (2) the relationship between energy imports, investment rates, and the balance of payments; (3) the scope for substitution between energy and other factors of substitution; (4) and the effect of energy prices on income distribution and employment. The time horizon also is important, since many adjustments to higher energy prices and costs take many years to complete.

This implies that if there were such a thing as an "ideal" model, it would be disaggregated into many sectors of production with endogenous factor substitution, have many consumers with different factor endowment and consumption behavior, contain a complete set of fiscal accounts, include foreign borrowing opportunities, embody efficient rules for savings generation and allocation of investment, etc. While theoretical models could be formulated with these characteristics, in practice no single model could serve all these diverse purposes.[14]

The model prepared for Sri Lanka is in the same spirit as the medium-term general equilibrium models in which prices determine factor allocations, production, and final demands. Investment is determined by some "closure" rule, and this generates the capital stocks used to calculate a solution for later years. As noted above, this procedure is not fully satisfactory, since it does not guarantee that investment decisions are made efficiently or optimally. While arguably, a dynamic optimizing model focussing on

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[14] For reviews of these methods, see Blitzer, Clark, and Taylor (1975), Taylor (1979), and Dervis et al. (1982).

intersectoral investment and technology choice might be the most desirable to analyze the energy-economy problems of Sri Lanka, construction of such a model was not feasible in this project. Neither the necessary data nor manpower were available.

As with all economy-wide general equilibrium models, we specify a discrete set of sectors producing goods and services which are bought and sold. Most of these must be aggregates of similar commodities in order to stay within data limitations and to keep the size of model within manageable limits. In this model, there are eleven sectors: (1) paddy and other annual agricultural crops; (2) tree crops; (3) industry; (4) transportation; (5) housing; (6) services; (7) refined petroleum products; (8) electricity; (9) non-competing imports; (10) crude oil; and (11) traditional fuels.

All of these except for crude oil and the general category "non-competing imports" (which is primarily capital goods) are produced in Sri Lanka. Thus the model keeps track of domestic production in nine sectors which generate all domestic value added. Of these, six are non-energy sectors. International trade is allowed in agricultural and industrial goods, as well as in services (e.g., tourism). Housing and transportation are non-traded, which means that domestic supply must equal domestic demand.

Three energy sectors are distinguished. The refining sector uses crude oil (which must be imported) to produce products which are used in the production process of other sectors and by households and the government. Any shortfalls or surpluses can be balanced by imports or exports. Electricity is produced either by hydropower or by thermal generation (using petroleum products as an fuel) and, of course, is non-tradable. Traditional fuels (such as wood and crop wastes) are also non-tradable.

The transactions matrix for 1983 (the base year) is presented as Table 1. Along the rows of this table shows the deliveries (or sales) of each good to other sectors, domestic final demand categories, and foreign trade. Net imports are positive for those sectors in which imports exceed exports, and are negative where imports are greater than exports. The columns of the transactions matrix show the amounts of each good purchased by the various sectors, households, the government, and investment. Consistent accounting implies that the sum of final demands must equal the sum of value added. In effect, the model is designed to project such transactions tables for future years. These then indicate changes in aggregate growth, sectoral composition, energy demands by sector, foreign trade, etc.

Generally, the model calculates the level of sectoral production in a year as a function of the level of previous investment in that sector and the output and input prices and wages that the sector faces. Non-energy intermediate demands are derived using fixed input-output coefficients. More sophisticated procedures are used to calculate the energy demands of each sector. In these latter procedures, the input-output coefficients become variables which change in response to the relative prices among energy sources and the relative price of energy and non-energy inputs.

Labor demand in tree crops, industry, transportation, housing, and the service sectors depends on both output and the real wage. Employment in electricity and refining, which accounts for only a small proportion of total employment, are exogenous. Employment in paddy agriculture is not modelled explicitly, implicitly assuming surplus labor in this sector. This roughly corresponds to the assumption of a "dual" labor force, which is a realistic approximation for most developing countries and is used typically in these types of macromodels.

Table 1: 1983 INTERSECTORAL INPUT-OUTPUT TABLE (AT PRODUCERS PRICES)
(UNITS: BILLIONS OF 1983 RUPEES)

SECTORS	FOOD AGRIC	TREE CROPS	INDUSTRY	TRANSPORT	HOUSING	SERVICES	REFINED PETROLEUM PRODUCTS	ELECT.	TRANS. FUELS	INTERMEDIATE DEMAND	FINAL DEMAND	URBAN CONSUM.	RURAL CONSUM.	GOVT.	ISI	TOTAL FINAL DEMAND	TOTAL NET EXPORTS	TOTAL NET FACTOR INCOMES	GROSS OUTPUT
FOOD AGRICULTURE	1.467	0.115	8.267	0.000	0.000	0.002	0.000	0.000	0.000	9.871	16.538	4.113	0.196	0.000	-2.548	18.317	[illegible]	0.172	[illegible]
TREE CROPS	0.000	6.040	0.525	0.000	0.000	0.000	0.000	0.000	0.000	6.565	2.196	0.337	0.000	0.000	10.681	13.213	[illegible]	0.650	[illegible]
INDUSTRY	2.740	1.660	6.824	0.572	0.594	1.006	0.007	0.624	0.000	14.775	15.795	8.664	1.657	14.573	-2.701	38.192	[illegible]	[illegible]	[illegible]
TRANSPORTATION	0.406	0.153	2.903	0.676	0.651	0.379	0.236	0.177	0.000	4.957	9.147	3.939	0.315	0.000	0.000	13.401	[illegible]	[illegible]	[illegible]
HOUSING	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.350	1.235	0.000	0.000	0.000	3.117	[illegible]	[illegible]	3.117
SERVICES	0.894	0.157	6.732	1.614	0.117	2.407	0.119	0.171	0.000	12.210	16.203	5.036	4.813	0.000	2.010	31.[illegible]	5.[illegible]	[illegible]	[illegible]
REFINED PETROLEUM	0.000	0.087	0.528	3.004	0.000	0.367	0.003	2.268	0.000	6.273	0.681	1.321	0.337	0.000	-0.321	2.[illegible]	3.[illegible]	0.111	[illegible]
ELECTRICITY	0.014	0.006	0.432	0.016	0.000	0.432	0.001	0.769	0.000	1.710	0.917	1.761	0.330	0.000	0.000	3.[illegible]	[illegible]	[illegible]	[illegible]
NON-COMP. IMPORTS	0.121	0.075	0.721	1.567	0.000	0.218	0.003	0.106	0.000	2.[illegible]	0.000	0.000	1.100	[illegible]	21.446	-2.[illegible]	[illegible]	[illegible]	[illegible]
CRUDE OIL	0.000	0.000	0.000	0.000	0.000	0.000	7.819	0.000	0.000	7.819	0.000	0.000	0.000	0.000	-7.819	-7.819	7.[illegible]	[illegible]	[illegible]
BIOMASS	0.000	0.354	0.271	0.000	0.000	0.113	0.000	0.000	0.000	0.738	1.106	0.312	0.000	0.000	0.000	1.[illegible]	[illegible]	[illegible]	[illegible]
TOTAL INTERMEDIATE	5.643	8.606	27.316	7.419	0.541	5.413	8.[illegible]	4.119	0.000	67.[illegible]	67.[illegible]	27.111	9.[illegible]	[illegible]	25.371	[illegible]	[illegible]	[illegible]	[illegible]
VALUE ADDED	22.571	11.163	25.175	10.704	3.575	33.006	0.129	0.759	2.175	114.763	0.973	1.133	0.000	0.000	0.000	1.9[illegible]	[illegible]		
WAGE INCOME	0.000	8.640	12.213	2.655	0.000	10.673	0.108	0.289	0.000	33.711	53.417	20.[illegible]	9.[illegible]	[illegible]	25.371	[illegible]	[illegible]		
PROFIT INCOME	0.000	2.523	12.962	8.049	3.575	27.407	0.021	0.470	0.000	75.057									
GROSS OUTPUT	28.214	19.820	52.[illegible]	18.113	4.117	43.519	8.[illegible]	4.877	2.175	181.750									

Once the distribution of income is determined, the model calculates private savings and the composition of private consumption using the income tax rates paid by rural and urban workers and on profit income, fixed marginal savings rates, and price sensitive consumption functions.

Government consumption expenditures are assumed to grow at a predetermined rate regardless of the size of the government deficit, although this rate can be changed in alternative scenarios. On the revenue side, there are income and indirect taxes, the latter creating distortions between domestic and international relative prices. Once government investment is determined, the deficit can be calculated.

Imports of agricultural and industrial goods, services, and refined petroleum products are adjusted up or down in order to ensure that total supply (domestic production plus imports) equals total usage (intermediate demand, private and public consumption, investment, and exports). The level of crude oil imports depends on refinery production. The amount of other non-competing imports depends on sectoral production and total investment. The model is "closed" by specifying a rule for relating aggregate investment and the balance of payments deficit to national income (GDP). In some cases, the trade deficit is fixed in terms of GDP, and in others aggregate investment is fixed as a share of national income.

For the tradable goods, prices are exogenous. The implicit assumption is that, as a small country, changes in the level of Sri Lankan trade do not affect world prices.[15] Thus, for tradable goods, domestic prices are world

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[15] While this is certainly reasonable for imports and industrial exports, Sri Lanka is a major producer of tea, rubber, and coconut products. Wide swings in exports of these may have an effect on world prices. This can be handled either by introducing a specific demand function into the model or by an iterative procedure in which prices are adjusted up or down depending what results the model has produced.

prices plus or minus any tariffs or subsidies, times an exchange rate which is exogenous. Electricity prices also are set by government policy. However, the model itself, calculates equilibrium prices for transportation and housing. These are adjusted to insure supply/demand equilibrium for these non-traded sectors.

Finally, the allocation in any one year of investment among the various sectors determines the amount of capital stock which is available in the following year for additional production. In this way the model can be run forward in time, calculating consistent paths for production, trade, investment, employment, income distribution, energy demands, and so forth. Since the model solves for only one year at a time, there are no computational difficulties in extending the time horizon for additional years. However, the myopic investment behavior of the model, in which investment allocations do not respond fully to intersectoral differences in rates of return, imposes an effective upper bound on how many years can be usefully tested. In model such as this, 10-15 years usually is an appropriate horizon.

The equations of the model are described in the following sub-sections. Lower case Latin or Greek letters represent fixed parameters, upper case letters represent endogenous variables, and upper case letters with a bar over them represent exogenous variables. The subscripts "i" and "j" represent sectors, "k" stands for income groups, and "t" stands for time periods. The symbol "Δ" is notation for changes in variables between two years. Numeric subscripts refer to specific goods and sectors as follows: 1=paddy and other annual agricultural crops, 2=tree crops, 3=industry, 4=transportation, 5=housing, 6=services, 7=refined petroleum products, 8=electricity, 9=non-competing imports, 10=crude oil, and 11=traditional fuels. Variables and parameters are defined in Tables 2 and 3.

Sectoral Production and Factor Demands

Paddy and Other Annual Crops

This aggregate sector primarily produces food. As shown in Table 1, this sector accounted for about 20% of GDP in 1983. Typically for developing countries, a much larger share of the labor force works in this sector, about 40-45%. The 1983 transactions matrix also indicates very little direct use of energy in production. However, indirect energy use is substantial. The most important intermediate inputs are industrial goods, which include fertilizers.

In terms of production, the basic assumption is that growth is primarily a function of the rate of new investment (i.e., land clearing, irrigation, machinery) which will be undertaken. That is:

(1) $$X_{1,t} = X_{1,t-1}(1-d_1) + (1/k_1)\Delta K_{1,t-1}$$

All intermediate demands, including direct energy demands, are calculated as fixed proportions of gross output.[16]

(2) $$INT_{j,1,t} = a_{j,1}X_{1,t}$$

Tree Crops

The tree crop sector includes tea, rubber and coconut production. Although this sector represents for only 10% of GDP, it accounts for about three-fourths of export revenue. Production is based on a plantation system, with wage labor, rather than a village system with family farms. Most of the sectors's direct energy needs are met by traditional fuels, with petroleum products being more important than electricity from the grid.

For this sector, changes in gross output between any two years are related to depreciation of existing capital stock and changes in the inputs of

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[16] These proportions can be varied in different runs to test the effects of different kinds of technical change.

Table 2: Definition of Variables

C_t	Aggregate private consumption expenditures in year t.
$C_{i,t}$	Level of private consumption of good i in year t.
$C_{i,k,t}$	Level of consumption of good i by consumer group k in year t.
$E_{i,t}$	Exports of good i year t.
G_t	Aggregate public consumption expenditure in year t.
$G_{i,t}$	Level of public consumption of good i in year t.
GDP_t	Gross domestic product in year t.
GR_t	Government revenue in year t.
I_t	Aggregate investment expenditures in year t.
$I_{i,t}$	Demand to investment good i in year t.
IN_t	Aggregate real investment undertaken in year t.
$INT_{j,i,t}$	Intermediate deliveries of good j to sector i in year t.
$L_{i,t}$	Total employment in sector i, year t.
$M_{i,t}$	Net imports of good i in year t.
$P_{i,t}$	Domestic price of good i in year t.
$PC_{i,t}$	Domestic consumer price of good i in year t.
$PR_{i,t}$	Profits of sector i in year t.
$PW_{i,t}$	Border price of good i in year t.
$S_{k,t}$	Savings of group k in year t.
S_t	Aggregate private savings in year t.
TD_t	Trade deficit in year t.
$TRFS_{r,t}$	Government transfer payments to the rural sector in year t.
$TRFS_{u,t}$	Government transfer payments to the urban sector in year t.
$VA_{i,t}$	Value added in sector i in year t.
$X_{i,t}$	Gross output in sector i, year t.
XH_t	Gross output of hydropower in year t.

XT_t	Gross output of thermal electric generation in year t.
$Y_{r,t}$	Disposable income of the rural sector in year t.
$Y_{u,t}$	Disposable income of the urban sector in year t.
$q_{i,t}$	Proportion of total investment spent on good i in year t.
$\Delta E_{i,t}$	Increase in aggregate energy demand by sector i, year t. new capital stock.
$\Delta INT_{j,i,t}$	Increase in demand for energy input j by sector in year t.
$\Delta K_{i,t}$	New capital available to sector i in year t.
$\Delta L_{i,t}$	Labor employed by sector i in year t in conjunction with previous year's investment.

labor and capital using Cobb-Douglas production functions. This is also a "putty-clay" formulation in which the factor input proportions respond to relative price changes when new investments are made. But, once made, these cannot be changed during the life of the capital equipment. The more rapidly a sector grows or its capital stock "turns over", the higher the short run price elasticities.[17] That is:

$$X_{2,t} = X_{2,t-1}(1-d_2) + A_{2,t}\Delta L_{2,t}^{\alpha 2}\Delta K_{2,t}^{\beta 2} \tag{3}$$

$$L_{2,t} = L_{2,t-1}(1-d_2) + \Delta L_{2,t} \tag{4}$$

The first term on the right-hand side of equation (3) is the output which can be produced this year using the capital stock and technology which existed in the immediately preceding year. The second (more complicated) term represents new output in year t, and allows for substitution between capital and labor. The same approach is used in equation (4) to derive total labor demand.

Non-energy intermediate demands and electricity demand (which is small) are projected using exogenous input-output coefficients. That is:

$$INT_{j,2,t} = a_{j,2}X_{2,t} \tag{5}$$

for all j, except for j=7,11 (petroleum products and traditional fuels).

Petroleum product and traditional fuel demands are derived in a more complicated way which allows the input-output coefficients to respond to prices. Specifically, the ΔE term in equation (3) refers to an aggregation of of these two types of energy, as shown in equation (7).[18] We assume that this aggregate demand for energy is complementary with capital, its total increasing in the same proportions as in equation (6).

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[17] While these probably overstate the degree of substitutability among factors (and ignore complementarity entirely), they are used in this here because of their simplicity and the inferences which can drawn from national income accounts about parameter magnitudes.
[18] A Cobb-Douglas aggregation is used.

(6) $$\Delta E_{2,t} = e_2 \Delta K_{2,t}$$

(7) $$\Delta E_{2,t} = H_2 \Delta INT_{7,2,t}^{h2} \Delta INT_{11,2,t}^{(1-h2)}$$

Therefore, once demand for either petroleum products or traditional fuels is known, for any level of total energy use, the demand for the other can be derived. In this way, the model allows substitution between these two energy sources. Total energy demands for j= 7, 11 are:

(8) $$INT_{j,2,t} = INT_{j,2,t-1}(1-d_2) + \Delta INT_{j,2,t}$$

The model solves a sub-problem whose objective is the maximization of sectoral profits, given these equations, previous year's investment, the wage rate, and prices. The model hires labor and chooses the levels of energy demand in order to maximize:[19]

(9) $$P_{2,t}Y_{2,t} - w_{2,t}L_{2,t} - \Sigma_j(P_{j,t}INT_{j,2,t})$$

Industry

The industrial sector accounts for almost one-quarter of GDP, and has in the past grown more rapidly than the agricultural or service sectors. It is also a sector which the Sri Lankan authorities believe has significant export potential. Perhaps surprisingly, Table 1 shows that existing industry is only a moderate user of energy. Total energy costs represent about 5% of value added. the sector uses about 10% of electricity and traditional fuels output and 6-7% of all refined products. Nonetheless, as a growing sector it may account for substantial new energy demands and thus it needs to be analyzed carefully.

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[19] The energy and labor demand functions can be derived straightforwardly by solving this problem.

Table 3: Definition of Constants and Parameters

$a_{j,i}$	Intermediate demand for good j, per unit of gross output of sector i.
ah_j	Intermediate demand for good j, per unit of gross output of hydropower.
at_j	Intermediate demand for good j, per unit of gross output of thermal generation.
b_i	Share of total public consumption spent on good i.
d_i	Annual rate of depreciation of capital stock in sector i.
d_h	Annual rate of depreciation in hydropower sector.
e_i	Aggregate energy demand per unit of new investment, sector i.
h_i	Energy aggregation elasticity parameter, sector i.
k_i	Incremental capital-output ratio in sector i.
k_h	Incremental capital-output ratio in hydropower sector i.
l_i	Demand for labor per unit of gross output in sector i.
s_i	Sector i's share of real investment in the non-energy sectors.
sh_i	Share of labor employed in sector i living in rural areas.
tc_i	Consumption tax rate on good i
tr_i	Tariff on traded good i.
tx_p	Tax rate on private urban profit income.
tx_r	Tax rate on private rural income.
tx_u	Tax rate on urban wage income.
v	Demand for investment goods form the industrial sector, per unit of real investment.
$w_{i,t}$	Wage rate in sector i in year t.
$A_{i,t}$	Scaling parameter for incremental production in sector i, year t.
H_i	Energy aggregation scaling parameter, sector i.
α_i	Labor's share of total incremental production cost in sector i.
β_i	Capital's share of total incremental production cost in sector i.

η_i	Energy's share of total incremental production cost in sector i.
$\gamma_{i,k}$	Share of incremental consumption spent on good i by consumer group k.
$\varphi_{i,k}$	Constant in consumption demand function for good i of consumer group k.

In most respects, the transportation sector is modelled similarly to industry and tree crops. However, instead of capital and labor being substitutable, we assume that capital and petroleum products can be substituted for each other, with the trade-off rate depending on their relative prices. All other intermediate demands, as well as employment, are projected using fixed coefficients. The sub-problem is to maximize:

(17) $$P_{4,t}X_{4,t} - w_{4,t}L_{4,t} - \sum_j (P_{j,t}INT_{j,4,t})$$

subject to the following equations:

(18) $$X_{4,t} = X_{4,t-1}(1-d_4) + A_{4,t}\Delta K_{4,t}^{\beta 3}\Delta INT_{7,4,t}^{\gamma 3}$$

(19) $$L_{4,t} = l_4 X_{4,t}$$

(20) $$INT_{j,4,t} = a_{j,4}X_{4,t}$$

(21) $$INT_{7,4,t} = INT_{7,4,t-1}(1-d_4) + \Delta INT_{7,4,t}$$

Housing

The housing sector is small in terms of value added, accounting for about 3% of GDP. However, because the capital-output ratio is higher than in the other sectors, growth of housing can have important feedbacks on the macroeconomy. Even though housing uses only negligible amounts of energy directly, the size and quality of the housing stock can have indirect effects on household energy demand.[20]

Production and intermediate demands are calculated using fixed coefficients. The amount of growth depends positively on the level of investment in the sector and negatively on the rate of depreciation of the housing stock. The direct use of energy by this sector is small, since household fuel use is accounted for as part of private consumption, and

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20 In this version of the model, these feedbacks enter through the cross-price elasticities for energy with respect to the cost of housing.

Production and factor demands are determined in the same way as described above for the tree crop sector. Capital and labor are substitutes in a Cobb-Douglas production function. Electricity demand and non-energy intermediate demands are derived using fixed coefficients. Capital and petroleum products and traditional fuels are complements, while these two energy sources are substitutes. Given previous investment, prices, and the wage rate, the model then solves in each year the following sub-problem. Maximize:

(10) $$P_{3,t}X_{3,t} - w_{3,t}L_{3,t} - \sum_j (P_{j,t}INT_{j,3,t})$$

subject to the following equations:

(11) $$X_{3,t} = X_{3,t-1}(1-d_3) + A_{3,t}\Delta L_{3,t}^{\alpha 3}\Delta K_{3,t}^{\beta 3}$$

(12) $$L_{3,t} = L_{3,t-1}(1-d_3) + \Delta L_{3,t}$$

(13) $$INT_{j,3,t} = a_{j,3}X_{3,t}$$

(14) $$\Delta E_{3,t} = e_3\Delta K_{3,t}$$

(15) $$\Delta E_{3,t} = H_3\Delta INT_{7,3,t}^{h3}\Delta INT_{11,3,t}^{(1-h3)}$$

(16) $$INT_{j,3,t} = INT_{j,3,t-1}(1-d_3) + \Delta INT_{j,3,t}$$

<u>Transportation</u>

Like services and industry, the transportation sector is an important provider of intermediate inputs to the other sectors. It also accounts for about one-seventh of private consumption expenditure. Although value added in this sector is only about 10% of GDP, it is the largest single user of petroleum products, utilizing about three-eighths of total refinery output 1983. Future energy demand growth is expected to be quite sensitive to how fast transportation grows and with what energy efficiency.

related to sectoral output with a fixed coefficient. These relationships are expressed in the following equations.

(22) $$X_{5,t} = X_{5,t-1}(1-d_5) + (1/k_5)\Delta K_{5,t-1}$$

(23) $$INT_{j,5,t} = a_{j,5}X_{5,t}$$

(24) $$L_{5,t} = l_5 X_{5,t}$$

Services

Services is the largest single sector in Sri Lanka, accounting for one-third of GDP. As indicated in Table 1, electricity is the major energy form used by services. But energy as a whole is not a very large part of total costs in this sector. For this reason, we also estimate future energy demand growth using a fixed coefficient approach.[21]

Capital and labor at the margin are substitutes in production, as is the case for industry and tree crops. Fixed coefficients are used in deriving the other intermediate demands. The sub-problem is to maximize:

(25) $$P_{6,t}X_{6,t} - w_{6,t}L_{6,t} - \sum_j (P_{j,t}INT_{j,6,t})$$

subject to the following equations:

(26) $$X_{6,t} = X_{6,t-1}(1-d_6) + A_{6,t}\Delta L_{6,t}^{\alpha 6}\Delta K_{6,t}^{\beta 6}$$

(27) $$L_{6,t} = L_{6,t-1}(1-d_6) + \Delta L_{6,t}$$

(28) $$INT_{j,6,t} = a_{j,6}X_{6,t}$$

Refining and Petroleum Products

This sector uses crude oil imports to produce products which are used for electricity generation, transportation, and by households and other

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[21] As in the other sectors, conservation strategies may be tested by parametric alteration of the fixed energy demand coefficients.

sectors for many purposes. As Table 1 shows, the costs of crude oil dominate the price of these products. Domestic pricing policy is such that value added in the sector is very low, both absolutely and as a proportion of gross output. Table 1 also indicates that in 1983 about 5% of output was not used domestically and was exported.

In terms of technology, we treat refining as a fixed coefficients sector. That is:

(29) $$X_{7,t} = X_{7,t-1}(1-d_7) + (1/k_7)\Delta K_{7,t-1}$$

(30) $$INT_{j,7,t} = a_{j,7}X_{7,t}$$

(31) $$L_{7,t} = l_7X_{7,t}$$

Electricity Generation

Electricity in Sri Lanka is generated by hydropower and thermal plants. Since the investment and intermediate cost structures of these are so different, the model treats these as two sub-sectors which produce the same good, electricity. In 1983, a large amount of petroleum products were used in electricity generation. But, as more hydrocapacity comes on stream, this level is expected to drop. The model is designed to capture these effects. That is, total intermediate demands depend on the sub-sectoral mix of generation in any one year. That is:

(32) $$INT_{j,8,t} = ah_jXH_t + at_jXT_t$$

The marginal operating costs of hydropower are less than for thermal generation. The sub-problem which the model solves, therefore, is to minimize thermal generation subject to several constraints. The first constraint (33) is that total generation must meet all demands for electricity, including transmission losses. Demands include household and government use, as well as purchases by other sectors of the economy. The second relationship is that

total electricity supply is the sum of thermal and hydropower generation. Hydropower generation in each year is constrained by the amount of capacity available which depends on previous investments.

(33) $$X_{8,t} = C_{8,t} + G_{8,t} + \sum_j INT_{8,j,t}$$

(34) $$X_{8,t} = XH_t + XT_t$$

(35) $$XH_t \leq XH_{t-1}(1-d_h) + (1/k_h)\Delta K_{h,t-1}$$

(36) $$L_{8,t} = l_8 X_{8,t}$$

Traditional Fuels

No specific data is available describing the cost structure in this sector. As shown in Table 1, we assume that there are no specific intermediate demands and that all value added accrues to labor. On the production side, the model supposes that production exactly equals the sum of all demands. The "reasonableness" of any future supply pattern must be judged outside the model. If a run of the model has demand growing at an unsusteinable rate, then adjustments (e.g., price increases, efficiency improvements) can be made on the demand side or through specific supply projects. Production is determined using the following equation.

(37) $$X_{11,t} = C_{11,t} + G_{11,t} + \sum_j INT_{11,j,t}$$

Value Added and Distribution of Income

Value Added, Profits, and GDP

Value added in each sector is defined as the difference between the value of gross output and the cost of all intermediate inputs. Sectoral profits are value added, less wage costs. Gross domestic product (GDP) is the

sum of value added across all sectors.[22] In calculating these values, we use current (net of inflation) producers' prices. That is:

(38) $$VA_{i,t} = P_{i,t}X_{i,t} - \sum_j (P_{j,t}INT_{j,i,t})$$

(39) $$PR_{i,t} = VA_{i,t} - w_{i,t}L_{i,t}$$

(40) $$GDP_t = \sum_i VA_{i,t}$$

Rural Disposable Income

The gross income of the rural sector (which can be used for either consumption or savings) includes all the value added generated in the rural sectors (sectors 1, 2, and 11), and a share of wage income in the other sectors.[23] To get disposable income, an average tax is applied to this gross income and then government transfers are added. That is:

(41) $$Y^*_{r,t} = (1-tx_r)(VA_{1,t} + VA_{2,t} + VA_{11,t} + \sum_i (sh_i w_{i,t}L_{i,t})) + TRFS_{r,t}$$

Urban Disposable Income

Urban gross income includes all wage income not going to the rural sector, as well as profits from the industry, transportation, housing, and services sectors. Since the refinery and electricity sectors are public, their profits do not affect private income directly. In deriving private disposable income for the urban sector, separate tax rates are applied to wage and profit income, and government transfer payments are added. That is:

(42) $$Y_{u,t} = (1-tx_u)(\sum_i (sh_i w_{i,t}L_{i,t}) + (1-tx_p)\sum_i (PR_{i,t})) + TRFS_{u,t}$$

where the summation on profits covers sectors 3-6.[24]

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[22] Value added can be calculated using any consistent set of prices. Base year prices are used to generate quantity indexes. Using border prices for traded goods is commonly used in studies of trade distortions. National accounts are typically done using purchasers' prices.
[23] This is because many workers in the "urban" sectors live in rural areas.
[24] Urban wage and profit income are aggregated because the expenditure data cover only rural and urban spending and do not treat profit income separately. More careful econometric analysis might be able to estimate the parameters needed to have three expenditure groups.

Government Revenue

Government revenue includes the income taxes applied to wages and profit income in the rural and urban area, the profits of the refining and electricity sectors, and indirect taxes. The model allows the government to specify tariffs on tradable goods and consumption taxes on all goods.[25] Total government revenue is determined using the following equation.

$$(43) \qquad GR_t = PR_{7,t} + PR_{8,t} + tx_r(VA_{1,t} + VA_{2,t} + VA_{11,t} + \sum_i(sh_i w_{i,t} L_{i,t})) + tx_u(\sum_i(sh_i w_{i,t} L_{i,t}) + tx_p(\sum_i(PR_{i,t})) + \sum_i(P_{i,t} - PW_{i,t})M_{i,t} + \sum_j(PC_{j,t} - P_{j,t})C_{j,t}$$

In this equation, the first two terms are energy profits, the next three terms are income taxes on the rural and urban sectors, the next term is tariff revenue, and the final term represents consumption tax revenue.

Final Demand Expenditures

Private Consumption and Savings

Disposable income in both the rural and urban sectors is either spent on consumption or saved. The savings ratio for each group and the proportions of total consumption spent on each good are determined in the model on the basis of net disposable income and the prices which consumers face.

For both groups, an extended linear expenditure system is used to project a consistent set of these expenditures. These equations include a full set of price elasticities for consumption demand, including cross price elasticities. Parameters have been estimated separately for the two groups of

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25 Tariffs act as a wedge between border and producers' prices, while the consumption taxes are wedges between producers' and final consumers' prices. These are significant policy variables for two reasons. Not only do they affect the size of the public deficit, but indirect taxes distort relative prices and thereby have an effect on technology choice and the composition of demand.

consumers. The following equations define how disposable income is allocated and define aggregate consumption and savings. Here, the "k" subscripts refer to either rural or urban consumers.

(44) $$C_{i,k,t} = \varphi_{i,k} + \mu_{i,k}(Y_{k,t} - \sum_j (PC_{j,t}\varphi_{j,k}))/PC_{i,t}$$

(45) $$S_{k,t} = (1-\sum_i \mu_{i,k})(Y_{k,t} - \sum_j (PC_{j,t}\varphi_{j,k})$$

(46) $$C_{i,t} = C_{i,r,t} + C_{i,u,t}$$

(47) $$S_t = S_{r,t} + S_{u,t}$$

(48) $$C_t = \sum_i (PC_{i,t}C_{i,t})$$

Government Consumption

The level and composition of public consumption are exogenous variables which can be set at different levels for each scenario. That is:

(49) $$G_t = \text{exogenous}$$

(50) $$G_{i,t} = b_i G_t / P_{i,t}$$

where the b_i sum to unity. Transfer payments to urban and rural households are also projected exogenously.

Investment Demand

There are two investment goods in the model. One type can be produced domestically by the industry sector (mostly construction, but also some machinery); other machinery must be imported and is classified as a non-competing import (good 9). Data availability (as well as a desire to preserve simplicity) necessities the assumption that the composition of the demand for specific investment goods (the proportions required of these two kinds of goods per unit of real investment) is not affected by the sectoral destination of the investments.

This assumption allows us to project the demand for investment goods on the basis of knowledge of aggregate investment expenditures and the prices of industrial and non-competing goods. While the physical proportions of investment demand (here, the parameter "v") are constants, the expenditure proportions on construction and machinery, the "q_i's", are endogenous and depend on relative prices. That is:

(51) $$I_{i,t} = q_{i,t} I_t / P_{i,t}$$

where,

(52) $$q_{3,t} = (vP_{3,t})/(vP_{3,t} + (1-v)P_{9,t})$$

(53) $$q_{9,t} = ((1-v)P_{9,t})/(vP_{3,t} + (1-v)P_{9,t})$$

Trade Flows

As discussed above, there are two types of traded good in the model, competing and non-competing. For the competing goods (sectors 1, 2, 3, and 6), the demand for imports is the difference between domestic demands plus exports, and domestic production. That is:

(54) $$M_{i,t} = \sum_j INT_{i,j,t} + C_{i,t} + G_{i,t} + I_{i,t} + E_{i,t} - X_{i,t}$$

For the non-competing goods (miscellaneous non-competitive imports and crude oil), there is no domestic production to subtract. For goods 9 and 10:

(55) $$M_{i,t} = \sum_j INT_{i,j,t} + C_{i,t} + G_{i,t} + I_{i,t}$$

Investment Allocations

Future production in each sector is determined, in part, by the level of investment in that sector in each year. In deciding how to allocate total investment among the various sectors, the model follows a predetermined set of rules. These rules represent alternative policies which the government might

follow in its planning process.[26] These rules can be readily changed to test the implications of alternative investment policies.

We first calculate total real investment, which depends on expenditures and prices. That is:

(56) $$IN_t = I_t/(vP_{3,t} + (1-v)P_{9,t})$$

Real investment in the energy sectors is exogenous, part of the scenario plan, and these demands are satisfied first. Whatever investment resources are left over are divided among the other six sectors in predetermined proportions. For the energy sectors (i= 7, 8, and 11), we have:

(57) $$\Delta K_{i,t+1} = \text{exogenous}$$

For the other sectors (i= 1, 2, 3, 4, 5, 6), we have:

(58) $$\Delta K_{i,t+1} = s_i(IN_t - \sum_j(\Delta K_{j,t+1})$$

where the "j" index covers investment in energy sectors.

Model Closing and Solution

In order to have the model calculate a fully consistent set of accounts (similar to the transactions matrix shown in Table 1), only one more relationship need be specified. Consistency in national income accounting implies that the sum of value added across sectors (GDP) must equal domestic absorption (or spending), less the trade deficit and tariffs. That is:

(59) $$TD_t = \Sigma(PW_{i,t}(M_{i,t} - E_{i,t}))$$

(60) $$GDP_t = C_t + G_t + I_t - TD_t - \sum_i(P_{i,t} - PW_{i,t})(M_{i,t} - E_{i,t})$$

where the last term in equation (60) represents net tariff revenue.

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[26] Although Sri Lanka has a mixed economy, the government exercises considerable direct and indirect controls over investment decisions, including intersectoral allocations.

To "close" the model, some rule relating investment expenditures and the trade deficit must be specified. As presently formulated the model can be solved using either one of two rules. In one, real investment is set to grow at an exogenously specified rate. This implied that adjustment costs in different scenarios will show up primarily in the trade deficit (and ultimately foreign debt) rather than in real growth. The other closing rule specifies a fixed time path for the trade deficit, which implies than the burden of adjustments which may be needed falls on investment and hence economic growth. Either (61) or (62) must hold.

(61) $$IN_t = \text{exogenous}$$

(62) $$TD_t = \text{exogenous}$$

Finally, there is the matter of how prices are determined. For the traded goods (i= 1, 2, 3, 6, 7, 9, and 10), border prices are taken as predetermined for the reasons discussed previously. So are tariffs, which means that for these goods:

(63) $$PW_t = \text{exogenous}$$

(64) $$P_{i,t} = PW_{i,t}(1+tr_i)$$

Similarly, the consumption taxes on each good are exogenous, which implies:

(65) $$PC_{i,t} = P_{i,t}(1+tc_i)$$

The price of electricity is also fixed by policy, with the model adjusting the level of thermal generation to insure supply and demand balance in the manner described above. However, there is no specific constraint which insures that for the other two non-traded sectors, transportation and housing, demand does not exceed supply. The model achieves this by adjusting the prices of these goods. That is, if transportation demand exceeds supply with one set of prices, the model raises the price to stimulate supply and dampen

demand. The model finds a set of prices which satisfy the following identities (for i= 4, 5):

(66) $$X_{i,t} = \sum_j INT_{i,j,t} + C_{i,t} + G_{i,t} + I_{i,t}$$

IV. Results

General equilibrium models, even those as simplified as this one, can be used to analyze into a large number of interesting macro and microeconomic issues. Its multisector accounting structure allows the model to check on the internal consistency of the government's medium term economic scenario. Sensitivities and elasticities of key micro and macroeconomic variables to changes in prices, economic policy, and the external environment can be derived by running parametric changes on the model. To illustrate how the model can be used, we describe a few experiments which have been done, focussing particular attention on energy demand and prices.

Three cases are reported. The first case reflects the reported plans and forecasts of the government. This is the Base case, and it is used as a benchmark in measuring the other cases. In the latter cases, world oil prices increase faster than in the Base case. The higher world prices are not passed onto domestic purchasers in Case 2, while in Case 3 they are. The trade deficit is held constant (relative to the Base case) in these tests. Although the model can be run forward in time for 10-15 years, we report only on simulations covering the 1983-89 period.[27]

For the Base case, oil prices are projected to increase at a 1% yearly rate starting from 1985. These increases are passed on to the domestic economy in the form of higher prices for petroleum products. Food and tree crop prices also increase at a slow rate, while the relative price of services declines. Industrial and electricity prices remain stable. Aggregate investment, government consumption expenditures, and sectoral exports are set at officially forecast levels. Energy supply forecasts also come from

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[27] Time and data limitations precluded projection of many exogenous variables beyond 1990.

official plans. Refinery production is expected to peak in 1985 and remain constant thereafter. Significant increases in hydropower capacity have already come on line and more large increases are projected, presumably leading to reduced need for thermal generation. Planned energy sector investment amounts to about one-sixth of total investment in this period, mostly for hydropower projects. About one-third of non-energy investment is allocated to services, one-quarter to services, one-sixth to agriculture, one-tenth each to transport and housing, and the small remainder to tree crops.

The model has been tuned to the base year, 1983, in the sense that it reproduces the base year outcome (Table 1). The parameters of the consumption demand functions were estimated using data from household expenditure surveys. Production function parameters were derived indirectly from input-output data, national accounts, and plan documents. These and other parameters can, and should be, estimated with more care. But, data and time limitations precluded our going farther. For these reasons, it is important to look at these results as tentative, but at the same time indicative of general trends and sensitivities.

The results of the Base case are presented in summary form in Table 4. Values for 1983 and projections for the years 1985, 1987, and 1989 are shown. More detailed projections are contained in the accompanying transactions matrices (Tables 5, 6, and 7). The transactions matrices labeled "at base year prices" represents quantity changes only. The other transactions matrix for each year is labeled "at producers' prices" and the values shown are the quantities times current prices.[28]

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[28] Current prices refer to the real price changes which occur over time such as increases in oil prices. Inflation itself is not considered.

Table 4

BASE CASE

MACROECONOMIC PROJECTIONS
(UNITS: BILLIONS OF 1983 RUPEES)

	1983	1985	1987	1989	GROWTH RATE 1983-89
PRIVATE CONSUMPTION	94.70	105.41	115.62	123.12	4.5%
PUBLIC CONSUMPTION	9.75	10.96	11.63	12.41	4.1%
GROSS INVESTMENT	35.29	39.16	41.77	46.46	4.7%
EXPORTS	33.80	43.71	49.44	55.80	8.7%
IMPORTS	53.76	63.74	69.70	79.29	6.7%
OIL IMPORTS	7.82	9.74	9.94	10.14	4.4%
TRADE DEFICIT	19.96	20.03	20.25	23.48	2.7%
NET INDIRECT TAXES	5.42	4.98	5.40	6.14	2.1%
GROSS DOMESTIC PRODUCT	114.37	130.53	143.36	152.36	4.9%

ENERGY PRODUCTION AND USAGE
(UNITS: THOUSANDS OF TONS, GWH)

	1983	1985	1987	1989	GROWTH RATE 1983-89
REFINED PRODUCTS	1777	2171	2171	2171	3.4%
-INTERMEDIATE USES	842	837	908	978	2.4%
-FINAL DEMAND	541	678	804	923	9.3%
ELECTRICITY	2114	2334	2473	2586	3.4%
-INTERMEDIATE USE	408	451	514	568	5.7%
-CONSUMPTION USE	1373	1424	1464	1501	1.5%
BIOMASS	3750	3883	4140	4366	2.6%
-INTERMEDIATE USE	1271	1304	1458	1591	3.8%
-CONSUMPTION USE	2479	2579	2682	2775	1.9%

SECTORAL GROSS OUTPUT
(UNITS: BILLIONS OF 1983 RUPEES)

SECTORS	1983	1985	1987	1989	GROWTH RATE 1983-89
PADDY AGRICULTURE	28.21	29.14	30.09	30.96	1.6%
TREE CROPS	19.83	21.17	23.01	24.93	3.9%
INDUSTRY	52.49	60.09	67.83	74.92	6.1%
TRANSPORTATION	18.11	19.67	20.79	21.88	3.2%
HOUSING	4.12	4.51	4.88	5.22	4.0%
SERVICES	43.52	51.25	58.27	63.72	6.6%
REFINED PETROLEUM	8.41	10.28	10.28	10.28	3.4%
ELECTRICITY	4.88	5.38	5.71	5.97	3.4%

The top part of Table 4 summarizes the path of the macroeconomic variables at producer prices. In most respects this is an optimistic scenario. GDP increases at almost 5% per year. Domestic absorption grows a little more slowly as the trade deficit declines moderately as a share of GDP. However, these results pointed up some inconsistency between the official projections of aggregate growth, investment, and the trade deficit. In the Base case, the trade deficit grows at almost 3% yearly, while the official forecast is for a decline. The model indicates that one of the targets will have to be modified.[29] This is a good example of how the model can be used in investigating the internal consistency of the many independent forecasts which typically enter a medium term macro forecast.

The fastest growing sectors are services and industry, both increasing in excess of 6% annually. Agriculture and transportation increase at a slower rate than might be expected. This is probably due to their comparatively small shares in the investment allocation plan. This, in turn, suggests the utility of further experimentation with sectoral investment plans, as well as with the production function parameters themselves.

The energy projections also appear favorable. Total energy usage (aggregated at base year prices) increases at only 1.6% annually, which is only one-third the rate of increase in real GDP.[30] Several factors account for this low rate of energy demand growth. The most important single factor has to do with the demand for refined petroleum products by the electricity sector. As new hydropower capacity comes on line, the need to use petroleum

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29 We should add, however, that if Sri Lanka does achieve a 5% aggregate growth rate, trade deficits on the order of those in this case would probably not be difficult to finance.

30 This can be calculated by comparing the transactions matrix for 1989 (Table 7) with the transactions matrix for 1983 (Table 1).

Table 5

1985 TRANSACTIONS MATRIX AT BASE YEAR PRICES

BASE CASE

(UNITS: BILLIONS OF 1983 RUPEES)

SECTORS	PADDY AGRIC	TREE CROPS	INDUSTRY	TRANS-PORT	HOUSE-ING	PETROL SERVICES	PETROL PRODS	ELEC-TRIC	BIO-MASS	TOTAL INTERMED DELIV.	PRIVATE CONS.	PUBLIC CONS.	GROSS INVEST.	NET TRADE	TOTAL FINAL DEMAND
PADDY AGRICULTURE	1.515	0.123	9.465	0.000	0.000	0.026	0.000	0.000	0.000	11.129	23.386	0.204	0.000	-5.579	18.012
TREE CROPS	0.000	6.449	0.601	0.000	0.000	0.000	0.000	0.000	0.000	7.050	3.885	0.000	0.000	11.236	14.121
INDUSTRY	2.830	1.772	7.812	0.567	0.409	1.891	0.008	0.351	0.000	15.640	28.449	1.864	18.449	-2.308	44.455
TRANSPORTATION	0.420	0.163	3.333	0.746	0.056	0.448	0.290	0.135	0.000	5.578	12.936	1.164	0.000	-0.007	14.093
HOUSING	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.494	0.000	0.000	0.012	4.506
SERVICES	0.924	0.167	7.764	1.753	0.128	2.634	0.146	0.186	0.000	13.924	25.554	5.710	0.000	0.055	37.352
REFINED PETROLEUM	0.000	0.084	0.566	2.893	0.000	0.338	0.084	0.192	0.000	4.158	2.674	0.537	0.000	2.910	6.121
ELECTRICITY	0.015	0.006	0.503	0.018	0.000	0.497	0.021	1.059	0.000	2.099	2.846	0.439	0.000	0.000	3.285
NON-COMP. IMPORTS	0.125	0.080	0.829	1.702	0.000	0.256	0.004	0.162	0.000	3.158	0.000	1.316	22.715	-27.190	-3.158
CRUDE OIL	0.000	0.000	0.000	0.000	0.000	0.000	9.551	0.000	0.000	9.551	0.000	0.000	0.000	-9.551	-9.551
BIOMASS	0.000	0.340	0.284	0.000	0.000	0.133	0.000	0.000	0.000	0.757	1.497	0.000	0.000	0.000	1.497
TOTAL INTERMEDIAT	5.828	9.184	31.147	7.677	0.532	6.423	10.085	2.088	0.000	73.024	104.722	11.234	39.165	-24.392	130.730
VALUE ADDED	23.314	11.987	28.947	11.994	3.913	44.832	0.194	3.296	2.253	130.730					
WAGE INCOME	23.314	9.297	14.026	2.884	0.000	12.014	0.108	0.298	2.253	64.192					
PROFIT INCOME	0.000	2.690	14.921	9.110	3.913	32.818	0.086	2.998	0.000	66.537					
GROSS OUTPUT	29.142	21.171	60.095	19.671	4.506	51.254	10.279	5.384	2.253	203.754					

1985 TRANSACTIONS MATRIX AT PRODUCERS PRICES

BASE CASE

(UNITS: BILLIONS OF 1983 RUPEES)

SECTORS	PADDY AGRIC.	TREE CROPS	INDUSTRY	TRANS-PORT	HOUSE-ING	PETROL SERVICES	PETROL PRODS	ELEC-TRIC	BIO-MASS	TOTAL INTERMED DELIV.	PRIVATE CONS.	PUBLIC CONS.	GROSS INV.	NET MKT PRICE TRADE	TOTAL FINAL DEMAND	BORDER PRICE TRADE
PADDY AGRIC.	1.628	0.132	10.165	0.000	0.000	0.028	0.000	0.000	0.000	11.952	25.119	0.219	0.000	-5.992	19.346	-5.992
TREE CROPS	0.000	6.545	0.510	0.000	0.000	0.000	0.000	0.000	0.000	7.155	3.920	0.000	0.000	11.405	14.333	14.258
INDUSTRY	2.830	1.772	7.812	0.567	0.409	1.891	0.008	0.351	0.000	15.640	28.449	1.864	18.449	-2.308	44.455	-1.848
TRANSPORTATION	0.395	0.154	3.130	0.702	0.053	0.420	0.273	0.127	0.000	5.254	12.186	1.097	0.000	-0.037	13.276	0.000
HOUSING	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.064	0.000	0.000	0.013	5.078	0.000
SERVICES	0.887	0.161	7.454	1.683	0.122	2.721	0.140	0.181	0.000	13.348	24.532	5.482	0.000	5.842	35.856	5.842
REFINED PET.	0.000	0.086	0.578	2.954	0.000	0.345	0.086	0.197	0.000	4.246	2.730	0.548	0.000	2.971	6.249	2.169
ELECTRICITY	0.015	0.005	0.503	0.018	0.000	0.497	0.001	1.059	0.000	2.099	2.846	0.439	0.000	0.000	3.285	0.000
NON-COMP. IMP.	0.125	0.080	0.829	1.702	0.000	0.256	0.004	0.152	0.000	3.158	0.000	1.316	22.715	-27.190	-3.158	-24.715
CRUDE OIL	0.000	0.000	0.000	0.000	0.000	0.000	9.743	0.000	0.000	9.743	0.000	0.000	0.000	-9.743	-9.743	-9.743
BIOMASS	0.000	0.353	0.295	0.000	0.000	0.139	0.000	0.000	0.000	0.788	1.558	0.000	0.000	0.000	1.558	0.000
TOTAL INTERMED.	5.879	9.289	31.377	7.624	0.584	6.297	10.255	2.077	0.000	73.383	105.413	10.964	39.165	-25.008	130.534	-20.028
VALUE ADDED	25.419	12.199	28.718	10.996	4.494	42.907	0.240	3.307	2.345	130.534	2.001	0.000	0.000	0.000	2.001	IND. TAX
WAGE INCOME	25.419	9.297	14.026	2.884	0.000	12.014	0.108	0.298	2.345	66.391	107.414	10.964	39.165	-25.008	132.536	TOTAL
PROFIT INCOME	0.000	2.902	14.692	8.022	4.494	30.853	0.132	3.009	0.000	64.143						
GROSS OUTPUT	31.298	21.488	60.095	18.530	5.078	49.204	10.495	5.384	2.345	203.917						

Table 6

1987 TRANSACTIONS MATRIX AT BASE YEAR PRICES

BASE CASE

(UNITS: BILLIONS OF 1983 RUPEES)

SECTORS	PADDY AGRIC	TREE CROPS	INDUSTRY	TRANS-PORT	HOUSE-ING	SERVICES	PETROL PRODS	ELEC-TRIC	BIO-MASS	TOTAL INTERMED. DELIV.	PRIVATE CONS.	PUBLIC CONS.	GROSS INVEST.	NET TRADE	TOTAL FINAL DEMAND
PADDY AGRICULTURE	1.565	0.133	10.683	0.000	0.000	0.029	0.000	0.000	0.000	12.410	26.005	0.212	0.000	-0.537	17.680
TREE CROPS	0.000	7.008	0.678	0.000	0.000	0.000	0.002	0.000	0.000	7.687	3.148	0.000	0.000	12.174	15.322
INDUSTRY	2.922	1.926	8.818	0.599	0.443	2.150	0.008	0.342	0.000	17.208	32.214	1.977	17.542	-1.112	50.621
TRANSPORTATION	0.433	0.177	3.751	0.786	0.061	0.507	0.292	0.142	0.000	6.149	13.454	1.197	0.000	-0.008	14.643
HOUSING	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.881	0.000	0.000	-0.001	4.831
SERVICES	0.954	0.182	6.763	1.853	0.138	3.222	0.146	0.202	0.000	15.458	26.754	6.300	0.000	5.743	42.808
REFINED PETROLEUM	0.000	0.092	0.656	3.075	0.000	0.385	0.084	0.000	0.000	4.292	3.250	0.558	0.000	2.179	5.987
ELECTRICITY	0.015	0.007	0.579	0.019	0.000	0.565	0.001	1.141	0.000	2.327	2.913	0.465	0.000	0.000	3.378
NON-COMP. IMPORTS	0.129	0.087	0.936	1.799	0.000	0.291	0.004	0.171	0.000	3.418	0.000	1.396	24.225	-29.039	-3.418
CRUDE OIL	0.000	0.000	0.000	0.000	0.000	0.000	9.552	0.000	0.000	9.552	0.000	0.000	0.000	-9.552	-9.552
BIOMASS	0.000	0.368	0.327	0.000	0.000	0.151	0.000	0.000	0.000	0.846	1.556	0.000	0.000	0.000	1.556
TOTAL INTERMEDIAT	6.018	9.980	35.191	8.132	0.642	7.301	10.085	1.997	0.000	79.347	114.177	12.111	41.767	-24.147	143.908
VALUE ADDED	24.072	13.028	32.637	12.660	4.239	50.965	0.194	3.708	2.402	143.905					
WAGE INCOME	24.072	10.209	15.863	3.048	0.000	13.053	0.108	0.311	2.402	69.077					
PROFIT INCOME	0.000	2.620	16.774	9.612	4.239	37.902	0.086	3.398	0.000	74.831					
GROSS OUTPUT	30.091	23.009	67.829	20.793	4.881	58.266	10.280	5.705	2.402	223.255					

1987 TRANSACTIONS MATRIX AT PRODUCERS PRICES

BASE CASE

(UNITS: BILLIONS OF 1983 RUPEES)

SECTORS	PADDY AGRIC	TREE CROPS	INDUSTRY	TRANS-PORT	HOUSE-ING	SERVICES	PETROL PRODS	ELEC-TRIC	BIO-MASS	TOTAL INTERMED. DELIV.	PRIVATE CONS.	PUBLIC CONS.	GROSS INV.	NET MKT PRICE TRADE	TOTAL FINAL DEMAND	BORDER PRICE TRADE
PADDY AGRIC.	1.713	0.146	11.698	0.000	0.000	0.032	0.000	0.000	0.000	13.589	28.475	0.233	0.000	-9.348	19.360	-5.348
TREE CROPS	0.000	7.219	0.699	0.000	0.000	0.000	0.002	0.000	0.000	7.917	3.243	0.000	0.000	12.539	15.782	15.680
INDUSTRY	2.922	1.926	8.818	0.599	0.443	2.150	0.008	0.342	0.000	17.208	32.214	1.977	17.542	-1.112	50.621	-0.892
TRANSPORTATION	0.421	0.172	3.646	0.766	0.059	0.493	0.282	0.139	0.000	5.977	13.078	1.163	0.000	-0.007	14.233	0.002
HOUSING	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.959	0.000	0.000	-0.001	5.959	0.000
SERVICES	0.879	0.168	8.080	1.708	0.127	2.971	0.135	0.184	0.000	14.252	24.668	5.814	0.000	6.986	39.469	0.968
REFINED PET.	0.000	0.095	0.683	3.202	0.000	0.400	0.088	0.000	0.000	4.468	3.383	0.581	0.000	2.268	6.233	1.655
ELECTRICITY	0.015	0.007	0.579	0.019	0.000	0.565	0.001	1.141	0.000	2.327	2.913	0.465	0.000	0.000	3.378	0.000
NON-COMP. IMP.	0.129	0.087	0.936	1.799	0.000	0.291	0.004	0.171	0.000	3.418	0.000	1.396	24.225	-29.039	-3.418	-26.396
CRUDE OIL	0.000	0.000	0.000	0.000	0.000	0.000	9.943	0.000	0.000	9.943	0.000	0.000	0.000	-9.943	-9.943	-9.943
BIOMASS	0.000	0.398	0.354	0.000	0.000	0.164	0.000	0.000	0.000	0.916	1.685	0.000	0.000	0.000	1.685	0.000
TOTAL INTERMED.	6.080	10.218	35.492	8.092	0.629	7.066	10.461	1.977	0.000	80.017	115.619	11.629	41.767	-25.655	143.360	-20.254
VALUE ADDED	26.869	13.480	32.336	12.119	5.330	46.655	0.240	3.728	2.602	143.359	2.136	0.000	0.000	0.000	2.136	IND. TAX
WAGE INCOME	26.859	10.209	15.863	3.048	0.000	13.053	0.108	0.311	2.602	72.072	117.755	11.629	41.767	-25.655	145.496	TOTAL
PROFIT INCOME	0.000	3.272	16.474	9.070	5.330	33.592	0.132	3.417	0.000	71.287						
GROSS OUTPUT	32.949	23.699	67.829	20.211	5.959	53.721	10.701	5.705	2.602	223.376						

Table 7

1989 TRANSACTIONS MATRIX AT BASE YEAR PRICES

BASE CASE

(UNITS: BILLIONS OF 1983 RUPEES)

SECTORS	PADDY AGRIC	TREE CROPS	INDUSTRY	TRANS-PORT	HOUSE-ING	SERVICES	PETROL PRODS	ELEC-TRIC	BIO-MASS	TOTAL INTERMED DELIV.	PRIVATE CONS.	PUBLIC CONS.	GROSS INVEST.	NET TRADE	TOTAL FINAL DEMAND
PADDY AGRICULTURE	1.610	0.145	11.800	0.000	0.000	0.032	0.000	0.000	0.000	13.586	28.010	0.222	0.000	-10.856	17.377
TREE CROPS	0.000	7.592	0.749	0.000	0.000	0.000	0.000	0.000	0.000	8.341	3.355	0.000	0.000	13.229	16.584
INDUSTRY	3.006	2.066	9.739	0.630	0.474	2.351	0.008	0.358	0.000	18.654	35.266	2.109	19.513	-0.623	56.264
TRANSPORTATION	0.446	0.193	4.143	0.829	0.065	0.554	0.290	0.149	0.000	6.668	13.924	1.275	0.000	0.000	15.209
HOUSING	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.236	0.000	0.000	-0.014	5.222
SERVICES	0.982	0.197	9.679	1.949	0.146	3.524	0.146	0.209	0.000	16.833	27.972	7.163	0.000	11.753	46.885
REFINED PETROLEUM	0.000	0.099	0.740	3.258	0.000	0.421	0.084	0.002	0.000	4.602	3.770	0.600	0.000	1.308	5.677
ELECTRICITY	0.015	0.007	0.649	0.020	0.000	0.618	0.001	1.193	0.002	2.504	2.967	0.496	0.000	0.000	3.463
NON-COMP. IMPORTS	0.133	0.095	1.034	1.892	0.000	0.319	0.004	0.179	0.000	3.656	0.000	1.489	26.946	-32.091	-3.656
CRUDE OIL	0.000	0.000	0.000	0.000	0.000	0.000	9.551	0.000	0.000	9.551	0.000	0.000	0.000	-9.551	-9.551
BIOMASS	0.000	0.393	0.364	0.000	0.000	0.166	0.000	0.000	0.000	0.923	1.610	0.000	0.000	0.000	1.610
TOTAL INTERMEDIAT	6.193	10.806	38.898	8.578	0.687	7.984	10.085	2.086	0.000	85.319	122.110	13.355	46.459	-26.837	155.087
VALUE ADDED	24.770	14.119	36.021	13.298	4.536	55.737	0.194	3.876	2.533	155.087					
WAGE INCOME	24.770	11.186	17.560	3.207	0.000	13.341	0.108	0.324	2.533	73.030					
PROFIT INCOME	0.000	2.933	18.461	10.091	4.536	42.396	0.086	3.554	0.000	82.057					
GROSS OUTPUT	30.963	24.926	74.918	21.876	5.223	63.722	10.279	5.966	2.533	240.406					

1989 TRANSACTIONS MATRIX AT PRODUCERS PRICES

BASE CASE

(UNITS: BILLIONS OF 1983 RUPEES)

SECTORS	PADDY AGRIC	TREE CROPS	INDUSTRY	TRANS-PORT	HOUSE-ING	SERVICES	PETROL PRODS	ELEC-TRIC	BIO-MASS	TOTAL INTERMED DELIV.	PRIVATE CONS.	PUBLIC CONS.	GROSS INV.	NET MKT PRICE TRADE	TOTAL FINAL DEMAND	BORDER PRICE TRADE
PADDY AGRIC.	1.798	0.161	13.180	0.000	0.000	0.036	0.000	0.000	0.000	15.176	31.288	0.248	0.000	-12.126	19.410	-12.126
TREE CROPS	0.000	7.942	0.784	0.000	0.000	0.000	0.000	0.000	0.000	8.725	3.509	0.000	0.000	13.838	17.347	17.291
INDUSTRY	3.066	2.086	9.739	0.630	0.474	2.351	0.008	0.358	0.000	18.654	35.266	2.109	19.513	-0.623	56.264	-0.498
TRANSPORTATION	0.434	0.187	4.031	0.807	0.063	0.539	0.282	0.145	0.000	6.488	13.548	1.241	0.000	0.008	14.797	0.000
HOUSING	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.608	0.000	0.000	-0.018	6.591	0.000
SERVICES	0.850	0.171	8.382	1.688	0.126	3.052	0.126	0.181	0.000	14.578	24.224	6.203	0.000	10.176	40.605	10.176
REFINED PET.	0.000	0.100	0.755	3.369	0.000	0.435	0.087	0.000	0.000	4.758	3.898	0.620	0.000	1.352	5.871	0.988
ELECTRICITY	0.015	0.007	0.649	0.020	0.000	0.618	0.001	1.193	0.002	2.504	2.967	0.496	0.000	0.000	3.463	0.000
NON-COMP. IMP.	0.133	0.095	1.034	1.892	0.000	0.319	0.004	0.179	0.000	3.656	0.000	1.489	26.946	-32.091	-3.656	-29.171
CRUDE OIL	0.000	0.000	0.000	0.000	0.000	0.000	10.144	0.000	0.000	10.144	0.000	0.000	0.000	-10.144	-10.144	-10.144
BIOMASS	0.000	0.443	0.411	0.000	0.000	0.187	0.000	0.000	0.000	1.041	1.814	0.000	0.000	0.000	1.814	0.000
TOTAL INTERMEDIAT	6.297	11.191	38.975	8.405	0.665	7.536	10.653	2.056	0.000	85.722	123.122	12.407	46.459	-29.625	152.363	-23.482
VALUE ADDED	28.288	15.735	26.943	12.880	5.926	47.647	-0.024	3.910	2.855	152.363	2.179	0.000	0.000	0.000	2.179	IND. TAX
WAGE INCOME	28.288	11.186	17.560	3.207	0.000	13.341	0.108	0.324	2.855	76.930	125.300	12.407	46.459	-29.625	154.542	TOTAL
PROFIT INCOME	0.000	3.692	16.383	9.673	5.926	34.306	-0.132	3.586	0.000	75.433						
GROSS OUTPUT	34.585	26.072	74.918	21.285	6.591	55.183	10.629	5.966	2.855	238.085						

products for thermal generation declines rapidly, and is nothing after 1986.[31] Since this intermediate energy demand accounted for 26% of all domestic demand for refined products in 1983 the impact is considerable. In fact, total domestic demand for petroleum products is projected to decline somewhat until 1989. Looking at Tables 1 and 6, if only the growth in non-energy demand for energy is considered, the rate increases to 4.2% or 85% of GDP growth.

Prices play an important role. The costs to producers of petroleum products and biomass rises steadily, and, since the sectoral demand curves for these goods is price sensitive, less is demanded per unit of output. The middle section of Table 4 shows this.[32] Here intermediate demand for energy includes only the non-energy sectors. Intermediate demand for electricity, whose price remains constant, increases at about the same rate as the average of the sectoral gross output growth rates which are shown in the bottom of Table 4. Demand for fuels increases at about half that rate. Another important factor is the sectoral composition of output. In this scenario, transportation grows slower than the economy as a whole. Since this is the largest sectoral user of energy the impact is significant.

For private consumption, the picture is somewhat blurred. Demand for petroleum products grows faster than aggregate consumption. Apparently, the effects of the high estimated income income elasticity outweighs the price elasticity effects. Household demand for electricity increases very slowly. This is due largely to the low income elasticity which was used, suggesting

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[31] This can be seen in Table 6. Purchases of petroleum products by the electricity sector are zero in 1987, indicating that there is no longer any need for thermal generation.

[32] For this table, "intermediate uses" includes only non-energy sector demand. The refined products row is actual domestic production. The difference between this and the sum of intermediate uses and final demand is electricity demand and net trade. For electricity, the difference between generation and deliveries to non-energy sectors is due almost entirely to transmission and distribution losses.

that this parameter be re-estimated. The cross-price elasticity of electricity with respect to other energy prices may be negative, which would further dampen demand growth.

Electricity demand in this scenario grows at a lower rate than hydropower capacity. One implication is that medium term investment strategy might put greater emphasis on projects which can make economic use of this potential capacity. As demand for fuels for electric power generation declines, refinery capacity becomes greater than total domestic demand and the model disposes of the surplus through exports. Combining crude oil imports (shown in Table 4) with product trade (shown in the transactions tables), demand for imported fuels increases at 1% a year and total import costs at 2%. Thus energy import costs, while not insignificant, do not account for a very large proportion of the total import bill or the trade deficit.[33]

The exogenous assumptions for Cases 2 and 3 are same as those used for the Base case, except for crude oil and petroleum product prices. The alternative cases test the impact of a moderate rise in world prices. Instead of the 1% increase in the Base case, these prices are projected to increase at 5% annually. The trade deficit is held at the same levels as in Base case, implying that adjustments must be made in investment to maintain consistency. In Case 2, domestic petroleum product prices are increase at only 1% a year, the Base case assumption, indicating that the increases in international prices are not passed through. The domestic economy, therefore does not see the changing relative price picture and does not adjust downward either the petroleum-output ratios or the share of household consumption spent on energy.

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[33] Of course, other scenarios (including those which allocate more investment to transportation) might lead to much more rapid growth in petroleum product demand and import costs.

Table 8

HIGHER WORLD, CONSTANT DOMESTIC OIL PRICES--TRADE DEFICIT PREDETERMINED

MACROECONOMIC PROJECTIONS
(UNITS: BILLIONS OF 1983 RUPEES)

	1983	1985	1987	1989	GROWTH RATE 1983-89
PRIVATE CONSUMPTION	94.70	105.35	115.25	122.15	4.3%
PUBLIC CONSUMPTION	9.75	10.96	11.63	12.41	4.1%
GROSS INVESTMENT	35.29	38.96	41.10	45.44	4.3%
EXPORTS	33.80	43.86	49.97	57.01	9.1%
IMPORTS	53.76	63.88	70.23	80.51	7.0%
OIL IMPORTS	7.82	10.12	11.17	12.31	7.9%
TRADE DEFICIT	19.96	20.02	20.25	23.51	2.8%
NET INDIRECT TAXES	5.42	4.93	5.21	5.72	0.9%
GROSS DOMESTIC PRODUCT	114.37	130.32	142.51	150.77	4.7%

ENERGY PRODUCTION AND USAGE
(UNITS: THOUSANDS OF TONS, GWH)

	1983	1985	1987	1989	GROWTH RATE 1983-89
REFINED PRODUCTS	1777	2171	2171	2171	3.4%
-INTERMEDIATE USES	842	836	896	945	2.0%
-FINAL DEMAND	541	660	737	771	5.1%
ELECTRICITY	2114	2333	2470	2577	3.4%
-INTERMEDIATE USE	408	451	513	564	5.5%
-CONSUMPTION USE	1373	1424	1463	1497	1.5%
BIOMASS	3750	3884	4144	4373	2.6%
-INTERMEDIATE USE	1271	1305	1464	1603	3.9%
-CONSUMPTION USE	2479	2579	2680	2770	1.9%

SECTORAL GROSS OUTPUT
(UNITS: BILLIONS OF 1983 RUPEES)

SECTORS	1983	1985	1987	1989	GROWTH RATE 1983-89
PADDY AGRICULTURE	28.21	29.14	30.05	30.84	1.5%
TREE CROPS	19.83	21.17	22.97	24.78	3.8%
INDUSTRY	52.49	60.09	67.69	74.42	6.0%
TRANSPORTATION	18.11	19.66	20.70	21.61	3.0%
HOUSING	4.12	4.51	4.87	5.20	4.0%
SERVICES	43.52	51.25	58.13	63.26	6.4%
REFINED PETROLEUM	8.41	10.28	10.28	10.28	3.4%
ELECTRICITY	4.88	5.38	5.70	5.94	3.4%

Summary results for Case 2 are presented in Table 8. Through 1989, the macroeconomic projections are not very different from the Base case. This is because the price increases do not start until 1985 and their effect is gradual. GDP growth is about 10% less during the last half of this period. The impact on investment, as expected, is somewhat greater. Investment growth by the late 1980s is about 20% less than previously.

Even though prices do not change, domestic demand for petroleum products about about 10% lower by 1989 than in the Base case. Most of this reduction is due to slower growth of consumption, which when combined with an income elasticity of demand in excess of unity, leads to substantial fall-off in demand growth. Intermediate demand growth falls at the same rate as sectoral production since prices are unchanged. The increase in crude oil import costs is partially offset by increased product exports due to reduced domestic demand. The net effect is a 13% increase in the total costs of imported fuels in 1989 when compared with the Base case. Again, the effects would be more substantial if transportation grew at a faster rate. In any case, since the price increase is gradual and the full adjustments on the production side to higher energy costs occur with long lags, the effects can be expected to be very substantial during the 1990s.[34]

The only difference between Cases 2 and 3 is that the latter assumes that the higher border prices for petroleum products are passed on to domestic users. The effect of this policy should be a reduction in sectoral petroleum product-gross output ratios and in household demand for these products (per unit of total expenditure. These changes lead to lower fuel demand which should free additional resources for investment. The model captures those

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[34] This strongly suggests that to make full use of the model, a longer time horizon should be utilized.

Table 9

HIGHER WORLD OIL PRICES--TRADE DEFICIT PREDETERMINED

MACROECONOMIC PROJECTIONS
(UNITS: BIILIONS OF 1983 RUPEES)

	1983	1985	1987	1989	GROWTH RATE 1983-89
PRIVATE CONSUMPTION	94.70	105.32	115.27	128.27	4.4%
PUBLIC CONSUMPTION	9.75	10.96	11.63	12.41	4.1%
GROSS INVESTMENT	35.29	39.04	41.41	46.02	4.5%
EXPORTS	33.80	43.86	49.97	57.01	9.1%
IMPORTS	53.76	63.89	70.24	80.50	7.0%
OIL IMPORTS	7.82	10.12	11.17	12.31	7.9%
TRADE DEFICIT	19.96	20.03	20.26	23.50	2.8%
NET INDIRECT TAXES	5.42	4.88	5.07	5.54	0.4%
GROSS DOMESTIC PRODUCT	114.37	130.42	142.96	151.66	4.8%

ENERGY PRODUCTION AND USAGE
(UNITS: THOUSANDS OF TONS, GWH)

	1983	1985	1987	1989	GROWTH RATE 1983-89
REFINED PRODUCTS	1777	2171	2171	2171	3.4%
-INTERMEDIATE USES	642	835	893	938	1.8%
-FINAL DEMAND	541	651	709	726	5.0%
ELECTRICITY	2114	2333	2470	2578	3.4%
-INTERMEDIATE USE	408	451	513	565	5.6%
-CONSUMPTION USE	1373	1423	1463	1497	1.5%
BIOMASS	3750	3884	4149	4387	2.6%
-INTERMEDIATE USE	1271	1306	1469	1616	4.1%
-CONSUMPTION USE	2479	2579	2680	2770	1.9%

SECTORAL GROSS OUTPUT
(UNITS: BIILIONS OF 1983 RUPEES)

SECTORS	1983	1985	1987	1989	GROWTH RATE 1983-89
PADDY AGRICULTURE	28.21	29.14	30.07	30.89	1.5%
TREE CROPS	19.83	21.17	22.98	24.84	3.8%
INDUSTRY	52.49	60.09	67.73	74.59	6.0%
TRANSPORTATION	18.11	19.65	20.68	21.58	3.0%
HOUSING	4.12	4.51	4.88	5.21	4.0%
SERVICES	43.52	51.25	58.17	63.42	6.5%
REFINED PETROLEUM	8.41	10.28	10.28	10.28	3.4%
ELECTRICITY	4.88	5.38	5.70	5.95	3.4%

effects, as well as the positive feedback of greater investment on production and income. These second round effects will tend to push energy demand back up.

Table 9 summarizes the projections for Case 3. Although the differences are not too large in absolute terms, the results clearly illustrate how the price mechanism works. Aggregate economic growth is about in the middle of the results for the Base case and Case 2. The most significant macroeconomic result is that investment levels are only slightly lower than in the Base case. This is what permits faster growth than in Case 2, despite the decline in the endogenous output-capital ratios due to higher energy costs

Tables 8 and 9 demonstrate the impact of changing energy prices on demand. Total gross output in the non-energy sectors is 3% higher by 1989 in Case 3, but intermediate demand for petroleum products actually falls by 1%. Household demand for petroleum products declines 5%, with aggregate consumption unchanged. The net effect on the costs of imported fuels is a 2% reduction by 1989. These results provide a general equilibrium rationale for passing future price changes through to the economy. Whatever direct losses there are due to higher costs for producers and households are quickly made up for in terms of greater growth of production and real income than would otherwise be possible. These positive effects would show up more dramatically as the model looks farther into the future.

V. Conclusions

The interrelations between energy issues and general development problems and policies are complex and the analysis which deals with such interrelationships should take into account the essential features of that complexity. The interactions between energy policies and other features of an economy must certainly be one of those essential features. The relationships are seldom, if ever, one way, from energy policies to the rest of the economy or from economic influences to energy issues.

The major approaches to energy policy analysis have been reviewed here: project evaluation, technology assessment, energy sector assessment, macro simulation models, economy-wide optimization models and computable general equilibrium models. Each of these approaches has certain strengths which make it useful in particular applications. Problems arise when the methods are applied to problems for which they are inadequate or in circumstances in which they are unwieldy, if not infeasible. In principle, all of the approaches, except the first and the last two suffer from two major deficiencies. First, they are partial in nature, i.e. they take into account only one or a few relations between energy and economic issues. Second, the relationships which they embody are one-way, from energy to the economy, or vice-versa, but not back and forth.

The use of correctly estimated shadow prices in project evaluation can, in principle, resolve these deficiencies. The difficulty in making the principle into a practical tool is in estimating shadow prices, not just for energy in various applications, but for all the other changes which reverberate through an economy. When an energy project is small, relative to the economy as a whole, those reverberations will also be small and can be expected to be dampened relatively quickly. When a project or policy is

large, or has an sector-wide or economy-wide scope, project evaluation is, at best, unwieldy or at worst, infeasible. If it can be implemented at all, in such circumstances, project evaluation essentially turns into one of the two last approaches mentioned above: economy-wide optimization models or computable general equilibrium models.

These latter models are general in scope and do take into account energy-economy interactions. While they can become complex, in terms of the number of features which they contain, each one of those features reflects a rather standard aspect of conventional microeconomic analysis and can be made readily understandable. Each approach has certain advantages and disadvantages The economy-wide optimization models treat intertemporal issues in a more satisfactory manner but are unwieldy in analyzing price, tax and subsidy question. The computable general equilibrium models are better with the latter type of issues but are myopic in their intertemporal analysis. Yet both types of models are general in scope and take energy-economy interactions fully into account.

The difficulties associated with these latter two types of models have to do with the demands which they make for data, time and resources of expertise and computational capabilities. These difficulties were the inspiration for the particular model developed here, which is a simple intertemporal version of a computable general equilibrium model. We have demonstrated the feasibility of constructing such a model rather quickly, with a quite limited budget and with data no better than in many developing countries by actually creating and applying the model to the Sri Lankan economy under these constraints. Three alternative solutions are provided to demonstrate the potential of the model.

The test of the Sri Lankan model is not only in its formulation and embodiment with data but also in the insights which it can provide. The three alternative solutions presented are intended to illustrate such insights and should not be interpreted as being definitive. The base case solution demonstrates the interrelationships in the economy and raises a number of questions. One of these, for example, is related to the consistency of the official forecast or plan. That projects a decline in the trade deficit while the model forecasts an increase, when all the other conditions of the official forecast are embodied. Since there are some questions of interpretation which could not be resolved, this result should not be taken as a definitive criticism but, rather, intended only as an illustration of a potential application.

In the second application the effects of a significant increase in international oil prices are analysed under the assumption that the price increase is not passed on to the domestic economy. Even so, the constraint on the trade deficit leads to a reduction in domestic income and, consequently, in energy and other types of consumption. In the third application, the assumed increase in energy prices are passed on to the domestic economy and the contractionary effects of the price increase become even more pronounced.

The qualitative character of these last results could be deduced without going to the trouble of constructing this or any other type of quantitative model. But only a model such as this could give assurance that quantitative estimates of the implications of policies and shocks were estimated with a technique whose essential features matched the character of the real interactions in the economy.

Finally, it should be noted that, while there are no deep mysteries involved in the construction of a model of the type presented, neither is the

exercise an obvious one. The first time is the hardest, however, and practice, if it will never achieve perfection, will, at least, quicken and improve the approximation.

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Introduction

In many developing countries, transportation is the major market for liquid fuels. Although the share of oil supplies accounted for by the transport sector varies from country to country, it is estimated that for developing countries as a group about half of the oil used is consumed in transport.

Consumption of transport fuels is expected to rise rapidly with economic growth. Industrialization and agricultural development imply increased freight and passenger transport; further, higher real incomes stimulate demand for leisure related transportation.

In transport, unlike the other end-use sectors, possibilities of fuel switching are limited, at least for the time being. Given the existing stock of transport equipment, virtually all of the increase in consumption of transport fuels for the next fifteen years or so will be in the form of petroleum products.

A continued rapid expansion in consumption of petroleum products will exacerbate problems of economic management in the oil-importing developing countries. For many of these countries the importation of transport fuels alone is equivalent to 20 percent of total export earnings. Rising consumption of transport fuels, by cutting into exportable surpluses, also poses problems for some oil-exporting countries.

In these circumstances a clearer idea of the relationships determining consumption of transport energy, the likely growth in consumption of transport fuels, and an evaluation of the policies which could modify this trend, while still providing the transport services necessary for economic development, is of interest not only for energy management but also for wider macro-economic policy aims.

Trends in Transport Fuel Consumption

We group our selected countries into low, medium and high income developing countries, and high income oil exporters, centrally planned economies and industrial countries for reference.

There are considerable contrasts in transport energy consumption among these income categories. From 1971 to 1981 consumption in the low income developing countries rose very gradually, by about one percent a year (see Table 1). By contrast, the increase in consumption in both middle and high income developing countries was much more rapid, about 3.5 percent annually. Per capita consumption of transport fuels in the high income oil exporting countries rose even more rapidly, by 14 percent annually. In the industrialized countries the overall annual average increase at 1.5 percent was barely higher than in the low income developing countries.

Although the period covered by these data is not long it includes two major events, the increases in the international price of petroleum in 1973/74 and 1979/80. These events appeared to have a distinct impact in the different groupings. In the selected low income developing countries consumption continued at a relatively stable level throughout the two oil shocks. In the middle and high income developing countries rapid rates of growth came to a halt in both 1974/75 and 1980/81. In the high income oil exporters rapid rates of growth continued throughout the period. In the industrial countries consumption levelled off after 1974 and fell after 1979.

Another set of contrasts lies in the wide variation in consumption of transport fuels among country groupings (see again Table 1). Per capita consumption of transport fuels is almost 40 times higher in the industrial countries as in the low income developing countries. Consumption in the

Table 1

Per Capita Transport Energy Consumption
in Selected Countries by Categories of Countries
(koe)

	1971	1973	1974	1979	1980	1981	Annual Avg. Increase
Low Income Dev.[1]	24.1	22.8	23.5	25.1	25.7	26.6	1.0
Middle Income Dev.[2]	58.0	69.5	71.7	88.2	88.1	83.2	3.7
High Income Dev.[3]	177.2	201.4	203.0	247.2	252.3	250.2	3.5
High Income Oil Exp.[4]	215.0	245.8	281.6	589.2	688.8	772.9	13.6
Centrally Planned	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
Industrialized[4]	887.5	985.0	958.9	1102.3	943.4	1030.1	1.5

Note: Weighted averages

[1]Includes Bangladesh, Burma, India, Kenya, Pakistan, Zaire, Zambia.

[2]Includes Bolivia, Colombia, Ecuador, Egypt, Indonesia, Iran, Ivory Coast, Jamaica, Korea, Morocco, Nigeria, Peru, Philippines, Thailand, Tunisia, Turkey.

[3]Includes Algeria, Argentina, Brazil, Chile, Gabon, Greece, Hong Kong, Iraq, Malaysia, Mexico, Panama, Portugal, Singapore, Taiwan, Uruguay, Venezuela.

[4]Includes all countries listed in Appendix Table 1.A.1.

middle and higher income developing countries is also much lower than in the industrial countries though less so in 1981 than ten years earlier. In 1971, for example, per capita consumption in the middle income developing countries stood at 6 percent and high income developing countries at 20 percent of industrial countries levels. By 1981 these shares had increased to 8 percent and 25 percent, respectively. But the most striking of all is the case of the high income oil exporters. In 1971 per capita consumption of transport fuels in these selected countries was about one quarter the level of the industrial countries. By 1981 their consumption had risen to 77 percent of industrial countries.

Road transport is, for most countries, the largest single transport sector accounting for about 80 percent of the total. Gasoline is the major road transport fuel accounting for about 70 percent of the total. Data (see Table 2) on gasoline consumption are available for a larger number of countries (67 in all) for the 1960 to 1982 period thus enabling us to make a more complete analysis of gasoline use.

Note the wider variation in rates of increase in gasoline consumption over the 22 year period--a much longer period than we have available for other transport fuel products. in the 1960/70 period, that is before the increase in oil prices, the lowest annual rates of growth (2%) were in the low income developing countries. Rates of growth were much higher in the other groups--3.5 percent in the middle income developing countries, 4.4 percent in the high income developing and 5.7 in the high income oil exporters. So far it appears that the rates of increase of gasoline consumption accelerated as average incomes rose. However, at the highest income levels, in the industrial countries, rates of increase fell back to 4 percent. In this latter case the lower rate of consumption was largely

Table 2

Per Capita Motor Gasoline Consumption
(koe)

	1960	1965	1970	1975	1980	1982	Annual average income 1960-70	1970-82
Low Income Dev.	3.2	3.5	3.9	3.2	3.4	3.6	2.0	-0.7
Middle Income Developing	20.0	21.2	28.1	37.9	42.3	40.9	3.5	3.2
High Income Developing	70.6	84.4	108.1	124.9	138.0	135.2	4.4	1.9
High Income Oil Exporters	69.8	97.3	121.1	204.5	397.9	408.9	5.7	10.7
East bloc.	103.5	136.5	182.2	242.4	257.1	275.4	5.8	3.5
Industrial Countries	399.7	476.2	595.7	677.1	694.0	668.9	4.1	1.0

Countries not included from base list are: Bangladesh, China, Malawi, Zambia, Malaysia, Panama, Taiwan, Trinidad & Tobago, Yugoslavia, Czechoslovakia, New Zealand.

due to the U.S. where consumption of gasoline rose by only 2.6 percent a year in this period. In many other industrialized countries consumption per capita doubled from 1960 to 1970, that is an annual average increase of over 7 percent. Thus the picture emerges of a rapid increase in annual consumption as incomes rise tapering off only at the very highest income levels as in Sweden and North America.

This pattern was disturbed during the 1970/82 period when oil prices rose five fold in real terms. In all countries except for the high income oil exporters the rates of increase in consumption after 1970 fell significantly. However, there was little indication of a consistent pattern of growth rates across categories of countries as there was before 1970.

Another noticeable characteristic of gasoline consumption is the wide variation in consumption levels among countries. Per capita consumption in the industrial countries is well over 100 times higher than in the low income developing countries. The extremes are even greater between individual countries. Gasoline consumption in the United States is, for example, over 300 times higher than in India and the People's Republic of China.

Part of the wide disparity in gasoline consumption between the lowest and highest income groups could be due to differences in consumption of diesel, the other major road transport fuel. Data for diesel fuel consumption in road transport are not available for many countries and are in any event subject to some inaccuracy. With this reservation the rise in diesel fuel consumption in transport appears to have been much more rapid than the rise in gasoline.

Consumption in the other transport sector is much smaller and tends to decline or at most remain constant as a share of total transport energy.

The Determinants of Transport Energy Consumption

The level of income would be expected to be a major factor in the amount of transport demanded and therefore in consumption of transport fuels. Indeed, this relationship has already been built into the summary tables presented earlier where categories of countries were defined by income level. From these tables it will be recalled that level of income appeared to have a strong influence on energy consumption. Invariably levels of transport energy consumption were lower in low income countries and higher in the rich countries.

The reasons for this pattern are clear enough. As economic activity expands there is need for more transport of both freight and passengers. At the same time, higher incomes lead to increased demand for leisure related travel. Freight transport increases faster--about 10 to 20 percent faster--than GDP in developing countries and only slightly less in the industrial countries. In some countries, especially those undergoing structural change, the increase in freight transport is much higher than the rate of increase in GDP. The increase in passenger traffic far exceeds the rise in freight traffic. Thus passenger traffic in the developing countries rise by 2 to 3 times the rise in GDP.

One of the most debated, and debatable, issues in transportation is the influence of the price of transport fuels--gasoline and auto diesel--on consumption. Prices of gasoline and diesel vary widely across countries even though they are highly standardized products. For premium gasoline,

prices range from just over 30 cents a gallon (in Trinidad and Tobago and Venezuela) to over $5.000 (in S. Korea and Uganda). For diesel, prices range from around 10 cents a gallon (Venezuela and Egypt) to over $3.00 (in Burundi and Uganda).

A second feature of comparative energy prices illustrated in Table 3 is that countries are not distributed evenly throughout this wide range but tend to be concentrated, or clustered around three distinct levels, low, medium and high. For premium gasoline, for example, low prices are defined as those under $1.60 a gallon. Although there is a considerable range of prices in this category, this group of countries is quite distinct from the next group of countries (with medium price levels) whose prices are concentrated in the $2.10 to $2.60 a gallon range. In the third group of countries with high prices, prices are typically near $3.00 and over.

A similar pattern of concentration applies to diesel prices, though at generally lower levels. Thus in the low price group prices are well under $1.00 per gallon, medium prices are concentrated in the $1.20 to $1.70 level, and high prices are well in excess of $2.00. The distinction between medium and high diesel prices is much clearer than between medium and high gasoline prices.

A further observation from Table 3 is that differences in price levels of transport fuels are not closely related to level of income and development. Poor, middle income and rich countries appear in each category for both premium gasoline and diesel.

There are two main reasons for these differences in price levels among countries--differences in tax treatment of transport fuels and differences in crude oil prices. A third factor, of importance to a limited number of

Table 3

Premium Gasoline: Selected Countries
Ranked by Price Level
(US $ at 1981 prices and exchange rates)

LOW (under $1.60 a gallon)

Developing				Industrial & Saudi Arabia	
Argentina	156	Mexico	110	Canada	126
Bolivia	140	Nigeria	128	USA	136
Burma	42	Peru	110	Saudi Arabia	25
Colombia	96	Trinidad & Tobago	35		
Ecuador	80	Venezuela	31		
Egypt	71				
Indonesia	33				
			12		

MEDIUM ($1.61 TO $2.80)

Developing				Industrial	
Bangladesh	207	Singapore	191	Australia	183
Cameroon	240	S. Africa	223	Belgium	280
Chile	207	Thailand	214	Japan	272
Dom. Repub.	257	Turkey	174	Netherlands	258
El Salvador	256	Greece	237	Switzerland	249
Honduras	208	Ethiopia	266	Sweden	266
India	253	Guatemala	200	United Kingdom	265
Jamaica	217	Malaysia	213		
Kenya	274	Nicaragua	272		
Morocco	275	Sierra Leone	238		
Pakistan	216	Sri Lanka	200		
Panama	226	Sudan	230		
Philippines	250	Yugoslavia	286		
			26		7

HIGH (over $2.81)

Developing				Industrial	
Brazil	300	Uruguay	417	Denmark	289
Burundi	450	Zambia	432	Finland	288
Ghana	394	Paraguay	451	France	299
Israel	307	Rwanda	283	Italy	284
Ivory Coast	365	Senegal	302		
Korea, Rep. of	582	Tanzania	437		
Malawi	317	Uganda	544		
Portugal	299	Zimbabwe	312		
			16		4

countries, is exceptionally high transport and distribution costs which are largely responsible for the high prices in landlocked countries such as Malawi and Zambia. For most countries, however, variations in tax policies and crude oil costs are the major source of variation.

Gasoline has traditionally been subject to excise taxes, imposed originally for revenue raising purposes rather than conservation. As a taxable commodity gasoline had several advantages: sales of gasoline until recently rose steadily and rapidly thus ensuring an increasing tax revenue, and, as private motoring was confined in many countries to the relatively well to do, excise taxes on gasoline did not raise politically difficult problems of social equity.

Gasoline taxation is widespread, even in those countries such as the oil exporters where pump prices are quite low. Table 4 illustrates tax levels for a number of countries for which data are available. These data for 1981 indicate a considerable range in tax rates for premium gasoline, from under 20 percent to over 60 percent. Most countries, however, fall into the 30 to 50 percent range. In the majority of countries therefore, whether developing or industrial, taxes accounted for between one third and one half of the pump price of regular gasoline in 1981.

As the pump price varies so greatly taxes expressed as a share of the total can be misleading. The 30 percent tax of a country with $3.00 gasoline ($1.00) is obviously higher than the 70 percent tax of a country with $1.00 (70 cents). Table 4 therefore also gives the amount of tax in cents per gallon. Again this varies widely from under 20 cents (Saudi Arabia, the US, Bolivia, Venezuela) to well over $1.50 (in Portugal and France). As might be expected, the tax per gallon tends to be lower in low price countries.

Table 4

Premium Gasoline Prices and Taxes, 1981
Selected Countries
(US cents per US gallon 1981 prices
and exchange rates)

Country	Pump price Premium gasoline	Taxes	Price before tax	Tax as share of pump price %
Developing				
Bolivia	140	16	124	11
Brazil	252	99	153	39
Colombia	96	72	24	75
Greece	237	95	142	40
India	253	106	147	42
Jamaica	217	79	138	36
Kenya	274	120	154	44
Mexico	110	67	43	61
Pakistan	216	68	148	31
Peru	110	40	70	36
Philippines	250	121	129	48
Portugal	299	185	114	62
Singapore	191	66	125	35
Spain	284	97	187	34
Thailand	214	125	89	58
Turkey	174	8	166	5
Venezuela	31	13	18	42
Industrial				
Belgium	280	146	134	52
Canada	126	34	92	27
Denmark	289	149	140	52
France	299	164	135	55
Finland	288	95	193	33
Germany	243	111	132	47
Japan	272	99	173	36
Netherlands	258	127	131	49
Sweden	266	121	145	45
Switzerland	249	111	138	45
United Kingdom	265	136	129	51
USA	136	13	123	10
Saudi Arabia	24	-	24	-

It is not easy to generalize about the reasons behind different tax rates. History, tradition, fiscal needs, and the structure of revenues have all played a part. In recent years balance of payments problems and security concerns have played a larger role. In 1981 for example virtually all of the countries in the high price category were totally dependent on imports for their oil supplies and therefore more likely to be concerned about both the cost of imports and the vulnerability of their economies to disruption.

Differences in pump prices are also due to differences in pricing policies for crude oil. Countries which import all petroleum supplies have little choice but to pass on the full costs to consumers. Countries which have domestic production, however, can and frequently do price supplies to the domestic market lower than international prices. Thus, for gasoline, all the countries in the low price category are oil producers. Nine out of a total of 15 are net exporters, and 5 are virtually self-sufficient. The United States is the only country in the low category which imports a significant share of its petroleum supplies. Within the low price category there is a marked tendency for prices to be lower in the producer exporter countries than in the self-sufficient or importing countries.

In the most general terms, the difference in gasoline prices between the low price countries and the others is about 40 percent due to higher taxes and 60 percent to higher pre-tax prices.

Diesel prices are invariably lower than gasoline. This differential is related to the different markets for the two fuels. Traditionally gasoline has been used for private passenger transport, and diesel in mass transit and freight transport. Governments, especially in developing

countries, therefore kept tax rates lower on diesel in order to help develop these markets.

The differential between diesel and gasoline prices varies from country to country. A fairly typical range is for gasoline prices to be some 50 to 100 percent higher than diesel but there are examples of gasoline prices being 3 times higher or more. If the gap between the two grows too wide the purpose of the differential will be defeated as the cheaper diesel fuel will be diverted increasingly to private passenger use or other nontransport use. There is evidence that this happened on a significant scale in both Costa Rica and Brazil during the 1970's.

The foregoing analysis on the structure of transport fuels applies to one year, 1981. Over the past 10 years or more, however, there have been major changes in the crude oil market which have affected both trends and the structure of transport fuel prices.

The outstanding development has been the increase in prices of transport fuels since 1973. Before 1973 in most countries real gasoline and diesel prices had declined, reflecting the decline in the real price of crude oil which took place in the 1960's. From 1973, however, this trend was reversed, with significant increases in gasoline prices in almost all countries, averaging about 85 percent in developing countries. Diesel prices in the developing countries probably rose by about 40 percent.

The reason behind this difference in rates of increase of crude and gasoline prices lies largely in the tax structure--the higher the tax, the smaller the increase in the final price resulting from higher crude prices. In countries with high taxes, crude represents a relatively small part of the total sales prices so that even a large increase in crude oil prices has quite a limited impact on the final price.

Car ownership is a major factor in gasoline consumption. Table 5 illustrates both the rapid increase in car ownership rates and the variation in rates across groups of countries. The increase in car ownership was greater than the rise in gasoline consumption leading to a decline in gasoline consumption per car (see Table 6). This decline could be due to changes in automobile technology, decrease in car use, and changes in the composition of the car fleet.

An estimate of car prices was made for selected countries. These are compared in Table 7 with gasoline prices. Only one of the selected countries, Republic of Korea, has both high car and gasoline prices (as we have noticed before both car ownership and gasoline consumption is lower than in other comparable countries). At the other end of the scale only 5 countries U.S. and Canada, Saudi Arabia, Libya and Kuwait have both low car and gasoline prices. Here again there are exceptionally high rates of car ownership and gasoline consumption in these countries.

In the other countries levels of gasoline and car prices are not closely correlated. Industrial countries typically have low car prices but high gasoline prices, perhaps a legacy of the revenue raising motives behind gasoline taxation. Many of the developing countries with low gasoline price countries have high car prices suggesting that cars are considered luxury items of consumption. From a policy point of view, therefore, in many countries mixed signals are being provided to the motorist, who may be faced with high car prices and low gasoline prices, or low car prices and high gasoline prices.

Table 5

Car Ownership
(# cars per 1000 people)

	1960	1965	1970	1975	1980
Low Income Dev.[1]	0.85	1.1	1.4	1.6	1.7
Middle Income Dev.	2.58	3.52	5.19	7.41	11.99
High Income Dev.	14.44	20.79	31.27	49.72	69.54
High Income Oil Exp.	10.91	20.56	33.59	55.11	123.35
Eastern Bloc.	4.88	7.72	13.62	29.31	53.17
Industrialized	154.1	203.3	261.2	323.5	385.2

excluding China.

Table 6

Consumption of Gas per Car
(koe per car)
(unweighted average, using subset of 75 countries)*

	1960	1970	1982
Low Income Dev.	4288	2819	2467
Middle Income Dev.	8870	6106	3957
High Income Dev.	6284	3431	2519
High Income Oil Exp.	6192	3747	3018
East Bloc.	15006	10901	3339
Industrial	3684	1635	1303

*Countries that were excluded are: Bangladesh, China, Malawi, Zambia, Burma, Malaysia, Panama, Taiwan, Trinidad & Tobago, Yugoslavia, Czechoslovakia.

Table 7

Selected Countries Categorized by
Price of Cars and Gasoline

		Gasoline Prices		
		Low	Medium	High
Car Prices	Low	Kuwait Libya S. Arabia Canada USA	Cameron Netherlands Sweden UK Germany	Malawi Denmark France Italy Brazil
	Medium	Bolivia Colombia Nigeria Peru Argentina Mexico	Kenya Dom. Republic Jamaica Morocco Chile Malaysia Australia Switzerland	Ghana Israel Finland
	High	Ecuador Egypt Indonesia	Bangladesh India Pakistan Philippines	Rep. of Korea

Case Studies

This study will contain two case studies of India and Ecuador. As the Ecuador study has been delayed it is not possible to compare the two countries at this point. For information Table 8 gives some comparative data for illustrative purposes.

Regression Analysis

In an effort to estimate the effect on transport energy consumption of per capita income, price and a set of socioeconomic variables, we carried out a series of regression analyses. This was done in two stages. First, transport variables on a per capita basis were related only to per capita income and price to yield estimates of income and price elasticities. The elasticity shows the percent change in a transport variable for a given percentage change in the explanatory variable, here income or price. Then the transport variables were related to income, price and the socioeconomic variables, yielding elasticity estimates for all of those variables. For both developing and industrial countries the results obtained for income and price were essentially the same for the two stages. The first stage, however, afforded us larger samples and more detail on the effects of income and price than we could obtain from the second stage, which had the primary goal of examining the effects of the socioeconomic variables. Those variables included density of the road network; three measures of population distribution: population density, percent of population in urban areas, and percent of the urban population in the largest city; year, to measure time trend; percent of the population of medium age (15-65); and change in per capita income ranking from 1960 to 1980, a measure of a

Table 8

Ecuador and India: Transport Sectors Compared - 1980 and 1981

	Ecuador	India
Per capita transport fuel consumption (koe)	264	27
Per capita gasoline consumption (koe)	179.4	2.6
Increase in gasoline consumption (annual average %)	5.8	1.1
Gasoline as % of total transport	68	10
RGDP per capita (1975$)	1639	516
Transport fuels (koe per 000 1975$)	161.1	52.3
Gasoline (koe per 000 1975$)	109.5	5.0
Gasoline prices (1981 US cents per gallon)	80	253
Diesel prices (1981 US cents per gallon)	44	119
Car ownership (# per 000 population)	11.2	1.3
Truck ownership (# per 000 pop.)	24.6	1.2

country's relative growth in income. Use of competitive transport mode was also included in some of the equations.

Major conclusions based on the regression results were as follows:

(1) Per capita consumption of transport and of transport fuels increases somewhat more than proportionately as per capita income increases.

(2) Per capita consumption falls less than proportionately as price increases. The price response is more limited in developing than in industrial countries.

(3) In conjunction, the first two conclusions imply that world and developing country levels of transport energy consumption should increase considerably over time.

(4) Our evidence suggests that higher energy prices have caused some shift from road to rail use in the developing countries.

(5) Not surprisingly, alternative energy modes are usually competitive; increased use of one reduces the use of another.

(6) Increased density of the road network implies general increases in transport consumption and fuel use, with increases not limited to directly related consumption categories. This suggests there are complementary as well as competitive relations between modes, for example rail "piggybacking" of trucks. In the developing countries, fuel efficiency appears to increse with increased road density.

(7) As urbanization increases, fuel use probably decreases. Increased population density is clearly associated with decreased fuel consumption.

(8) Long term trends in use are running against rail use and in favor of road and air transport use.

(9) Among the developing countries, higher than average income growth was associated with reduced rail consumption and increased auto registrations and air transport fuel consumption. Among the industrial countries exactly the opposite effect prevailed. Cause and effect relations are not obvious here. However, the results for developing countries may be an indicator or even display a source of development. Those for the industrial countries probably are heavily weighted by the experience of Japan and France, which had high income growth and considerable rail investment.

Our estimates for income and price elasticities were as follows:

	Income elasticity estimates	
	Developing countries	Industrial countries
Fuel		
Gasoline	1.4	1.3?
Road fuel	1.3	1.3
All transport fuel	1.2	1.3
Air transport fuel	1.1	1.5
Rail transport fuel	0.2?	1.5
Water transport fuel	0?	0.3
Transport Category		
Auto registrations	1.65	1.3
Truck registrations	1.1	0.8
Rail passengers	1.0	-0.7
Rail freight	1.5	2.6
Fuel Efficiency		
Gasoline/car	-0.3	0.4

Questions marks indicate both the exercise of judgement and some concern about possibly anomalous results, subject to revision given better evidence.

	Price elasticity estimates	
	Developing countries	Industrial countries
Fuel		
Gasoline	-0.4	-0.6?
Road fuel	-0.2	-0.6
All transport fuel	-0.15	-0.6
Air transport fuel	-0.3	-0.9
Water transpot fuel	0.2	-1.2
Rail transport fuel	0.8	-0.8
Transport category		
Auto registrations	-0.65	-0.3?
Truck registrations	-0.4	-0.2?
Rail passengers	1.0	1.0
Rail Freight	1.5	-0.6
Fuel Efficiency		
Gasoline/car	-0.6	-0.6

Fuel price elasticities are lower, but auto and truck registration elasticities are higher for the developing than for the industrial countries.

For the developing countries, the positive price elasticities for rail transport fuel and water transport fuel were interpreted as indicating some switching to rail and water transport from road transport given the large price increases of the 1970's.

For the groups of developing countries categorized by income level, the key elasticity estimates were:

	Income elasticity			Price elasticity		
	Low income	Medium income	High income	Low income	Medium income	High income
Motor gasoline	1.2	1.4	1.5	-0.5	-0.4	-0.3
All transport fuel	0.85	1.3	1.1	0	-0.2	-0.1
Auto registrations	1.7	1.5	1.6	-0.6	-0.6	-0.6
Truck registrations	1.2	1.1	1.0	-0.6	-0.4	-0.5

The divergence in income elasticity pattern between motor gasoline and auto registrations may be explainable by differences in gasoline use per car, with lower income developing countries apparently using their cars more intensively than higher income developing countries.

Future Transport Energy Consumption

The results of the regression analysis can be combined with assumptions about increases in prices and incomes to estimate future levels of transport energy consumption (see Table 9). Note the high income elasticities, the relatively modest increase in gasoline prices and the low to moderate price elasticities. This means that consumption of transport fuels and vehicle ownership will continue to rise rapidly, outstripping in most part the increase in economic activity; and that the expected rise in prices of transport fuels will not be sufficient to moderate the trend significantly (see Table 10).

Given the many unknowns it is not easy to judge how great a burden consumption at this level will be on the economies of these countries. However, a fifty percent increase in oil consumption combined with a fifty percent increase in the dollar price of oil implies, in the absence of reduced oil consumption in other sectors or substantially increased domestic oil production, a more than doubling of the oil import bills for the oil importing countries. Oil imports account at present for about 37 percent of export earnings, an unsustainably high level. The reduction of this share to a more manageable level, say about 20 percent would therefore require an average growth in exports of over 10 percent annually--not an impossibly high level by 1960s and 1970s standards (when economic growth rates were also much higher) but higher than the 1980s levels and high in

Table 9

Increases in Price and Income and Price and Income Elasticities

	Increase in Income 1981-2000 (%)	Income Elasticity	Increase in Price 1981-2000 (%)	Price Elasticity	Time Trend
Total transport Fuels					
1. Low income dev. countries	56	0.85	22-42	0.0	
2. Middle income dev. countries	53	1.3	38-64	-0.2	
3. High income dev. countries	54	1.1	33-58	-0.1	
Gasoline					
1. Low income dev. countries	56	1.2	22-42	-0.5	
2. Middle income dev. countries	53	1.4	38-64	-0.4	
3. High income dev. countries	54	1.5	33-67	-0.3	
Car Ownership					
1. Low income dev. countries	56	1.7	0-50	-0.6	0.5
2. Middle income dev. countries	53	1.5	0-50	-0.6	0.5
3. High income dev. countries	54	1.6	0-50	-0.6	0.5
Trucks					
1. Low income dev. countries	56	1.2	0	-0.6	0.5
2. Middle income dev. countries	53	1.1	0	-0.4	0.5
3. High income dev. countries	54	1.0	0	-0.5	0.5

Table 10

Per Capita Consumption of Transport Fuels, and Car and Truck Ownership

	1981	2000	Annual increase %
Total Transport Fuels (koe)			
1. Low income developing countries	26.6	37.93	1.9
2. Middle income developing countries	83.2	131.0-135.6	2.4-2.6
3. High income developing countries	250.2	392.7-399.5	2.4-2.5
Gasoline (koe)			
1. Low income developing countries	3.6	6.4-6.9	3.0-3.5
2. Middle income developing countries	41.6	61.4-65.8	2.1-2.4
3. High income developing countries	136.6	217.5-229.1	2.5-2.8
Cars (# per 1000 pop.)			
1. Low income developing countries	1.7	3.5-4.4	3.9-5.1
2. Middle income developing countries	11.4	18.8-23.9	2.7-4.0
3. High income developing countries	68.2	119.1-151.9	3.0-4.3
Trucks (# per 1000 pop.)			
1. Low income developing countries	1.4	2.7	3.5
2. Middle income developing countries	6.9	12.0	3.0
3. High income developing countries	23.0	39.9	2.9

relation to projected GDP growth rates. Conservation of oil in all uses and especially in the transport sector is therefore likely to continue to be high on the policy agenda.

Our analysis leads to a number of conclusions relevant to policy. The first is that given low price elasticities especially for total transport fuel, the magnitude of the price rises resulting from higher crude oil prices alone will not be sufficient to achieve significant savings in transport energy. Increased taxes on gasoline could have a substantial effect on gasoline consumption, and a consistent policy towards both cars and gasoline could achieve savings in gasoline without causing unduly disruptive taxes increases on either. This last consideration is important given the possibilities of substituting diesel for gasoline. Substitution imposes limits on the extent to which gasoline prices can be raised without also increasing diesel prices.

Important though pricing policies are the combination of low price elasticities combined with high income elasticities in the context of extreme foreign exchange constraints implies that additional actions to moderate the rise in transport energy will be needed. The most promising appear to be increased efficiency in the vehicle fleet, improvements in alternatives to private passenger transport (bus services, "informal" transport) reduction in congestion, and improvement in truck load factors.

PETROLEUM PRICING IN DEVELOPING COUNTRIES

by

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INTRODUCTION

Oil prices are regulated in virtually every developing country.[1] Economists, oil businessmen, politicians, and government bureaucrats usually have diverging views on the "best price" for petroleum products. There should be consensus, however, on the following statements of priority:

> For governments of developing countries, it is far more important to get the **overall** oil price right than to get individual product prices right.
>
> For agencies disbursing development assistance, it is far more important to help governments implement a **program** of reform than a **one-shot** price change.
>
> For students of petroleum (and other) pricing policies in developing countries, **institutional** and **political** factors dominate the policy-making process, and these factors deserve far more systematic study than they have received. In the absence of "creative tension" between groups favoring lower and higher prices, it is unlikely that a sound pricing program can exist.

A complete oil pricing analysis should be a kind of Input/Output exercise, as illustrated in figure 1. Certain costs, objectives, and political influences are inputs to energy price determination. The outputs are sets of energy prices over time that influence the welfare of particular groups in society as well as, naturally, society as a whole. Some sets of prices may be more efficient than others, some may be regarded as more equitable.

FIGURE 1

ENERGY PRICING: INPUTS, OUTPUTS, EFFECTS

```
INPUTS                                          OUTPUTS            EFFECTS

 Accounting,
 economic                                                     o Income Distribution
 Supply  -----------o                        o-- Absolute---- o Macroeconomic impact
 Costs              |   ____________          |   prices       o Balance of Payments
                    |  |    PRICE    |        |
 Government ---------o --| DETERMINATION |---o-- Relative-----o Energy consumption incentives
 Objectives         |  |   PROCESS   |        |   prices       o Energy production incentives
                    |  |_____________|        |
 Political  ---------o                        o-- Wholesale----o Energy production incentives
 Influences         |                         |
                    |                         o-- Retail-------o Energy consumption incentives
 Consumer-----------o                                          o Government revenues
 Preferences                                                          |
   |                  ___________                                     |
   |- - - - - - - - - | FEEDBACK |                                    |
                      | "Creative | - - - - - - - - - - - - - - - - - o
                      |  Tension" |
                      |__________|
```

The diagram provides a framework for discussion of the principal findings of a study of petroleum product pricing in developing countries.[2] Research focused on Brazil, Argentina, Ecuador, the Sudan, South Korea, and Thailand. This article describes the evolution of overall and relative petroleum product prices, both retail and wholesale. It then reviews the price determination process and arrives at several propositions about countries' propensities to implement efficient pricing systems.

The project's principal purpose has been to review in considerable detail the state of petroleum prices in the subject countries, and to assess the institutional constraints on the implementation of efficient pricing systems. Hence this article deals more with the policy process than with measurement of economic efficiency, it is

more a study of the application of economic principles than of the principles themselves.

THE OVERALL PRICE OF OIL AND MACROECONOMIC POLICY

The absolute or overall price of oil[3] affects a nation's aggregate demand for goods and services, the balance of payments, public sector finance and the money supply. When domestic prices of oil change suddenly, demand for other goods and services is likely to change. If oil is an important import or export, the demand for foreign currency or the supply of foreign currency changes, causing the domestic currency to tend to appreciate or depreciate. When changes in the price of oil cause the changes mentioned above, the money supply may also be affected if the domestic monetary authorities choose to reflate or deflate in reaction to other changes in these macroeconomic variables.

The scale of the effect of oil prices on other macroeconomic variables, of course, is the real issue. In the set of developing countries studied here, the 1979 oil price increase was one economic shock, and the devaluation of national currencies was another shock that forced governments to reexamine their internal oil pricing policies. In both shocks -- the latter following very closely after the former -- governments had to decide whether to align overall oil prices gradually or suddenly or not at all with the international price structure.

With respect to the level of the overall price of oil, a government has four basic options:

1) Autarchic strategy: do not align the domestic overall oil price with the world price; base it instead on some other factor such as the cost of domestic oil production (Ecuador, Argentina)

2) "Managed market price" strategy: the domestic overall oil price is loosely based on international prices, but does not follow every twist and turn of international spot or even contract prices (Brazil, Sudan, Thailand)

3) "Industry security" strategy: set the overall price at levels that safeguard the financial

viability of the domestic oil industry. Typically, this approach creates an overall price higher than international spot prices, and calls as an auxilary policy for product import restrictions (South Korea).

4) Free market: very few countries, either developed or developing, allow oil prices to be determined without government interference. Among developed countries, the United States, West Germany, and the United Kingdom do not regulate prices. Among developing countries, Chile, Singapore, and Hong Kong are among the very few who refrain from regulating oil product prices.

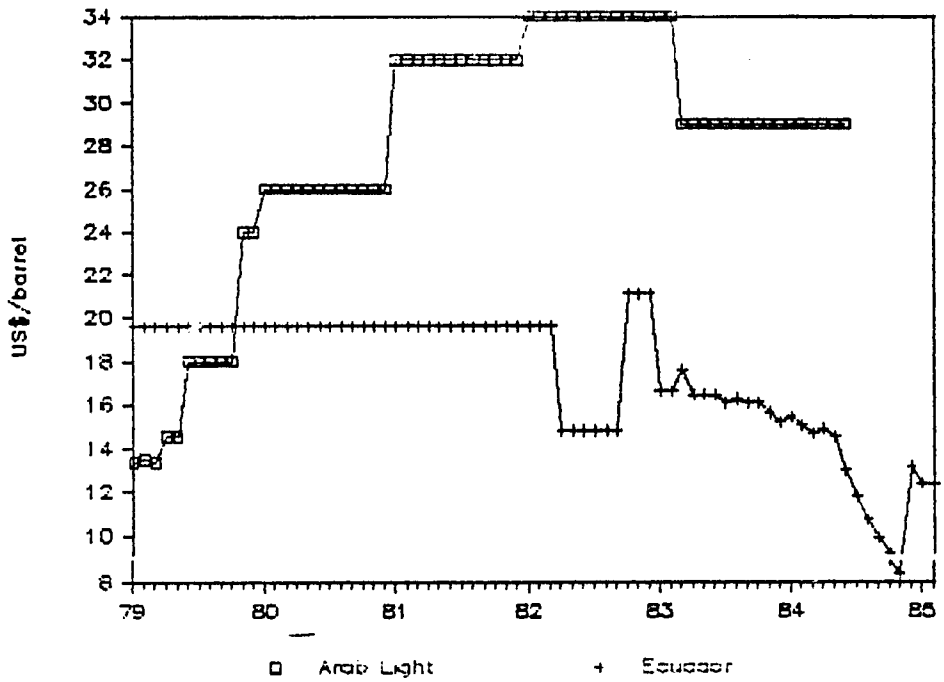
Ecuador and Argentina

Among the developing countries included in our study, we found that the governments of oil-sufficient and exporting countries (Ecuador, Argentina) had difficulty aligning domestic with international prices as they went up in 1979 and 1980. Ecuador ignored increases in international petroleum prices and depreciation of its currency against the dollar and continue to charge an extremely low overall price for oil to its own citizens. For example, in January 1978 the overall price of petroleum products was 10 sucres/gallon, which at the prevailing exchange rate was $0.33/gallon. Seven years later, the overall price was 34 sucres/gallon, still about $0.30 cents per gallon at the "high official" exchange rate ($0.38 at the "low official" exchange rate of 90 sucres per dollar). During this same period the "international" oil price (that of the benchmark Arab Light) increased from $14 to $28 and the sucre/dollar exchange rate had deteriorated from 30 to 120. In 1978, had Ecuador implemented a policy to keep its overall price at world levels, it would have risen to at least 60 sucres/gallon by 1985.

The government in Quito has the luxury of choice because the country produces over 250 thousand b/d of oil while consuming less than 100 thousand b/d. Oil consumers in Ecuador are merely paying the average cost of the oil products they use. Figure 2 shows the result of Ecuador's oil pricing policy.

FIGURE 2

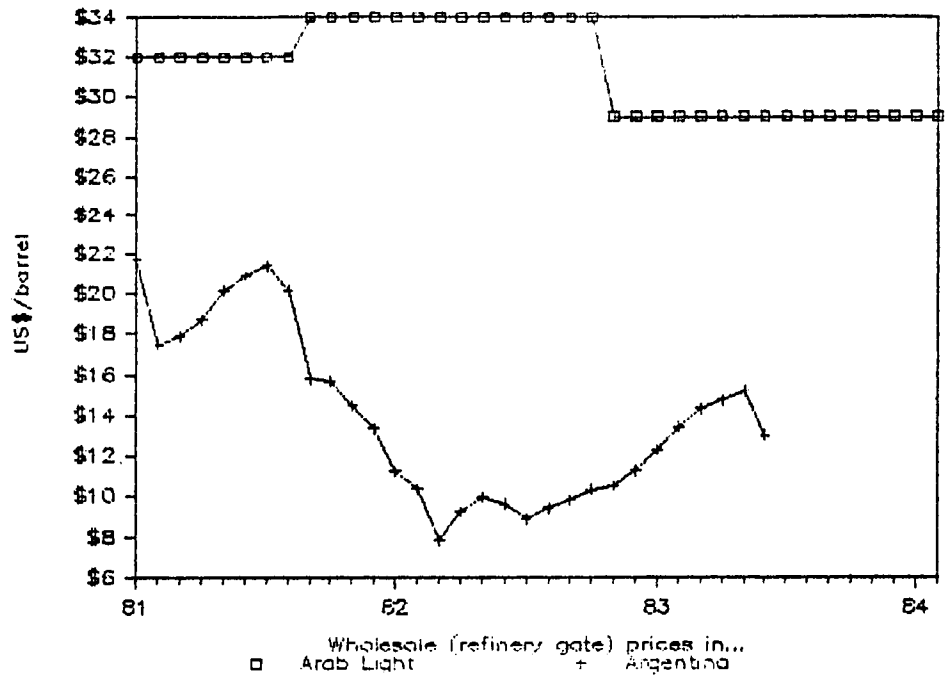
ADJUSTMENT OF ECUADORIAN OIL PRICES:
1978 TO 1985



Argentina presents a case in which overall petroleum price declined dramatatically in the 1981-1984 period, when it isolated itself from the world oil market. As is readily evident in figure 3, the Argentine domestic oil price was well below world levels in 1981. Because Argentina is self-sufficient in oil, this "subsidy" had no immediate, adverse effect on the demand for foreign exthange. In 1982, however, local oil prices in dollar terms plummeted as a result of the government's decision to freeze them during the Falklands crisis. In an economy where the rate of inflation exceeds 400 percent, a freeze in local prices is a very dramatic event.

FIGURE 3

ARGENTINE OVERALL OIL PRICES AND
THE PRICE OF ARAB LIGHT: 1981-1984



In Argentina, the factors that usually contribute to keeping overall oil prices at world levels were missing. First, YPF, the Argentine national oil company, was unable to prevent the oil price freeze from being implemented. Second, the central bank did not regard oil pricing as being of vital concern to its mission. The political elite, therefore, encountered little opposition to its decision to freeze oil prices.

In Argentina's circumstances, the oil price freeze had a particular short-term, macro-economic effect: a shift in revenues from the oil sector, YPF in particular, to oil consumers. In Argentina, unlike in oil-importing countries, pricing oil far below world levels had no immediate effect on the foreign exchange situation.

Thailand and South Korea[4]

Among the oil-importing developing countries, both Thailand and South Korea were able to adjust domestic

petroleum prices quite promptly in response to the 1979-80 world price increases. In both cases, the short-run inelasticity of oil demand to price, the conservative monetary and fiscal policies of the governments, and the relative sluggishness of the market for exports meant that the massive diversion of domestic expenditures to the oil sector had a strongly deflationary impact on the Thai and Korean economies. Moreover, in South Korea the domestic wholesale overall price rose so far above international levels that the domestic refining industry collected a substantial rent.

The Thai economy was not shielded by price controls from the sharp increases in world oil prices in 1979-80. The Thai authorities allowed the overall domestic oil price to rise with international posted (not spot) prices, with a lag of only a month or two. Because the increases in the price of oil were directly passed on to consumers, and because consumer demand for oil products was inelastic in the short run, national expenditures on oil imports rose sharply: from 16.5 billion baht in 1978 to 23.4 billion baht in 1979 to 39.3 billion baht in 1980.

The increased import cost of oil was recovered, however, by the domestic price increases. While there were subsidies on particular products, the overall price was increased sufficiently so that enough baht were collected to exchange for the dollars needed to buy the oil. There was no subsidy hidden by the exchange rate in the Thai pricing system.

As a result of the sharp domestic price increases and of the short-term inelasticity of oil demand to price, expenditures on goods and services other than petroleum were curtailed. Domestic oil expenditures (excluding excise taxes) rose from 5 to 8.5 percent of GDP during the period 1978 to 1980. In the same years, GDP growth fell from 10 percent in 1978 to 6 percent in 1979 to 5.8 percent in 1980. These superficial comparisons suggest that international oil price increases, passed on rather promptly to consumers, probably contributed to a 4 percent drop in GDP growth in Thailand.

The Thai government did not try to offset the recessionary effects of the oil price increase with a stimulative money supply policy. IMF data show that the rate

of growth of the money supply actually decreased from 20 percent in 1978 to 17 percent in 1979 and 12 percent in 1980.

Thus, the Thai government managed the oil price transition of 1979-80 in what can only be called a conservative fashion. International oil price increases were promptly passed on to consumers, and the recessionary impact was allowed to run its course without major offsetting fiscal or monetary policy responses. As a result of this conservative policy, the oil price increase did not materially affect domestic inflation. Wholesale prices rose by 8.4 percent in 1979, 16.7 percent in 1980, (probably reflecting a one-shot effect of oil price increase on price indicators), and by 9.5 percent in 1981.

Korean prices, like those in Thailand, were increased rather quickly in response to world oil price increases. IMF figures show that expenditures on crude petroleum imports increased from 1.06 trillion won in 1978 to 1.502 trillion won in 1979 to 3.425 trillion won in 1980. As a percentage of gross domestic product (GDP), these import expenditures were 4.4 percent in 1978, 4.8 percent in 1979, and 9.1 percent in 1980. These cost increases were recovered by increasing local prices. Indeed, the very sharp price increases of 1980 and the size of the difference between the overall wholesale price and world prices suggests that Korean oil enterprises collected substantial additional profits in the course of the transition from the pre-1979 to the post-1980 oil price situation.

The very large increase in domestic expenditures on oil also suggest that purchases of non-oil goods and services should have fallen in 1979 and 1980. Indeed, the rate of increase in Korean GDP does show a dramatic change: in 1978, GDP (measured in constant terms) increased by 11.6 percent; in 1979, GDP grew by 6.8 percent; and in 1980, GDP declined by 6.2 percent. The fall in real GDP had various causes, to be sure. A decline in exports might have been expected to be a factor. But exports, in dollar terms, increased by 16 percent in 1979 and by 17 percent in 1980. Thus, the recessionary impact of the increased expenditures on imports and the massive shift of domestic resources to the petroleum sector seems to have played a critical role in the Korean recession of 1980.

Brazil and The Sudan

In Brazil and the Sudan, we saw countries that seemed able to manage the initial effects of the oil price increases well: both managed to increase domestic prices substantially in 1979. In subsequent years, however, both countries had difficulty dealing with the exchange rate crisis. Both governments let the overall domestic oil price decline in real terms to the point where the petroleum sector was subsidized by the economy as a whole. The immediate culprit in both cases was a willingness on the part of the authorities to allow oil importers to exchange local currency for dollars at special exchange rates that did not reflect the market value of foreign currency.

Before 1978, the overall wholesale price of oil in Brazil was substantially above the official price of Arab Light. This suggests that before the price shock of 1979, the government wanted a pricing schedule that would give Petrobras a substantial surplus for reinvestment in Brazil's ambitious energy production program. With the exception of the first half of 1980, Brazilian pricing policy was able to make local wholesale prices remain, on average, comfortably above world levels. In essence, the Brazilian government succeeded in managing the oil price adjustment of 1979-80 in a manner similar to that employed by Thailand: the world price increases were relatively promptly passed through to consumers. In late 1982, however, the program ran into difficulty coping with the emerging exchange rate crisis.

Beginning in 1982, the value of the cruzeiro depreciated at a seemingly exponential rate. The managers of the quarterly oil price adjustment process did not anticipate the speed of the cruzeiro's fall in that year. As a result, the cruzeiro revenues Petrobras collected during this period fell below the levels required to purchase the quantity of dollars, at the market exchange rate, needed to obtain the required amount of oil. At this point, a political judgment was made to allow Petrobras to buy dollars at a subsidized "dolar petroleo" exchange rate. The result of this decision was to establish domestic oil prices at levels sufficient perhaps to balance the books of Petrobras, but not sufficient to cover the true costs of dollars. In effect, the Bank of Brazil subsidized the petroleum sector.

In the case of the Sudan, before 1979, the overall

retail price (wholesale price data were not available) was multiples larger than the international FOB price of Arab light. When the international price of oil began to rise sharply in early 1979, the Sudanese government responded relatively quickly with domestic price increases--from about $28 to $44 per barrel-- in the summer of that year. Unlike the quarterly price changes of Brazil, however, the Sudanese government changed prices and exchange rates only once a year. By 1981, instead of a retail price that was multiples of the international price, the retail price barely exceeded the international price, and hence barely covered the import cost. In effect, the full costs of refining and distributing oil were not being paid by the oil consumers, and the government was not collecting any real tax revenues on oil sales. The Sudanese oil sector was being subsidized by the rest of the economy.

The adverse effects of this subsidy might have been far worse had consumers been able to procure all the petroleum products they wanted. Reports of widespread and chronic fuel shortages suggest that if oil imports had not been under government control, consumers would have bought more and the size of the overall subsidy to the oil sector would have been larger. In this respect, the adverse effects of one economic distortion (price controls) were held in check by another distortion (import controls). In turn, the supply-side shortages probably created productivity losses: it is important to note the damage that price controls create if, for example, diesel oil shortages prevented farmers from irrigating their fields at the right time.

RELATIVE PRICES: INCENTIVES TO CONSUMERS

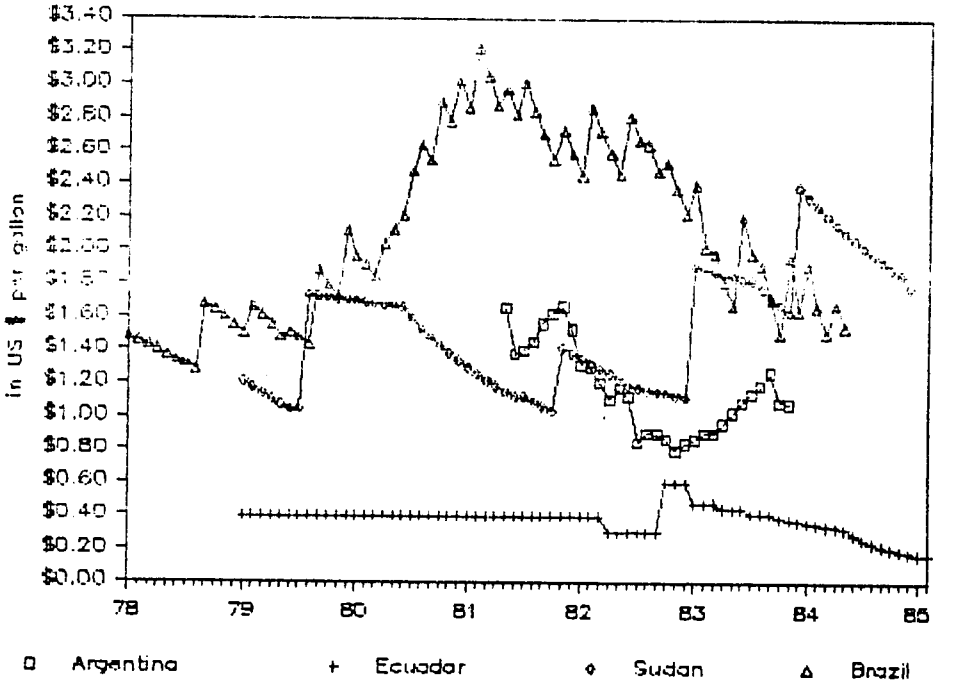
From the standpoint of overall economic analysis, the <u>overall</u> price of petroleum in an economy is a more important variable than the price of any particular product. From the standpoint of energy policy planning, however, governments of developing countries pay much more attention to particular product prices. In fact, there are few cases, at least among developing countries, where regulators establish <u>first</u> the overall price, and <u>then</u> derive a set of particular prices for the various products. This emphasis on the particular at the expense of the general is forced on them by political phenomena. At the extreme, regulators may have learned from past incidents of civil unrest that price

increases of some oil products require special treatment. At a minimum, some petroleum products have "constituencies" that lobby for special treatment.

In many developing countries, kerosine and diesel oil are regarded as "social products," in the sense that they are used by people in the country's lower income brackets, or they are intermediate goods strongly influencing the price of other social products, especially basic foodstuffs. Gasoline, on the other hand, tends to be the "cash cow" of the petroleum sector. Figure 4 provides a comparison of regular gasoline retail prices in four of the countries in this survey.

FIGURE 4

COMPARISON OF RETAIL PRICES OF REGULAR GASOLINE



The premium on gasoline can be in the ex-refinery price -- giving the oil company a bigger margin on gasoline makes it possib e to ask them to do without a margin in a 'social' product like kerosine. The premium can also be in the form of a tax -- allowing the government to collect whatever overall level of revenues it can from this group of citizens.

In many countries, governments not only cross-subsidize one product with another, they also charge different prices to different consumers of the same product. Ecuador provides several examples. Since 1981, the fishing industry has paid 15 to 30 percent less for diesel oil than the regular consumer. Jet fuel purchased for flights within Ecuador by Equatoriana, the national airline, is priced at a fraction of the amount foreign airliners have to pay when they buy in Quito.

PATTERNS OF RETAIL PRICES

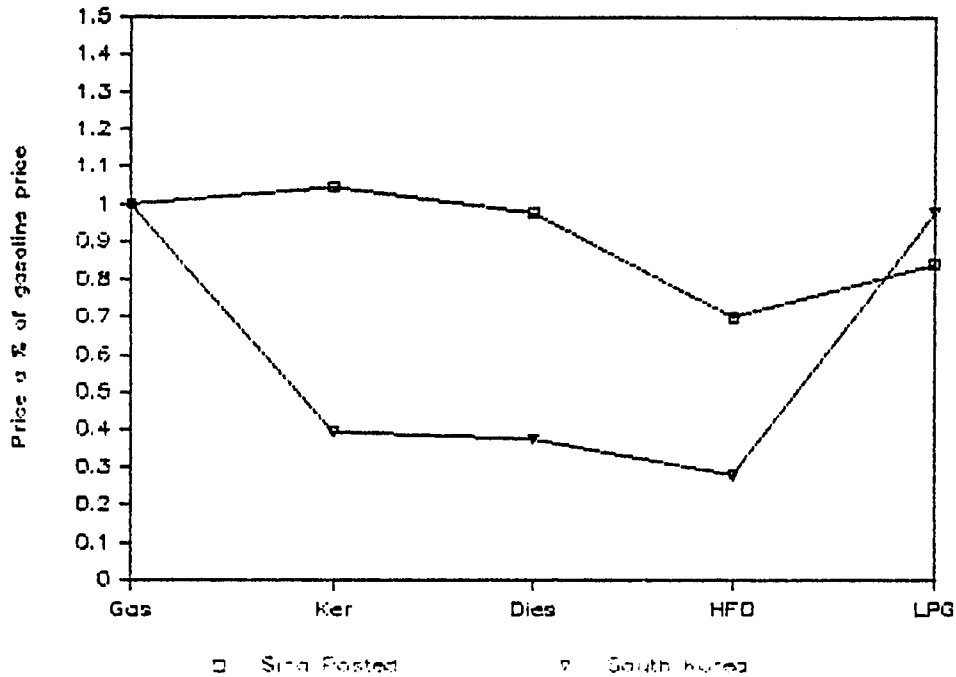
Terms such as "social products" and "cash cows" are used to designate some of the political forces behind petroleum pricing programs. There are others. For example, there are "international competition products," whose prices are controlled at relatively low levels as part of an industry development strategy. The prices of residual fuel oil and naphtha in Japan were kept well below world levels for years while the industrial base was being built.

More generally, in regulated economies the price of specific petroleum products is a function of the price-setters' political objectives. In some countries, the strongest political force, and hence the starting point of the price setting process, is aimed at subsidizing social products. Once that decision has been made, it generates a need to designate other products as sources of cash to pay the subsidy. In this manner, the <u>pattern</u> of relative petroleum prices in any countries is a kind of diagram of political sensitivity.

Figures 5 through 7 present three such diagrams. Each figure presents a snapshot of the retail price pattern in which prices of kerosine, diesel oil, fuel oil, and LPG are shown in relation to the price of regular gasoline. Figure 5 shows the singular case of South Korea, where, as has already been mentioned, the retail price of gasoline is extremely high in relation to the price of the other products. Figure 5 compares Korea's retail price pattern (in March 1982) with the pattern of prices posted by Singapore refiners.

FIGURE 5

SOUTH KOREA: RETAIL PRICING PATTERN

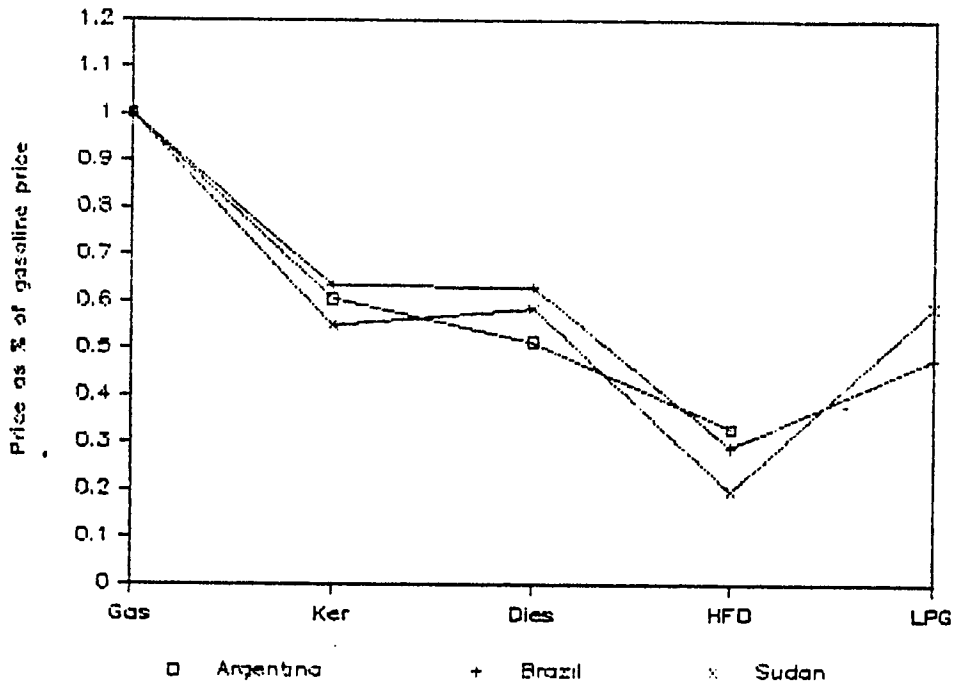


The Singapore pattern can be interpreted as reflecting the marginal cost of producing products in the Pacific market. Note that among posted prices, residual fuel oil (HFO on the X-axis of figure 5) is the lowest in proportion to gasoline, about 75 percent. Among Korean retail prices, residual fuel oil is only about 30 percent of the price of gasoline. What is distinctive about South Korean retail prices, however, is that all the products, except LPG, are low relative to gasoline.

Figure 6 presents a picture of the retail price patterns in June 1983 in Argentina, Brazil, and the Sudan, all grouped together as "fuel oil subsidizers." There are various similarities. Each country has three tiers of prices: gasoline, distillates (kerosine and diesel oil) at about 55 to 65 percent of regular gasoline prices, and fuel oil at about 25 to 35 percent of gasoline prices.

FIGURE 6

RESIDUAL FUEL OIL SUBSIDIZERS



In all cases, the diesel prices are relatively lower than the international price pattern. Figure 5 showed that in Singapore postings, diesel and gasoline prices were about the same. In Brazil, Argentina, and the Sudan, they are 35 to 45 percent lower than gasoline prices. This simply reflects the difference in excise taxes: as a motor fuel, diesel oil is taxed less stringently for the sake of keeping the cost of industrial transport and mass transit down. Similarly, kerosine, while not heavily subsidized in these countries, is not taxed because it is a social fuel.

Fuel oil prices, however, are not only not taxed in Argentina, Brazil, and the Sudan, they were absolutely subsidized in these countries when the snapshot presented in figure 6 was taken (June 1983). For example, in the Sudan, the retail price of "furnace oil" was only $16 per barrel, in comparison with a posted price in the Persian Gulf of about $26 per barrel. In the Sudan, the principal cause for such a subsidy on fuel oil was the perceived need to keep to a minimum the oil costs of the electric utility, whose financial condition was more tenuous than that of the oil

industry. In Brazil and Argentina, relatively low fuel oil prices were probably rooted in the government's intention to minimize the fuel costs of export-oriented industries.

Figure 7 presents yet a different pattern of retail prices. Ecuador and South Korea are kerosine subsidizers. Kerosine, the most obvious social product amongst all the petroleum fuels, is only 40 percent of the gascline price in these countries. In both cases, the relatively low price of kerosine is aimed at minimizing the fuel costs of lower-income oil users.

FIGURE 7

KEROSINE SUBSIDIZERS

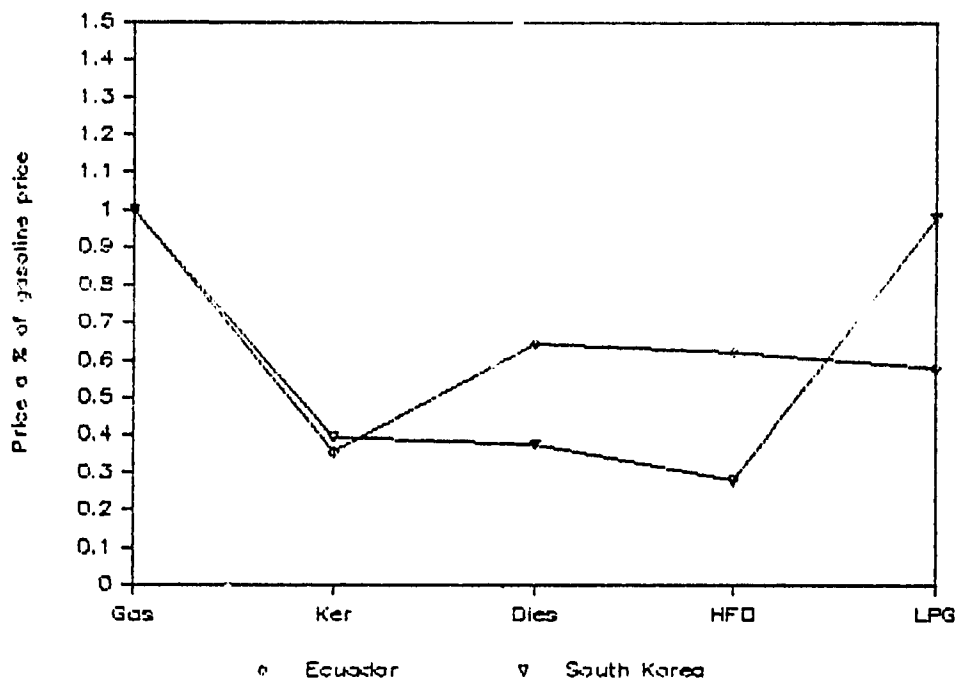


Figure 7 conceals, however, the enormous difference in the absolute prices of kerosine in Ecuador (about $0.15 per gallon) and South Korea ($1.50 per gallon).

RETAIL PRICES: PETROLEUM PRODUCT TAXES AS SOURCES OF GOVERNMENT REVENUE

Governments impose variable taxes on petroleum products. Social products are lightly taxed, as often are products that are inputs to export-oriented manufacturing industries. Because the choice of social products varies from country to country (kerosine in Korea, fuel oil in the Sudan), the simplest way to start this review is to compare the level of overall retail prices. In this manner, it is possible to get a picture of the overall incidence of taxes on petroleum products. That in turn sets the stage for looking at tax levels on specific products.

Although the subject has received much attention, there is no simple, a priori guideline on the appropriate level of taxation on particular products like gasoline in developing countries. If one examines tax opportunities, however, a very simple general principle--that in developing countries taxes ought to be imposed where they can be collected--emerges. The difficulty of collecting personal income taxes in countries with large subsistence sectors and low literacy rates is obvious. Import and export taxes and taxes on products coming out of refineries, on the other hand, are easier to collect because the number of points of collection is limited. Thus, for ease of administration, it makes sense to impose petroleum taxes.

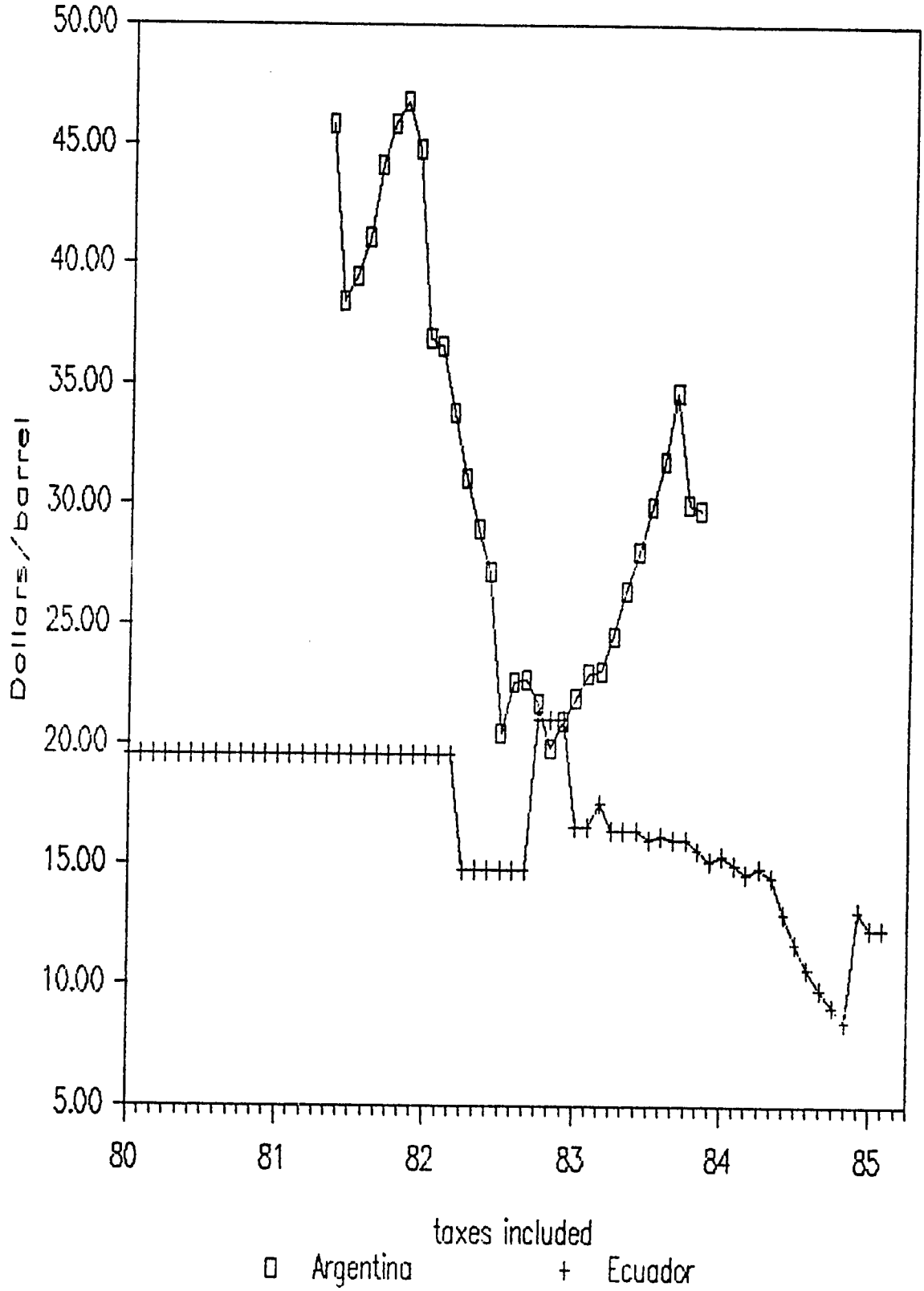
Governments of both developed and developing countries typically regard taxes on petroleum products as a convenient way of raising revenues. In most developing countries, gasoline prices carry the largest burden. This policy represents a political judgment: car owners deserve to be taxed. Excise tax levels are also part of a long-term oil demand management program. Very high taxes on, say, LPG can prevent demand for that convenient fuel to outstrip domestic refiners' ability to supply it. As in so many other respects, one can emphasize that the "overall" (weighted average for the representative barrel of petroleum products) price will affect overall demand for oil products, while relative excise taxes influence the pattern of product demand.

Our calculations of overall retail prices produce a not-too-surprising dichotomy. Overall retail prices, like overall wholesale prices, are substantially lower in Argentina and Ecuador than in the Sudan, Brazil, South Korea, and Thailand. Figure 8 provides a picture of the changes in overall retail prices in the self-sufficient countries.

Notice that Argentina's overall retail price, measured in dollars per barrel, fell sharply from around $45 per barrel in 1981 to as low as $20 per barrel in 1982. This drop was the result of the price freeze (discussed in previous sections) and the extremely rapid depreciation of the peso. One can surmise that when the retail price was $45 per barrel, the government was collecting substantial real revenues. When the price fell to $20 per barrel, the government was still collecting a lot of pesos from its excise taxes, but the real value of those pesos had declined sharply.[5]

FIGURE 8

OVERALL RETAIL PRICES IN SELF-SUFFICIENT DEVELOPING COUNTRIES



The overall retail prices of the oil-importing countries stand in vivid contrast to those of the self-sufficient countries. Figure 9 compares overall retail price levels in the Sudan, Thailand, and Brazil.

FIGURE 9

OVERALL RETAIL PRICES IN OIL IMPORTING DEVELOPING COUNTRIES

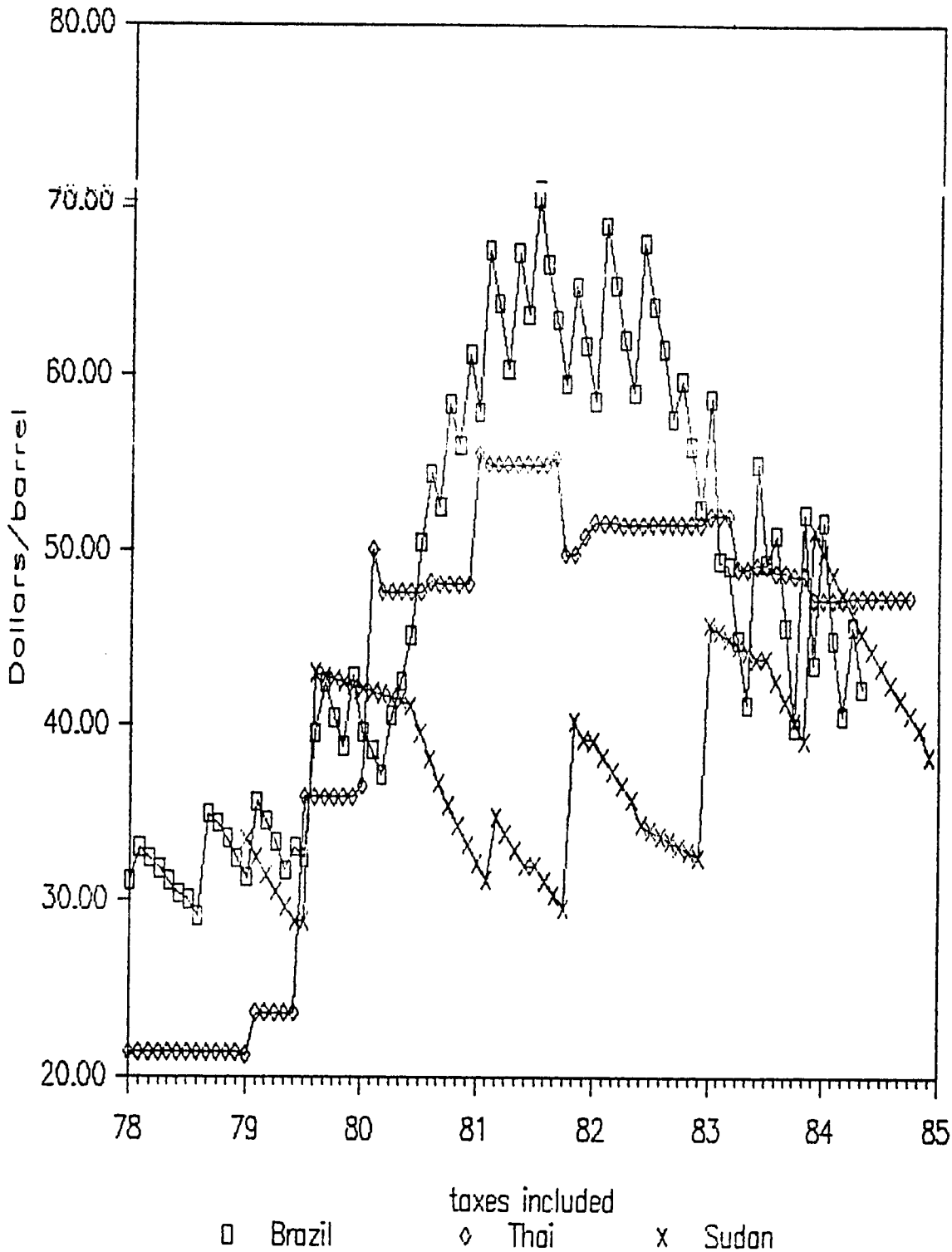


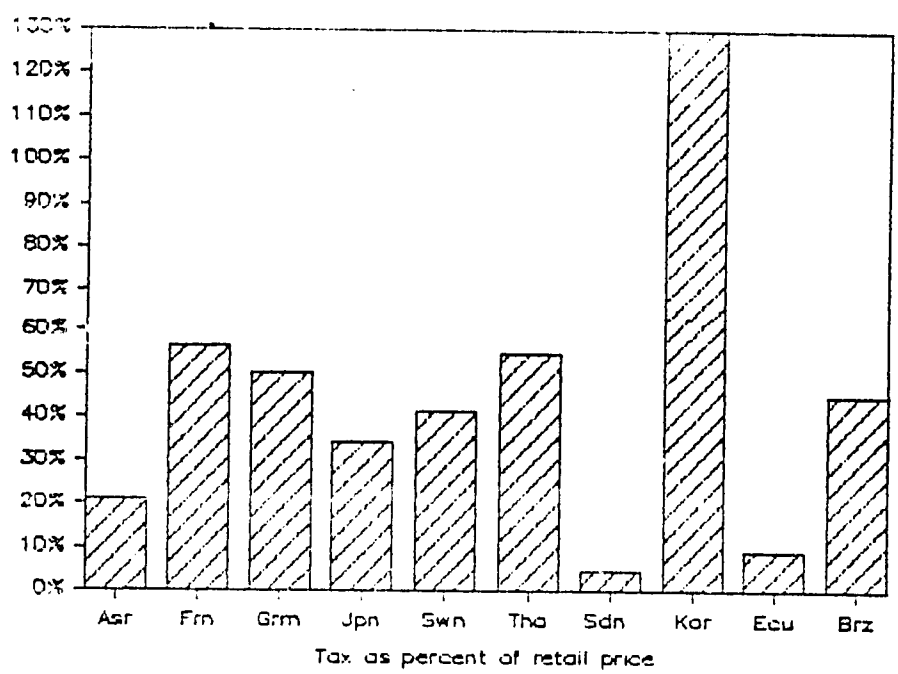
Figure 9 shows that in 1978, before the large international oil price increases, the overall retail prices of all three countries were between $20 and $30 per barrel. When the 1979 price explosion occurred, Thai prices increased in step with international prices, and then decreased in step with international prices. The Thai pattern does not exhibit the "sawtoothed" pattern evident in Brazilian and Sudanese prices because the baht/dollar exchange rate did not change significantly during this period.

PRODUCT BY PRODUCT TAXES

This section compares the excise taxes imposed by the developing countries included in this survey with excise taxes in selected developed countries. We begin with gasoline taxes. Figure 10 shows excise tax levels in 1983 on gasoline.

FIGURE 10

GASOLINE EXCISE TAX RATES IN SELECTED COUNTRIES

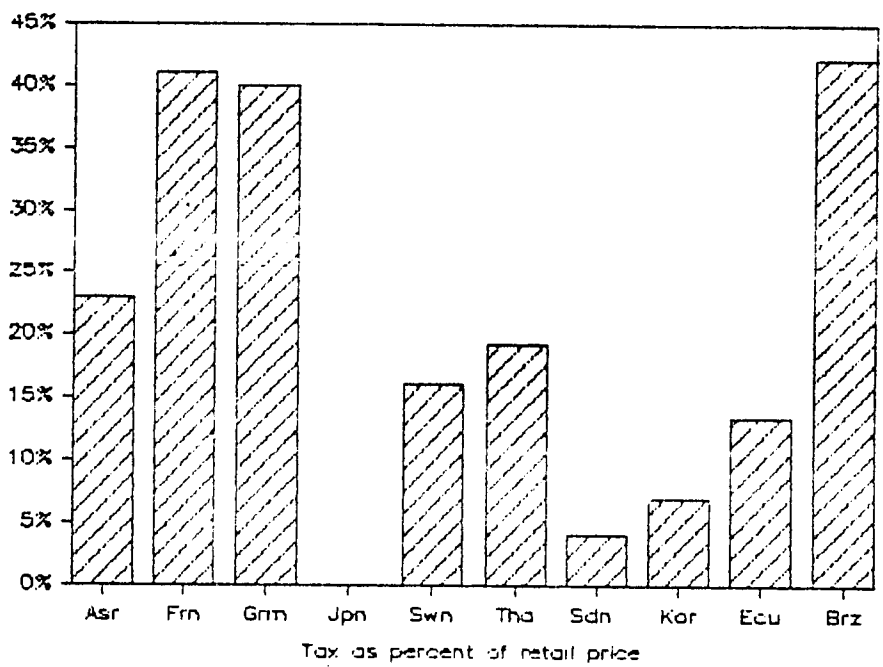


The comparison in figure 10 indicates that the selected developed countries had gasoline excise tax rates ranging from 20 percent to 50 percent of the retail price. South Korea, with a tax rate of 130 percent, was clearly in a league of its own. At the other extreme, the Sudan and Ecuador had a tax rate of under 10 percent. Brazil and Thailand's tax rates were in the range defined by the developed countries.

Figure 11 shows excise tax levels in 1983 on automotive diesel oil.

FIGURE 11

AUTOMOTIVE DIESEL OIL EXCISE TAX RATES IN SELECTED COUNTRIES



Among the developed countries, diesel oil taxes ranged from a low of 17 percent in Sweden to 40 percent in France and Germany. Among the developing countries, Brazil was alone in imposing a diesel tax comparable to that of France and Germany. In the Sudan, the diesel tax was very

small, a result of the government's concern about the effect of higher diesel prices on food prices and costs in the agricultural sector. In South Korea, diesel was lightly taxed as part of a deliberate cross-subsidy strategy that made gasoline bear the bulk of the tax-raising burden.

This brief survey of petroleum product taxes establishes several points relevant for pricing policies. While it is difficult to make a general prescription about what petroleum taxes "ought" to be that applies to all types of developing countries, general observations about importing and self sufficient countries can be hazarded.

From the standpoint of economic efficiency, oil-importing developing countries should have a relatively high overall petroleum product tax for the sake of restraining the growth in demand for oil imports. One basis for this proposition is the "disruption tariff" argument: oil import prices do not reflect the damage done by the occasional disruptions, hence a "disruption tariff" is appropriate. This view applies only problemmatically to developing countries, since it presumes that tax or tariff-induced decreases in oil import demand will affect the world oil price. The United States may have a measurable "monopsony power," but the Sudan clearly does not. Even in the Sudan, however, it is possible to argue that because the exchange rate chronically understates the value of foreign exchange, it is useful (at least in principle) to impose taxes that reflect this scarcity value (or the "shadow price" of foreign exchange).

The discussion of the ersosion in the <u>effective</u> tax take in Argentina and Brazil, due to the decline in constant oil prices, provides another general rule. Petroleum product taxes need to be indexed to the inflation rate to assure that the real revenue stream of the government does not erode. If this is not done, the fiscal purposes of these revenues will have to be met from other sources. At a minimum, of course, taxes on the oil sector ought to pay for subsidies granted within the oil sector. More broadly, oil tax revenues should be maintained to finance the social infrastructure, e.g. highways, that petroleum utilization demands.

For oil exporting countries like Ecuador, governments might be well-advised to look to petroleum product taxes to offset the decline in revenues caused by

reductions in the international price of oil. Projects that in the 1970s could be financed with export earnings may in the 1980s have to be financed at least partially by petroleum product taxes on local consumption.

WHOLESALE PRICES: INCENTIVES TO PRODUCERS

The significance of a given wholesale pricing program can be evaluated with the same framework as retail prices. The overall wholesale price has its effect principally within the oil sector, the pattern of relative wholesale prices has its effect principally among energy sources. Put another way, there are intra-oil issues and intra-energy issues. The intra-oil issues influenced by the overall wholesale price level in a given country include such things as the incentives a refinery has to invest in upgrading its capacity. A refiner is more interested in its overall "realization" on all petroleum products (what has already been referred to as the overall price) than in the difference between the price of gasoline and diesel oil. Of course, the refiner is very interested in the pattern of relative wholesale prices, but his vital interest is in the overall price.

A coal company, on the other hand, is less concerned about the overall price than in the wholesale price of the oil products that compete with coal. The supply-side incentives created by wholesale pricing decisions of particular products are especially interesting when one company -- e.g. Petrobras in Brazil -- has a choice between putting its investment dollar in competing fuels. Because state enterprises in developing countries so often have monopoly positions, such intra-company "conflicts of interests" are not uncommon.

There are yet further layers of complication between normal wholesale price levels and the supply-side consequences. One is the role of subsidies. Regulating the wholesale price of, say, fuel oil in a country (for a particular reason like reducing the costs of production of companies manufacturing goods for exports) may require subsidizing the production of competing energy resources. For example, if fuel oil prices are kept down to help the steel industry, coal production may have to be subsidized as

a result.

A final variable is the reaction of international companies, if the government wants them to participate in the oil market, to wholesale product prices. One can argue that this "commercial" perspective is not terribly important in countries like Argentina, where the state owned company, YPF, presumably does what its shareholder tells it to do. As studies of publicly-owned enterprises have shown, however, in the course of time such firms do tend, in Paul Frankel's words, to put greater stress on the enterprise than on the public part of their name. In time, even state-owned companies will covet a level of wholesale prices that puts them in a situation similar to that of their private counterparts in other countries.

"TOP DOWN" VERSUS "BOTTOM UP" APPROACHES TO OIL PRICING

Wholesale pricing issues naturally receive most attention in countries where the petroleum sector is relatively independent from the government sector. Hence, wholesale pricing is important in Thailand, South Korea, and Brazil and less important in the Sudan and Ecuador (and in the early 1980s), Argentina.

To take a specific example, governments of developing countries with relatively a independent petroleum sector and refineries typically regulate the margin the refiner earns. This can be done from the "bottom up", literally monitoring, or trying to monitor, actual costs and determining product prices on the basis thereof; or it can be done from the "top down," using some reference market as a benchmark and making home refiners operate within that benchmark. Thailand's uses a "top down" approach, basing its domestic prices on prices in a reference market (Singapore postings) and South Korea uses a"bottom up" approach in which the government monitors costs and calculates allowable prices and margins.

The results of these different approaches, in terms of the overall wholesale price, is shown in figure 12.

FIGURE 12

COMPARISON OF OVERALL WHOLESALE PRICES:
THAILAND AND SOUTH KOREA

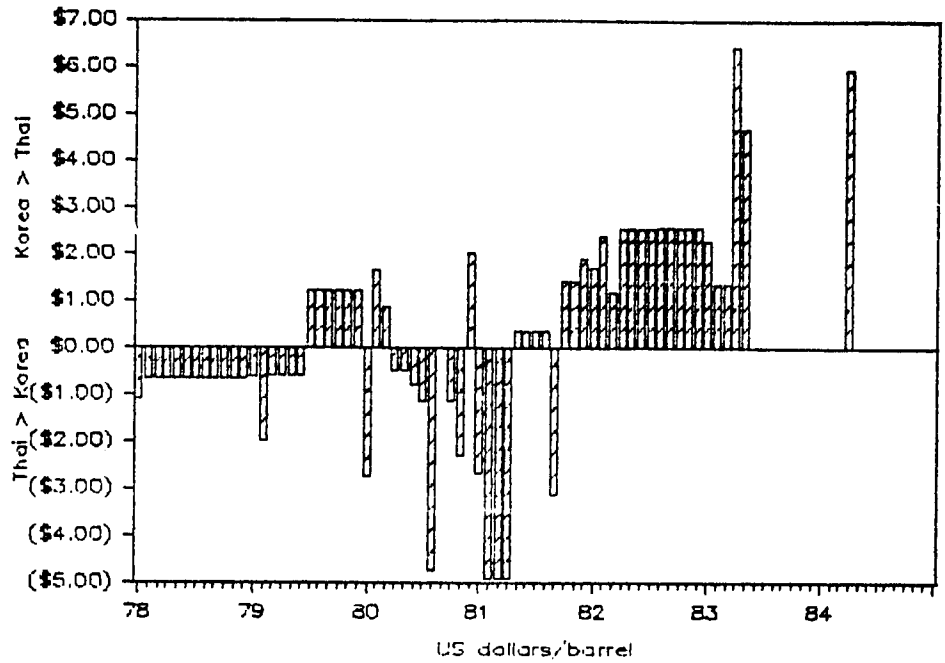


Figure 12 indicates that the Thai program has yielded a lower overall wholesale price than that of South Korea. Our study suggests that one prominent reason is that managers of the "bottom up" pricing approach have a tendency to grant additions to costs on a piecemeal basis that, over time, can add up to a considerable subsidy.

Price regulation in a market with a well-established refining industry, especially when foreign companies are present, requires attention to technical detail, to "pennies per gallon" distinctions that strongly influence the profitability of the enterprises. In these circumstances, price regulations also becomes inextricably enmeshed in broader trade and industrial policy issues. For example, in South Korea the levels of wholesale prices shown in the discussion could not be maintained if Korea allowed unrestricted imports of finished products.

Such issues are far less germane in countries where the state-owned oil company has a monopoly on oil

procurement. In Brazil, Argentina, the Sudan, and Ecuador the significance of wholesale pricing decisions is almost exclusively a function of the strength of the oil company. In Brazil, Petrobras has been able to obtain overall wholesale prices that (at the subsidized exchange rate in 1982 and 1983) allowed it to recover costs. But the wholesale pricing pattern, especially the prices of gasohol and fuel oil, have raised intra-energy complications. One of the consequences is a structure of incentives that may have discouraged Petrobras from developing natural gas with enthusiasm. In Argentina, YPF was unable in 1982 and 1983 to prevent the deterioration of the overall wholesale price from devastating its cash flow.

Thus, the propensity of a government to implement "efficient" wholesale pricing policies can be seen as a function of the political strength of the petroleum industry. This point figures prominently in the discussion in the next section.

CONSTRAINTS ON PETROLEUM PRICING POLICIES

To get beyond recitation of anecdotes about the "politics" that hinder "rational" decision-making, we now provide some principles that seem to be important in all the countries under review. They are:

- The propensity to adopt an efficient pricing system is a function of the relative political influence of supply-side and consumer-oriented political forces. In Argentina and Ecuador, the consumer-oriented view has preponderant influence. In South Korea, the supply-side influence dominates.

- The propensity to adopt an efficient pricing system is also a function of the extent to which government agencies play roles that promote "rational" economic planning. In Brazil and the Sudan, the central banks have failed to persuade the authorities that the foreign currency needed to purchase petroleum imports should <u>not</u> be made available at a subsidized exchange rate. In South Korea, the political leadership has not forcefully protected consumer interests. In Ecuador, the

Sudan and Argentina, the national oil company has failed to have a strong influence on oil price determination.

- The propensity to adopt an efficient pricing system is also a function of the degree to which the development assistance agencies are able to present the government with petroleum pricing advice that contributes to long-term reform. In some countries, too much emphasis has been given to individual product prices, rather than the overall price. In addition, the distinction between wholesale and retail prices, essential in the development of robust national oil companies, tends not to be made as forcefully as possible. This may be due to the strong emphasis given to economic analysis, rather than on the financial condition of the petroleum company, or to a bias against national companies.

- Finally, given a propensity to adopt an efficient pricing system, governments need tools to help them develop or reform pricing programs. Pricing formulas developed in other countries are useful at a minimum as frameworks for the construction of programs appropriate to local circumstances.

Analysts concerned about efficiency and economic growth prescribe certain economic criteria that should govern oil pricing. The World Bank, the International Monetary Fund, and other international and national agencies such as the U.S. Agency for International Development have developed a broad consensus on how energy prices should be determined. These institutions often make assistance contingent on certain changes in energy pricing. The changes are often accepted in principle by the aid- receiving governments, but when policies are reviewed to determine whether changes indeed occurred, frequently they did not.

There are various reasons why pricing policies are resistant to change, even when there is considerable pressure from important external agencies. Some are patently obvious: it is almost tautological to note that there must be strong **internal** pressures against changing oil prices.

POTENTIAL FOR EFFICIENT PRICING

While we are interested in whether a society has (or does not have) a potential for economically efficient pricing, we cannot assume that such efficiency is the optimal policy goal. Many governments believe they have to regulate the petroleum sector to enhance its contribution to overall economic efficiency because they believe the local market has "distortions" such as inadequate competition.

From the standpoint of economic efficiency, there are regulations that ignore economic principles and there are regulations designed with full cognizance that the fundamental principle underlying rational economic pricing policies "...is the well-know proposition that the costs of providing the last unit consumed should be just equal to the willingness of somebody to pay for it."[6] Neither discriminatory pricing by private companies nor discriminatory regulation by government agencies necessarily violates this principle: "While aggregate welfare, or economic efficiency, does not change as a result of well-designed discriminatory pricng practices, what changes profoundly is the distribution of income between different groups."[7]

The political implications of a given distribution of income is the driving issue in most regulated pricing systems. In general, the potential for political acceptance of an efficient pricing program is a function of several political factors. On the supply side, an important factor is the standing of the energy industry, the financial autonomy, and the place of energy executives within the politically relevant elite groups. On the demand side, a crucial factor is the degree of consumer organization and the ability of political dissidents to mobilize consumers to protest price increases. In the procedural context, the variable of note is the government's objectivity vis-a-vis energy interest groups. With respect to the society's external linkages, the key factor is the nature of the government's vulnerability to external influences, such as IMF conditions on foreign exchange assistance.

Each of these factors is in turn a function of other, more concrete societal, economic, and external factors. The standing of energy industry in a society is a

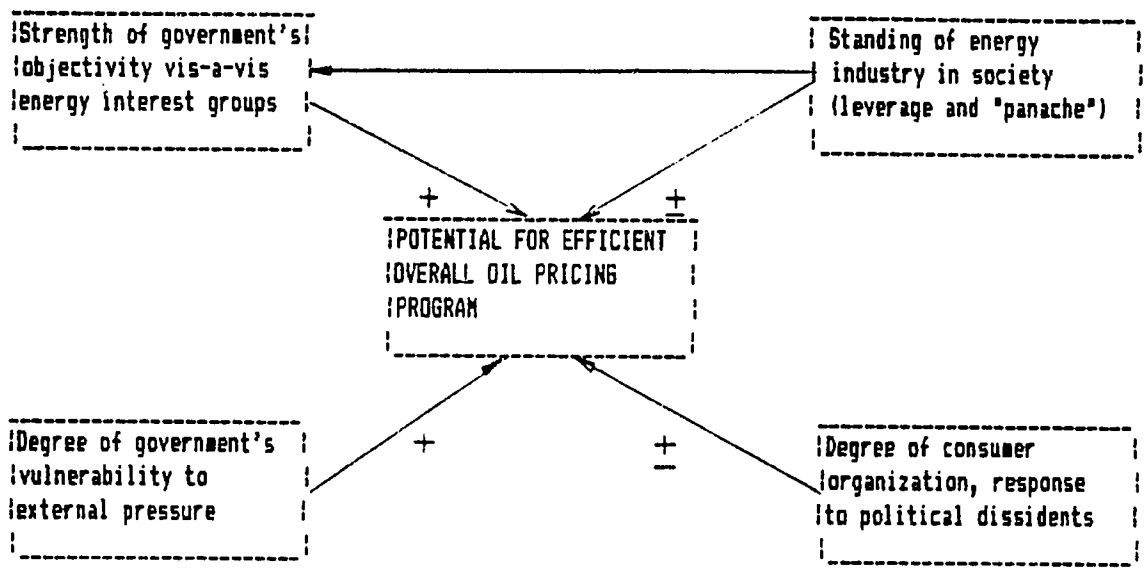
function of historical developments, (e.g. has the national oil company been in existence for a long time? Is it highly regarded by elite groups?), national resource endowment (is there much oil production, is the oil industry a major national employer of scientists?), and the frequency of elite "turnover" (whether a revolution has displaced the established energy elite).

The degree of consumer organization and mobilization is a function of the extent to which dissent can be publicly displayed, the organizational skills of dissidents, and the ratio of individual's average energy costs to total disposable income. The government's objectivity vis-a-vis energy interest groups is a function of the degree of professionalism in the civil service, and the nature of the government's hold on power. The degree of the government's vulnerability to external pressure is a function of its need for external assistance, which in turn is a function of the cumulative effect of preceding economic policies.

Because these are social phenomena, it would be foolish to attempt to construct a rigidly deterministic hypothesis of the conditions promoting or reinforcing the potential for efficient pricing. It is possible, however, to construct a looser set of causal propositions based on the discussions in the preceding sections. The diagram below summarizes a set of propositions:

FIGURE 13

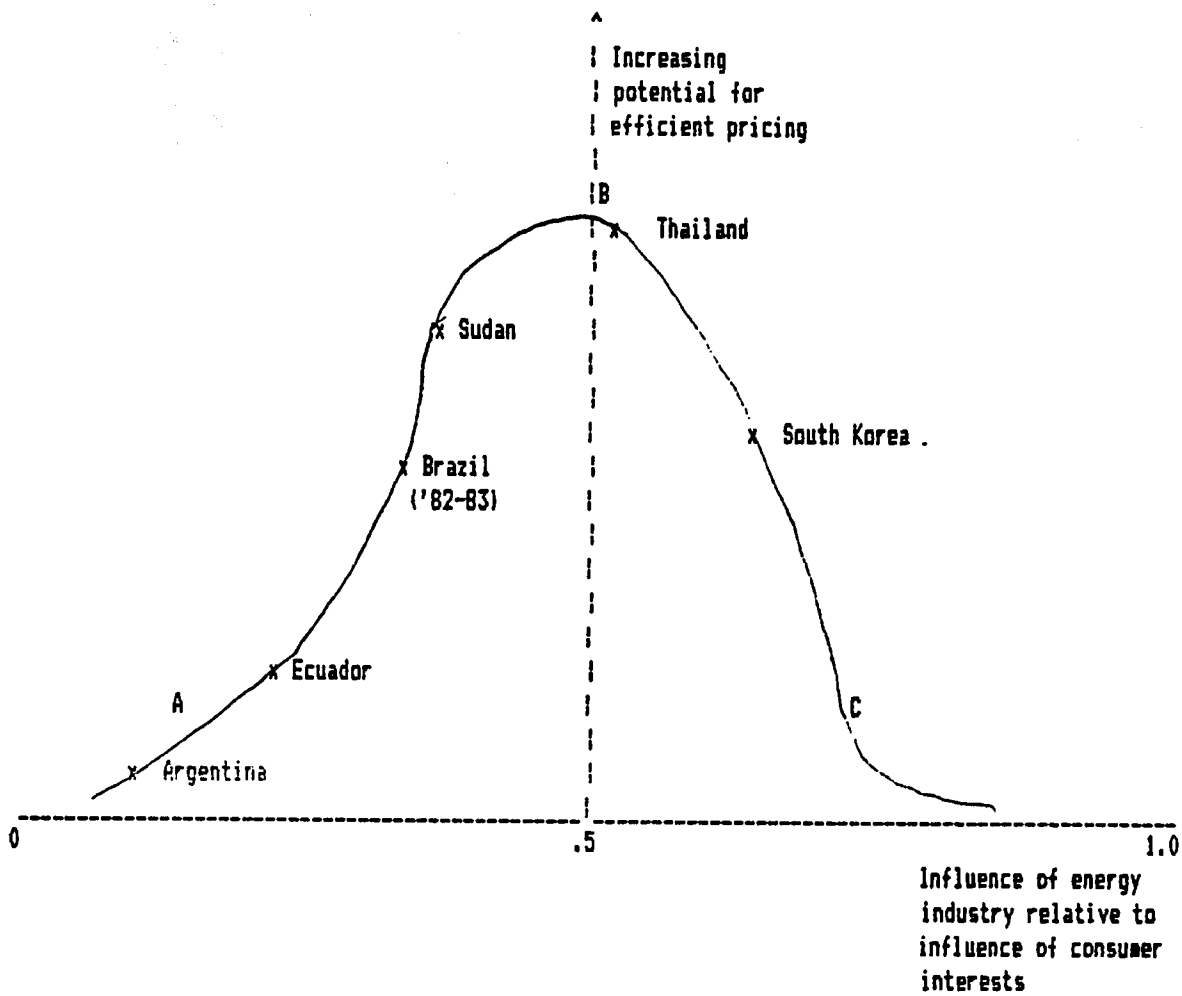
FACTORS INFLUENCING POTENTIAL FOR EFFICIENT PRICING



Each of the causal relations between the various institutions noted in figure 13 above is treated further in the set of propositions below. The first deals with the standing of the energy industry.

Proposition 1

The relationships between the standing of the energy industry, the degree of consumer organization, and the potential for efficient pricing can be described as being in the shape of the bell curve shown below. At point A, the energy industry's influence <u>relative</u> to that of consumer interests is very low, and there is a high probability that energy prices will be too low, i.e. that energy consumers will capture rents at the expense of the citizenry as a whole. From the discussion in the preceding sections, Ecuador and Argentina can be said to be close to position A.


Increasing
potential for
efficient pricing
B
Thailand
Sudan
South Korea
Brazil
('82-83)
Ecuador
A
C
Argentina
0
.5
1.0
Influence of energy
industry relative to
influence of consumer
interests

At point C, the influence of the energy industry relative to consumer interests is very high, and there is a strong probability that wholesale oil prices will be very high. South Korea provides the best example of this situation.

Interest groups bring pressure to bear on pricing policy, but some pressure is for higher and some for lower or steady prices. Thus, one must consider how this political pressure is handled by the price-setters in the government. This is a question of bureaucratic behavior, an enormous area of study in its own right. One way to begin to peel the layers of government in a systematic way is to assign different pricing roles to different parts of the whole government. Most governments have departments corresponding to the various interest groups. The energy industry is typically regulated by an industry or energy ministry. Prices, however, are typically the province of finance ministry, and exchange rates are often the policy responsibility of the central bank. Consumer interests are seldom safeguarded by a particular ministry (e.g. there are few ministries of consumer affairs), but are watched over by the chief executive's office and by the legislature. The extent to which these parties get involved in oil pricing decisions differs substantially in the countries surveyed in this report.

The lesson we can draw from our survey is that how the government "processes" political inputs from the energy industry and consumers interests is an important factor in its own right. To put it more explicity:

Proposition 2

a) The finance ministry and the central bank bear primary responsibility for advocating an efficient <u>overall</u> pricing policy;

b) The more the central bank accedes to multi-tier exchange rates, the higher the probability that oil purchases will be transacted at the low (subsidized) exchange rate, and the more likely that overall energy pricing policy will be inefficient.

The implications of this proposition are evident in the oil pricing process in the Sudan. In 1984, the Bank of Sudan made dollars available to the General Petroleum Corporation (GPC) at the lowest "official" exchange rate. As a result, GPC's true costs of oil imports were understated. It could balance its accounts, in which its true costs were understated due to the exchange rate subsidy, with lower oil prices. In these circumstances, GPC dropped its role as advocate of efficient pricing. It assessed its interests according to the criteria of financial, not economic, analysis: it was satisfied with price levels that covered the costs of the firm, even though they did not cover the costs of oil to the economy as a whole. In addition, the finance ministry, with its eye on the government budget, could refrain from active advocacy of oil price increases because it was collecting its customary level of tax receipts from oil. Thus, charging the lowest official exchange rate robbed the Sudanese price-setting system of the "creative tension" that tends to encourage rational oil pricing.

In countries self-sufficient in petroleum, but which are not major exporters, external influences, in particular the International Monetary Fund and the World Bank, may be the only advocates of efficient energy pricing. In countries where the U.S. Agency for International Development (AID) has substantial missions, (e.g., the Sudan), it can also exert a strong influence. These external voices are unquestionably important. All perceive of their roles in terms well beyond providing financial assistance. Clearly, the more a government needs external assistance, the greater the potential constructive influence towards efficient pricing the external agencies can have.

The potential, however, must be realized, and to do so, the advise must be carefully constructed. How is such advice to have the best effect?

Proposition 3

a) In oil-importing countries, the highest priority should be placed on advising the government to align the <u>overall wholesale</u> price with international prices.

b) Advice dealing with the prices of individual products must be given with full consideration of the political and technical context of the country in question. In the political sphere, cross-subsidies may be a highly effective means of income redistribution. In the technical sphere, there is no a priori reason for cross-subsidies to be inefficient. They often balance other distortions, and aligning an individual product price with international prices, without taking other distortions into account, may decrease overall economic efficiency.

c) In self-sufficient countries where the overall petroleum product price is far below international levels, emphasis should be placed on a long-term program of reform which may take years to implement, and not on "one-shot" increases in prices in return for assistance on a particular development project.

d) In all cases, high priority should continue to be placed on the development of institutions that contribute to the emergence of the "creative tension" between supply-side and consumer advocates. In many developing countries, the national oil company can play a vital role in this respect. Conditions on development assistance that denigrate the role of such national institutions are likely to be counterproductive.

The first part of this proposition deals with the question of the limits to which the external agencies become involved in social and political life in their client countries. If pricing of individual petroleum products is a political process, affecting national income allocation to various groups in society, it seems most useful to provide advice on oil pricing that accomplishes the most essential purpose.

The implication of this principle in oil-importing countries is that development assistance should encourage the government to align overall wholesale prices with

international prices, and refrain from insisting that each and every product be so aligned. This principle accomplishes the most important objectives. First, it ensures that wholesale prices recover import costs, at a realistic exchange rate (see proposition 2). Second, by focusing on wholesale prices, it contributes to maintaining a distinction between the revenues needed for cost recovery and the intended level of tax revenues.

Any recommendation on the price of individual products has to be assessed in the context of other price distortions in the country. For example, in Brazil, diesel prices are substantially lower than gasoline prices. Because the government prohibits importing diesel vehicles, another "distortion," this price difference is of less consequence than the unintended reduction in overall prices resulting from the exchange rate crisis. Thus, while aligning every product price with international prices is in principle the best policy from an economic standpoint, aligning the overall wholesale price may be a useful "second best" policy. In the Sudan, fuel oil prices are low because the government wants to subsidize the electric utility. Tying development assistance to the "rationalization" of fuel oil prices may be useful only if assistance to the utility is studied as well.

In arguing in favor of price reform, officials from development agencies can help demonstrate the long-held presumptions of the existing program. For example, many programs presume that regulating petroleum prices is the most efficient way to protect certain groups from the impact of higher prices. In many least developed countries, this presumption has never been subjected to detailed scrutiny. Thus, analytical projects can be designed to examine the subject country's petroleum consumption by user group to help determine with as much specificity as is practical 1) which groups the government wants to protect from price increases and 2) how such protection can be most efficiently rendered. This includes consideration of technical and financial instruments for granting "discriminating" relief.

In oil-exporting countries where the overall level of wholesale prices is far below international levels, the key need is likely to be a blueprint for <u>long-term</u> price reform. Again, focusing on individual products avoids the main issue. Implictly or explicitly, the government must 1) evaluate the economic and social effects of the existing

program, 2) evaluate the economic effects of changes in prices on the various social groups whose welfare is of primary concern, and 3) consider various candidate reform programs based on experiences of other countries. In addition, the government can be encouraged to launch a campaign aimed at influencing elite perceptions of the benefits of a more efficient pricing program. The public, legislators, the press, and some in government have become so accustomed to the status quo, that change, especially any increase in prices, is regarded as not being in the public interest. In many countries, the debate over oil prices has yet to focus on the cost of petroleum subsidies to the country as a whole. The concept that all citizens may be better off if petroleum prices more closely reflected the world value of oil is seldom put forth.

One of the obstacles to change is that petroleum pricing reform in any country typically requires that attention be given at various levels. First, on the technical level, existing regulations often invite abuse by those who have access to information. In some countries, it may be necessary to review the conduct of petroleum sales, and to reform the importer-refiner-distributor-marketer relationship, as part of a process pricing reform.

At the "program" level, it may be useful to encourage the government to specify in detail what criteria will be employed to determine petroleum prices. Various programmatic options exist. Which ones should be employed is in part a function of the choices made at the third, the policy level.

At the policy level, the first major decision that must be made is whether to base domestic petroleum product prices on costs or on value. This presumes, of course, that the government is not prepared to let market forces determine prices. In the cost-based system, the government monitors cost and adjusts prices when predetermined variance thresholds are crossed. In the value-based system, the government monitor oil prices (and also elements of total costs such as interest and exchange rates) and adjusts local prices whenever conditions in either the home or reference markets warrant. Development agencies can help this process along by disseminating information about the experience of other countries and by sponsoring assessments of how various types of systematic pricing programs would affect the

economy.

While the dissemination of information and careful evaluation of the benefits and costs of the current program and of alternatives are useful steps, their essential purpose must not be overlooked. We have argued that a country's propensity to implement an efficient pricing system is strongly influenced by the degree of "creative tension" between advocates of supply-side and consumer-oriented pricing programs. In countries where the supply-side is underrepresented (the Sudan, Ecuador, Argentina), one of the most useful roles external development agencies can play is to strengthen these institutions.

In this respect, a policy to withhold assistance to national oil companies for the sake of promoting a more market-oriented energy policy, or to persuade governments to open up their oil markets to multinational firms, may be counterproductive. If the principal objective of development assistance is to improve the overall efficiency of the economies, surely a reform of the pricing system is an important initial step. Multinational companies will not be interested in participating in national markets where product prices are ill-regulated (although they may be very interested if bad regulations lead to high wholesale prices, but that is not a recipe for efficiency). In countries like the Sudan, reform is more likely to occur if the General Petroleum Corporation becomes a forceful advocate of rational pricing than if it remains a mere appendage, with no autonomous financial accounts, of the energy ministry. In addition, many countries like Argentina are so committed to state ownership of the long-established oil company that pressure to privatize that sector will little or no effect. This is not an argument for the superiority of nationalized oil companies, rather it is an argument for recognizing political realities and setting priorities: first, provide assistance to "get the price right." That lays the basis for opening the market to greater competition.

When governments have made the decision in principle to deal with the petroleum pricing problem on a systematic basis, whether or not as a result of the persuasion of development agencies, the regulators must turn to the technical task of establishing or changing the pricing program. At this time, they will begin to look for technical models of pricing programs. That leads to the next

proposition.

Proposition 4

a) Given the development of a propensity to embrace the principles of efficient petroleum pricing, regulators' ability to maintain efficient prices in the face of market fluctuations is a function of their ability to develop a technical pricing program that satisfies critical social and political objectives

b) The principal elements of successful pricing programs are 1) pricing formulas that clearly spell out the variables that set the thresholds for price changes, 2) a commitment to change petroleum prices, at a minimum on a quarterly basis, and preferably on a monthly basis, and 3) automatic implementation of these changes.

proposition.

Proposition 4

a) Given the development of a propensity to embrace the principles of efficient petroleum pricing, regulators' ability to maintain efficient prices in the face of market fluctuations is a function of their ability to develop a technical pricing program that satisfies critical social and political objectives .

b) The principal elements of successful pricing programs are 1) pricing formulas that clearly spell out the variables that set the thresholds for price changes, 2) a commitment to change petroleum prices, at a minimum on a quarterly basis, and preferably on a monthly basis, and 3) automatic implementation of these changes.

After reviewing petroleum pricing programs in our sample of developing countries, and considering the findings of our previous study of pricing programs in industrial countries, we offer one general programmatic conclusion: "formula-based" pricing programs based on prices in external reference markets have several important advantages over ad hoc pricing schemes. First, they can help make progress towards depoliticizing domestic oil pricing. An integrated pricing formula for can "automate" price adjustments from the refinery to the pump.

Government desiring to move from an ad hoc to a formula-based program based in whole or in part on "reference markets" have to accept a dimunition of their day-to-day influence over prices. The offsetting advantage: in time, the pricing process become less politicized, and the expectations of the public and the oil industry change towards acceptance of the fact that when international prices change, domestic prices will also change, gradually and systematically.

Such a program can be difficult to design in countries where readily available benchmarks, such as the value of crude and products, have not gained acceptance, as

in South Korea. One of the great advantages in Thailand's case is that one central benchmark--Singapore postings--is already well-established, obviating the need for complex cost-based formulas on crude and crude freight.

Brazil, Argentina, the Sudan, and Ecuador all have cost-based pricing systems. The social and political objectives of their pricing programs could still be achieved in an automatic price-formula program because those objectives relate principally to the prices of individual petroleum products, whereas the initial focus of a price formula is the overall price. Argentina and Ecuador, where the overall wholesale price has been far below world levels, could creat a pricing formula that continues to subsidize critical products, but gradually raises the prices of others so that in time (say, five years) the overall wholesale price reaches near-parity with international levels. Once that is accomplished, the prices of the subsidizied products could also gradually be brought in line.

In Brazil and the Sudan, the difference between the overall wholesale price and international prices has not been as egregious. In these countries, the pricing formula (quite explicit and sophisticated in Brazil, implicit in the Sudan) can be modified by assuring that the exchange rate used in determining the overall price be the highest, rather than the lowest rate.

NOTES:

1. They are also regulated in the majority of industrialized countries, even if one considers only those within the Organization for Economic Cooperation and Development (OECD). For a survey, see E.N. Krapels, Pricing Petroleum Products: Strategies of Eleven Industrial Nations (New York: McGraw-Hill Publiching Company, 1982).

2. The full report is titled "Fuel for the Engine of Growth," and includes detailed wholesale and retail price data for the surveyed countries for the period 1978 to 1984.

3. By "absolute" price level we mean the weighted average price of a representative barrel of oil products consumed in the market. From an analytical standpoint, the absolute price of oil in a given market is important because it provides a way to "net out" the effects of subsidies. For example, kerosine prices in Thailand are subsidized, gasoline prices are negatively subsidized. An issue of great concern is whether the negative subsidy on gasoline "pays for" the subsidy on kerosine.

To illustrate, consider a simple case in which a country imports crude oil at $30 per barrel CIF. Domestic demand requires that one-third of the crude be refined into gasoline, one-third into kerosine, and one-third into heavy fuel oil. The price regulations of the country are such that gasoline is "negatively subsidized", selling at $40 per barrel; kerosine is heavily subsidized, selling at $15 per barrel, and residual fuel oil is sold at world prices, assumed to be $27 per barrel. The "absolute price" of oil is

.33	x	$46	= $13.20
.33	x	$15	= 5.00
.33	x	$27	= 9.00
			$27.20

The cost of oil is $30, and assuming the cost of refining is $2 per barrel , it is clear that the cost exceeds the absolute price by $4.80 per barrel. This difference does not account for any distribution or marketing cost; it obtains simply at the oil-refinery level.

4. The macroeconomic statistics used in the following paragraphs were taken from the International Monetary Fund's

Monthly Financial Statistics.

5. The value of the peso fell from 328 to the dollar in May 1981 to 1,400 in May 1982 to 8,110 in May 1983.

6. M. Munasinghe and G. Schramm, Energy Economics, Demand Management, and Conservation Policy (New York: Van Nostrand Reinhold Company, 1983), p. 102.

7. Ibid.

BARRIERS TO EXPANDING IRRIGATED AGRICULTURE IN SUBSAHARA AFRICA IMPOSED BY PUMPING COSTS

Prepared Under the

ENERGY POLICY RESEARCH PROGRAM
BUREAU OF SCIENCE AND TECHNOLOGIES
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1.0 BACKGROUND AND INTRODUCTION

1.1 Project Background

This report is the result of a study undertaken as part of a series of programs initiated in 1983 undertaken by the Office of Energy within U.S.A.I.D to assess critical policy issues functioning to the energy sector and its relationship to other critical economic activities and, in particular, agriculture.

During early 1983 a team from Arthur D. Little, Inc. completed a project in Pakistan dealing with the relationship between rural electrification, irrigation pumping, and agricultural output.[1]* This project exhibited in quantitative terms the important links between rural electrification, national energy planning, and the expansion of agricultural outputs. If dealt with many practical issues which impact near term decisions such as the cost to benefit ratios of increasing agricultural output via pumped irrigation, the impacts of electrified pumping on electric system capacity requirements, and the trade offs between diesel pumps, electrified pumps, and, in the future, photovoltaic pumps. Similar critical policy and project oriented issues are arising with increasing frequency.

In order to obtain additional insights into the connection between agricultural expansion using irrigation and energy sector planning, a member of the project team participated in an assessment of irrigation options at specific sites along the Senegal River[2] and made preliminary assessments of the potential impact of irrigation expansion plans on the energy sector (and vice versa). This work reinforced the conclusion of the vital role of energy related costs on agricultural economics where irrigation pumping is an important input.

*Numbers in parentheses refer to references at the end of the report.

The experience referred to above indicated that it is critical that energy related issues be formally addressed when considering large expansions in agriculture based on pumped irrigation. Otherwise, irrigation projects might be implemented which cannot be economically sustained over the long term once the recurrent costs associated with energy delivery to the pumping systems become transparent.

1.2 Importance of Irrigation Pumping

The expansion of agricultural output in many LDC depends increasingly on pumped irrigation systems. This is true for countries as diverse as Bangladesh, where irrigation pumping is essential for multiple cropping, to Egypt, where further expansion of agriculture is planned in arid new land areas and Senegal where development of the Senegal River Valley depends almost entirely on pumping. The expansion of irrigation pumping is now or could be accomplished via rural electrification programs. These programs are extremely important elements in energy sector planning and policy development. For example, in Pakistan, electric sector expansion consumes over 80 percent of the total energy sector budget. The major donors are also heavily involved in electric sector expansion programs amounting to well over $3 billion in 1982. Roughly 16 percent of World Bank financing and 25 percent of Asian Development Bank financing is devoted to electric sector infrastructure development - much of which is either directly of indirectly associated with rural electrification.

Irrigation pumping is a highly energy intensive process. As a result, the operation of the irrigation pumping systems is often the predominant load within the rural sector. For example, in Pakistan over 20 percent of all power generated is used for operation of pumping systems. Along the middle and upper sections of the Senegal River Valley over 90% of power generated is to operate irrigation pumps*. The large impact of pumping on electric loads is readily understandable given the typically low use in individual homes in LDC (.5-1 kWh per day) as compared to even a modest sized irrigation pump (50-200 kWh/day for a 10 kW pump).

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*All power in these regions is produced by Diesel generators or Diesel pumps.

The role of pumped irrigation in increasing agricultural productivity and the well being of rural populations is becoming very important in some countries. For example, Pakistan is now marginally self-sufficient in food largely as a result of pumped irrigation, which is now used in over 15 percent of the arable land. Similarly, increasing agricultural production along the Senegal River Valley depends almost exclusively on the more than 300 pumping units most of which have been installed in the last five years.

In these and other countries, the continued operation of diesel and electrified pumps is becoming increasingly critical to the overall productivity and predictability of the agricultural sector. These pumping operations are, in turn, totally dependent on a predictable supply of energy at economically justifiable costs.

The issues associated with the cost of pumping water may already be influencing thinking on the role of the types of irrigation systems in Africa. For example, one World Bank official indicated that the extensive development of over 1,000,000 acres in Sudan based primarily on irrigation pumping might need to be reconsidered in light of increasing energy cost and lack of electric generating capacity. The higher capital cost options of gravity feed via use of dams and dikes would be an alternative in some areas.

This report deals primarily with the full range of costs associated with irrigation pumping and associated ramifications for agricultural economics and irrigation project planning. It is, however, recognized that many of the problems associated with irrigation projects in general and within Africa, in particular, are associated with institutional, social, and management issues. This view is described , in detail, in Reference 2.0 and was reinforced by a field worker on an irrigation project in Senegal who stated that "90% of my time is spent on managerial and institutional problems and only a small portion at technical and system design issues". It should be noted, however, that irrigation pumping often exacerbates these related managerial and social problems. For example, in Senegal a major portion of the managerial effort

associated with operating the small (20 - 40 hectares) perimeters is associated with keeping the diesel driven pumps running. This is one reason that the mission reviewing pumping options in this region leaned toward electrifying the pumps where this was a reasonable option and, thereby, relieving the local irrigation perimeter management of much of the burden of maintaining and operating engine driven systems. In short, the effective management of the water distribution system, cropping schedules, and finances is a difficult enough task without the added complexities of the pumps. The evaluation of irrigation pumping options, therefore, should take into account the persistent problems in running and maintaining complex mechanical equipment as well as the conventional economic comparisons between pumping options.

There is, therefore, a vital link between agricultural production and energy sector capabilities which must be addressed if irrigation projects depending on pumped water are to have long term viability and, in particular, have recurrent cost structures (fuel, O&M, and capital) which are sustainable based on the increased value of agricultural outputs.

2.0 APPLICATION TO SUBSAHARA AFRICA

2.1 Irrigation Expansion Plans

Much of subsahara Africa has been experiencing drought or near drought conditions for over 10 years. This, combined with rapid population increases, has resulted in persistent food production shortfalls in almost all countries affected with associated periodic famine which have gotten renewed public attention as a result of the situation in Ethiopia. As a result of this persistent flirting with agricultural disaster, all the donors in this region are now or are considering placing major emphasis on the agricultural sector.

A significant portion of these resources will be directed toward projects involving the improvement or expansion of irrigation systems. For example, the CDSS for the Sahel[4] states "Our investigations have convinced us that the most likely evolution of rain-fed agricultural production will not yield the output goals and schedule we have set for the program. This production will inevitably be hostage to periodic severe drought. It is, therefore, advisable and necessary to undertake a major effort in irrigation development to exploit the considerable volumes of rive water which now pass through the Sahel unused. While much irrigation is currently practiced, only about ten percent of the potential is being exploited. A.I.D. and others have hesitated to undertake major efforts in irrigation because of the expensive infrastructure required, the technical sophistication involved in the operation, and the dismal experiences with many initiatives to date. Yet, irrigation development is required to realize the region's production potential and assure food security and we are convinced that these problems can be overcome. We propose to proceed deliberately, to acquire the necessary knowledge in selected pilot investments, to rehabilitate infrastructure in place and to gradually expand the activity as our competence improves."

On a similar note the Annual Budget Submission for U.S.A.I.D., MALI[5], indicates "From a national and regional planning framework, it is likely that only improved utilization of the Niger River for irrigation will close the gap between food production and population growth." As suggested above, the expansion of irrigation in the Sahel and other drought prone regions of Africa is an almost unavoidable result of a policy to expand agricultural output. As a practical matter, irrigation will be carried out wherever possible using gravity fed systems where the basic water supply is a river. However, in many (if not most) areas the topography is not conducive to gravity fed systems. For example, the Senegal River experiences changes of level of up to 30 feet between the dry season and flood stage and, as a result, almost all irrigation in MALI, Senegal, and Mauritunia along this river would (and does) require pumping with significant vertical lifts.

In most countries of Subsahara Africa, long range plans for expanding irrigated areas are still in the development stage or are just beginning to be formulated. As a result it is difficult to project with much certainty the growth in irrigation and the nature (pumped, gravity, etc.) of the irrigation systems themselves.

A recent report on irrigation prospects in the Sahel[6] does, however, provide some figures in the gross potential for irrigation and possible rates of development. Table 2.1 provides an overview of current irrigated areas, potential to the year 2000 based on current trends or government plans, and ultimate potential of all or most lands suitable for irrigation are brought into cultivation. This table deals only with the 8 Sahelian countries. Other countries in a similar subsahara arid zone subject to recurrent drought conditions include Ethiopia, Sudan, Somalia, and sections of Nigeria and the Central African Republic. For the Sahelian region alone the FAO estimates that there is an estimated 12 million acres (4.85 million hectares) of land with potential for irrigation. By comparison, roughly 2 to 3 million hectares of land are now under some form of controlled irrigation in the countries indicated. The figures for the year 2000 are very uncertain for all of the countries which

TABLE 2.1

Overview Of Irrigated Areas In Selected African Countries (in thousands of hectors)[1]

COUNTRY	1978	1985	2000	POTENTIAL
Cape Verde	1.9			5
Chad	4.5			280
Gambia	2.2	2.8		70
Mali	111.0	150		1000
Mauritanie	1.9			200
Niger	5.8	6	200	220
Senegal	91.0	160[3]	170[4]	250[2]
Upper Volta	9.0	-	-	130
Sudan[5]		1610	2020	3000

1.0 Most figures from reference 10-3

2.0 Along Senegal River Basin alone

3.0 Introducing 25 along the Senegal River

4.0 Assuming 80 along the Senegal River

5.0 Based on discussions with World Bank

do not have long range plans. However, it appears that something on the order of 4 to 6 million hectors of land might be brought under irrigated cultivation as a minimum requirement to approach food self sufficiency.

2.2 Energy Implications of Irrigation Expansion

Table 2.1 indicates projections for total irrigated areas in the Sahel. A significant portion of this area will, however, be gravity fed in total or in part. For example, in the Niger River delta area most irrigation can be gravity fed by use of barrages and dikes. However, even in areas which use gravity fed irrigation during high water period, pumping may be required during the dry season to ensure a double cropping capability. This appears, for example, to be the case in parts of Niger.

Based on discussions with USAID staff and World Bank officials, it appears that the percentage of area requiring pumping will range between roughly 90% (Senegal) to about 50% (MALI). It is expected other drought prone countries of the subsahara will be equally dependent on active pumping to increase irrigated areas from present levels and allow for reliable multiple cropping.

The energy implications of pumped irrigation depend on several factors including:

- The volume of pumped water (cubic meters/hectare per crop) requirements of the crop as determined by rainfall, climatic conditions, soil conditions, irrigation system design, and crop selection.
- The depth from which water must be pumped.
- The efficiency of the pumping system (engines, motors, pumps, etc.)

The impacts of these factors on pumping energy and infrastructure requirements are discussed in section based on recent field experience in Senegal and

Mauritania. As indicated in Section 3.0, if diesel pumps are used, the fuel use can range from 100 liters/HA per crop for rainy season rice and modest lifts (5m) to almost 400 liters/HA per crop for dry season rice with low river levels. Even larger volumes of fuel (over 1000 litres per hector) are required to pump groundwater from depths quite common in the Sahel (30-60 m). This in itself could limit the use of groundwater resources in many areas - particularly for irrigating low value crops such as rice.

If the pumps are electrified, the corresponding electric sector capacity requirements range from 0.3 to 1 kW of generating - transmission capacity per hectare of land.

Of course, the above are just general "rules of thumb" based on water use and equipment characteristics in one regions. It is likely, however, that these figures are indicative of energy use and infrastructure requirements in other regions of subsahara Africa with similarly arid conditions and low rainfall to supplement pumped water.

Using the above general guidelines, that the Sahelian countries alone might have to import over__ barrels of oil annually and/or install up to ___ MW of generating capacity to serve irrigation growth to the year 2000. By comparison, total generating capacity in these countries is now only about __ MW. The energy use and infrastructure remifications of achieving a significant portion of ultimate potential in this region are large compared to present capabilities.

The above strongly suggests that plans to significantly increase irrigated agriculture in subsahara Africa must be closely integrated with energy system and fuel availability planning.

2.3 Energy Related Barriers to Agricultural Expansion

The previous section indicating that the costs of fuel importation and energy sector infrastructure development will be formidable if the role of irrigated agriculture is expanded significantly in Subsahara Africa. Clearly, much of the

costs associated with infrastructure development will have to be assumed by donor organizations given the marginal financial condition of all the countries involved. However, a necessary condition for long term viability of expanding irrigated agriculture is that the projects at least support the recurrent fuel, O&M, and capital costs associated with servicing debt, fuel purchases, and O&M. If this condition is not met either the government (usually with donor support) will have to subsidize the systems indefinitely or the systems will fall into a state of disrepair as the farmers find themselves unable to provide their share of costs.

As indicated in Section 3.0, energy related costs impose several practical restrictions on pumped irrigation in the Sahel. These include:

Depth of Pumping:

Pumping energy requirements are directly related to the vertical lift through which water must be pumped. Particularly in regions where rainfall is minimal this can impose severe restrictions on the depth of wells or the height of irrigated areas above rivers. For example, in Senegal it was determined that pumping water through vertical lifts in excess of 10 meters had to be examined very closely based on energy related costs alone. This factor could often cast doubts on the use of groundwater resources even in regions where such resources are widespread.

Double Cropping Potential:

A major incentive for pumped irrigation is to allow for reliable multiple cropping. However, "off season" crops are likely to be during dry periods (typically September through June in much of the Sahel) when rainfall is minimal and tran-evaporational rates very high. The result of these factors is that pumped water needs might be twice those of the "rainy season" crops. The economic viability of such hot weather crops should be examined closely in regions with significant pumping heads based on energy considerations alone.

Crop Selection:

For historical reasons, rice is now a staple in many regions of the Sahel. This is unfortunately an example of a crop with very high water requirements even in zones with proper (high clay) soil conditions. In addition it is a crop with ample supplies at low cost in world markets. The combination of high water requirements and low value make rice an example of a marginal crop for pumped irrigation in many areas. The relationship between pumping needs, crop value, and alternative crop selections needs to be examined closely in all situations with significant pumping heads (over 5 meters). For example, in the upper regions of the Senegal River valley the pumping related costs alone are over 60% of the rice crop value. The above suggests the increasing importance of crop related research for the Sahel in order to identify crops with lower water needs than those traditionally grown in this region.

Irrigation System Design and Management:

Currently most pumped irrigation systems in the Sahel use open canals and unlined ditches to distribute water to the crops. These systems are relatively easily implemented in the field and use mostly local labor and materials. They also tend to have rather high losses - usually 30-50% of the water entering the system. In addition, there is a strong tendency to over irrigate, in part, a reaction by individual farmers to ensure that they get "their share" of the water. The net result of these factors is for the amounts of water being pumped to easily be twice that necessary if a low loss, carefully managed, irrigation system were utilized. With natural gravity irrigation the above factors are usually not very important and the open canal, furrow systems, represent an optimal choice for irrigation system design. However, with pumped irrigation the cost of water can be quite high (1-2¢/m^3) and the use of high loss irrigation networks increasingly unacceptable.

The question of balancing costs of irrigation networks (possibly involving canal lining, piping, etc.) in order to lower losses against lower pumping costs requires increasing attention as the role of pumped irrigation expands.

The above indicates several of the issues where pumping energy costs can restrict the options for pumped irrigation or significantly impact on the conditions under which pumped irrigation projects proceed. The situation is seen to involve a complex mix of energy systems, crop selection, and irrigation technology, issues which will be resolved differently in each area. However, the above suggests that it is important that the right questions be asked in the early stages of pumped irrigation project design so that projects are not implemented where energy costs alone call into question longer term economic viability.

3.0 ENERGY IMPLICATIONS OF PUMPING OPTIONS (Senegal Example)

3.1 Pumping Options Considered

As a practical matter, most systems for irrigation pumping in the near term will rely either on diesel driven pumps or on electricity supplied by a grid. The "grid" power will often, in turn, be supplied by a thermal power plant burning fuel oil, diesel fuel, or natural gas. In both cases, petroleum products may have to be imported to support the operation of the irrigation pumping system. The following discusses the fuel use by the two primary modes of energizing irrigation pumping so that their potential impacts on energy balances can be estimated.

a. Direct Diesel Drive

Figure 3.1a is a schematic of a direct diesel drive pumping system typical of those widely used where suction lifts are low. These systems usually consist of a Diesel engine directly driving a centrifugal pump.

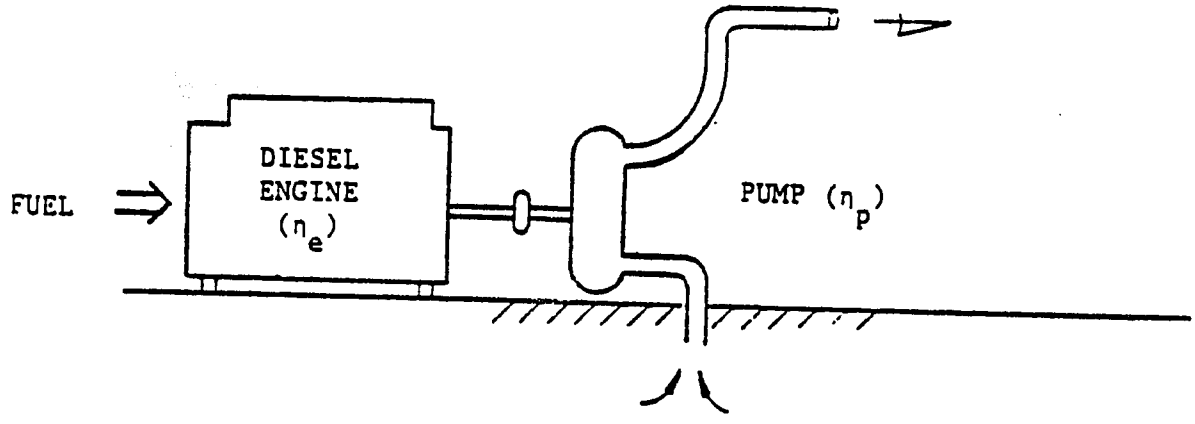
The primary parameter determining fuel use in such a system is the system efficiency defined as:

$$\eta_s = \eta_e \times \eta_p$$

where:

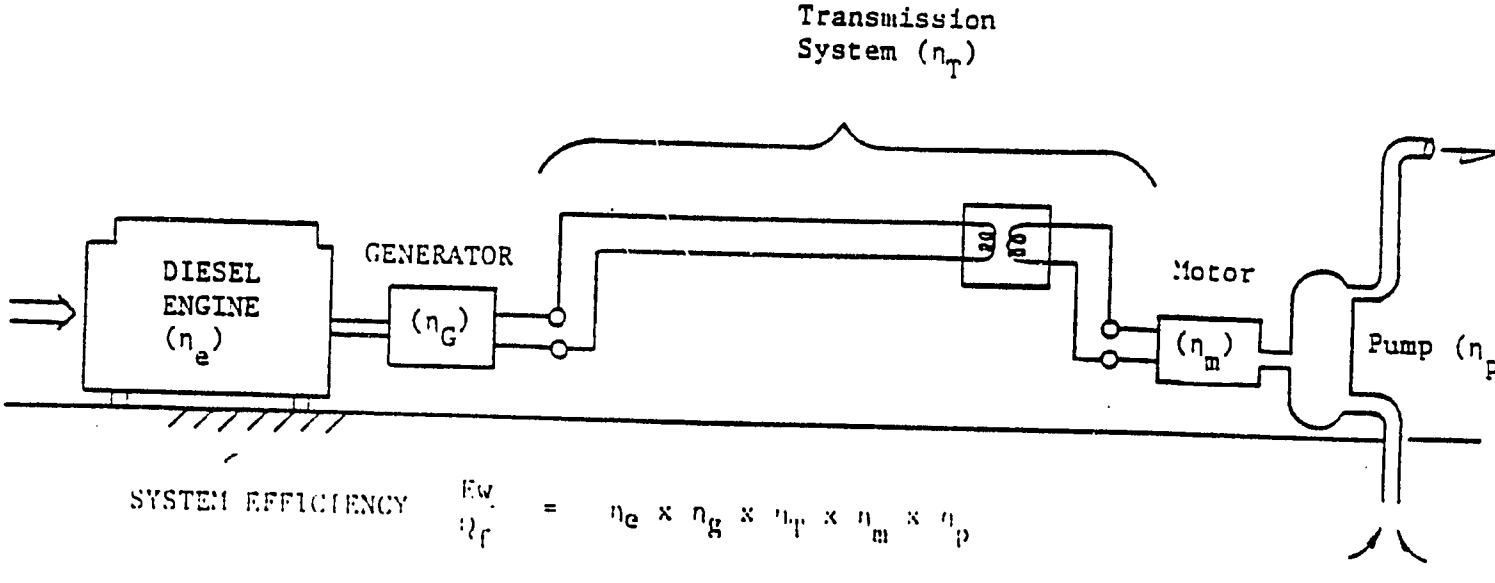
η_e - diesel engine efficiency
η_p - pump efficiency

As indicated in Reference 2, Diesel engine efficiencies in modest size (3 - 30 kw) typical of use in the Sahel are in the 20-25% range under field conditions. Properly selected pumps can operate with efficiencies of 70-80%. The net system efficiencies of direct drive Diesel systems is, therefore, in the 14-17% range. Achieving this efficiency range is still contingent on properly matching engines and pumps for the applications in question. For example, centrifugal pump



$$\text{SYSTEM EFFICIENCY} = \frac{\text{Energy to Water}}{\text{Fuel Input}} = \eta_e \times \eta_p$$

(a): EFFICIENCY OF DIESEL PUMP UNIT



$$\text{SYSTEM EFFICIENCY } \eta_f = \eta_e \times \eta_g \times \eta_T \times \eta_m \times \eta_p$$

(b): EFFICIENCY OF ELECTRIC PUMP SYSTEM

FIGURE 3.1 SCHEMATIC OF EFFICIENCY TRAIN IN PUMPING STATIONS

efficiencies can easily drop to 50-60% if used under inappropriate head conditions and/or poorly maintained inlet suction conditions. Improper pumping system can easily increase pumping fuel requirements by 30-50%.

b. Electric Driven Pumping System

Figure 3.1b is a schematic of an electric driven pumping system assuming the source of electricity is a thermal plant (shown as a diesel generator). As indicated, the efficiency of this arrangement (which includes many rural electrification systems) is given by:

$$\eta_s = \eta_e \times (\eta_g \times \eta_T \times \eta_M) \times \eta_p$$

η_g = electric generator efficiency
η_T = transmission/distribution line efficiency
η_M = electric motor efficiency

There is a common perception that the electric option would be more energy intensive than the direct drive Diesels due to losses in electricity generation, transmission, and motors. Indeed, if the engine and pump efficiencies for the two options are the same, then the electric option will require 20-30% more fuel than direct drive Diesel systems even with line losses within accepted ranges. In practice, however, the electric option will often involve larger Diesel generators operated by the utility which, on average, might be more efficient than small, locally maintained, engines. For example, this appears to be the case in Senegal. The small (500 kW) of Diesel capacity at the towns along the Senegal River operate with efficiencies of 25-28% which is higher than would normally be expected from a 20 kW field unit. In properly designed systems (particularly those with low line losses), the higher engine efficiencies will tend to counteract the electric conversion/transmission inefficiencies.
To account for the wide range of possibilities two cases are considered below:

(i) High Efficiency System

This case assumes a well maintained electric generating and transmission system and use of high quality electric driven pumps. The efficiency assumptions are:

η_e - 28 percent (good central diesel generators or small steam power plant)
η_g - 90 percent
η_T - 90 percent
η_M - 90 percent
η_p - 70 percent

System Efficiency = η = 14.3 percent

(ii) Low Efficiency System

This case corresponds to one commonly found in LDC which have a combination of:

- Low efficiency electric generation facilities comprised of some mix of small (poorly maintained) steam plants, gas turbines, or old diesel engines.
- High transmission/distribution losses due to a combination of undersized lines, poor connection practices, and long distances.

The efficiency assumptions of this case are:

η_e - 23 percent
η_g - 90 percent
η_T - 75 percent
η_M - 90 percent
η_p - 70 percent

System Efficiency = η_s = 9.7 percent

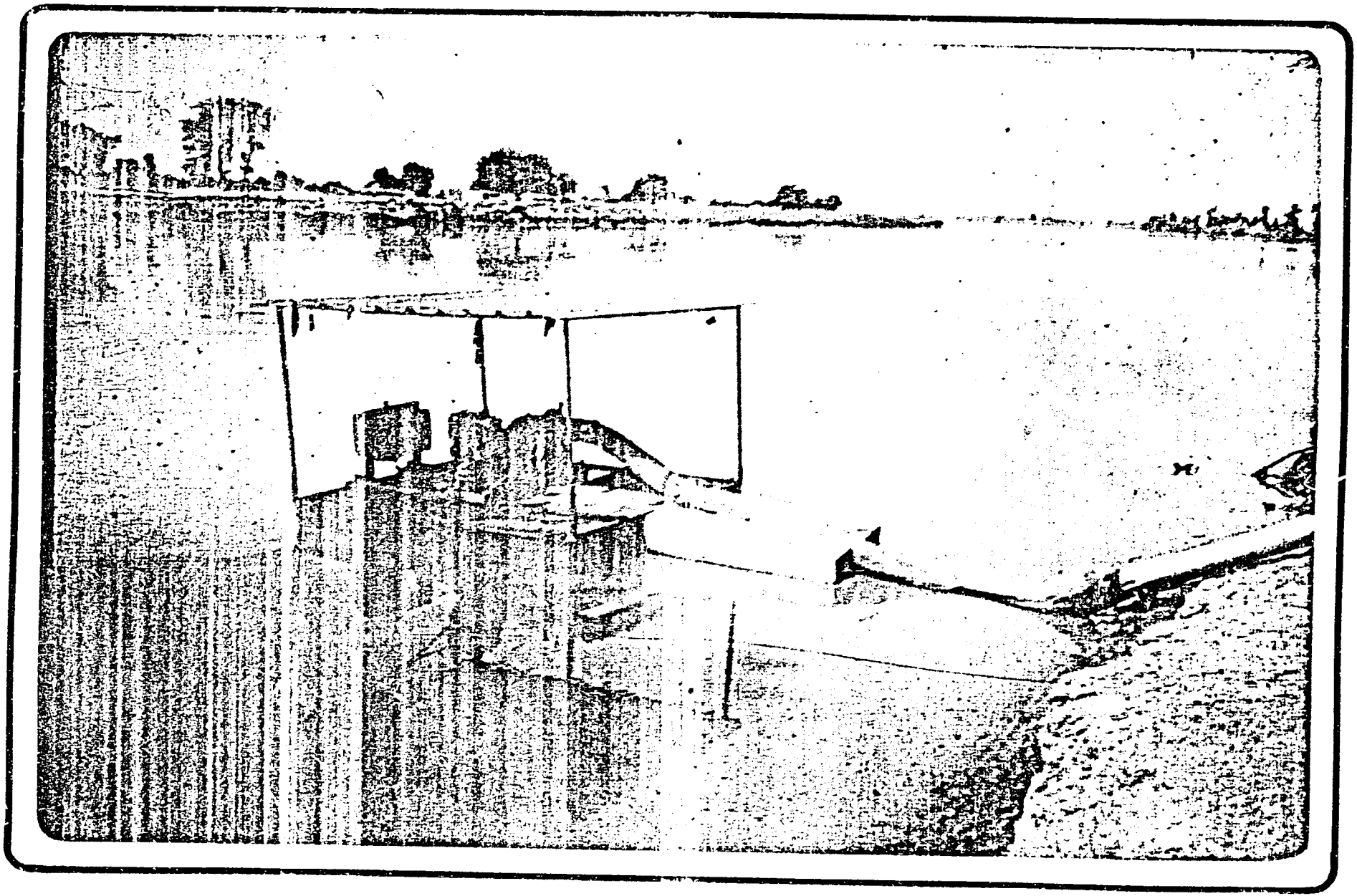
Figure 3.2 indicates the resultant fuel consumption per M^3 of water pumped for these two cases.

3.2 Capital Cost Implications of Pumping Options (Large vs. Small Scale Pumping)

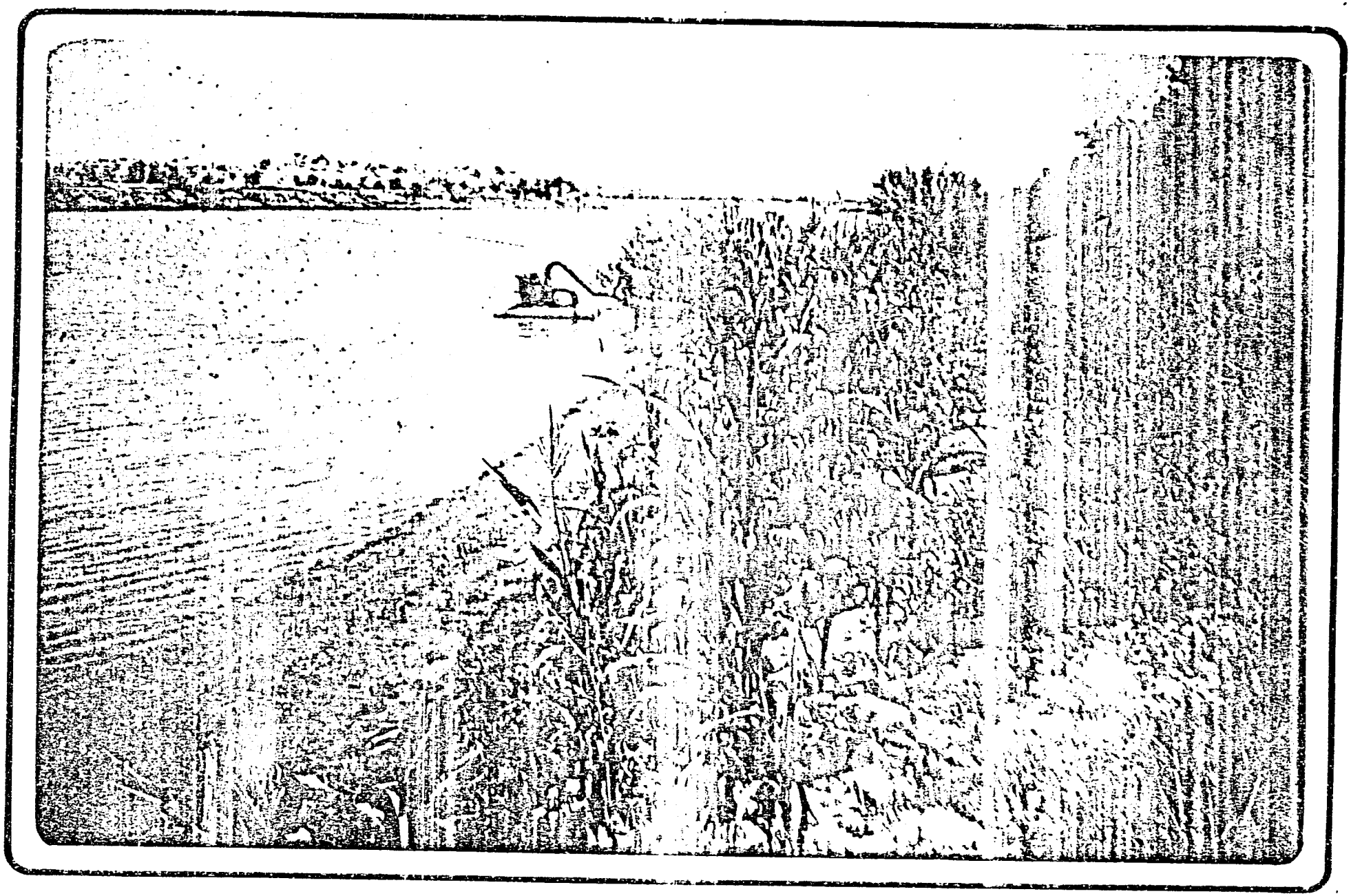
Each situation will have specialized characteristics affecting the selection of pumping system. Table 3.1 indicates a range of pumping system arrangements specifically addressed in a study on pumping options in Senegal and Mauritania. These options are also those in use or which could be considered for use in other areas where irrigation pumping is required. Of the options indicated, the Diesel driven floating pumps (GMP) are most commonly used along the Senegal River. Similar units are also used in Mali and Niger. One incentive for floating units along such rivers is the large variation in river level by season and associated shifting of river channels (per Figure 3.3). Each of these units can irrigate 20-50 hectares of land.

There are also a small number of fixed pumping stations in place or being considered for providing water to large projects (500-1000 hectares). Figure 3.4, 3.5, and 3.6 are views of several of these pumping options as they are used along the Senegal River. Figure 3.4 shows a 22 Hp floating platform GMP unit with its associated flexible piping line to account for large changes in river level. Figure 3.5 shows views of an electric pumping system using four floating submersible pumps. Electricity in this system is provided by a 100 kw generator set placed on shore thereby facilitating maintenance. Figure 3.6 is a view of the pumping house and discharge canals of a 1000 HA irrigation project at PODOR. Electric power for the system is provided by a 500 kw dedicated generating facility. However, a similar installation at KAEDI (Mauritania) is served by the local, (Diesel based) electric utility.

There is often a perception that large projects might offer economies of scale and have larger developmental impacts. However, experience in the Sahel

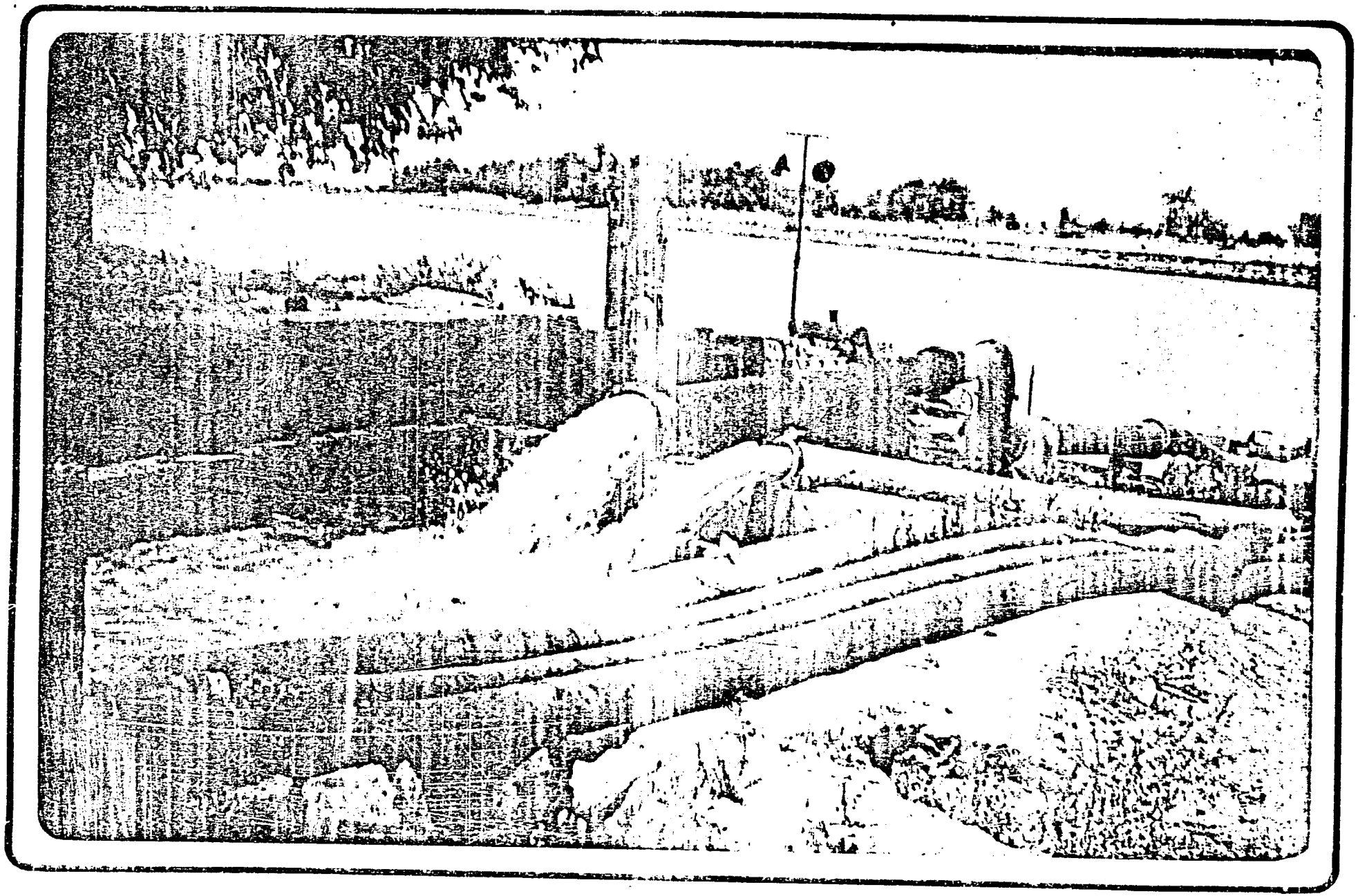


3.4a CLOSEUP OF FLOATING DIESEL PUMP SYSTEM

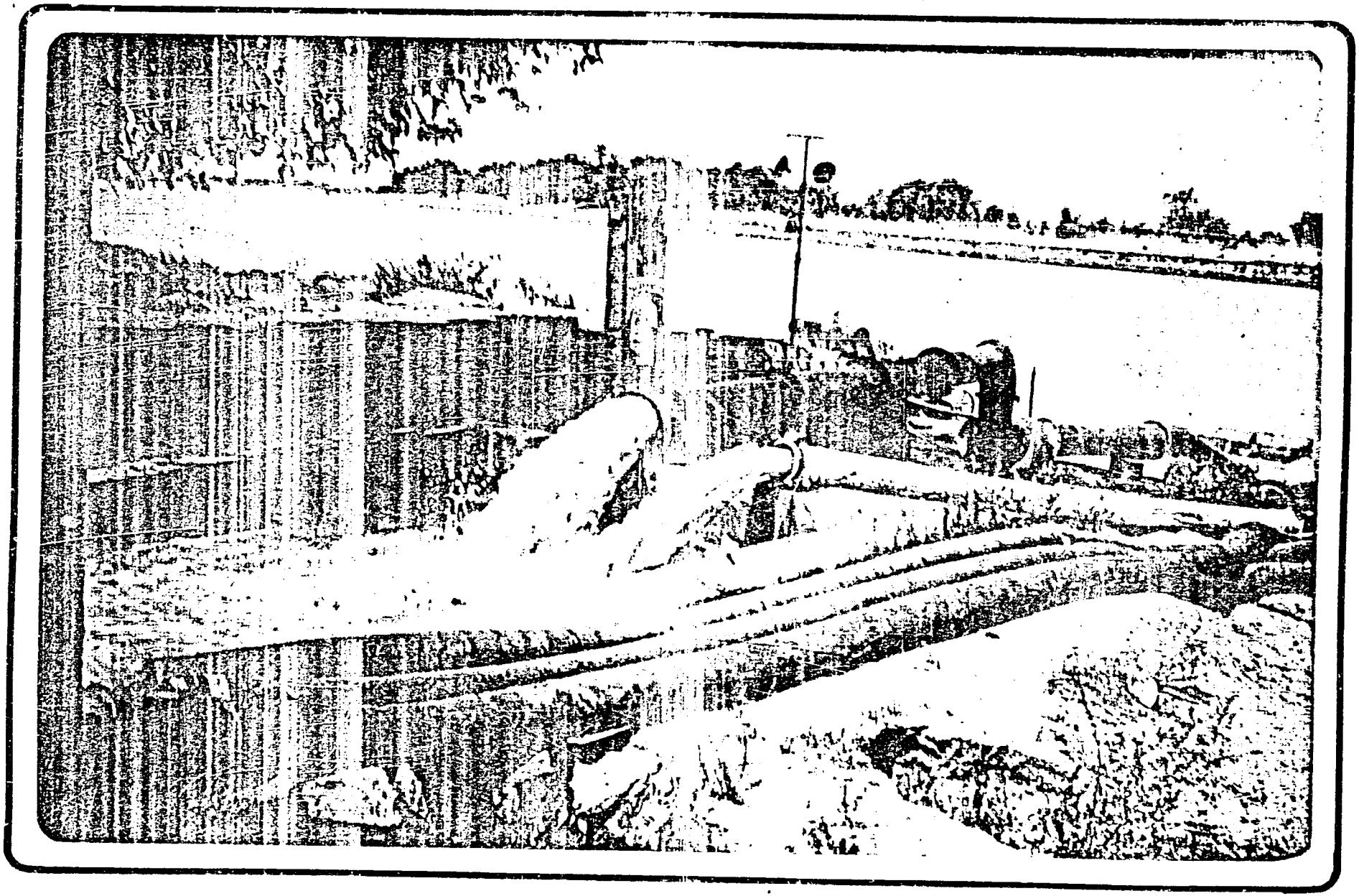


3.4b FLOATING DIESEL PUMP SYSTEM (GMP) ALONG THE SENEGAL RIVER

(Note: Flood recession Maize crop in the foreground)



3.5a VIEW OF THE SUBMERSIBLE PUMP SYSTEM FLOATING PLATFORM, DISCHARGE
(Note: Pumps are suspended beneath the floating platform and are not visible)



3.5a VIEW OF THE SUBMERSIBLE PUMP SYSTEM FLOATING PLATFORM, DISCHARGE
(Note: Pumps are suspended beneath the floating platform and are not visible)

3.5b VIEW OF THE CONTROL PANEL FOR THE SUBMERSIBLE PUMP SYSTEM (4 separate pumps)

3.5c VIEW OF 100 kw DIESEL GENERATOR FOR OPERATING THE SUBMERSIBLE PUMPS

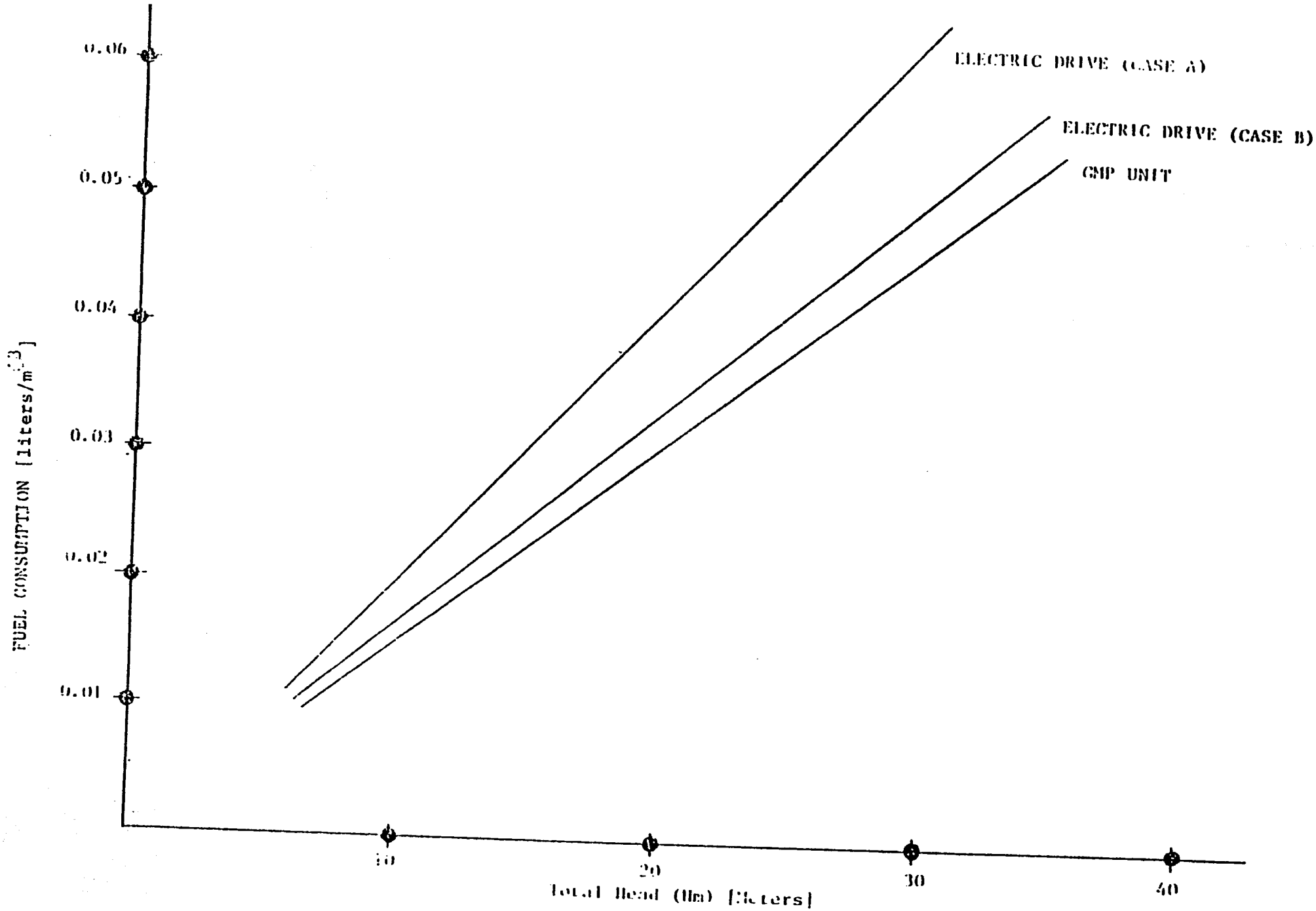


FIGURE 3.2 FUEL REQUIREMENTS OF IRRIGATION PUMPING

TABLE 3.1

PUMPING SYSTEM OPTIONS

- FLOATING PLATFORM DIESEL PUMPS
- FLOATING PLATFORM ELECTRIC-DRIVEN SUBMERSIBLE PUMPS
  - DEDICATED DIESEL GENERATORS
  - CONNECTION TO LOCAL ELECTRIC GRID (BADEL AND FODOR ONLY)
- PHOTOVOLTAICS
  HAND PUMPS
- STATIONARY PUMPS (USING DEDICATED DIESEL GENERATORS)
  - RIVER WATER
  - GROUND WATER

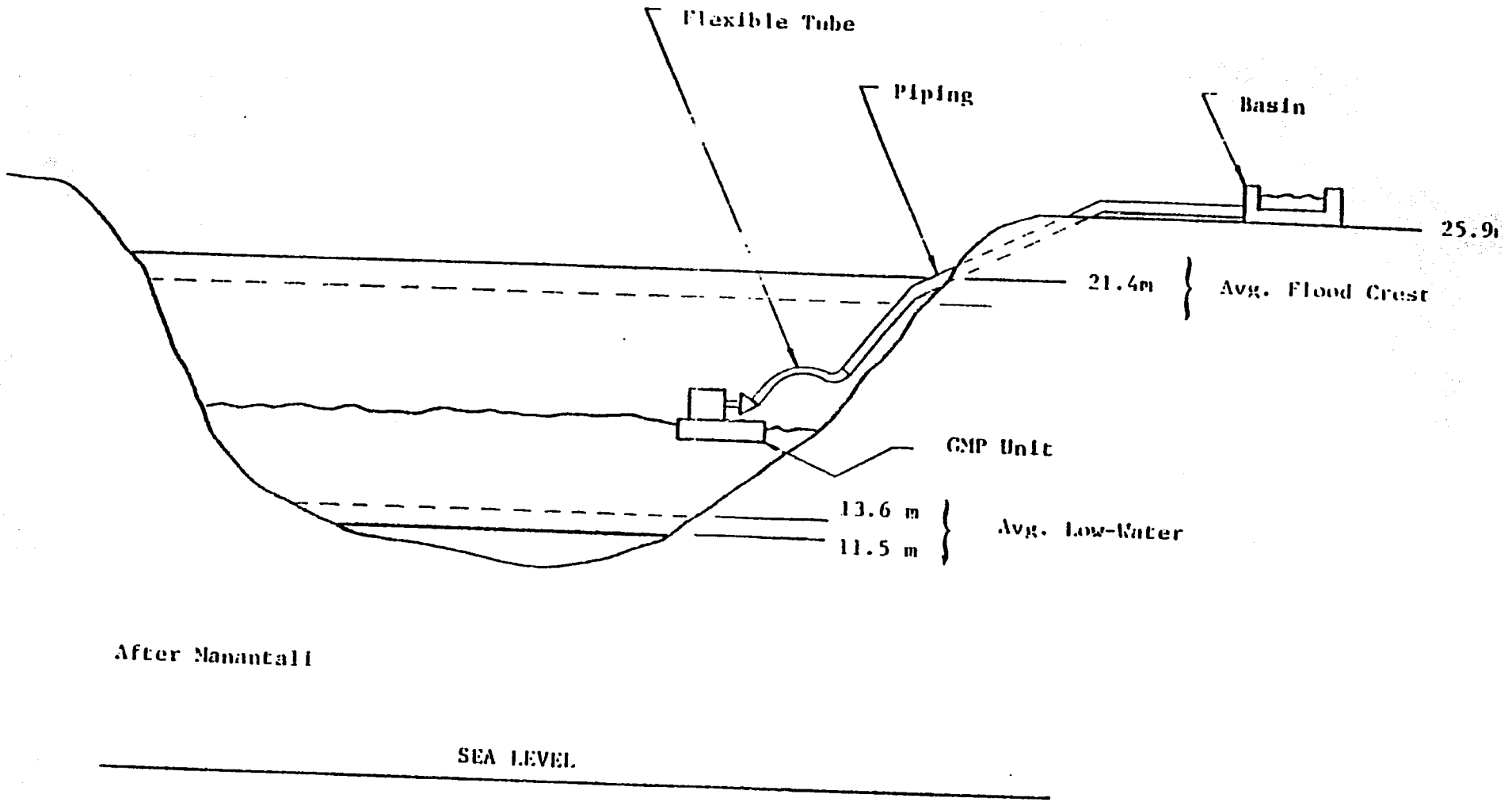
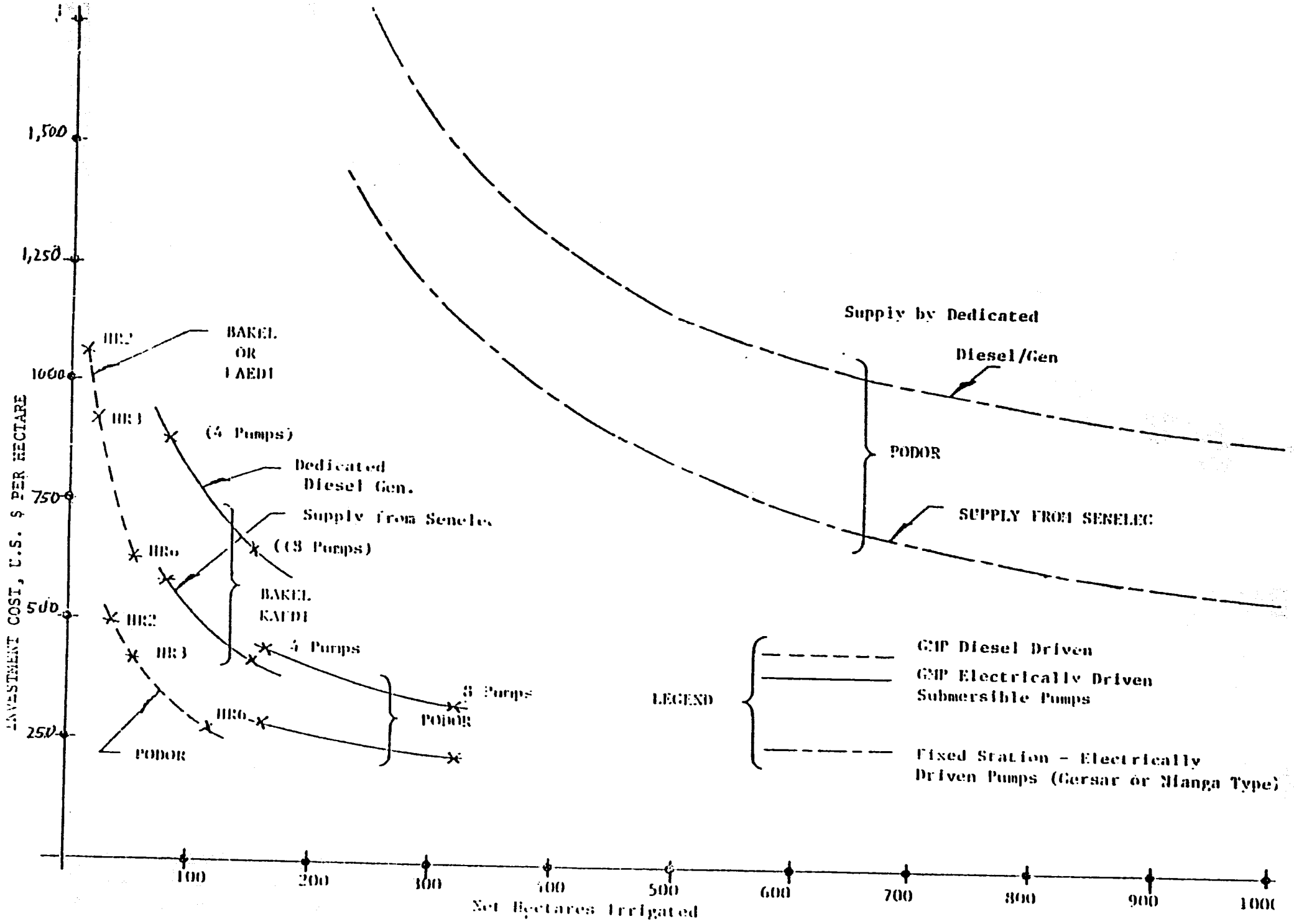


FIGURE 3.3 SCHEMATIC OF FLOATING PUMP SYSTEM (BAKEL REGION)



GENERAL COMPARISON OF INVESTMENT COSTS OF PUMPING OPTIONS

suggests that such large projects are difficult to properly manage. In addition, as indicated in Figure 3.7, there is no incentive to pursue large projects based on the capital costs of the pumping systems. In fact, the fixed pumping systems are considerably more costly than either Diesel or electrically driven floating units. This is due to the extensive civil work required to install fixed pumping systems, particularly along waterways with large seasonal fluctuations in water level. The costs for fixed pumping units will certainly be site specific. However, the implications of these previous studies is that any assumptions relative to inherent economies of scale in pumping systems should be examined very closely during the design of projects.

If each increment of irrigated area is considered as a separate project, the most flexible and lowest cost option for providing pumping is probably a GMP unit (whether floating or positioned on a river bank). However, if the expansion of irrigated areas is considered on a regional basis over time, then consideration should be given to electrifying the pumps. As indicated in Figure 3.7, floating platform electric driven submersable pumps can often be the lowest cost option. Additional practical advantages associated with this option include:

- A multiplicity of pumping units can be served from a "central" power system serving local or regional needs. Even if using Diesel fuel, the "central" power unit can be professionally run and maintained, thereby improving reliability and better ensuring efficient operation. Also, in some cases the central power unit might provide the flexibility to be able to utilize locally available fuels for the operation with significant reductions in fuel costs.
- The basis of many pumped irrigation projects has been the inability of local farmers to consistently maintain and operate small Diesel pumps. By comparison, the operation of small electric pumps is quite straightforward and relieves the farmers of the onerous need to gain significant mechanical skills. As such, the farmers can focus their attention on the difficult enough task of managing the irrigation system itself. The use of electrified pumps served by local or regional grids could therefore improve the chances of success in the irrigated perimeters.

- The electrification of the pumps even at a local level paves the way by establishing local distribution networks for more comprehensive electrification via grid extensions in the future once the loads increase to warrant such extensions.

There are, therefore, a number of practical reasons for considering the use of electrified pumps, particularly if irrigation projects are considered in an overall regional development context. Also, such longer term planning does not necessarily result in higher initial capital costs for those electric pumps installed during the earlier stages of development when dedicated Diesel generators are used for pump energization.

The investment costs indicated by figure 3.7 range from less than 500 to $1,500 per hectare depending on pump type used, location, and size. In general, these costs are often relatively modest compared to the overall costs of implementing irrigation projects in Africa. These costs often run over $10,000 per hectare which is one of the reasons that expansion of irrigation in Africa has proceeded rather slowly. However, some of the smaller perimeter developments with large inputs of local labor (for example, Bahel-Collerga) have reported costs as low as $2,000 per hectare. In general, the capital investments associated with properly selected pumping systems do not appear, in themselves, to represent a major barrier to expanding irrigated areas. The primary issues are the recurrent costs associated with fuel use, maintenance, and rapid depreciation (note: engine driven pumps will usually have useful lives of less than 10 years).

3.3 Crop Selection and Water Use

The crops grown along the Senegal River Valley are typical of those in many regions of the Sahel. They include rice, sorghum, corn, and garden type crops such as onions. Most of the irrigated perimeters are now devoted to rice during the rainy season crop (August through October in Senegal) and to "mixed crops" during other seasons. It should be noted that, with the exception of rice, the crops grown in irrigated areas are also grown using traditional methods of flood recessional and rain fed agriculture.

Crop selections and associated pumped water use requirements are dependent on a complex range of site specific variables including:

- soil conditions
- climatic conditions
- crop strain and fertilizer use
- irrigation system efficiency and type

In general, rice is usually selected for areas with soil having higher clay content and low permeability and grains for lighter soils with higher permeability. Both types of crops are, however, commonly grown in parallel (or in series during different seasons) on the same irrigated perimeters along the Senegal River.

Table 3.2 shows estimates of pumped water requirements for three locations along the Senegal River by crop types. As indicated, there is a significant variation in water use by crop, location, and season. Reasons for this include:

- o Locations, such as Bakel, have higher rainfall than the other two locations resulting in lower rainy season pumping requirements.
- o Kaedi in Mauritainia is very dry and hot resulting in particularly high transevaporational losses.
- o Grain crops (surghum, etc.) require much less water than rice even when grown in areas having soil with higher permeability.

The reason stated above for variations in pumping water requirements (i.e., different rainfall patterns, climate and crops) will result in similar variations throughout the Sahelian region. Pumping water requirements of 3,000 m^3/HA to 25,000 m^3/HA per crop will be common in this region based on present crop selections and irrigation technologies utilized.

TABLE 3.2

CROP PUMPED WATER REQUIREMENTS - SELECTED SITES
ALONG THE SENEGAL RIVER VALLEY
(CUBIC METERS PER HECTARE)

	PODOR	KAEDI[3]	BAKEL
HIVERNAGE[1] RICE	20,000	14,000	8,800
CONTRA SEASON[2] RICE	25,500	23,200	17,800
MIXED CROPS (RAINY SEASON)	9,900	9,900	3,700
MIXED CROPS (CONTRA SEASON)	15,100	5,100	5,400

[1]"HIVERNAGE" REFERS TO MAIN RICE CROP GROWN THROUGH THE RAINY SEASON,
JULY - NOVEMBER.

[2]"CONTRA SEASON" REFERS TO AN OFF-SEASON RICE CROP TYPICALLY GROWN FROM JANUARY TO MAY

[3]KAEDI IS IN MAURITANIA, THE OTHER TWO SITES IN SENEGAL.

3.4. Fuel Use Per Crop

The source of water for all the locations considered along the Senegal River was the river itself. The vertical lifts varied significantly by location and by season. In the upper valley, the vertical lifts range from 5m to 10m during the year while in middle valley location (Podor) the lifts are much lower (2-6m). These large differences in lifts are reflected in large variations in pumping energy requirements. As indicated by Table 3.3 the primary fuel consumption in a Diesel engine pumping unit for rainy season crops in Bakel are about 100 liters/HA. This increases to over 350 liters/HA during the dry season for rice when both pumping lifts and water requirements are higher. By contrast pumping energy in Podor for rice ranges from 120 liters/HA to 315 liters/HA. The lower pumping needs as compared to Bakel are due entirely to the lower vertical lifts associated with perimeters near the river.

The fuel use for "mixed crops" is seen to be much lower than for rice in all locations due to the more modest water requirements of these crops. Nevertheless, in areas with large vertical lifts pumping energy for mixed crops can easily exceed 150 liters/HA, even if river water used.

3.5 Observations on Fuel Consumption Trends

Figure 3.2 displays several important trends relative to primary energy use in the operation of irrigation pumping systems. These include:

- The energy required is directly proportional to the lift through which the water is pumped. This requires careful examination of irrigation projects which entail pumping from wells of significant depth (certainly over 20 meters) or in the sizing of pipes which might be used to transfer water over large distances.
- A well designed direct diesel drive is probably the most energy efficient method of pumping water - particularly for larger systems which generally have higher efficient engines.

TABLE 3.3

FUEL USE BY DIESEL ENGINES AT
SELECTED SITES ALONG THE SENEGAL RIVER
(LITRES PER HECTARE PER CROP)

	PODOR	KAEDI	BAKEL
RICE HIVERNAGE	126	118	113
RICE CONTRA SEASON	315	398	365
MIXED CROPS (RAINY SEASON)	98	36	58
MIXED CROPS (CONTRA SEASON)	155	138	95
GRAIN CROP*	1000+	-	-

*BASED ON THE USE OF GROUNDWATER AT A DEPTH OF 60 M ON HIGHER GROUND AWAY FROM THE RIVER.

- The primary fuel consumed by a rural electrification system is critically dependent on the technical characteristics of the system. For a well maintained system, primary fuel consumption is comparable to that of a direct diesel drive. However, for a poorly maintained and operated system, primary fuel consumption of the power plant could be twice that for a good diesel drive.

As a practical matter, therefore, the energizing of irrigation pumps via rural electrification does not have favorable energy use impacts if the electricity is generated by oil fired thermal plants. The energy use related advantages of electrically driving the pumps will depend on a major portion of electricity being generated by some combination of:

- thermal facilities burning low cost fuels such as coal, peat, or residual oil.
- low cost hydropower.
- renewable energy systems such as wind or solar.

In these cases, the energy content of irrigation pumping will be the same as indicated in Figure 3.2 (thermal equivalent) but the cost of energy will be different for diesel engines (which must burn high quality distillates) and central electric facilities.

4.0 ECONOMICS OF IRRIGATION PUMPING

4.1 Cost of Water Delivery

The costs of pumped irrigation include:

- the cost of fuel required to operate the engine system.
- the O&M costs of the engine/pump system.
- the capital charges (interest and depreciation) on the capital purchases.

For some USAID funded projects the full impact of all these costs is not "seen" by the end users. For example, in Senegal the farmers are required to pay only for fuel and a portion of O&M costs. The attractiveness of irrigation pumping in these projects would be significantly diminished if the farmers had to finance the system at market interest rates. The World Bank also pursues an implicit policy which appears to require the recipient country to pay only recurrent costs and not the investment cost associated with implementing the project. The cost structure of water delivery for irrigation is discussed in more detail in this section for the case of Diesel driven pumps. Reference 2 provides similar analysis for other pumping system options.

a. Fuel Costs:

Previous sections have discussed the fuel requirements for pumping water (per figure 3.2) through specified lifts and the total water requirements per crop type in one area of the Sahel. The associated cost of fuel for water pumping is then dependent on the cost of Diesel fuel (for engine drives pumps) or electricity. There are tremendous variations in these costs between countries and even between regions within a country. Figure 4.1 shows fuel cost per cubic meter at water pumped based on the energy requirements of Figure 3.2. Curves are shown for two levels of Diesel fuel cost:

(i) $1 per gallon ($0.26 per liter) which corresponds roughly to the case in Senegal.

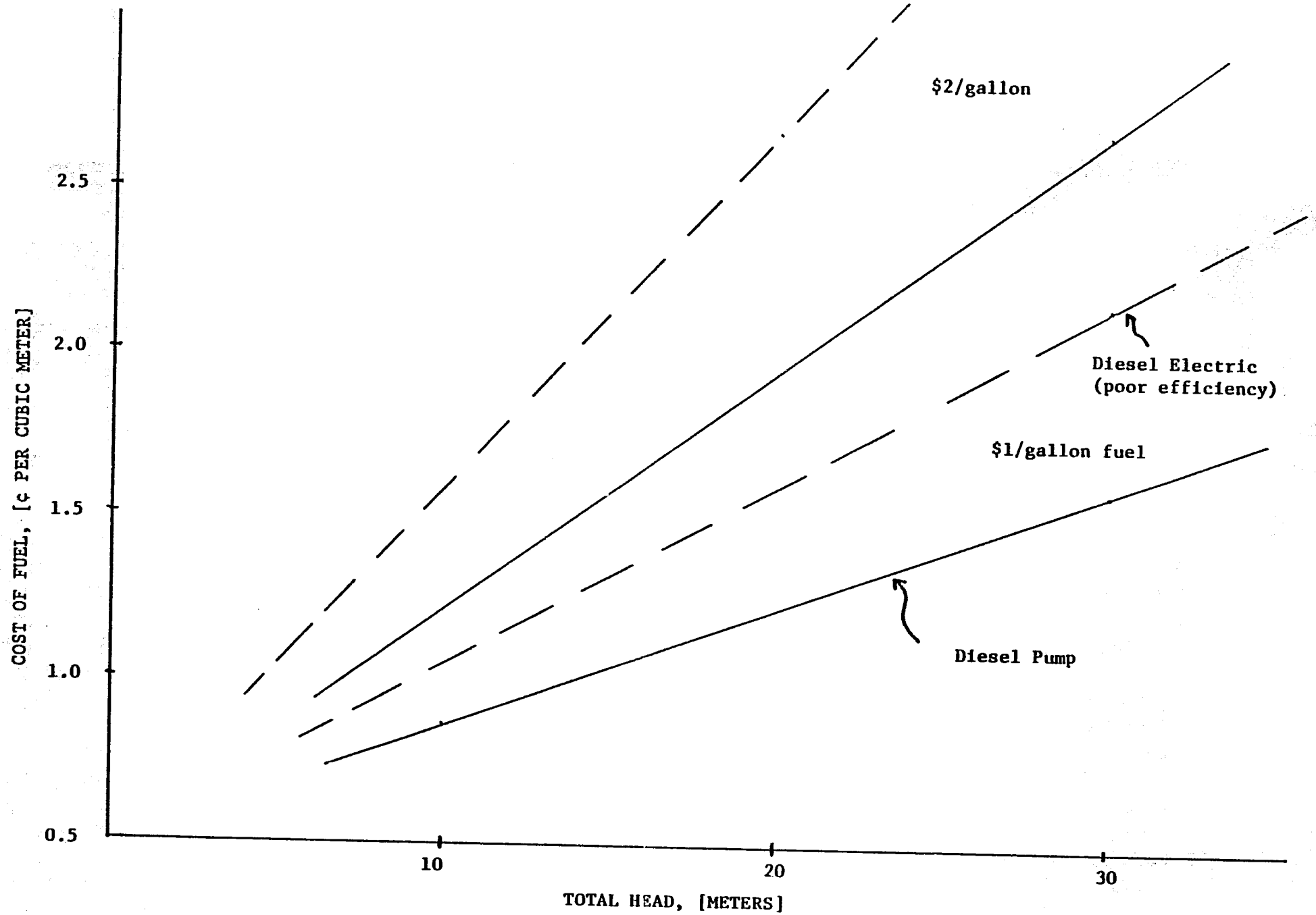


FIGURE 4.1: "FUEL COST" OF WATER PUMPING FOR DIESEL AND DIESEL/ELECTRIC PUMPING SYSTEMS

(ii) $2 per gallon ($0.52 per liter) which is consistent with delivered costs in many regions of Africa - particularly those with poor road access.

It should be noted that many regions of Africa have even higher delivered fuel costs than that indicated above. As a practical matter, irrigation pumping probably should not be encouraged in such areas.

Using $1/gallon fuel, the fuel cost alone for water pumping using a diesel pump is roughly 0.4 ¢ per cubic meter assuming a 10 meter lift. The use of a "lossy" electric drive, higher lifts, or higher cost fuel can easily increase this cost to over 1.5 ¢ per cubic meter of pumped water - a cost level for fuel alone which is probably unacceptable in many cases.

b. O & M (non fuel) Costs:

Operations and maintenance (O&M) costs can be divided into three segments:

- Operational personnel who undertake routine chores such as changing oil, filling the gas tank, etc. (referred to as a "Pompiste" in Senegal)

- Parts and materials for undertaking needed field maintenance (oil, filters, etc.)

- Parts, materials, and labor for undertaking periodic overhauls (usually every 4,000 hours even for robustly built, well maintained engines)

Operations and maintenance costs are among the more difficult to estimate. They depend on who does the O&M, the degree to which manufacturers maintenance schedules are adhered to, and the local cost of replacement parts.

TABLE 4.1

O&M COST SUMMARY FOR THREE DIESEL PUMP SYSTEMS

ENGINE MODEL	RATED CAPACITY (Hp)	TOTAL ANNUAL COST $	WATER COST (¢/M^3) BAKEL	PODOR
HR-2	22.6	530	0.4	0.1
HR-3	33.9	760	0.35	0.076
HR-6	75.5	1350	0.27	0.062

Assumptions:

1.0 Annual operating hours - 1200

2.0 Cost of overhauls annualized assuming a 10% discount rate.

Appendix 2 presents estimates of O&M costs based on field experience in Senegal and the maintenance schedule at one of the leading manufacturers of high variability Diesel pumps. The resultant overall O&M costs for this specific area are shown on Table 4.1. The variation in pumping costs by region is due to large variations in water flow due to different pumping heads.

The annual cost indicated are approximately 15% of the initial capital cost of the engine/pump assembly (i.e. those parts requiring maintenance). If anything, this is on the lower end of O&M experience and reflects the reasonably effective infrastructure developed in Senegal to service the pumping units. Also maintenance costs were estimated based on about 1200 hours of operation per year which corresponds to a single cropping season. Annual O&M costs would increase if pumps are used throughout the year i.e. more hours per year. The primary contributors to the maintenance costs indicated are lubrication oil and parts. The O&M costs are, therefore, similar to fuel costs in being primarily associated with foreign exchange.

c. Capital costs:

Capital costs depend on a range of parameters including investment cost, useful life, salvage values, and interest rates. There are several approaches for estimating annual capital costs. The approach used herein is to assume that a fixed amount of money must be set aside each year to cover replacement of equipment (i.e. a replacement fund). In addition, if the equipment is purchased on credit, there will be additional annual outlays to cover financing charges. Table 4.2 shows the annual replacement fund charges assuming funds set aside are invested at 10%.

These would be the only charges in the situation where the equipment is initially provided free to the irrigation perimeter owners and they are only required to replace it as it wears out. This is the case in many doner funded irrigation projects such as the USAID program in Senegal.

FIGURE 4.2

SUMMARY OF ANNUALIZED REPLACEMENT COSTS FOR THREE DIESEL PUMP SYSTEMS

ENGINE TYPE	CAPACITY (Hp)	INVESTMENT COST $	ANNUAL REPLACEMENT COST $	COST OF WATER (BAKEL) ¢/M^3
HR-2	22.6	16,000	620	0.42
HR-3	33.9	20,450	800	0.36
HR-4	75.5	31,800	1,250	0.26

Assumpti

- Life of engine drives of 7 years with other subsystems of between 10 - 15 years.
- 20% salvage value.
- Discount rate of 10%.

It should be noted, however, that one of the persistent management problems with pumped irrigation projects is the establishment of and consistent contributions to a replacement fund. A source of serious concern to donors is that when the initial equipment (provided by the donors) wears out that insufficient funds will be available for pump replacement leading to collapse of the irrigation project unless additional donor support is provided.

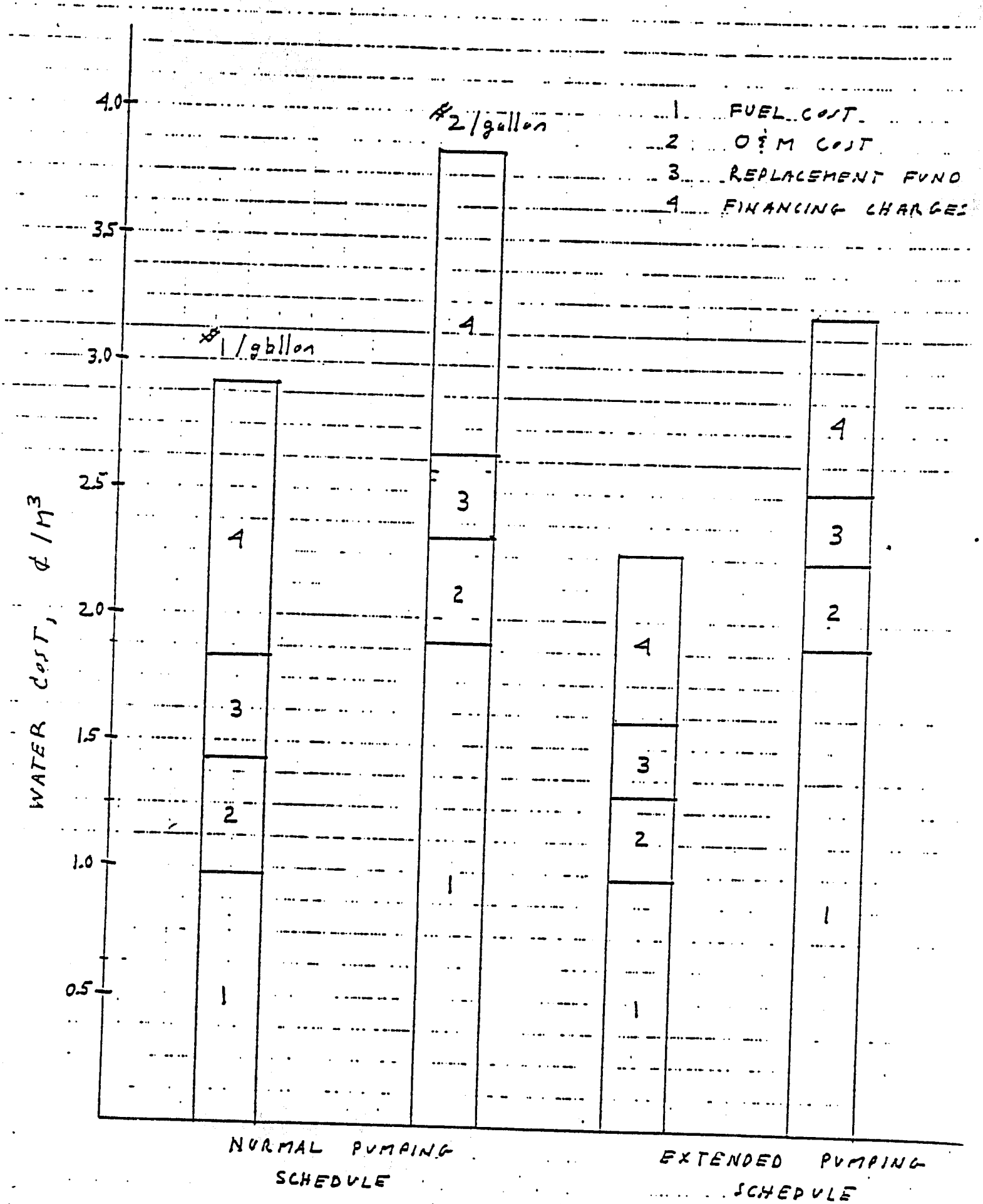
As indicated by Table 4.2, the annualized replacement fund costs are about $620 per year for the HR-2 system. The replacement fund cost only represents about 4% of total pumping system cost. This relatively low figure reflects the long life (10-15 years) associated with such static assets as platforms and piping. As a practical matter most of the replacement fund is associated with the engine. The replacement fund represents about 20% of initial engine investment costs.

The contribution of capital costs to water costs ranges from .26 ¢/M^3 to .42 ¢/M^3 depending on financing assumptions.

Figure 4.2 shows the impact of fuel, O&M, and capital costs on the overall delivered cost of water for Bakel in Senegal. As indicated, fuel cost is a major component of the cost structure, particularly with $2/gallon fuel. However, capital costs associated with financing and depreciation are also major cost components and, as previously indicated, often not realistically accounted for in assessing the long term viability of irrigation projects. The cost of water is seen to range between 2¢/M^3 to 3¢/M^3 for the cases cited. This corresponds to about $400 per hectare per rainy season rice crop assuming 20,000 M^3 of water per crop.

As indicated in Figure 4.2, capital charges represent a major portion of overall pumping costs for the case considered. One of the major assumptions in the analyses leading to Figure 4.2 was that pumping occurred during an 8 to 10 hour period through the day as is now normal practice on the small perimeters in Senegal. This pumping schedule is certainly the path of least resistance since

COST OF DELIVERED WATER SUMMARY
(HR-2 GMP, BAREL)



it corresponds to existing living patterns of the local population. However, capital costs could be significantly reduced if the pumps were operated for longer durations and thereby each pumping unit could irrigate more lands. For example, Figure 4.3 indicates pumping costs assuming a 16 hour/day pumping schedule. This schedule results in a % reduction in the overall cost structure.

Particularly if electrified pumps are used, it may be necessary to improve the utilization of costly generating/transmission equipment by insisting on nighttime pumping schedules.

This certainly adds to the complexity of the social and institutional problems associated with organizing and implementing irrigation projects. In cases with marginal local farmer support, the need for nighttime irrigation might even tip the balance against project implementation. However, the realities of the efficient utilization of high capital cost power and pumping systems have lead to day long (or nearly so) pumping in many LDC'. For example, in Kaedi (Mauritania) over 1.000 HA were irrigated as a 24 hour cycle using electric power provided by a local grid (total capacity of 500 kW). Similarly, 16 hour pumping cycles are under considèration in Sudan to ensure efficient use of regionally supplied electric power.

4.2 Impact on Crop Economics

The impact of the pumping costs of Section 4.1 on overall crop economics depends on a number of factors including:

- the requirements for other cash impacts such as fertilizers, purchased seeds, and labor.
- the increased value of crops grown as the result of the pumped irrigation.
- the alternatives for using capital available to the farmers.

The second item above is particularly critical in many countries of the Sahel. Most of these countries set official prices for major crops. These prices are often set at levels which make it unprofitable to grow cash crops even without the additional expenses of pumped irrigation. Such situations exist for example in Mali. In Senegal the official price of rice is set at 130 CFA/kg (___/__).

This price is roughly comparable to the cost (at the dock) of imported rice from southeast Asia (usually Thailand). The official price in Senegal is not truly reflective of overall importation costs if all handling and transportation charges are taken into account. Nevertheless, the pricing policies in Senegal are more realistic than in some of its neighbors which makes it a reasonable example for assessing the impact of pumped irrigation costs on agricultural profitability.

Table 4.3 is a cost summary for rice farming in Bakel and for a similar operation in Podor. The figures for fertilizers, labor, and seed were obtained from a recent study by M. Meita of the Senegal Mission (ref. 9) which apply to Bakel only. The Podor figures assume only pumping costs are different between the two locations.

As indicated by Table 4.3, in Bakel the cost of irrigation pumping for the rainy season crop account for over 24% of crop value if capital costs are considered. Even in the rainy season the growing of rice on pumped irrigated areas is only

TABLE 4.3

IMPACT OF PUMPING COSTS ON
ECONOMICS OF RICE PADDY PRODUCTION

(CFA/Kg)

	HIVERNAGE*	CONTRASAISON*
A. BAKEL		
o PUMPING COST	14.4	25.8
o OTHER COSTS	45.0	45.0
TOTAL	59.4	70.8
B. PODOR**		
o PUMPING COST	9.2	16.6
o OTHER COSTS	45.0	45.0
TOTAL	54.2	61.6
OFFICIAL SELLING PRICE	70	70

* Assumes 5 ton yield per hectare

** Assume "other costs" same as for Bakel

marginally profitable and allows very little margin of error in yields or unexpected operational difficulties (pump breakdown). As a result, most farming in this region is still done on a subsistance basis with little economic incentive to product marketable surplusses.

If a dry season crop were to be produced in Bakel, the irrigation related costs would increase to over 35% of total production costs. The resultant cost would about equal crop value making such second season crops unprofitable. In such regions as Bakel (characterized by high lifts) the merits of double cropping will require careful examination.

By contrast, irrigation pumping accounts for only about 17% of crop value in Podor in either the rainy or contrasaison due to the much lower pumping heads. This is still a heavy burden to bear but results in much larger margins of safety than in regions with higher pumping lifts and allows for profitable multiple cropping.

Figure 4.4 shows estimates for agricultural costs in Bakel and Podor if the cost of Diesel fuel were to increase to $2.00/gallon - a cost which is more representative of real costs on a delivered basis to many regions of the Sahel. In this case, the cost of pumping is so high that it would not be only marginally economical to farm rice even in the rainy season in high lift areas. This suggests the extreme sensitivity to energy costs of agriculture which is highly dependent on pumped irrigation, particularly in regions with high pumping heads.

The above discussion applies only to one region of the Sahel. Nevertheless, the results provide useful insights into the major role that pumping costs can play for irrigated agriculture in the Sahel and other regions of subsahara Africa.

In particular, for projects where pumped water is a major portion of overall water needs, pumping costs will be a, if not, the major factor in determining economic viability. The situation will be mitigated somewhat where pumped water

TABLE 4.4

IMPACT OF PUMPING COSTS ON
ECONOMICS OF RICE PADDY PRODUCTION

(CFA/Kg)

	HIVERNAGE*	CONTRASAISON*
A. BAKEL		
o PUMPING COST	19.5	35.0
o OTHER COSTS	45.0	45.0
TOTAL	64.5	80.0
B. PODOR**		
o PUMPING COST	12.5	22.5
o OTHER COSTS	45.0	45.0
TOTAL	57.5	67.5
OFFICIAL SELLING PRICE	70	70

* Assumes 5 ton yield per hectare

** Assume "other costs" same as for Bakel

is only supplemental to gravity feed water due to significant (<300 mm) rainfall.

As a result, each case would have to be examined based on project specific conditions, to ensure that the recurrent costs associated pumping can be sustained by the local farmers after the donor organizations have completed their infrastructure development activities.

4.3 Potential for Electrification

The prior discussion focuses on the impacts of pumping costs on crop economics assuming the use of direct drive Diesel pumps which are now in prevalent use along the Senegal River and elsewhere in Subsahara Africa. The aforementioned pumping study for this region also closely examined the potential for electrifying the pumps and the economic implications of so doing. Two general options were considered:

- Electrifying specific pumping units using Diesel generated electricity from nearby local grids.
- Extending the grid along the valley to make use of central power generated by thermal means (on the coast using lower cost fuels) or, in the future, by low cost hydropower from the Manantalli Dam. Only generalized long term implications of this option were provided within the limited scope of the Senegal River study.

The impacts of each option we discussed briefly below:

- **Diesel Generated Electricity:**

  The electrification of pumping units at both Bakel and Podur would require the installation of roughly 3 km of 15 kVA electric transmission lines with associated interface transformers and controls. In each case is was assumed the submersible pumps on

floating platforms would be utilized. Power would be provided by existing Senelic facilities (500 kw) which are currently operated at very low capacity factors due to small household loads in these regions. The analyses indicated that this option was lower cost by about 15% than the use of direct drive Diesels due to a combination of:

- lower O&M costs (as a unit output basis) on the margin since O&M staff were already needed for a system operation to service non pump loads.
- reduced capital costs due to the longer life of larger, well maintained, stationary Diesel units, and the fact that new units were not required to serve the incremental pumping loads.

The modest estimated difference in pumping costs between local electrification and direct drive Diesels is probably, in itself, not very important in affecting the general conclusions arrived at in previous sections and, as a practical matter, fall well within the range of calculational errors used in the estimation process i.e. the conclusion that local electrification is lower cost than direct drive Diesels is not a very firm one and certainly not generally applicable.

There are, however, several other significant advantages associated with the local electrification option in addition to possible lower costs. These include:

- the engine systems can be maintained by trained technicians thereby better ensuring reliable, long term, engine operation.
- the operation of the pumping units is greatly simplified from the farmers viewpoint thereby adding to the flexibility and desirability of implementing smaller scale pumped irrigation projects.
- the floating platforms can be placed further out in the river since daily access to the pumps is not required (as in the case with Diesel pumps). This results in simplified pump operation and

reduced possibilities for clogged inlet lines (an advantage on the Senegal River which will be applicable only in other locations with floating pump systems).

the pump electrification provides base load to the utilities which improves the operation efficiency of the local generating plants and provide additional incentives to expand the electric grid. This expansion often has other productive and social benefits in addition to energizing the pumping units.

The above factors, combined with a highly competitive cost structure, resulted in the Senegal River study recommending electrifying the pumps in those two locations with good access to available electric generation capacity. Although the results are by no means universal, pump electrification merits serious consideration wherever similar situations exist.

Central Grid Expansion:

The Senegal River Valley currently has only scattered electric service in three of the larger towns. The total installed capacity is roughly 1,500 kW of Diesel generators. Even this is operated at only about a 15% capacity factor attesting to the low level of normal household and light commercial loads in these areas. By contrast, the approximately 300 Diesel pumps already in use along the river have approximately 7,000 kW of capacity.

Some work has been done to assess the potential for transmitting hydropower from the Manantalli Dam across central Senegal to Dakar. Little attention was given to extending power from this source down the Senegal River valley in part due to the very low electric loads now prevalent in the region. However, consideration of the possible loads have not taken into account the major potential impact associated with electrifying the pumps. Based on current plans to bring an additional 50,000 hectares under cultivation by 2,000 and 100,000 hectares by 2010 the potential pumping load alone along the river could exceed 100 MW or roughly 50% of Senegal's allocation of Manantalli power (also equal to present nationwide generating capacity).

Preliminary studies have indicated that hydropower from Manantalli could have one third to half the cost of thermally generated power when serving loads with high capacity factors. This could be the case for pumping in the valley and, if so, would significantly improve the economics of pumping irrigation agriculture in the long term. VErifying this potential would, however, require detailed engineering cost studies which take into account actual transmission line costs, and projections.

The important issue is, however, that the economic viability of electrifying the valley (whether by thermal or hydropower means) is strongly dependent on the major, steady, loads which would result from pumped irrigation. This exemplifies the important linkages between agricultural expansion plans (based, in part, on pumping) and electric sector expansion which may often exist in regions of subsahara Africa.

5.0 POLICY ISSUES - OVERVIEW

Experience in several countries referenced in this report indicate that there are a number of important policy issues which must be considered when considering expansion of irrigation based on pumped water and the often associated role of rural electrification. Only by considering the costs and benefits of irrigation pumping within a broader context of agricultural and energy sector planning can reasoned assessments be made of overall economics and, in particular, the true nature of recurrent costs both on a project basis and a national basis.

These policy issues include those associated with:

- Diesel vs Electrified Pumping
- Electricity Pricing
- Grid Extension Economics
- Role of Distributed Power Systems
- Crop Selection - Irrigation System Design
- Coordination of Agricultural Expansion and Energy Sector Planning
- Food Pricing Policies

Clearly, there will be a wide variation in the importance of different policy issues between countries. Nevertheless, each of the policy issues can be addressed in a consistent manner to ensure that the right questions are being asked and to provide a general framework for project specific decision making.

Each of these policy issues is briefly discussed below.

5.1 Energy Pricing

There is a tendency to provide rural areas, in general, and farmers, in particular, with electric tariffs, and Diesel fuel costs which are, in effect, subsidized. For example, this was an overt policy in Pakistan and was a defacto policy in Senegal.

Energy pricing policies can have a dramatic affect on the perceived overall economics of irrigation projects and strongly influence the choice of pumping systems. For example, the switch from Diesel to electric pumps in Pakistan was due primarily to heavily subsidized electric tariffs specifically tailored to irrigation pumps.

One can question the wisdom of subsidized energy inputs for agriculture, however, in fact, rural America owes much of its earlier growth to what was, in effect, a heavily subsidized expansion of rural electrification. It is important, however, to understand before hand the extent and impact of subsidies in place or being contemplated. Otherwise, inappropriate policies relative to both the agriculture and energy sector could be inadvertently implemented, and encouraged by donor assistance.

Two such examples are cited below:

(a) Pakistan: One of the general policies guiding the rural electrification expansion in Pakistan was to focus on those areas where electricity would be used to displace Diesel pumps with electrified ones. The rationale for this was the much lower cost (to the farmers) of operating the electric pumps and the perceived national benefits of reducing Diesel fuel use. As indicated in Reference 1, this policy was seriously flawed. All new additions to rural load had to be accompanied by additional, costly, fuel fired (mostly oil) electric generating capacity and expansion of already strained transmission systems.Consequently, the real costs of electrifying the pumps were considerably higher than allowing existing Diesel pumps to continue operating. National policies to encourage electrifying the pumps merely shifted costs from the agricultural sector to an already strained electric sector with the additional costs hidden by the subsidies to the farmers on electricity purchased for pumping.

(b) Senegal: As indicated in Reference 2, the pump survey team recommended that consideration be given to electrify irrigation pumps in two specific locations using locally produced electric power. The report clearly stated, however, that the "apparent" favorable economics of the option were

in part the result of national policies to have uniform tariffs throughout the country which, in effect, subsidized relatively high cost rural power produced by autonomous Diesel generators. A policy of large scale electrification of the pumps would impose a large financial burden on the utility unless accompanied by a program to electrify the valley with low cost hydropower (possibly from Monentali) or thermal power produced using lower cost fuels.

As suggested by these examples, it is important that USAID (or other donors) does not adopt policy positions which, in effect, justify irrigation projects based on highly subsidized energy costs. So doing will only hide the true value of recurrent costs and jeopardize the longer term viability of the projects if energy costs are raised to more financially viable levels.

5.2 Crop Pricing Policies

Many countries have crop pricing policies which tend to undervalue agricultural produce in order to provide cheaper food for urban residents. Although politically popular, such policies are usually destructive of rural economies and hence we a frequent source of "policy dialogue" between USAID and host governments. This situation is particularly severe in some countries of Africa.

Such policies can also make irrigated agriculture highly uneconomic from the point of view of the farmers - even in cases where it would be profitable if the increased production were priced at realistic levels. This was exemplified by the case in Senegal where the official price for rice was such that pumped irrigation using the Senegal River valley was only marginally attractive (at best) if all costs were actually accrued by the farmers. As a result, most farmers with access to an irrigated perimeter along the middle and upper valleys still engage in subsistence farming producing very limited marketable surpluses - a situation common in Africa and one contributing to food shortages in this region. The marginal profitability of irrigated agriculture is responsible for the limited interest in commercial scale farming in this region on the larger irrigated perimeters, which would contribute to increased food production for marketing in urban areas.

In countries, therefore, where increases in agricultural output will depend on large part on pumped water, the need for rationale food pricing policies will be even more critical than when dealing with low capital input traditional forms of agriculture.

USAID and other donors should, therefore, reinforce policies which tie support for expanding agricultural output based on irrigation projects to food pricing policies which can make such agriculture potentially profitable while allowing for paying the substantial recurrent costs associated with irrigated agriculture.

5.3 Agricultural Expansion - Energy Sector Planning Coordination

There is a tendency for agricultural sector planning to take place with little, if any, reference to overall national energy impacts or rural electrification plans. The reverse of this is also true, i.e., energy sector planning often is done with little awareness of the impact of agricultural sector projects.

As a result, irrigation projects tend to be implemented without regard to or overall energy supply strategy which could lower costs in the long term. For example, in Senegal it appears that the long term agricultural expansion plans along the Senegal River could strongly influence the projects for electrification using hydropower. Due to the lack of coordination between the sectors this issue has not been adequately considered. Similarly, as suggested by the experience in Pakistan, the impacts of irrigation pumping needs on rural electrification infrastructure, central station generating capacity, expansion and fuel impacts are often not considered and rarely quantified.

Significant expansions of irrigated agriculture requiring pumping should be done consistent with overall energy sector planning to potentially lower costs, provide inputs as to selection of pumping system technologies, ensure that all the infrastructure and fuel cost factors are accounted for in the evaluation process, and to ensure that the energy related inputs are, in fact, available to the project.

5.4 Role of Distributed Power Systems

As a practical matter, the irrigation pumps will often be the largest load associated with rural development projects in LDC. This is certainly the case throughout the rural regions of Pakistan and along the Senegal River Valley. It also appears to be the case in many regions of the Sudan and several other African countries. The issue of energizing the pumps and providing rural power in general are therefore, often highly intertwined.

Implementing rural development projects is a complex undertaking involving myriad social, institutional, and technical issues and problems. The inclusion of irrigation with associated pumping further complicates an already difficult undertaking. The questions associated with how best to energize the pumps are understandably often relegated to secondary states in the overall planning process. The choice is usually made based on two options: individualized Diesel pumps or extending an already established electric utility grid.

However, as previously discussed, the recurrent costs associated with irrigation pumping can have a major impact on overall crop economics and, therefore, rural development prospects. As a result, donor organizations should give increased attention to alternative means of providing critical power needs in rural development projects; including the role of larger distributed power systems using minigrids to serve regional needs.

Although modest by U.S. or European standards, the regional power needs in LDC are often still measured in the megawatts. For example, providing sufficient power for 50 irrigation pumps along the Senegal River would necessitate about 2 megawatts of power. Similarly, the regional needs in the proximity of a medium size town (10,000) in Pakistan is often in excess of 10 MW. As a practical matter, regional development involving pumped irrigation will often require power generation capacities in the range of 1-50 MW. The common approach for serving regional load centers of this magnitude is to extend the central grid (high capital costs) or possibly, to install conventional diesel or gas turbine generating capacity which requires the consumption of high cost, imported distillate fuels. For this intermediate range of power levels, more

consideration should be given to an expanded technology base of distributed power system using some combination of:

- Biomass fired power systems;
- Coal or peat fired power systems;
- Local hydropower power systems;
- Hybrid power systems which combine the above or solar/wind systems with diesel generators (to conserve on imported fuel needs).

The use of distributed power system in this capacity range has several distinct advantages:

- The size is large enough to result in the efficient operation of a number of technological options which would be impractical at lower power levels. The economics of scale are associated with capital equipment costs and, perhaps more important, the ability to afford trained staff responsible for O&M and the management of the facility.

- The size is small enough to:

  a) Provide additional flexibility to use indigenous energy resources (wood, peat coal, etc.) which may not be (and is often not) available in sufficiently large quantities to support conventional (multi hundred megawatt) power plants.

  b) Provide appropriate capacity to serve regional load centers with local grids and often still be installed in multiple units to provide backup capability.

c) Be available in prepackaged systems which can be readily transported to the site and installed in a short period with a minimum of site labor.

d) Be made available in standard units resulting in interchangeable parts and a common O&M training program.

Utility planners in LDC were often trained in the U.S. or Europe where the bias is strongly in the direction of central grid expansion based on large central generating facilities. The option to use a variety of intermediate scale generating facilities with associated fuel flexibility, siting flexibility, and possibly lower capital costs (particularly if transmission and distribution networks are considered) is, therefore, not usually considered by LDC utility planners or by those in donor organization responsible for designing rural development or rural electrification programs.

5.5 Crop Selection - Irrigation System Design

This report dealt primarily with the mechanics and costs of pumped irrigation assuming water use patterns as a given. These water use patterns are, in turn, a function of crop selection, irrigation system design, and climate. The latter factor is beyond the control of project designers. The first two can, however, within some limits be influenced by proper policies and system design guidelines.

A. Irrigation System Design

Both the literature and discussions with field workers indicate that the amounts of water used for irrigation are usually well in excess of that needed. This is due to two primary factors:

(a) Poor design of irrigation system distribution and water management systems resulting in large losses of water by evaporation, runoff, and leakage.

(b) Over irrigation of crops by individual farmers based both on a desire to ensure adequate water within an unreliable system (better get it while it's available) and a lack of knowledge of proper irrigation practice.

Excess water use, in turn, has several deleterious effects:

- It directly increases pumping costs which, as indicated earlier, can be a major cost factor in crop economics.

- It can harm crop production by increasing salinity problems and waterlogging.

In the countries addressed in this report, irrigation distribution systems were in general open, unlined, ditches which had high losses, - probably underestimated in projecting crop water requirements. Losses from such systems run from 30% to 60% depending on soil conditions, canal maintenance, and water management practices. This situation is common throughout Africa and is probably a reasonable, low cost, choice where gravity fed irrigation is used. However, where pumped water is used the high losses associated with such rudimentary irrigation distribution systems adversely (and significantly so) affects overall pumping costs. These losses could be greatly reduced by such measures as lining canals, using piping for distribution, and various forms of drip irrigation (for some crops). However, these measures increase the initial cost of implementing irrigation projects. No sources were identified during this project where the tradeoffs between reduced pumping cost and increased capital costs for improved irrigation systems have been made. USAID and other donors should consider a policy whereby such tradeoffs are made early in the planning stages of rural development projects incorporating pumped irrigation. This could help ensure that irrigation project designs represent a reasonable compromise between initial capital costs and recurrent costs. Since the latter costs are the Achilles' heal of many irrigation projects, these tradeoffs could well indicate that more funds spent in reducing water losses would represent an appropriate approach in many cases - particularly in Africa.

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