Efficiency and the role of government in energy policy

Mathilde Benveniste

It is well established that the presence of a monopolist producer removes efficiency from the world oil market. Efficiency in energy resource utilization can nevertheless be the proclaimed objective of an energy policy by an oil-importing nation if imported oil is considered a non-produced resource available at a given price. This article presents an example of such a policy which consists of the institution of price guarantees for energy alternatives and of government subsidies for the development of new energy technologies. We illustrate how this policy will attain efficiency, and the ratio of benefits to the costs associated with its adoption are calculated.

Keywords: Energy Policy; Economic efficiency; Government

This work was conducted while the author was a member of the faculty of the University of Pittsburgh. The author is now at Bell Laboratories, Murray Hill, NJ 07974, USA.

When world oil prices started escalating in 1974, the immediate response of the government was to try to relieve the pressure on the consumers through price controls. For long-term relief, a programme involving public spending for research and development of new technologies was initiated. The rationale for the subsidy of energy technology development was based on the existence of substantial risk in energy technology investment; this risk tends to discourage and delay private investment in such ventures.

The perception of what ought to be the role of the federal government in energy technology development has since been changing. Based on the belief that a competitive market offers the best setting for the efficient allocation of resources, the current plan is to participate as little as possible in the shaping of energy policy. Instead, the private sector is being left to shape energy policy alone by responding to economic incentives. It is believed that risk taking will be accommodated through greater financial rewards, with public spending being considered only in areas where the private sector is unlikely to invest. A more detailed description of the rationale for the current energy policy is given in the *National Energy Policy Plan.*[1]

In this article we deal with the premise fundamental to the present energy policy: perfect competition ensures the efficient use of resources. We are concerned specifically with the monopolistic character of the oil producers' cartel. Even though this trait is known to remove efficiency from the world oil market, one can still speak of efficiency in the domestic energy markets where imported oil represents one of several primary resources; its supply cost is equal to the price set by the producers' cartel. An important consideration is the need for substantial lead times in the development of energy alternatives by the oil importing nations. In this article a policy that would ensure efficiency will be derived.

We approach this question by analysing the decision-making problem that arises when the producers and the oil importers are viewed as two parties having distinct and possibly conflicting objectives. One of the importers' objectives will be the attainment of efficiency in the utilization of resources. At the same time, the importers will want to pay

[1]US Department of Energy, *National Energy Policy Plan*, Department of Energy, Washington, DC, July 1981.

the lowest possible price for the oil they import. The producers' objective will be the maximization of their oil revenues. We derive optimal stategies for both parties, from which we infer the role of the government in an oil-importing nation.

Problem description

The first step in our analysis is the articulation of explicit objectives for the parties involved. This is followed by the description of the decision space.[2]

The goals of the oil importing nations

The first party consists of the industrialized nations of the western world that are the major net importers of oil. The group is assumed to behave as a monolithic entity. Whenever more than one nation comprises this group, the function of the 'government' would be performed by a jointly appointed agency charged with the responsibility to formulate and implement a common energy policy. The oil importing nations are assumed to have two goals:

- To use in an efficient way all resources available to them, including imported oil. This objective implies that the technology and capital stock mix is such that it makes the attainment of efficiency possible.
- To induce the producers' cartel to change the lowest possible price for their oil exports.

An *efficient* allocation of resources is one that meets user needs at least cost.

The goals of the oil producers

The oil producing nations of interest are the members of OPEC. The remaining exporting nations, even though their presence influences the strategies of the two principal parties, need not be included explicitly in our analysis. We assume that the OPEC member nations behave as a monolithic group having as its objective the maximization of the profits from the sale of its oil. We also assume that the total quantity of oil that can be exported is limited.

The decision space

The key to solving the two-party decision problem lies in defining properly the decision spaces for the two parties or actors and, in doing so, understanding the disparity that exists between them.

The producers' decision variables are either the prices of oil exports or their quantities. The importers' decision variables involve the development of new technologies. In the absence of oil import quotas, the development of new energy technologies is the main way in which an oil importing nation can influence oil pruchases. Because the oil quantity that will be imported is the net result of energy consumption decisions by billions of individuals, its magnitude cannot be controlled directly. However, since this quantity depends on the range of available technologies and on the capital stock in place, the nation's oil imports can be influenced through energy policies that shape the plant and technology mix in a desirable way.

The two actors' decision spaces differ with respect to the delay present between the time a decision is made and the time of its outcome.

[2]Some of the commonly cited literature in the area of energy policy planning and oil price forecasting is: C. Blitzer, A. Meeraus and A. Stoutjesdijk, 'A dynamic model of OPEC trade and production', *Journal of Development Economics*, Vol 2, 1975, pp 319–335; H. Brock and D. Nesbitt, *Large-scale Energy Planning Models: A Methodological Analysis*, Technical Report, Stanford Research Institute, Menlo Park, CA, May 1977; G. Cazalet, *Generalized Equilibrium Modeling: The Methodology of the SRI Gulf Energy Model*, Technical Report, Decision Focus, Inc, Palo Alto, CA, May 1977; Charles Rivers Associates. *Review and Evaluation of Selected Large Scale Energy Models*, Technical Report 231, CRA, Cambridge, MA, 1978; J. Cremer and M.L. Weitzman, 'OPEC and the monopoly price of world oil', *European Economic Review*, Vol 8, 1976, pp 155–164; Energy Modeling Forum, *Energy and the Economy*, Technical Report 1, Stanford University, Stanford, CA, September 1977; Energy Information Administration, *Annual Report to Congress, Volume 3*, Technical Report, Department of Energy, Washington, DC, 1980; Federal Energy Administration, *National Energy Outlook*, Technical Report, Federal Energy Administration, 1976, Appendix A; R.J. Gilbert, 'Dominant firm pricing policy in a market for an exhaustible resource', *The Bell Journal of Economics*, Vol 9, No 2, 1978, pp 385–395; K.C. Hoffman and D.W. Jorgenson, 'Economic and technological models for evaluation of energy policy', *The Bell Journal of Economics'*, Vol 8, No 2, 1977, pp 444–466; B.A. Kalymon, 'Economic incentives in OPEC oil pricing policy', *Journal of Development Economics*, Vol 2, 1975, pp 337–362; M. Kennedy, 'An economic model of the world oil market', *The Bell Journal of Economics*, Vol 5, No 2, 1974, pp 540–577; A.S. Kydes and J. Rabinowitz, 'Overview and spatial features of the Time-stepped Energy System Optimization Model (TESOM)', *Resources and Energy*, Vol 3, 1976, pp 379–406; A.S. Manne, 'ETA: A model for energy technology assessment', *The Bell Journal of Economics*, Vol 7, 1976, pp 379–406; W.D. Nordhaus, 'The allocation of energy resources', *Brookings Papers on Economic Activity*, Vol 3, 1973, pp 529–576; and R.S. Pindyck, 'Gains to producers from the cartelization of exhaustible resources', *Review of Economics and Statistics*, Vol 60, 1978, pp 238–251.

An actor with a negligible delay has an advantage over an opponent with a substantial delay, as the former can adjust his strategy at the last minute, after learning of this opponent's choice of strategy. In our problem it is the producers that have this advantage. Prices, or production levels, can be changed spontaneously without any commitment to previous pricing or production policies. Faced with a given demand for oil imports – which is determined by the importers' capital stock at hand – the producers can at all times select their oil prices so that their revenues are at a maximum.

In contrast, the importing nations can only effect oil-purchase reductions in response to higher prices by introducing new energy technologies. However, the lead times involved in research and development and the construction of new plants make it impossible to cause an immediate reduction in oil imports when the oil price increases. Therefore, the key to a successful energy policy lies in properly timing the development of new energy technologies. Delayed initiation of such development could result in high payments for oil imports that could have been averted had the new technology been available. Premature initiation, on the other hand, would bring losses to the private sector or would impose an unnecessary burden on the taxpayers if the government undertakes the development.

Theoretical analysis

Given the specification of the actors' objectives and their decision variables, we will find their optimal strategies. It will be assumed that their divergent objectives are pursued independently, without the possibility of cooperation between the two parties. Our analysis will employ two commonly used concepts in economics: the long-run and the short-run demand curves for oil imports.

The short-run demand curve gives the quantity of oil that will be imported by a nation after part of its demand is met by indigenous oil resources, imports from non-OPEC producers, or oil substitutes. There are many possible short-run demand curves for oil imports in the future. Different curves correspond to different configurations of the capital stock at hand and the technology mix. The short-run demand curves of interest are those for which there exists at least one oil price level at which the corresponding mix of technology and capital stock is efficient.

The collection of the efficient points on all possible short-run demand curves gives rise to the long-run demand curve. As a result, a long-run and short-run demand curve intersect at an efficient point B*, as illustrated in Figure 1. In that figure, f_k and f_k' are the slopes of the long-run and short-run demand curve, respectively, in period k. By virtue of its definition, the long-run demand curve can be used to express the efficiency goal posited for the oil importing nations. Specifically, when this goal is achieved, the oil imports occurring at a given price will yield a point along the long-run demand curve.[3]

The case for price guarantees

Inefficiency is inherent in the use of energy resources if no policies exist to encourage the timely development of new energy alternatives. Because of the lack of knowledge about future prices, the private sector would not normally undertake the development of oil alternatives until it is well assured that they will be competitive. This usually occurs once

[3] It is important to notice the difference between the short-run and the long-run demand curves, as they are used in this article. The demand for oil imports realized in the 'long term' is given by the *short-run* demand curve in that time, and contrary to what one might have expected, it is not given by the *long-run* demand curve. The latter represents the efficient oil import levels for various capital stock configurations; it is not an observed demand curve. As a consequence, decisions concerning technology development change the shape of the future short-run demand curves whereas the long-run demand curves remain unchanged.

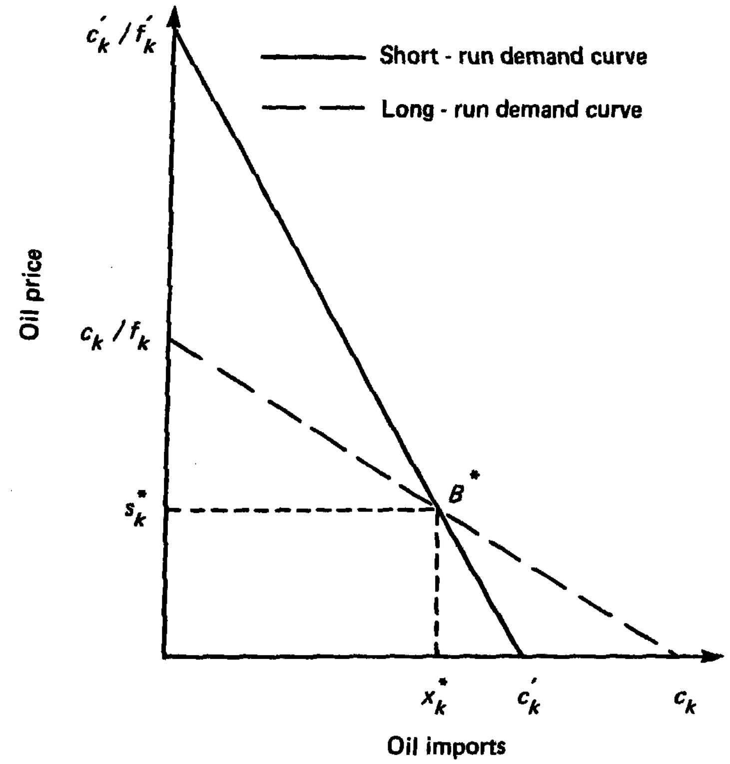

Figure 1. Short-run and long-run demand curves for oil imports.

the oil price has reached a certain level. But then it may be too late. The lead times involved in technology development cause the consumers to use high-priced oil while waiting for competitive alternatives to become available. This implies inefficiency.

What is needed is a means of encouraging the private sector to initiate the development of new technologies earlier so that they are available when they become competitive. The adoption of price guarantees for alternatives to oil will have this effect. Announcing well in advance the price that the government will support offers both time and economic incentives for the investment needed to attain the capital stock and technology mix that is efficient for selected oil prices, known as the *target prices*.

Price guarantees can take one of two forms: price subsidies or taxes. Price subsidies are payments made by the government to the domestic producers of energy alternatives when the price of imported oil falls below the target price. Taxes are imposed on oil imports in order to bring their cost to the consumer to the level of the target price. Both subsidies and taxes are intended to make the realized oil prices equal to the target prices. If this goal is accomplished, no payments will be necessary. Therefore, there is no substantive difference between the two types of measure from the stand point of cost. But, because it will be necessary to be explicit about our choice of measure for parts of the discussion that follows, we will assume that price guarantees have the form of price subsidies.

Although helpful, price guarantees alone will not suffice. For the efficiency goal to be achieved, the realized prices must be equal to the target prices used for the price guarantees. Therefore, additional measures would be needed that could induce the oil producers to select the target prices as the prices to charge for their oil. This requirement has a bearing on the choice of the targets.

Determining the target prices

The set of the lowest prices that can serve as targets for the price guarantees is the set that yields maximum profits to the producers, subject to the restrictions that:

- the total exports do not exceed the quantity available for export; and
- the quantities of oil exports are given by the long-run demand curve for oil imports.

The second restriction represents the importers' goal of efficiency in using resources. We use the objective of maximizing the producers' profits in order to ensure that it is possible to induce the producers to charge the derived target prices. Had lower targets been selected, this would have been impossible.

The derived target prices are shown in Figure 2, where we observe that the prices increase steadily, starting at 55% of the substitution cost. The substitution cost, which is the price at which no oil would be imported, is reached in 60 years.[4]

Realization of the target prices

While the adoption of price guarantees for energy alternatives is helpful in the attainment of the goal of efficiency, it is not sufficient by itself. In other words, if the importers' energy plan consisted of price guarantees only, then the realized prices would be different from the target prices.

To illustrate this, we simulate the producers' decisions. Given that the

[4]The assumptions and mathematical methods employed for the computation of the results of this article are presented by the author in *Energy Planning and Oil Pricing: A Method for the Analysis of the Decision Making Processes*, forthcoming.

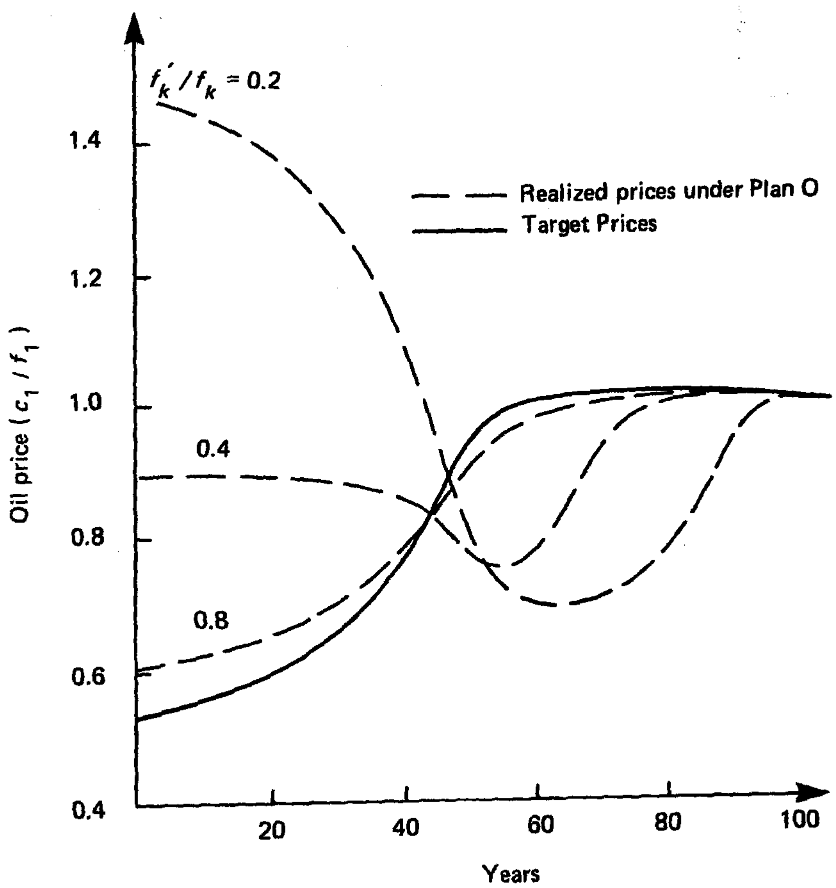

Figure 2. Target and realized oil-priced trajectories.

importers will pursue the above energy plan, which is referred to herein as Plan O, we solve the producers' profit-maximization problem. This computation requires an explicit assumption about the form of the price guarantees. We have selected price subsidies because they yield more conservative results.

As in the target-price computation, the objective is to maximize the producers' profits, subject to a restriction on the availability of oil reserves. However, unlike in the optimization problem solved earlier, the quantities of oil exports are not given by the long-run demand curves. Also unlike the target price trajectory, the trajectory of realized prices is not obtained by the solution of a single optimization problem; instead, a sequence of such problems is solved. At each step of the sequence the current price the producers will charge for exported oil must be found.

As the producers determine the current oil price they will take into consideration both current and future demand. The current demand is given by the short-run demand curve, which corresponds to the existing capital stock that resulted from past investment decisions. Under Plan O this curve is the short-run demand curve that crosses the long-run demand curve at the point representing the target price used for the present period, as illustrated in Figure 1, where s_k^* is the target price.

The future demand curves are not yet known to the producers because those curves depend on present and future investment decisions. We assume that the producers will select their current oil price with the expectation that the importers will eventually switch from Plan O to the plan most favourable to them. This plan, which will be the outcome of this analysis, has the effect of placing the importers on their long-run demand curve for a range of prices. So the demand curves used for all future periods will have the shape of the long-run demand curves.

Trajectories of realized prices have been computed for a range of parameter values representing the ratio of the slopes of the long-run and the short-run demand curves, as illustrated in Figure 2. Comparing each trajectory of realized prices with the trajectory of target prices, we observe that the two cross. In earlier years, the realized prices exceed the target prices because the current-period demand curve used in the computation of the realized prices is less elastic than the long-run demand curve employed in finding the target prices. Consequently, an increase in the oil price can easily outweigh any losses in the producers' revenues that would result from the ensuing decrease in oil exports. However, as time passes the quantity of oil that remains for export increases above that remaining under the target pricing policy. The excess oil can only be sold by dropping the oil price below the target price. The lower market price implies that a subsidy would be paid to the domestic producers of energy alternatives. For certain parameter values, the realized prices increase with time, as do the target prices. But for other parameter values, corresponding to a less elastic short-run demand curve, we observe that the realized oil prices decline for a significant portion of the life of the reserves, after which they increase to reach the substitution cost.

Desirability of the target prices

The realized oil price trajectory does not meet the goal of efficiency because it differs from the target price trajectory. A second basis of comparison is the relative magnitudes of the prices in the two trajectories. Since the two trajectories intersect – ie the realized prices do not exceed the target prices at all times – it is natural to question whether the target price trajectory is indeed preferable to the alternative.

The two trajectories are compared by computing the difference between the associated consumers' surpluses. The consumers' surplus is measured as the area under the short-run demand curve that would result after the announcement of the target prices. If the target price in the k^{th} period is s_k^*, and the realized oil price is s_k^o, the difference in the consumers' surpluses of the two price trajectories has magnitude equal to the area $s_k^* B B^* s_k^*$ in Figure 3. This difference is either positive or negative, depending on whether the realized price is greater or less than the target price in that period. The net gain from attaining the target prices is the discounted sum of the gains in each period, which was found to be positive for all cases. Therefore, we conclude that the energy plan capable of inducing the oil producers to charge the target prices is preferable to Plan O. We will refer to this plan as Plan I.

The role of energy technology development

The importers can influence the pricing policy of the producers only by modifying their short-run demand curve for oil imports. Thus, the problem that must be solved is to find the shape of the demand curve that will make the target prices computed earlier appear to the producers as the most profitable prices to charge.

Adjusting the shape of the demand curve is tantamount to determining those energy technologies that will be made available for use by the consumers. In the efficient technology mix associated with a point along the long-run demand curve, there exists a technology that is the most

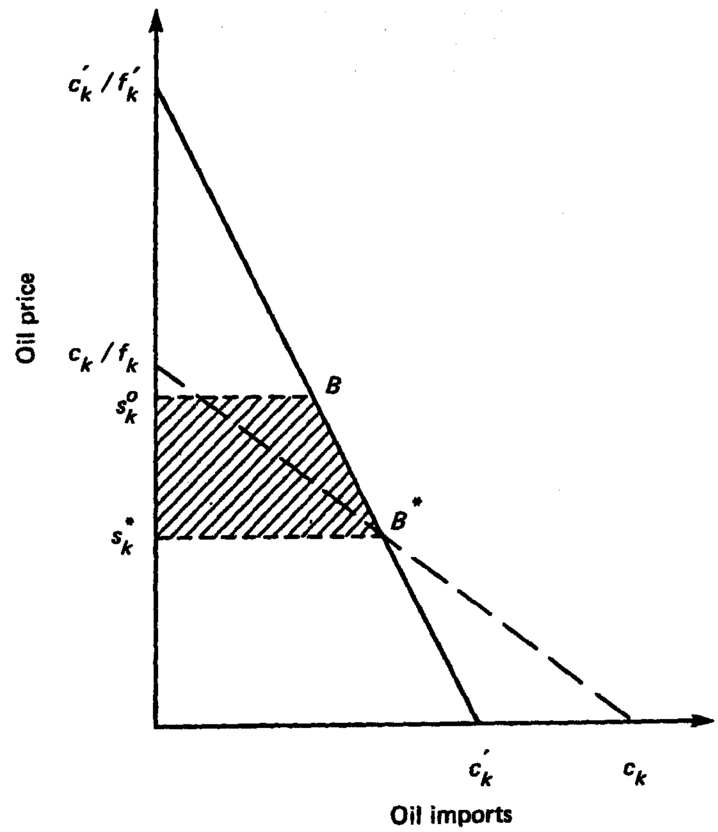

Figure 3. Gains in consumers' surplus for Plan I over Plan O.

likely to cease being competitive as the oil price drops. This is the *backstop technology*. The lowest oil price at which the backstop technology can compete with oil is the *backstop cost*.

Typically, if there is no involvement by the government in energy technology development, the backstop cost will be equal to the target price when price guarantees are announced in advance. The short-run demand curve in this case is a smooth curve crossing the long-run demand curve at the point corresponding to the target price (as in Figure 1).

The shape of the short-run demand curve that will accomplish our aim is the 'bent' demand curve, illustrated in Figure 4. This curve corresponds to the situation in which the backstop cost s_k' exceeds the target price s_k^*. The bent short-run demand curve is obtained through the participation of the government in technology development. The separation between the backstop cost and the target price implies that, while there will be some technologies that will be competitive with oil at the prevailing oil price, there will also be some others – called the *marginal technologies* – that will not. The competitive technologies will be pursued by the private sector. The private sector will have no incentive to pursue the marginal technologies because they cannot compete with oil. For this reason, the government would be the only one left to step in and support the development of the marginal technologies.

When first introduced, the marginal technologies are not competitive. However, this is not to say that they will not be used eventually. As the target prices increase in time, the existing marginal technologies will become cost effective and will be pursued by the private sector. Thus, the purpose of the government's involvement in energy technology development is to help bring on line new technologies *before* they become competitive. Their presence is necessary to act as a deterrent to higher oil prices.

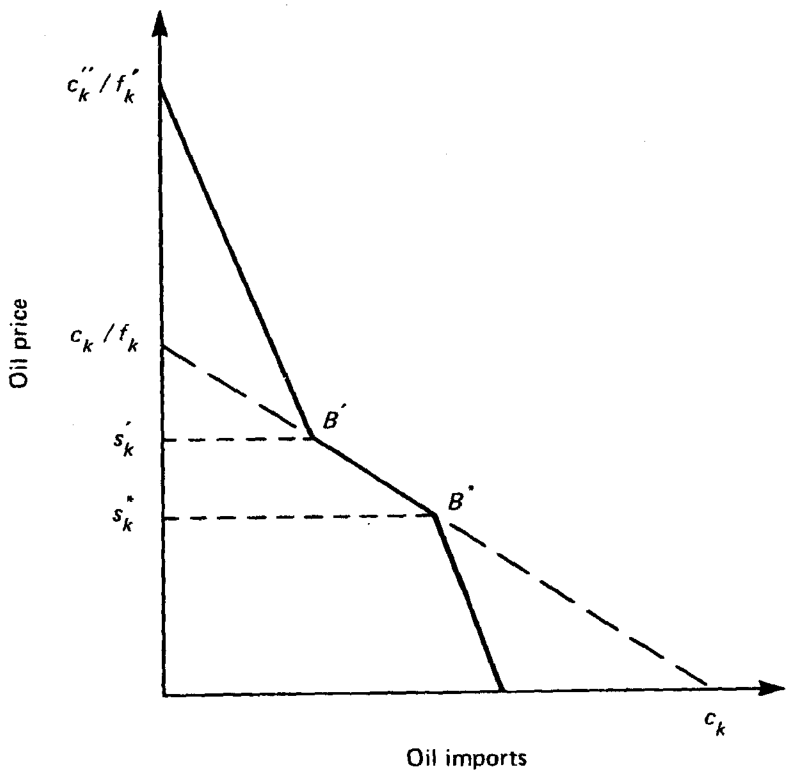

Figure 4. Bent short-run demand curve.

The derived bent demand curve consists of three sections, each having a different slope. Assuming that the price guarantees adopted have the form of price subsidies, the portion of the demand curve below the target price has the slope typically assigned to the short-run demand curve. The slope of the demand curve for prices ranging between the target price and the backstop cost is the same as that of the long-run demand curve. The use of this slope implies either that the lead time for the construction of plants is negligible or that the production capacity is already in place. The slope of the demand curve for oil prices above the backstop cost is again that of the short-run demand curve.

Once the target prices have been determined, the backstop cost remains to be computed. Since the cost of the energy plan increases with the backstop cost, we seek the lowest possible backstop cost that would serve our goal of inducing the producers to charge the target prices. The trajectory of backstop costs is shown in Figure 5, where it is plotted for various values of the ratio of the slopes of the long- and short-run demand curves.

Benefits and costs of the energy plan

As established earlier, the attainment of the target prices brings gains in consumers' surplus to the importing nations. However, the desirability of the energy plan cannot be ascertained until it has been shown that the cost associated with this plan does not exceed its benefits.

The energy plan consists of two types of policy measures: the adoption of price guarantees and the development of marginal technologies. The cost of the price guarantees is negligible as long as the realized prices equal the target prices, which is the object of the energy plan. Consequently, the major cost associated with Plan I is the cost of the marginal technologies.

Initially this cost will involve capital outlays for research, development and plant construction, as well as the cost of maintaining the equipment while it is sitting unused. Eventually, most of these costs will be recovered as the marginal technologies become competitive and are purchased by private firms. However there will still be some losses associated with the early incurrence of the capital costs and the aging of plants and equipment.

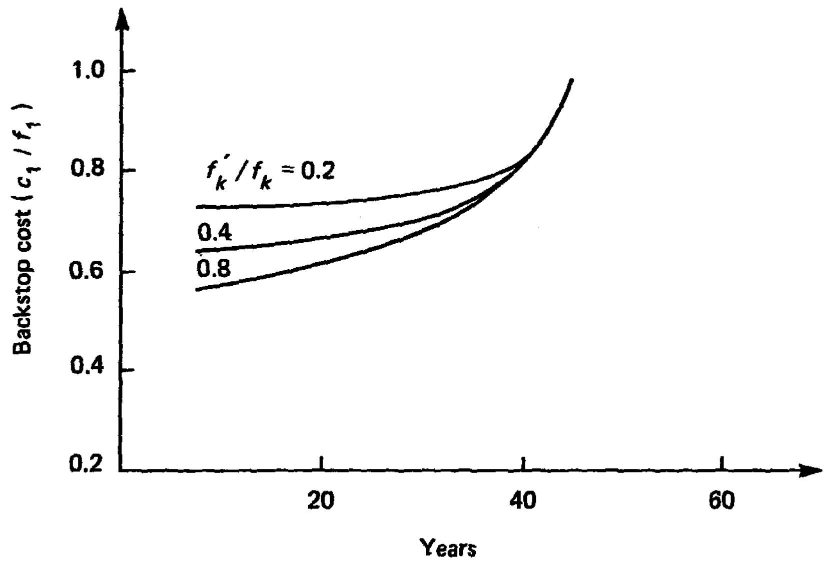

Figure 5. Backstop cost trajectory.

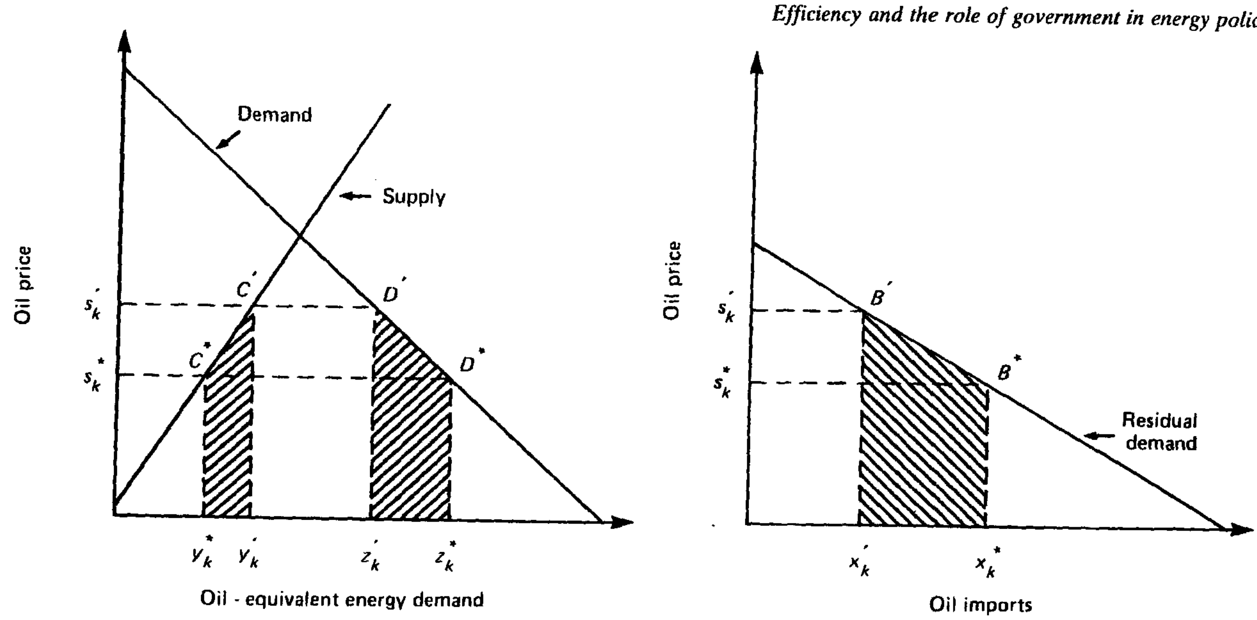

Figure 6. Estimate of the cost of the marginal technologies.

A conservative estimate of the cost of the energy plan is obtained by computing the cost that would be incurred were the marginal technologies fully utilized during the period between their installation and the time they become competitive. This figure overestimates the true cost because it includes operating costs, which would not be realized.

The estimate of the plan's cost is obtained from the long-run demand curve through a series of conservative approximations, as follows. The long-run demand for oil imports represents the difference between the total energy demand expressed as equivalent oil demand and the oil supply forthcoming from sources other than OPEC, as illustrated in Figure 6. Because the area under the supply curve represents the cost of meeting an increment of energy demand through alternatives to oil imports, the area under the demand curve for oil imports always exceeds this cost. Specifically, the area $y_k^*C^*C'y_k'$ under the supply curve in Figure 6 is equal to the area $x_k'B'B^*x_k^*$ under the demand curve for oil imports minus the area $z_k'D'D^*z_k^*$ under the energy demand curve. If s_k' represents the backstop cost and s_k^* the target price in the k^{th} period, the area under the demand curve for oil imports will give a conservative measure for that period of the cost of the marginal technologies, as these technologies are among the alternatives used to meet the total energy demand. The cost of the marginal technologies estimated in each period is discounted and summed over the entire planning horizon to give the cost of the energy plan.

Figure 7 presents the plan's cost, while Figure 8 gives the ratio of the benefits to the costs. We observe that if the slope of the short-run demand curve is less than 80% of the slope of the long-run curve, the benefits of the plan exceed the costs. A typical value of the ratio of the slopes would be 50%. Hence, we conclude that Plan I is preferable to Plan O.

Conclusions and discussion

The setting in which we have analysed the interaction between the oil producers and importers has the producers in the role of profit

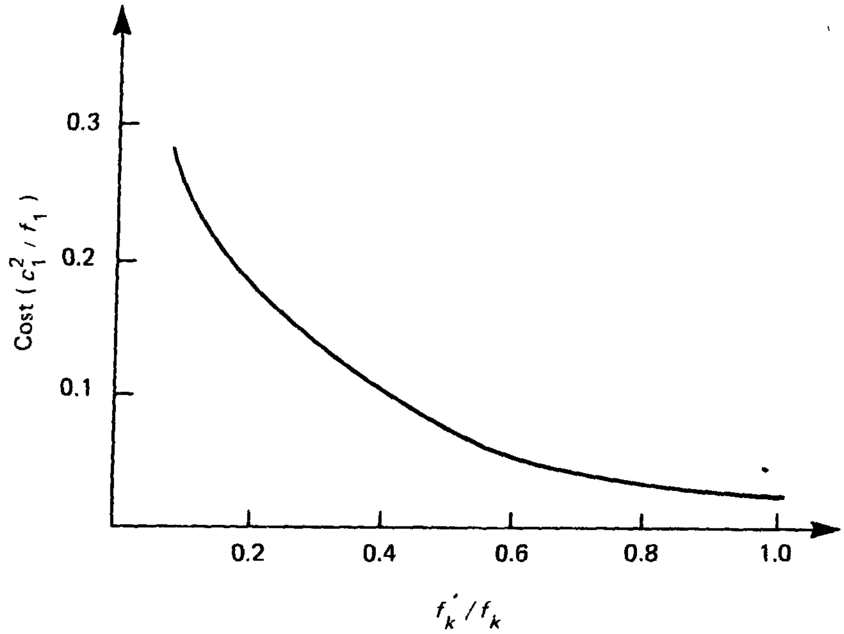

Figure 7. Cost of Plan I relative to Plan O.

maximizers, while the importers were viewed as trying to use their resources efficiently and at the same time pay the lowest possible price for oil imports.

Our analysis shows that the world energy market possesses characteristics which make it defy the dictum that a *laissez-faire* policy and efficiency go hand in hand. The long lead times necessary for the emergence of new technologies, in combination with the monopolistic character of the oil market, give rise to inefficiency in resource use. However, efficiency can be attained if a non-profit concern, such as the government, has a part in orchestrating national energy policy. Specifically, an energy policy with the following two basic features was considered:

- the adoption of price guarantees for alternatives to imported oil; and
- the subsidization by the government of the development of energy technologies to be made available prior to the time they would become competitive with imported oil.

The first measure is needed to attain a technology and capital stock mix that will enable the efficient utilization of resources. The second ensures that the efficiency goal will be met by inducing the producers to charge the prices used for the price guarantees.

Our analysis is based on several simplifying assumptions. Prominent among them is the absence of uncertainty from our calculations. We expect that it would be necessary to examine the effect of these assumptions before the proposed plan is implemented. Nevertheless, we feel that the model, in its present form, serves an important function – it illustrates the general applicability of our results. The use of such simple assumptions has helped make our conclusions independent of the specific values assumed by the various parameters typically used to describe the energy system. This independence lends power to the approach taken.

A simplifying assumption that merits special mention is that the producers are driven by purely economic motives. The possibility of

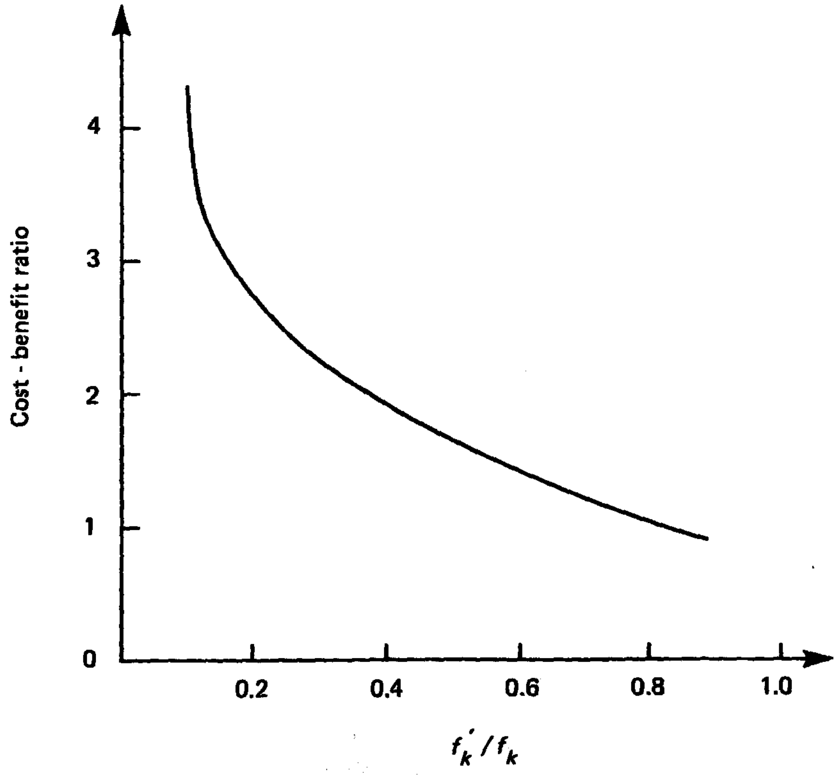

Figure 8. Cost – benefit ratio for Plan I.

politically motivated supply interruptions has not been considered. A qualitative judgment on this point is that such considerations would tend to increase the benefits associated with Plan I, as the existence of stand-by capacity would decrease the severity of a supply interruption, and possibly deter it.

Finally, the reader might question the desirability of Plan I compared to the policy prevailing today. It should be recalled that the consumers' surplus gains attributed to Plan I were measured relative to the surplus realized under Plan O – a plan consisting exclusively of price guarantees set in the same way as for Plan I. Current energy policy involves practically no price guarantees.

The question of the comparative desirability of Plan I cannot be answered with exactness, unless we are willing to postulate a model for the behaviour of the private sector in the setting of a monopolist-run oil market. We are reluctant to do so as we believe that, because of the monopolistic power of the producer, the response of investors to price signals would be different from that observed in the past in the energy or other capital intensive sectors. The knowledge that the producers can at any time drop prices in order to undercut the competition would discourage new investment in energy technologies. The effect of this awareness would be the same even if the producers did not follow such predatory pricing practices. Investor reluctance would be accentuated further by analytical studies that predict (as our results in Figure 2 indicate) a period of declining oil prices before the substitution cost level is reached.

Given this environment, we expect that the actual investment forthcoming under the *status quo* would correspond to prices lower than the target prices of Plan O. Consequently, the realized short-run demand curve would lie to the right of the demand curve realized under Plan O,

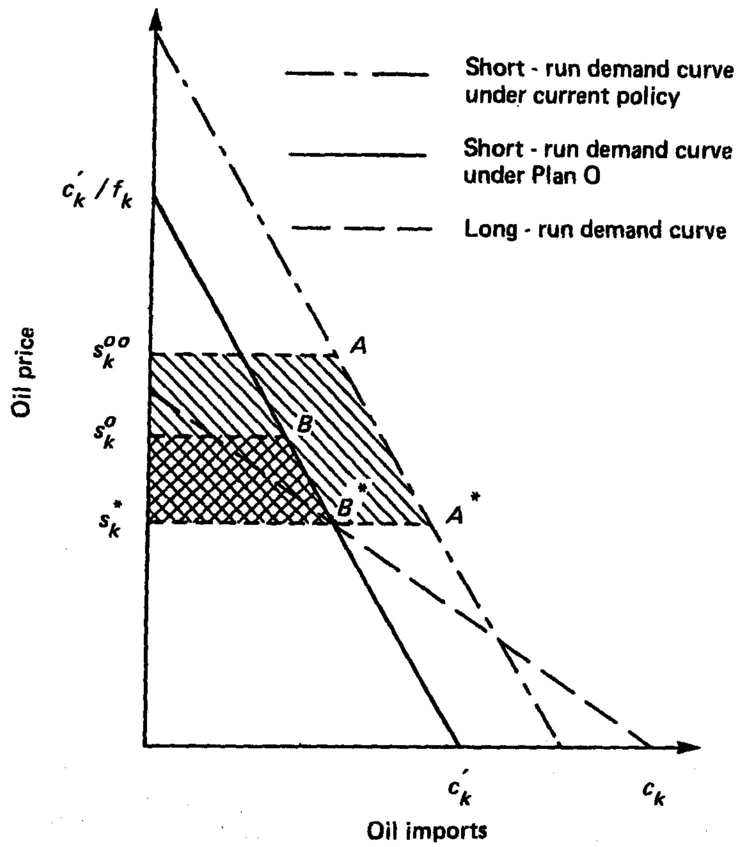

Figure 9. Gains in consumers' surplus for Plan I over current policy.

as illustrated in Figure 9, where s_k^{oo} is the realized price under current energy policy. The result would be higher prices, making the gains in consumers' surplus under Plan I even greater.

The enormity of the task of implementing the proposed energy plan does not escape the author. Major outlays are needed for the development of the marginal technologies, while the adoption of price guarantees represents an equally serious long-term commitment by the government. Many technical, legal, and financial issues would need to be resolved before the plan could be implemented. The sole aim of this article has been to point to a new direction in energy policy thinking by roughly assessing the benefits that the nation stands to gain from adopting the proposed energy plan.