Benefit – Cost Methodology For Evaluating Energy Conservation Programs

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Prepared for:

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Office of Conservation and Environment

SCIENCE APPLICATION, INCORPORATED

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EXECUTIVE SUMMARY

This report develops and presents for the layman the basic concepts of benefit-cost analysis for conservation, and specific procedures for computing conservation benefits under different economic conditions. In addition, the appendix to this report contains a discussion of this methodology as it applies to two major conservation options, the auto efficiency standard and home insulation. Using existing data, preliminary benefit-cost estimates are developed, and data requirements for improved estimation are discussed.

In brief, the benefits from actions to promote greater energy efficiency include:

- Cost savings from using less energy to achieve the same end result, plus
- Increased consumer's surplus (measures the value of a good to a consumer above what he pays for it) as a result of conservation.

From these must be subtracted any reduced returns to energy producers. These positive and negative components are added to get total benefits. The costs in terms of the resources used or the opportunities foregone must be subtracted from total benefits to compute net benefits (or costs).

The assessment of benefits and costs is straightforward if competitive markets are functioning properly. One can use market prices, including the market prices of energy, to measure value. On the other hand, if markets are distorted and energy is underpriced, a modification is required to compute benefits and costs correctly. For the case where energy is priced below competitive levels, two

subcases are analyzed:

(1) Where consumers are able to purchase all of the (artificially cheap) energy they wish (e.g., electricity from TVA), and

(2) Where consumers are not able to purchase all of the energy they wish (e.g., regulated interstate natural gas).

In contrast to the approach of simply seeking any and all ways to reduce energy, which may be expedient in an unanticipated crisis such as the Arab petroleum embargo, this approach leads to a focus on maintaining the greatest economic well-being in the face of increasing energy scarcity and costs. Energy is merely a means to the end of economic well-being. In fact, the heart of our energy problem is that rising energy costs pose a threat to the continued economic welfare of this and succeeding generations. Thus, the levels of energy utilization are incidental to determining the greatest net economic benefits for our society.

In the event of a serious energy shortage, a more narrow approach is appropriate which is directed toward curtailment of non-essential uses of energy and direct governmental allocations of energy resources for critical needs. It is important to distinguish between such curtailment and efficient conservation.

The primary role of conservation is to soften or eliminate the effects of rising energy prices on our national wealth. We can achieve this through the adoption of efficient conservation measures, and the benefit-cost framework provides a basis for determining what conservation measure is efficient. The procedures that are developed and presented in this report provide a basis for applying this framework to energy conservation on a continuing basis.

Section 1

INTRODUCTION

The Arab oil embargo, the high price of imported oil, and the threat of future supply interruptions have resulted in a wide range of suggestions for reducing energy consumption. By "conserving" we could reduce our dependence on foreign oil imports, reduce energy costs, and improve our balance of payments; but, at the same time, we realize that the use of energy is critical to our prosperity and that an arbitrary drastic reduction in energy use would significantly reduce our national wealth and welfare. Therefore, the basic question is not whether we should "conserve" energy, but how we should "conserve" it and how much we should "conserve." The answers to these questions are in turn part of the larger issue of efficient resource allocation.

Energy conservation should be evaluted with respect to the efficient use of all scarce resources including scarce energy resources, but not exclusively in terms of energy savings alone. The benefit-cost framework provides for the comparison of the value of benefits from energy conservation with its costs, and unless the benefits outweigh the costs, such conservation is not consistent with efficient resource use. If, however, the benefits from conservation exceed costs, such conservation would improve resource allocation and increase the total value of national production.

This approach to energy conservation shows that the beneficial effects of energy conservation go far beyond what is measured by the reduction in the amount of energy consumed and that the benefits from conservation exceed the market value of the energy saved. Further, in the very important case where fuels or energy are underpriced, government programs to promote energy conservation can play a critical role in improving the efficient use of energy. Such programs can be an essential element in getting public and political acceptance of a more rational price structure for energy. In short, since energy conservation can play a major role in bringing improvements in the nation's energy/economic picture by improving efficiency, conservation must be considered more than simply a reduction in energy use.

By considering energy conservation in terms of a more efficient use of our energy resources, we get the concept of conservation off the horns of the telling criticism that just cutting back on energy use for its own sake, and the more the better, is likely to produce severe adverse economic effects. The benefit-cost approach developed in this report provides a way of distinguishing conservation which is economically beneficial from that which is economically harmful. It also provides a way of measuring the degree to which types of conservation are beneficial or harmful. From an economic standpoint, a quad (i.e., 10^{15} BUTs of energy) saved is not just a quad saved; we have to find out where and how it was saved and with what effect.

Further, using this approach can throw light on the complex problems of how to respond to the threat of an oil boycott or to a significant price rise in foreign oil. These issues will be addressed as will the efficacy of energy independence as a national goal.

This report identifies the classes of costs and benefits associated with a range of conservation options and states how these benefits and costs should be measured. The methodology is then used to compute preliminary estimates of benefits and costs from two major conservation options — home insulation and an auto efficiency standard.

Further, the report analyzes whether government involvement is necessary to secure efficient energy utilization. If market forces provide efficient energy utilization without such involvement, then the involvement is not justified as it entails the cost of running the government's program without any corresponding increase in the net benefits from conservation. This report identifies the conditions under which government involvement can contribute to efficient energy utilization which in turn provides the basis for computing the benefits from government actions.

To summarize: The two basic questions addressed in this report are: (1) How should we decide what and how much energy conservation should be adopted? (2) What is the role of the government in promoting efficient energy use? To do this we:

- Identify the various sources, benefits, and costs,
- State how they should be measured,
- Demonstrate where government action can promote efficient conservation, and
- Specify how to estimate the net benefits produced by such action.

Section 2

RESOURCE ALLOCATION AND EFFICIENT ENERGY USE

2.1 THE POINT OF DEPARTURE

The point of departure for analyzing energy conservation is from a comparison of the current pattern of energy use with the pattern of energy use that would obtain if resources were efficiently allocated. To the extent that there is a discrepancy between how energy is being used and how it should be used if resources were allocated efficiently, there is the potential that conservation may concurrently improve our use of resources while reducing the quantity of energy consumed.

To make such comparisons economists use the fundamental fact that if the conditions of perfectly competitive markets were satisfied in the U.S. economy, then competition within these markets would produce an allocation of resources that would be efficient or optimal given U.S. (1) consumer preferences, (2) supplies of natural resources, (3) technical capabilities, and (4) import prices, including the price of oil.[1] Further, the price of each good in such an economy would represent its marginal value. For a consumption good this means that its price equals the amount people are willing to pay for an additional unit of that good. For goods used in production, the price equals the increase in value of production if an additional unit of that input went into the production process. For example, if the competitive price of a thousand cubic feet of natural gas were $1.00, then saving $1.00 worth of gas through conservation and putting it to an alternative use, gives it an incremental or marginal product value in this new use of $1.00. It is this property of prices in a perfectly competitive economy that justifies its use in computing benefits and costs.

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While economists agree that many markets in the economy are not perfectly competitive for any number of reasons, it is still helpful to use the competitive ideal as a point of departure. By identifying where and why energy markets fail to allocate resources efficiently, we can identify possible areas where conservation may improve efficiency. We can estimate benefits and costs by using estimates of what the competitive price would be.

To illustrate this last point, we consider the case of regulated natural gas where the regulated price is considerably below what the competitive market price would be. The non-regulated intrastate price, for example, is much higher than the regulated interstate price, and some customers in the interstate market cannot get all the gas they would like to have at the regulated price. At the same time, those consumers who can get gas at regulated prices find it profitable to use gas in ways that are inefficient from a national viewpoint. The reason is that the price they pay does not represent the full value of a unit of natural gas in some alternative use. Therefore, the consumers of natural gas use it instead of substituting other fuels or adopting energy conserving technologies. Conservation does not occur because the low price of gas does not make it profitable to the particular individual or the firm. The importance of this point becomes apparent when we discuss energy conservation measures, such as insulating buildings, that could produce a substantial savings of natural gas.

2.2 WHY MARKETS FAIL TO EFFECT EFFICIENT ENERGY CONSERVATION

One of the most important reasons that energy resources are not being efficiently used is the one just discussed, namely that some forms of energy are priced below their true marginal value. The regulated price of interstate natural gas, the regulated price of "old oil," and low electric power rates such as those of TVA and other federally owned projects are significant cases in point. Other reasons why energy prices may not reflect the true value of energy, and consequently the true cost of using it, are: (1) monopolistic elements in the energy industry, (2) special tax treatment given the energy producing firms, such as the oil depletion allowance, and (3) externalities such as effects on the environment. Perhaps the most important external cost of energy use that enters current policy discussion is that of dependence on foreign imports. This point will be treated in some detail later in the paper. A number of cases where energy is underpriced could result from monopolistic energy pricing or from special taxes that are levied on energy. Note that if the price of energy is higher than the true opportunity cost of it, there will be too much conservation from the point of view of the efficient resource allocation.

In the case of incorrect pricing, what is cost effective from the individual user's point of view is not cost effective from a national point of view. With rare exceptions, individual users will only conserve when the benefits to them exceed their costs. They will not consider the value of the scarce energy resource in some alternative use. Therefore, if natural gas is significantly underpriced, the demand and use of natural gas will be too great from a national point of view, but not from the point of view of an individual user. Given the price, the user will conserve only if the government intervenes and provides an incentive. In cases where energy is underpriced the optimal amount of conservation can be achieved only through some form of government action.

There are a number of other reasons why, even if energy were correctly priced, individuals and firms do not pursue energy conservation to optimal levels. One stems from ignorance or lack of information on the part of the consumers. A homeowner who is considering insulating his house may have very little information about potential benefits in terms of reduced heating and air conditioning costs, and therefore, he will not know that it is cost-effective. Another problem is financing energy conservation. Firms and households have limited capacity to borrow, and it may not be possible or prudent for them to increase their indebtedness to obtain the finances required to put in energy conserving improvements.

Both of these situations lead to what is referred to as the first cost bias with regard to buildings and durable goods. Because the consumer does not realize the energy savings that can be gained from energy conservation and because he may have difficulty arranging the financing, he may not be willing to pay the additional cost for a building or an appliance that will yield an unknown stream of future benefits in terms of reduced operating costs. Not only may the benefits not be obvious, but the increased initial cost may create a financing problem. Moreover, builders and appliance manufacturers do not incorporate costly energy saving features unless the consumer is willing to pay the extra initial cost.

An additional risk associated with investment in energy conserving technologies and devices results from uncertainty about the future price of energy. If, for example, energy prices were to fall from their current levels to their pre-embargo levels, much of the cost-effective energy conservation based on current prices would not be cost-effective given the old prices. This adds uncertainty about the benefits from energy conservation in terms of future savings, and this risk creates an additional barrier to investments in energy conservation.

Finally, there is basic inertia with respect to adopting new energy-saving devices even when price changes have made them cost-effective. Part of this inertia is associated with problems of information, financing, and risk. However, in addition, individuals and corporate management have limited time and energy and it may be some time before they take advantage of new investment opportunities. An investment in energy conservation is just one of the many possibilities that a firm or individual has to consider.

We will demonstrate that to the extent that government action can speed the adoption of energy-conserving investments with positive net benefits, this action is producing benefits over and above what would be obtained if the process were left to market forces alone. The reason for this is the time value of money. A dollar of benefits today is worth more than a dollar of benefits a year hence, so if government action can speed the adoption of energy conservation, and thereby obtain future benefits sooner, a net increase in benefits can be attributed to the government's program. This point will be developed more completely in connection with discounting and strategies for accelerating the market penetration of energy conserving devices.

2.3 COMPETITIVE MARKETS, PRICES, AND THE MEASUREMENT OF CONSERVATION BENEFITS AND COSTS

We will argue throughout this report that energy demand-reduction in and for itself should not be a national goal and that the effectiveness of conservation should not be measured merely in terms of quads or barrels of oil saved. While these measurements certainly will be used for policy planning, they should not be the primary measures by which to judge our conservation effort and should not be the basic terms used in public debate on energy. Clearly, we could prohibit the use of energy from all sources including food, in which case we would starve. The absurdity of this extreme is not always so obvious in proposals that don't go quite so far. Instead of concentrating on just units of energy saved, we should think about energy conservation in terms of the most efficient use of all our scarce resources including, but not exclusively, energy. The benefit-cost framework provides a structure for thinking about energy conservation issues in terms of economic efficiency. Note, however, the concept of efficiency in this context must include the uncertainties of supply posed by the threat of an oil boycott or price rise by foreign suppliers, effects on our balance of payments, and effects on the environment. More will be said about this.

To make the discussion of alternative policies more concrete, we will focus on energy conservation in space heating and in particular on building insulation. Consider first the case of a homeowner who heats his house with regulated natural gas which costs less than what the competitive market price would be. For this homeowner, insulation is economical only up to the point where the discounted value of additional future fuel savings equals the additional cost of adding more insulation. Assuming, for the moment, he is knowledgeable and not beset by financing or any of the other problems that have been discussed, he will insulate his house to the optimal level based on the cost of insulation and the price of gas. He has no incentive to increase his insulation beyond this as the incremental return to him would be negative. However, the marginal return from his further energy conservation to the country as a whole would be positive. This can be seen in terms of Figures 1a, b, c. Figure 1a depicts the demand and supply curves for natural gas for the nation as a whole. Price and cost are measured in dollars on the vertical axis and units of gas demanded or supplied on the horizontal axis. If the free market were allowed to operate, the equilibrium would be reached at point E with Q_E units supplied and demanded at a price of P_E. P_R represents the regulated price at which Q_R units will be demanded and Q_S units will be supplied. The amount demanded is greater than the amount supplied so that under regulation more consumers and potential consumers would willingly pay P_R or more for gas, but cannot get it at the regulated price. The amount of this unfilled demand is $Q_R - Q_S$.

Now consider Figure 1b which depicts the demand of User I who can buy as much natural gas as he wants at the regulated price. He will buy Q_R^I units and the value to him of the last unit consumed (in terms of what he would willingly pay) is just equal to the regulated price P_R. If the price were not regulated he would only buy Q_E^I units. The implication of this is that the last $(Q_R^I - Q_E^I)$ units that he buys at the regulated price are worth less to him than P_E per unit, and

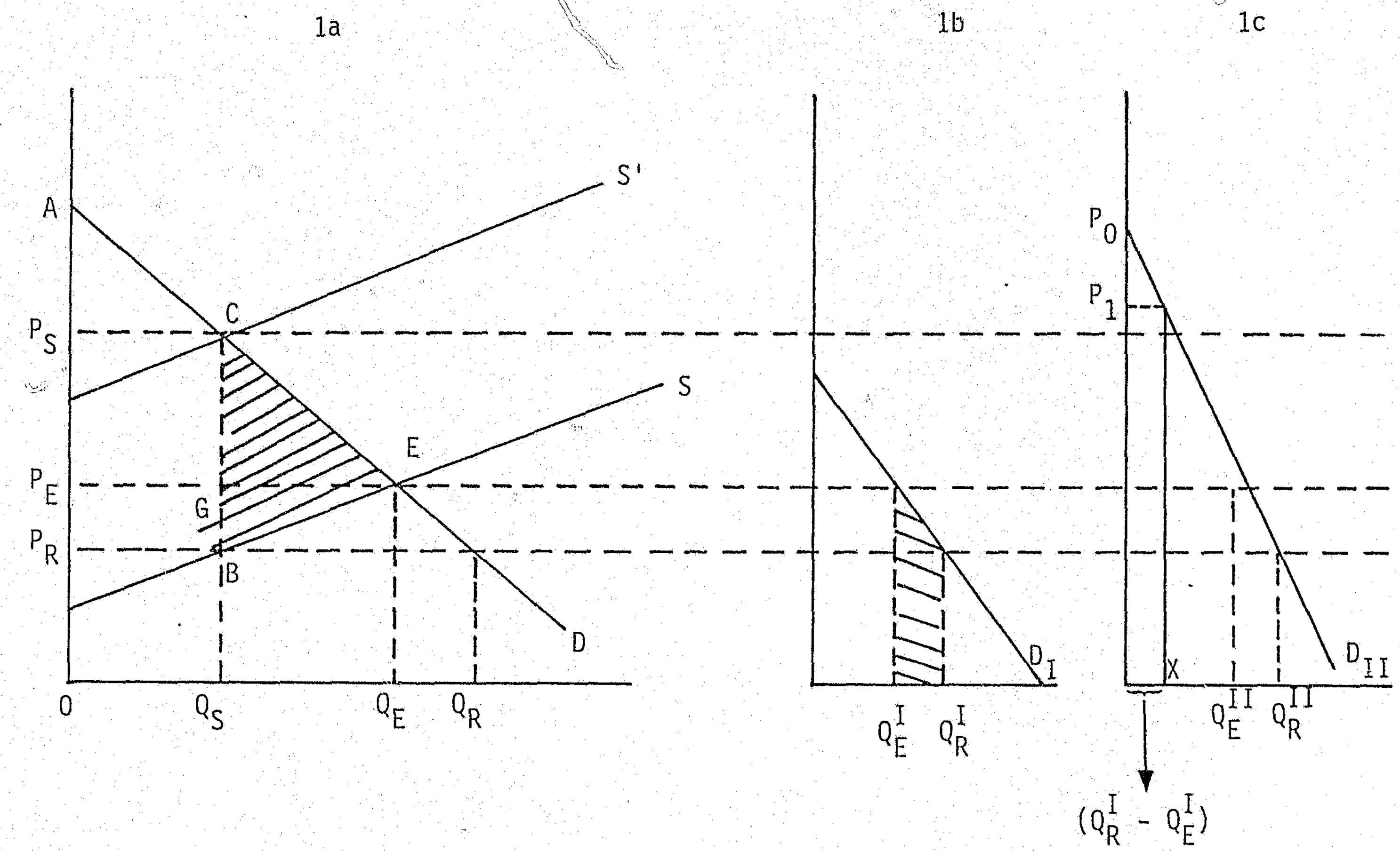

1a
1b
1c
A
S'
S
C
E
G
B
D
P_S
P_E
P_R
0
Q_S
Q_E
Q_R
D_I
Q_E^I
Q_R^I
P_0
P_1
X
D_{II}
Q_E^{II}
Q_R^{II}
$(Q_R^I - Q_E^I)$

Figure 1a, b, c.

if the price had been P_E, he would have chosen not to spend the money for those last units of gas. More precisely, it can be demonstrated that the amount the individual would have willingly paid for those last $(Q_R^I - Q_E^I)$ units of gas, and hence the benefits to him of having them,[2] is represented by the shaded area under the demand curve from Q_E^I to Q_R^I. In this case, where the demand curve is linear, the value of these benefits are equal to

$$\frac{P_E + P_R}{2} (Q_R^I - Q_E^I)$$

or simply the quantity of the additional gas multiplied by the average of the free market price and the regulated price.

Note from Figure 1a that there are consumers with unsatisfied demand who would be willing to pay more than P_E per unit to get additional gas. This follows because there is unsatisfied demand to the left of point E on Figure 1a. Now let Figure 1c represent the demand of User II who because of the gas shortage is not allowed to hook up to the gas line. If he could buy all the gas he wanted at either P_E or P_R he would buy Q_E^{II} or Q_R^{II} units respectively. Now suppose that $(Q_R^I - Q_E^I)$ units of gas were transferred from User I to User II. The value to User II would be the area under his demand curve up to point X and this equals

$$\frac{(P_0 + P_1)}{2} (Q_R^I - Q_E^I).$$

Since the value of the gas to User I was

$$\frac{(P_E + P_R)}{2} (Q_R^I - Q_E^I)$$

there has been a net increase in the benefits from using this gas equal to

$$\frac{(P_0 + P_1) - (P_E + P_R)}{2} (Q_R^I - Q_E^I).$$

The basic point is that some of the gas used by User I could have been put to a more valuable use if it had been transferred to User II and a net benefit would have been produced if this reallocation had occurred. It will be significant for a subsequent part of the discussion to note that if this gas had been made available to another user who would value it even less than User I, then net benefits from the transfer would have been negative. Therefore, while under conditions of price regulation there will be opportunities to conserve gas and to reallocate it to higher value uses thereby producing benefits, this will be achieved only if energy is conserved in low value uses and reallocated to high value uses.

One of the important features of using competitive markets and deregulation as a policy instrument is the assurance that the available gas is allocated to its highest value uses. This can be seen in Figures 1a, b, c. Every user will pay a price P_E and will purchase energy up to the point that the last unit purchased has a use that is just worth its price P_E. Every use for gas with a value greater than P_E to the user will be supplied; every use with a value lower than P_E will not. The total value of gas used in this optimal allocation is represented by the area under the demand curve up to the equilibrium point E, e.g., the area of the quadrilateral $OAEQ_E$.

The amount of the increase in the total value of gas achieved by moving to the optimal allocation from some non-optimal allocation will depend on how bad the non-optimal allocation is. If the regulated price P_R is significantly less than competitive price P_E, then the possibilities for costly misallocations are great, e.g., using natural gas in fire-burners in industrial establishments, and the potential benefits from reallocation are correspondingly great. Deregulation of the price will bring about both a reduction in low value uses and a reallocation to high value uses, thereby producing a net increase in the productivity of our natural gas resources.

Note, however, that at the higher deregulated price, P_E, the quantity used will be Q_E which is greater than the quantity, Q_S, used when there was price regulation. The reason for this is obvious. At the higher price, P_E, more will be supplied and purchased by users. At the same time, the difference between the excess of the amount demanded over that supplied will be reduced to zero with deregulation. One can again highlight the absurdity of using a reduction in energy use per se as an objective of policy by noting that one could reduce energy use to near zero levels by regulating the price at zero so that no energy supplies would be forthcoming. We must be concerned with not the level of energy use alone, but the relationship between supply and demand.

Now consider the alternative of continuing to regulate the price to the user, but adding a tax of $P_E - P_R$ to bring the market price of gas up to the level that would obtain under competitive conditions. Such a policy might be advocated in an effort to use prices to allocate gas effectively among users without allowing windfall profits to the current owners of gas reserves. However, if the price to the supplier is P_R the quantity supplied will be Q_S and there will still be excess demand equal to $Q_E - Q_S$. In order to bring supply and demand into balance and assure that the energy supplies Q_S are put to their highest value use, a price of P_S would be required, or equivalently, a tax equal to $P_S - P_R$. The problem with such a regulation and taxing scheme is that it does not provide the necessary incentive to increase supplies to the optimal level Q_E.[2]

Under conditions of competition the supply curve also represents the marginal cost of production at each production level. Therefore, given a supply of Q_S, the marginal cost of getting another unit of gas is equal to P_R. As the quantity supplied increases, the cost of supplying an additional unit of output increases and it will only be produced for a higher price. In the case of natural gas, expanding production requires drilling deeper wells, exploring frontier areas, drilling more and consequently somewhat less promising prospects, etc., all of which increase cost. Therefore, only at higher prices will new supplies be forthcoming, and the supply will increase right up to the point where the cost of another unit of supply just equals the price.

Consider this in terms of Figure 1a. Starting with production at Q_S, the marginal cost of increasing the production of gas by one unit is given by the supply curve at that point and equals P_R. At the same time, the amount that users would benefit, measured in terms of what they would pay for that additional unit of gas, is shown by the demand curve at that point and equals P_S. Therefore, the value of an additional unit of gas is P_S and the added cost of producing it is P_R. By increasing production by one unit, we create a product whose value is P_S at a resource cost P_R which creates a net benefit of $P_S - P_R$. This same argument holds for each increment of production up to the point where the supply and demand curve intersect at E. In other words, for each unit increment of supply from Q_S to Q_E the value of that increment is greater than the cost of that increment.

It is a basic principle of efficient resource allocation that production of any commodity be expanded as long as its incremental value is greater than its incremental cost. This is also common sense. If you can produce something you value more than the resource you had to forego to produce it, you should do so. At levels of supply less than Q_E, this is the case. However, at supply levels above Q_E, the value of an incremental unit is less than its cost and the supply should not be expanded beyond Q_E.

The net benefit from expanding the supply from Q_S to Q_E is equal to the shaded area CEB in Figure 1a. In other words, if for each additional unit of production from Q_S to Q_E we subtract its incremental cost from its incremental value and then take the sum of these differences, we would get the total net benefits from increasing production from Q_S to Q_E. Geometrically, this is simply the area of the triangle CEB.

Several important principles for benefit measurement emerge from this discussion. First, the level of benefits or the value of energy depends on how it is used and the maximization of its value requires that supplies go to the highest value uses. This can be achieved for any level of supply, by setting a price that just equates demand and supply. The higher value uses will outbid the lower value uses and the market price will equal the value of the last unit of supply. Note that if a fixed supply is allocated on some other basis, like first-come first-served, these supplies will almost certainly not be put to their highest value uses and the net benefit from reallocating these supplies to highest uses is simply the difference between their value in their optimal use as opposed to their previous use. Determining this is an important empirical problem for benefit measurement associated with energy savings as we shall see.

Second, the price mechanism not only can be used to direct scarce energy resources to their most valuable uses, but can also be used to direct production to the level that is optimal from the standpoint of economic efficiency. However, for this to happen, the price paid by the user must be the price received by the producer. This is what brings supplies up to the point where the incremental cost of the last unit produced equals its incremental value. No tax can create a difference between what the seller receives and the buyer pays without destroying this relationship.

Thirdly, one can immediately see two sources of inefficiency if the price is regulated below the competitive market level: (1) the amount supplied will be less than the amount demanded, so available supplies will have to be allocated by some system other than the price mechanism and it is likely that supplies will not be put to their highest value uses; and (2) the amount supplied will be below optimal with a loss in terms of net benefit foregone. A tax to consumers raising the price to a level that equates demand and a given supply can eliminate the first kind of misallocation, but not the second.

A fourth point can be made by turning the argument around. Suppose that natural gas was priced correctly and that the market for natural gas was in equilibrium at the point E in Figure 1a. Suppose some policymaker decreed that we were using too much gas and effected a tax of $P_S - P_R$ per unit raising the supply curve from S to S'. The quantity of gas used would be cut from Q_E to Q_S. There is a strong tendency to claim that the reduction in gas of $(Q_E - Q_S)$ units is a net benefit with a value equal to $Q_E - Q_S$ multiplied by the initial price P_E. This is a serious fallacy because in fact there is a net loss or cost equal to the shaded area CEB. The argument we used before to show that there is a net benefit from increasing production from Q_S to Q_E can be reversed to show there is an equivalent loss from decreasing it from Q_E to Q_S.

When you take $(Q_E - Q_S)$ units of gas off the market the user does not receive a benefit equal to the money he saved because he valued those units at more than what he had to pay. The value of his net loss is represented by the area CGE, i.e., his consumer's surplus. Similarly, the producer is worse off because his costs of production, which he now saves, were less than his receipts, which he loses. This net loss is represented by the area GEB, called the producer's surplus. The sum of the producer's surplus and the consumer's surplus is the entire shaded area CEB and represents the net loss, sometimes referred to as the dead weight loss, of restricting supply (and thus the quantity used) below Q_E.

Therefore, policies to reduce the quantity of energy demanded to a level below that which would obtain under competitive conditions will in general result in a net cost rather than a net benefit. This is because efficient resource allocation requires that production be expanded to the point where the incremental cost of producing an additional unit of output just equals the value of that unit in its highest value use. Competitive market forces bring this about.

The one case where competitive markets will result in too much production occurs when production or use of a commodity involves external costs that are not reflected in the cost to the producer or the price paid by the buyer.

For example, suppose that for every million barrels of oil consumed per day the optimal strategy for protecting the economy from a foreign supply interruption required the storage of a 90-day supply. Thus, if consumption were increased by one million barrels, there would be not only the cost of the oil, but also the cost of the additional required storage which would not be reflected in the market price. In this situation, users would buy oil up to the point where the marginal value of oil just equaled its cost exclusive of the cost of contingency storage. If the cost of storage were included, the marginal value of the last units consumed would be less than their marginal cost.

A way of correcting this situation is to place a tax on oil that equals the extra cost of storage per additional barrel of oil consumed. Given such a cost, the new supply curve for oil would reflect the true marginal or incremental cost of each unit supplied, and at the equilibrium price the marginal value of the last unit produced would just equal the marginal cost of supplying it, including the costs of ensuring against a supply interruption.

From this follows a somewhat unexpected but very important result. If we wish to reduce energy use through a tax as part of a plan to partially ensure against the possibility of supply interruptions, this tax should be related to the additional cost in terms of contingency measures that this additional use requires. More will be said subsequently on this subject.

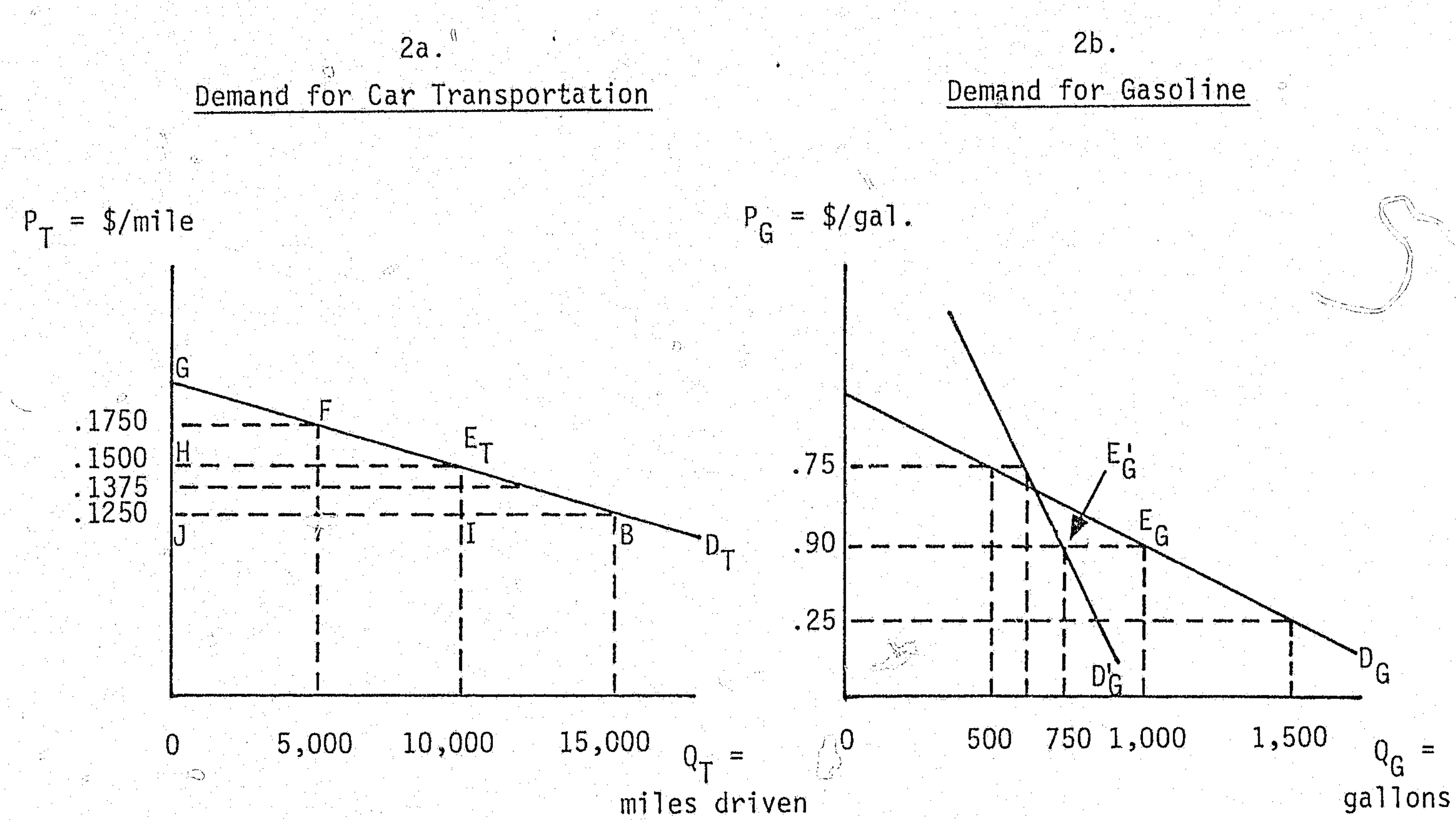
We can use the basic principles presented in the previous section as a basis for benefit measurement. To assure that these procedures will have broad applicability, we will state a general approach to benefit measurement and illustrate it with a number of examples. It is useful to analyze benefit measurement terms in two critically different situations: (1) where energy prices are set at levels consistent with optimal resource allocation (except in special cases these will correspond with free market prices), and (2) where energy prices are not set optimally and will not direct consumers to use energy efficiently (of particular importance is the case where energy prices are too low). It will be demonstrated that in the second situation, where prices do not reflect the marginal value of energy resources, the potential benefits from a government-sponsored conservation program are greater.

Section 3

PROCEDURES FOR MEASURING BENEFITS AND COSTS OF CONSERVATION WHEN ENERGY PRICES ARE CONSISTENT WITH EFFICIENT RESOURCE ALLOCATION

To evalute the benefits from conservation we start with an analysis of the demand for energy. With few exceptions, energy is demanded not for itself, but as an input into a production process that yields something we use directly. Further, this production process may be totally owned and controlled by the ultimate consumer or it may be under the control of a firm that produces a product for sale. For example, both private automobile owners and taxi companies buy gasoline as an input in providing transportation services. In the first case the automobile owner produces a service for himself; in the second case he produces it for someone else. Similarly, individuals buy fuel to provide heating for their homes, whereas apartment owners buy it to provide part of the services they sell to their tenants. The basic point is that in either case, the demand for fuel or energy is derived from the demand for a final product to which it is an input.

Again consider the case of an individual buying gasoline for his car to provide himself transportation services. His basic demand is for mobility (i.e., miles of travel) and from this demand, one can derive his demand for gasoline. How much gasoline he uses per mile depends on the characteristics of his car, how he drives, etc.; therefore, for a given amount of miles travelled by car, one can compute the amount of gasoline required. At the same time, the cost per mile of travel depends upon the price of gasoline. In Figures 2a, b are depicted the demand schedules for transportation services measured in miles and the demand for gasoline measured in gallons for a given


2a.
Demand for Car Transportation
P_T = \$/mile
G
F
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D_T
.1750
.1500
.1375
.1250
0
5,000
10,000
15,000
Q_T =
miles driven
2b.
Demand for Gasoline
P_G = \$/gal.
E'_G
E_G
D_G
D'_G
.75
.90
.25
0
500
750
1,000
1,500
Q_G =
gallons

Figure 2a, b.

individual. To be precise let us assume that the variable costs per mile of car travel excluding gasoline are 10 cents, that the initial price of gasoline is 50 cents per gallon, and that the individual in question has a car that gets 10 miles per gallon. Given the price of gasoline and the car's gas mileage, the gasoline cost per mile is 5 cents and the total variable cost per mile is 15 cents.

At a gasoline price of 50 cents per gallon, the cost per mile is 15 cents and the individual will drive 10,000 miles and buy 1,000 gallons of gasoline. At a price of 75 cents per gallon, the cost per mile driven is 17.5 cents, the number of miles driven is 5,000, and the quantity of gasoline purchased is 500 gallons. At a price of 25 cents per gallon, the cost per mile of automobile travel is 12.5 cents per mile, the number of miles travelled is 15,000, and the quantity of gas demanded is 1,500 gallons.

With a price of 50 cents per gallon, the equilibrium point for the consumer is represented by E_T and E_G, respectively, in terms of miles travelled and gasoline consumed. Now suppose that auto efficiency were increased without any effect on the comfort of the driver or the performance of his automobile so that the same automobile could get 20 miles per gallon. This increase in auto efficiency has the effect of reducing the gasoline cost per mile to 2.5 cents and, assuming all other costs remain the same, the total cost per mile to 12.5 cents. Under these conditions the total number of miles driven will be 15,000 and the total gas consumption will be 750 gallons. There will be a new demand curve for gasoline, D_G', going through the point E_G' where Q_G = 750 gallons. Suppose, however, the initial gasoline price had been 75 cents, then with a more efficient car the cost per mile of transportation will be 13.75 cents per mile and the individual will drive 12,500 miles and use 625 gallons of gas. Note that in this case the actual amount of gasoline consumed after auto efficiency has increased exceeds what would have been consumed at the lower level of efficiency given the same price of gasoline.

This example was constructed to demonstrate that this can happen. The reason is that when the energy-saving engine is introduced it makes the price of travel cheaper and people increase their travel. Therefore, while there is a savings in gas for the number of miles they travelled before, this savings is offset to some degree by the gasoline demanded due to increased travel and may exceed the savings in gasoline on the previous level of travel.

From this follows a basic proposition, namely, that the reduction in the amount of fuel or energy used as a result of the introduction of an energy saving technology or device will be less than the amount of energy that would be saved if the demand for the final product, in this case travel, remained constant. However, when the amount of energy required as input to any product is reduced, the cost of the final product is reduced and people will buy more of it. How much more will depend on the elasticity of demand for the final product and the degree to which the energy savings affects its cost.

We now can compute the benefit from such an energy conserving technology to the consumer. Consider the demand for transportation D_T in Figure 2a. Before the energy conserving technology was introduced, the individual travelled 10,000 miles per year. The total value or benefit to him of having this transportation is measured by the area under his demand curve up to the point E_T where $Q_T = 10{,}000$ as was explained in the previous section. Given the new lower cost of transportation he will travel 15,000 miles and the total benefit from this transportation is measured by the area under the demand curve up to the point B where $Q_T = 15{,}000$. Thus, the total benefit to consumer has increased by the area under the demand curve from $Q_T = 10{,}000$ to $Q_T = 15{,}000$, i.e., the area of the quadrilateral E_TBCA. At the same time he has to pay an amount equal to .125 x 5,000 = \$625, i.e., the area of the rectangle AIBC in Figure 2a, for this additional travel. Thus, the net benefit (subtracting the cost of the additional travel) is simply represented by the triangle E_TBI (or the consumer's surplus).

In cases where the demand for travel is linear, this equals the number of additional miles travelled multiplied by one-half the savings in the gasoline per mile driven as a result of a more efficient car.[3] Moreover, the consumer gets an additional net benefit from the savings in fuel costs on the first 10,000 miles travelled.

Putting this together, the net benefit to the automobile owner is the savings in gasoline cost per mile multiplied by the mileage he drove before the gasoline-saving technology was introduced plus one-half the savings in gasoline cost per mile times the additional mileage travelled. This is a simple and straightforward computation.

It is important to note that to some extent the benefits to the consumer from the energy conserving technology and the actual savings in fuel are inversely related. This can be seen as follows. If the increase in travel is small in response to the energy saving device, then the savings in fuel will be greater. In the limit where there is no increase in the amount demanded, savings will equal the energy-savings for the initial level of travel. However, when this is the case, the part of the benefit represented by the consumer's surplus measured by one-half the cost saving per unit times the additional units consumed will be small. When the number of additional units consumed as a result of the energy-saving technology is great, just the reverse is true, energy savings will be less and consumer benefits will be greater.

Up to this point we have analyzed the benefits to an individual consumer on the assumption that the price of gasoline remains fixed despite the shift-down (or perhaps up) in the demand for gasoline. This would be appropriate if either the supply curve of gasoline were horizontal (infinitely elastic) or the shift in demand were so small that there would be a negligible effect on the gasoline price as a result of the improvement in automobile efficiency.

Suppose, however, that the supply curve for gasoline is upward sloping and that the result of improved auto efficiency is a significant shift downward in demand with the result that the price of gasoline goes down. This is depicted in Figure 3. The lines D_1, D_2 and S represent respectively the total market demand for gasoline before auto efficiency was improved, the market demand after the improvement, and the supply curve for gasoline which equals the marginal cost curve. As a result of the demand shift, less gasoline will be purchased at a lower price. The consumer now gets even cheaper transportation because gasoline prices have gone down. The computation of the benefits to the consumer does not change except that the cost per mile savings in transportation costs must be computed taking into account the price decrease as well as the lower gasoline requirement per mile travelled.

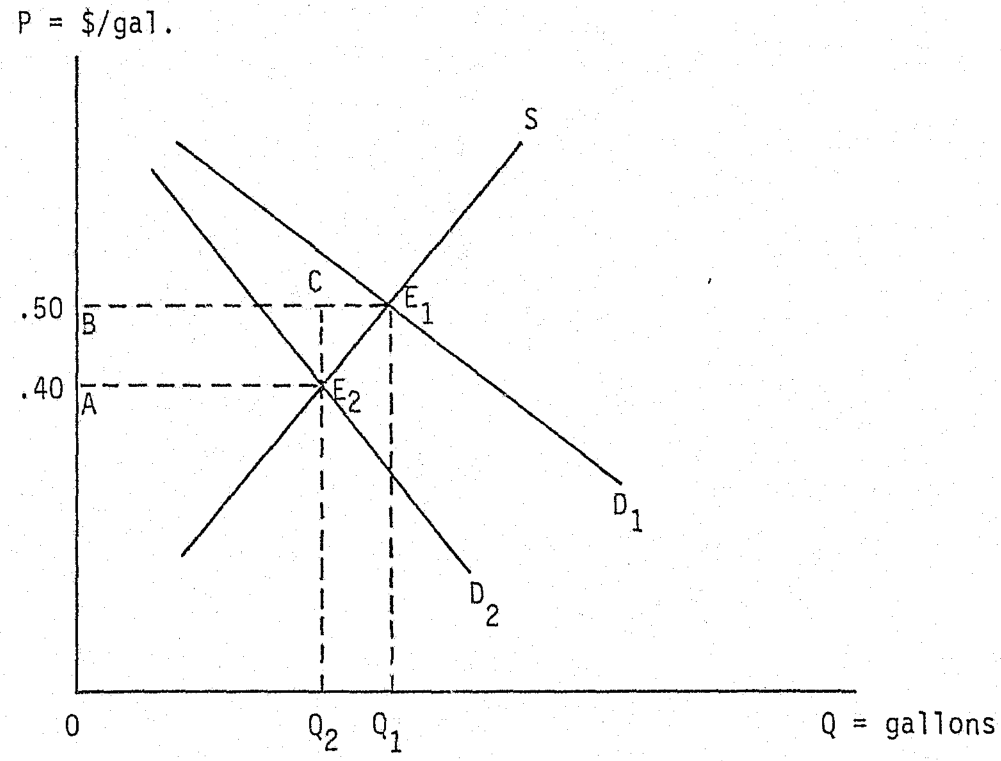

Figure 3

At the same time, there is a loss in benefits to producers (i.e., producers' surplus) equal to the area ABE_1E_2, which represents the net profit to the industry that is lost as a result of lowering the price and cutting back production, and this must be subtracted from the benefits to the consumers. Note the area BAE_2C just represents the savings to consumers on the gasoline they, in fact, buy. As noted above, these savings should be included in their benefits, but are simply a transfer from the gasoline producers to the consumers, and therefore, must be subtracted out so as not to overstate total benefits. The area CE_1E_2, represents a loss of producers' surplus, or a rent, that was earned by the industry on the amount of gasoline saved.

The loss of producer surplus represented by CE_1E_2 must be subtracted as it represents a loss to the producer that is not transferred to the consumer. Another way of putting this is that producing the last $Q_1 - Q_2$ units in Figure 3 only costs an additional amount equal to the area of $Q_2Q_1E_1E_2$, while the producers receive sales revenues equal to the area of the rectangle $Q_2Q_1E_1C$ or a net rent or profit equal to the area E_1E_2C.

3.1 SUMMARY OF PROCEDURE TO MEASURE BENEFITS

The benefit measurement procedure for an energy conserving device or technology in the case where prices are assumed to be consistent with efficient resource allocation is:

(1) Compute the cost saving per unit of the final product (in this case miles of travel) including both the effects of reduced energy consumption per unit and of the reduction in price of energy and multiply this by the number of units of the final product consumed initially.

(2) Compute the increase in the amount of the final product consumed because of the energy-saving technology, multiply by one-half the savings per unit of final product computed in (1), and add this product to the number obtained in (1).

(3) Multiply the reduction in the price of the energy input (gasoline) by the quantity demanded after the energy-conserving device is in place; subtract from the total of (1) and (2).

(4) Multiply the decrease in fuel used as a result of the energy-saving device and multiply by one-half the price reduction; subtract from the total of (1) + (2) - (3) to arrive at the net benefits.

It is important to note that under certain assumptions about supply and demand the benefit expression becomes exceedingly simple. First, suppose that demand for the final product is a vertical line, i.e., completely inelastic. Then the same amount of the final product will be purchased before and after an energy-conserving technology is introduced. In this case the number in step (2) will be zero and can be ignored. Second, suppose that the supply curve is horizontal, i.e., completely elastic. Then there will be no reduction in the energy price as a result of conservation and the numbers in both steps (3) and (4) will be zero. If we assume both a completely inelastic demand for the final product and completely elastic supply of the fuel or energy, the benefits reduce to the savings of fuel costs to the consumer given the amount of the final product he buys; the fuel savings are the amount of fuel saved in producing that output. This special case has generally been assumed when FEA calculates the benefits from insulating homes, etc., by just computing the savings in fuel costs.

While demand is almost never totally inelastic nor supply completely elastic there are cases where these simplifying assumptions may be reasonable for estimating benefits. Examples of such cases are where as a result of conservation, it appears that there will be a negligible increase in the amount of the final product consumed or where such conservation will have a negligible effect on the price of the fuel input. It should also be noted that if we can buy all the imported oil we might at the OPEC price, then once we reach a level where we are using this oil, the supply essentially becomes perfectly elastic.

There are other cases where these assumptions are not appropriate and would significantly underestimate benefits and overestimate fuel savings. For example, if the price of gasoline were extremely high, the introduction of a more efficient engine that significantly lowered the cost of automobile travel would certainly increase that travel. The gasoline required for this increased travel would offset some of the savings in gasoline on the previous level of travel. At the same time, consumers would not only enjoy the benefits of the lowered costs for their previous level of travel, but would also enjoy the benefits from increased travel at the lower cost.

3.2 EXTENSIONS

The method just developed was to measure benefits where the producer and consumer of the final product were one and the same person and the marginal cost curve for the final product was horizontal, i.e., a constant cost per mile driven. We now show that the same procedure is appropriate when energy is purchased by a firm as an input to a final product. Consider first the case where the supply (marginal cost curve) for the final product is horizontal. This situation is depicted in Figure 4 where D represents the demand for some product that uses energy or fuel as an input. S_1 is the supply and marginal cost curve for the industry producing this fuel. S_2 is the supply and marginal cost curve after an energy-saving technology has been introduced. P_1 and P_2 represent the price of the product with and without the energy-saving device, and Q_1 and Q_2 represent the corresponding quantities that are bought in the two situations.

The consumer again benefits in two ways; he gets the goods he purchased in the first place at a cheaper price and this savings equals $(P_1 - P_2)\ Q_1$ or the area of $P_1P_2AE_1$; he gets added consumer surplus on the increased purchases of $(Q_2 - Q_1)$ units and this equals one-half $(P_1 - P_2)\ (Q_2 - Q_1)$ or the area of the triangle AE_1E_2.

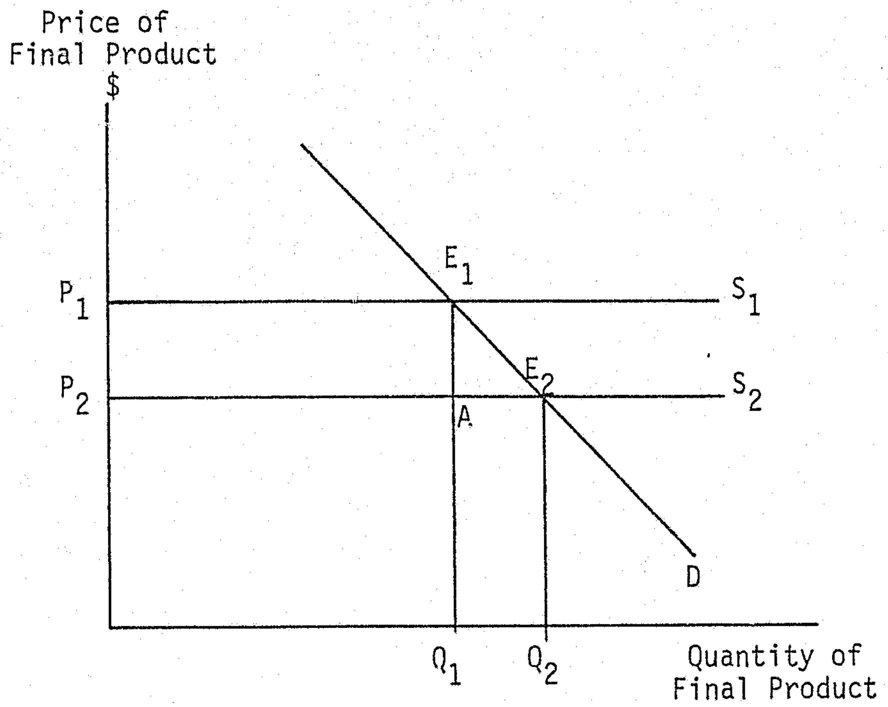

Figure 4

There is no producer surplus in either case, so no other benefits or costs are imposed on the producer of the final product. Again there will be a shift in the derived demand for the fuel as shown in Figure 2b, and the rest of the benefit measurement follows as before.

The situation is only slightly more complicated if the supply and marginal cost curves for the final product are upward sloping as is pictured in Figure 5. In this case the benefits to consumers are computed in the same way, but in expanding production from Q_1 to Q_2 an additional producers' surplus is created equal to the area of the quadrilateral P_2E_2AF. In this case the full per-unit cost saving from energy conservation is not passed on the the consumer; instead, part of it goes to the producer of the final product. The benefits to both this producer and the consumer are the sum of (1) $(P_1 - F) Q_1$, the cost-saving per unit of final product multiplied by the original quantity sold and (2) one half $(P_1 - F) (Q_1 - Q_1)$ which is the area of the triangle E_1E_2A that represents the total increase in both the consumer's and the producer's surplus as a result of increasing the output of the final product from Q_1 to Q_2.

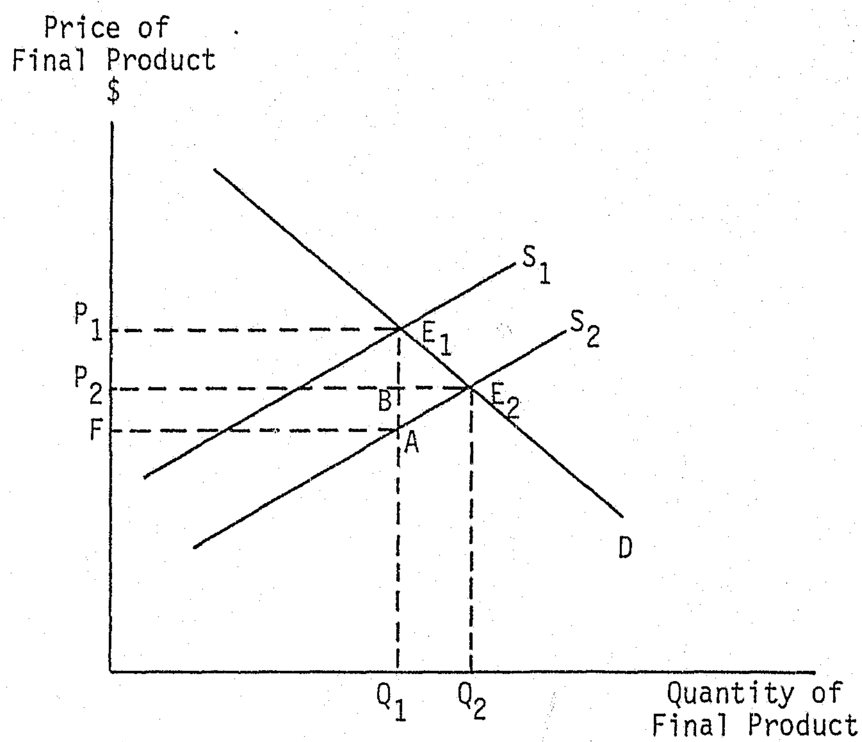

Figure 5

Since the effects on the benefits and costs from a shift in the derived demand for energy are exactly as before, it follows that the only difference between the case under discussion and the previous one is that the savings in fuel costs per unit of final product cannot be measured merely by the decrease in the price of the final product. Despite this fact, the previously summarized four-step procedure for computing benefits holds for the case where the supply curve is upward sloping, so that this method for benefit measurement has general applicability. It follows that this procedure is valid regardless of whether energy is an input to a consumer's or to a firm's production process.

3.3 MEASURING THE COSTS

Let us discuss the costs of energy conservation in terms of a more efficient automobile. Suppose, in the first place, we had the technology for producing such a car, but that it was more expensive to produce. The production of the efficient car would require more resources and under competitive conditions this would be reflected in the increased price of the car. Therefore, there would be an initial cost increase to the car owner that would just equal the value of the additional resources required to produce the more efficient car. In addition, the yearly meaintenance of the new car might go up or down. If it went up, the amount of the increase would be counted as a cost; if it went down, it would be counted as a benefit. The costs then can be divided into the capital costs and operating costs.

In the case where the technology for the more efficient car does not exist there will be research and development costs. Under some conditions, these costs will be accurately capitalized into new car prices so we could analyze the costs in terms of the costs to the automobile owner. However, it might be just as easy to estimate these costs directly and then to estimate separately the direct resource costs of the new cars. Under such a procedure one would estimate research and development costs over time, the costs of converting production facilities, the direct resource costs of the new cars, and the difference in their maintenance costs over time. Under the previous approach all but maintenance costs would be assumed to be represented in the price of the new car.

This approach can be used in computing the costs of new energy-saving investments of all kinds. For example, storm windows have an initial capital cost plus the yearly cost of putting them up and taking them down. Similarly, industrial investments in energy-saving equipment have an initial capital component and an operating component. These can be measured in terms of their market cost.

3.4 THE BENCHMARK FOR MEASURING COSTS AND BENEFITS

To compute benefits or costs requires a benchmark by which to measure changes resulting from the introduction of conservation. The appropriate benchmark is the situation that would have existed had conservation not been adopted.

It is particularly important to distinguish this procedure from that of comparing the situation before and after conservation is adopted. This point is simple and fundamental, but often not put into practice. For example, suppose the price of gasoline were rising so that at the future higher price, the transportation costs per mile will be the same if a more efficient car is developed as with the less efficient car and the previous gasoline price. This does not mean there are no savings and no benefits. The cost savings resulting from a more efficient car must be measured by taking the difference of the cost per mile travelled given future prices with and without the more efficient car.

To compute benefits and costs one has to project what will exist with and without conservation and then look at the differences. Therefore, projection of demand and supply equations over time as well as the projection of costs is critical to estimating the benefits and costs of energy conservation.

3.5 COMPUTING TOTAL NET BENEFITS

The basic benefit-cost approach is to sum the benefits and the costs in each year and to subtract total costs from total benefits to get net benefits. These yearly totals are discounted to their present value and added to get the present value of the entire net benefit stream. The choice of discount rates to be used in discounting presents a number of complex issues, some of which will subsequently be addressed. For the purpose of the present discussion, let us assume that 0.10 is the appropriate interest or discount rate.

To illustrate this procedure let us again consider the introduction of a new more efficient car and assume that the research, development, and retooling costs are accurately reflected in the purchase price of the new automobiles. Further, let us assume that beginning in 1980, the first of these more efficient cars will come on the market and that they will replace the older less efficient cars at a rate of 10,000,000 per year for ten years until the total stock of cars has been replaced. To further simplify the example, let us suppose that the cost of the more efficient car is $1,000 more than the less efficient one, but that the operating costs except for fuel savings are the same. Assume that the normal life of both cars is ten years.

In accordance with the example associated with Figure 2a, we assume that without conservation the cost of gasoline would be 50 cents per gallon, car mileage 10 miles per gallon, the cost per mile driven 15 cents, and the demand for transportation 10,000 miles per year per car. Further, let us make the simplifying assumption that the supply curve for gasoline is horizontal so the conservation measure will have no effect on its price.

Then as in Figure 2a, when the more efficient car is introduced the transportation cost per mile drops to 12.5 cents and the number of miles travelled per car increases to 15,000. Following the benefit procedure that has been outlined, one computes the benefit to each car owner by taking the per mile savings, 2.5 cents, and multiplying it times the initial level of travel, 10,000 miles, which equals $250.00 and adds to it one-half of the 2.5 cent savings multiplied by 5,000, the increase in the number of miles travelled. This gives yearly benefits of $250 + $125 = $375 over the ten-year life of the car.

Because of the simplifying assumption of a horizontal supply curve for gasoline, we do not have to take into account any savings to the consumer because of a price decrease or any loss of producer's surplus to the producers of gasoline. While this simplifies the procedure in this example, it does not represent any basic conceptual change in benefit measurement.

The car owner's stream of benefits and costs can be summarized as follows: He incurs an additional cost of $1,000 at the time he buys his car and he receives a benefit of $375 per year for the ten-year life of the vehicle at which time the cost and benefit stream will repeat itself unless conditions have changed. Over a ten-year period the discounted value of net benefits to the individual that buys the more efficient car is

$$\$\left(\sum_{i=1}^{10} \frac{375}{(1.1)^i} - 1{,}000\right) = \$2{,}304.21 - \$1{,}000.00 = \$1{,}304.21.$$

Since there are 10,000,000 car buyers in that year the present value of benefits from all new cars in that year is simply (10,000,000)($1,304.21) or $13,042,100,000. This represents the present value of net benefits from the more efficient engine in 1980 resulting from cars introduced in 1980.

Now suppose 10,000,000 more cars were introduced in 1981. Again, following exactly the same line of argument, the present value <u>in 1981</u> of the stream of net benefits resulting from the 10,000,000 cars introduced in 1981, is again $13,042,100,000. Therefore, if 10,000 cars were introduced each year for ten years there would be a net benefit stream equal to $13,042,100 per year beginning at the start of 1980. The present value of this stream as of the beginning of 1980, would be its value discounted back to 1980, namely

$$\sum_{i=0}^{9} \frac{13{,}042{,}100{,}000}{(1.1)^i}.$$

It is important to note that because of discounting, the present value today of the net benefits from efficient cars introduced in earlier years is greater than in later years.

In this particular example, we assumed for simplicity that the yearly benefits from the more efficient cars would remain the same over a nineteen-year period (the life of a car introduced at the beginning of the tenth year would end in the nineteenth year), and we assumed that these cars would be adopted over a ten-year period.

If we had assumed that new technical improvements would come on line before the end of ten years, or that changes in demand and supply conditions in either the markets for travel or for gasoline would occur, our analysis would have required modification to account for these changes. While the benefits and cost flows would be more complex the basic methodology would be the same.

3.6 QUALITY DEGRADATION IS NOT A BENEFIT

In the foregoing example, it is assumed that in getting more gas mileage per car, the quality of the car in terms of its size and its performance characteristics remains unchanged. In other words, it is assumed that people can drive the same cars, in all respects, that they chose to drive before except that they now get better gasoline mileage. Suppose, however, that instead of making any improvements in technology, smaller cars were put on the market and larger cars were kept off the market in order to meet a (sales-weighted) standard for greater new car gasoline mileage. Put differently, suppose that the way the auto manufacturers met the standard was simply to sell only smaller cars. What this means is that the consumer would be forced to buy a product that, from his point of view, was inferior to the product he would buy if he were given free choice. While he does get a savings in gasoline, this savings is more than offset by the cost of having to buy the smaller car.

The logic of this assertion is as follows. Suppose that individuals could choose between large cars that got 10 miles per gallon and small ones that got 20 miles per gallon. Then, the fact that individuals would choose to buy the larger car, even though they could have had the benefits of increased gas mileage by buying the smaller car, shows that they were willing not only to pay the additional cost of the larger car, but to pay the increased gasoline costs as well. Therefore, the features of the larger car were worth more than the cost-saving from the lower initial price and the lower gaoline costs.

Turning this argument around in the case of requiring a person to have a smaller car, it follows that you force the individual to forego benefits that were greater than or at least equal to the cost-savings that he would get from the smaller car. Put another way, what you have saved him in terms of gas savings and the savings in the initial purchase price of the car is more than offset by the costs that you have imposed in terms of decreased comfort.

This point comes into the analysis in a different way as is demonstrated in the Auto Simulation Model that was developed by Dr. James Sweeney in the Office of Energy Systems within the Federal Energy Administration. This model shows that if you increase the efficiency of automobile engines so that you decrease the cost of operating all cars, the response will be not only that consumers will drive more miles, but also that small car owners tend to switch to larger cars. What happens is that people will spend part of the savings from lower operating costs on more travel and part on more comfortable, larger cars. In the previous example, we could have expanded our analysis to include not only the benefits from more travel, but also the benefits of people being able to afford to drive larger cars. These benefits will always exceed the amount of the potential gasoline savings due to the increased consumer surplus that the consumer gets from more travel and from having larger cars. Here again the benefits from conservation may be very large, but the actual fuel saving may be somewhat smaller.

This line of argument appears at first blush to run counter to what our instincts tell us is "good" conservation. How can people driving big cars be considered anything but bad from the viewpoint of energy conservation? This question brings us to the heart of a subtle issue for conservation policy. To answer this question we must first realize that people don't drive big cars just to burn gasoline; in fact, they would prefer that these cars did not burn as much as they do. Big-car buyers pay the additional cost of more gasoline and a higher purchase price in order to achieve a greater comfort and performance that they value as an end in itself. When energy becomes scarce and its price rises, consumers are forced to give up things that they value, and unless one is moralistic about saving energy per se, one cannot argue that to give up the pleasures of cheap energy is a good thing. To do so is to completely invert the concept of productivity.

The basic reason we organize production to transform our resources into the good things in life is that we value these good things primarily, and the value placed on the resource input is ultimately based upon what it can be used to produce. It is antithetical to this concept that we should reduce production to save resources, unless we are saving them for some future higher value use. If the latter is the case, then we should compute the benefits from using our resources now and compare them with the benefits from using them later. This is amenable to economic analysis and again puts the issue of conservation back in the domain of efficient resource allocation.

A way of conceiving conservation that does not focus on a reduction in energy use alone, and thus avoids creating an "energy theory of value," is to see conservation as a way of mitigating the deleterious effects of increased energy scarcity and cost on the life-style and wealth of our country. A more efficient car means that we can go on having much of the comfort and travel we like and that the country will not face an economic upheavel in the transportation sector of our economy.

Energy conservation can play a major role in solving the true energy crisis; namely, mitigate the fact that in the face of greater scarcity and correspondingly higher energy prices, we would otherwise have to reduce our standard of living. Broadly conceived efficiency of energy utilization (i.e., conservation) can substantially reduce potential losses.

Except for the case of short-run emergencies such as might be created by an embargo, a war, or some catastrophic event, our problem is not that of running out of energy sources, but rather that of having to obtain energy at higher and higher costs. Rising energy costs, however, can have a major deleterious effect on our economy and our real wealth, even while potential sources of energy exist in abundance. Energy conservation offers a major option for mitigating the effects of rising energy costs on our national wealth. One must distinguish between the long-term goals of conservation which are to make more efficient use of our energy resources and thereby increase our national wealth, and short-term crisis management which is designed to allocate our relatively fixed short-term energy supply in case some source of supply is arbitrarily removed. In the latter case, minimizing short-term disruptions is the goal, whereas the goal of conservation is to maximize our long-term wealth. While related, these objectives are not the same. For example, in an abrupt shortage of crisis proportions, the market allocation mechanism would be put aside and attention would focus on curtailing "nonessential" uses of energy. Although energy "conservation" was in a sense born in such an environment, it is time for it to make the transition to a long-term efficiency orientation.

3.7 THE CONSERVATION ETHIC

One of the things frequently discussed in connection with conservation is the development of a conservation ethic. The basic idea is that by creating an awareness of the energy problem and the potentials for energy savings, we can get people to voluntarily conserve energy such as by driving a smaller car. In examining a conservation ethic from the benefit-cost perspective, it is important to distinguish two alternative meanings of a conservation ethic. (In this context, consider, for example, such measures as turning down one's thermostat, keeping the lights at lower levels, driving a smaller car, etc.)

If in the process of becoming aware of the energy shortage, people's tastes actually change, in the sense that they now prefer or like equally well having their houses two or three degrees cooler, driving smaller cars, and keeping lights at lower levels, then the savings they achieve represent a net benefit. They have lost nothing by keeping the thermostat at a lower temperature or by having a smaller car because they now prefer to do this and they benefit from a cost-savings as well. This type of energy conservation that results from people embracing a new life style lowers the amount of energy needed in their optimal consumption bundle.

Consider now a second meaning of the term. Suppose, you make people aware of the energy crisis and tell them they should conserve energy, and by doing this you create in them a sense that they are doing something bad if they use more energy. As a result a homeowner may keep his house at 65 degrees instead of 70 degrees, but he does so not because he would prefer it that way, but out of a sense of duty. In this case, the person pays a cost in terms of discomfort, but saves on fuel costs. This will produce fuel savings, but it is not clear that this is a good policy for the long-term, though it may be expedient in an emergency. The homeowner would choose to have his temperature at a higher level, except that he was convinced he needed to save energy and was voluntarily willing to assume the costs. In this case the benefits to the homeowner in terms of fuel savings are less than the cost in terms of discomfort, but the homeowner is willing to accept this discomfort as a part of his responsibility as a citizen. Even though he is doing this voluntarily, however, does not change the fact that he is incurring a real cost.

3.8 THE BENEFITS FROM GOVERNMENT CONSERVATION PROGRAMS

A fundamental point is that the benefits from energy conservation as such cannot indiscriminately be attributed to government program efforts. In the previous example of a more efficient car, consumers could obtain benefits of $2,304.21, with an investment of $1,000.

If consumers were informed about these benefits and were able to raise the necessary money, they clearly would buy the car. Further, if the technology were available or could be developed, there would be a strong market incentive for firms to develop and produce such a car. Given the circumstances, one would expect market forces to bring about its development and introduction. To the extent that this would have happened in the absence of a government program, the benefits cannot be attributed to a government program.

A government conservation effort, however, can create benefits in two ways: (1) It can effect efficient conservation when it otherwise would not occur, and (2) it can accelerate efficient conservation that would take place more slowly than would be optimal. If in fact efficient conservation would not take place in the absence of the government's program, then the entirety of the net benefits from such conservation are attributable to that program. These net benefits should be compared with the costs of the government's program to determine whether net benefits from the program are positive. This case is straightforward.

The more complex and interesting case is where conservation measures would be adopted over time, but slower than if the government promoted conservation. To be specific, consider the case of home insulation. Suppose, in order to keep the example simple, the supply and demand equations for home heat and heating fuel are such that the yearly benefits to the homeowner can be measured by the value of fuel savings. To be specific, suppose the initial cost of insulation is \$1,000, that the yearly fuel savings as a result of insulation are \$150, and that the life of the insulation is 30 years. Then the present value of net benefits to the individual and to society as a whole from his insulating now is

$$\$\left(\sum_{i=1}^{30} \frac{150}{(1.1)^i} - 1{,}000\right) = \$1{,}414.05 - \$1{,}000.00 = \$414.05.$$

Suppose, however, because of lack of information or inertia, he delays insulating for two years. Then the present value of net benefits two years from now is again \$414.05, but the present value of these benefits today is

$$\frac{\$414.05}{(1.1)^{i}} = \$342.19,$$

i.e., the value of these future benefits discounted back to the present. By delaying two years the value of the net benefits today have been diminished by \$71.86.

From this it follows that if a government conservation program results in the insulation being installed today as opposed to two years from now, it would have increased conservation benefits by \$71.86 over and above what they would have been without the program. These benefits are therefore attributable to the program.

In general, a government conservation program will both accelerate the availability and adoption of energy conserving technologies and bring about some conservation that would not have occurred at all. In the jargon of marketing it will both accelerate the rate of product penetration and increase the total level of final penetration. In the case where its primary role is to accelerate adoption of conservation measures that would otherwise occur at a later date, one must attribute only the difference of the discounted value of conservation initiated now as opposed to later to the government's program.

Under conditions where energy prices are set consistent with efficient resource allocation, the government's role is likely to be one of accelerating conservation that would ultimately occur given market forces. On the other hand, in the cases where energy is underpriced, much beneficial conservation may never take place without the promotion of government programs. In this case all the benefits from conservation can be attributed to government action. We will argue subsequently that it is the case of underpriced energy resources that represents the greatest potential for government programs to promote conservation.

Section 4

PROCEDURES FOR MEASURING BENEFITS WHEN ENERGY PRICES ARE INCONSISTENT WITH EFFICIENT ENERGY USE

We turn now to the case where the price of energy is below the price that would lead to efficient resource use. Here we distinguish two cases: first is the case where buyers get all of the energy they demand at the low price. An example would be where electricity is publicly produced and all consumers are able to buy their power at a rate below the marginal cost of producing that power. Second is the case where buyers cannot get all of the fuel or energy that they want to buy at the going price, as, for example, with natural gas.

Consider the first case, and for concreteness, let us assume that we are talking about electric power. Figure 6 depicts the demand for electric power and the marginal cost of producing that power. The marginal cost rises in steps which might be associated: (a) in the short-run, with bringing on line facilities in the systems that are more costly to operate, and (b) in the long-run, with constructing new facilities that are more costly because of siting problems or pollution control. P_R represents the regulated or the administered price of electricity and at this price Q_R units are purchased. However it was demonstrated earlier that efficient resource allocation requires that a product only be produced up to the point where marginal cost of the last unit produced is just equal to the marginal value to the buyers of that last unit. Thus, the optimal level of production and use is reached at the point where the marginal cost curve intersects the demand curve which is at point A where the quantity produced and used is Q_E. One way of achieving this is to set the price of P_E and let market forces correct the situation, reducing use from Q_R to Q_E.

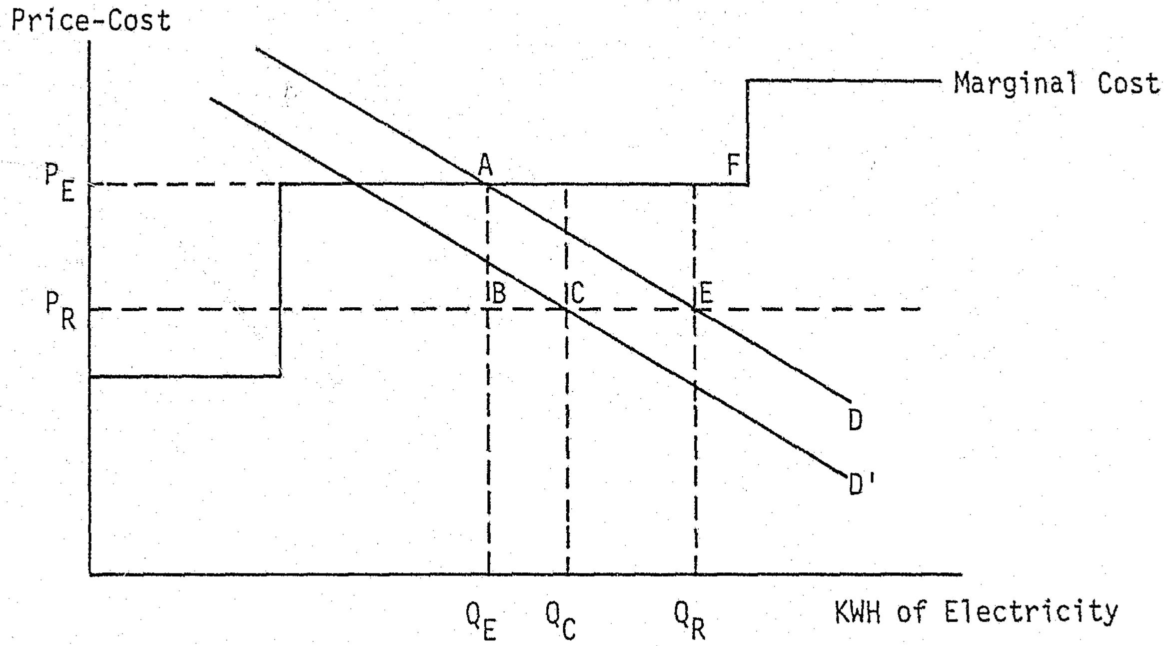

Figure 6

Assuming, however, that the low price P_R remains in force, how does one estimate the benefits from the conservation that might occur? The procedure is much the same as before, but has several important modifications. First, we can analyze the effect on the purchase of electricity precisely as in the case where we assumed energy was correctly priced. Suppose, for purposes of this discussion that a homeowner has electric heating and that he is considering the benefits from insulation. The object of his ultimate demand is the optimum temperature of his house. To simplify the discussion we assume that the average ambient temperature in his house is a linear function of the amount of electricity he uses, i.e., for every so many KWH he uses, he can raise the temperature one degree. Figure 7 depicts his demand for degrees of heat as a function of its cost which in turn depends on the price of electricity. Insulation lowers the KWH (and thus, the cost) required to heat his house at the previous level and increases the temperature at which he keeps his house. Thus, benefit to him is equal to the savings in the cost of attaining the level of

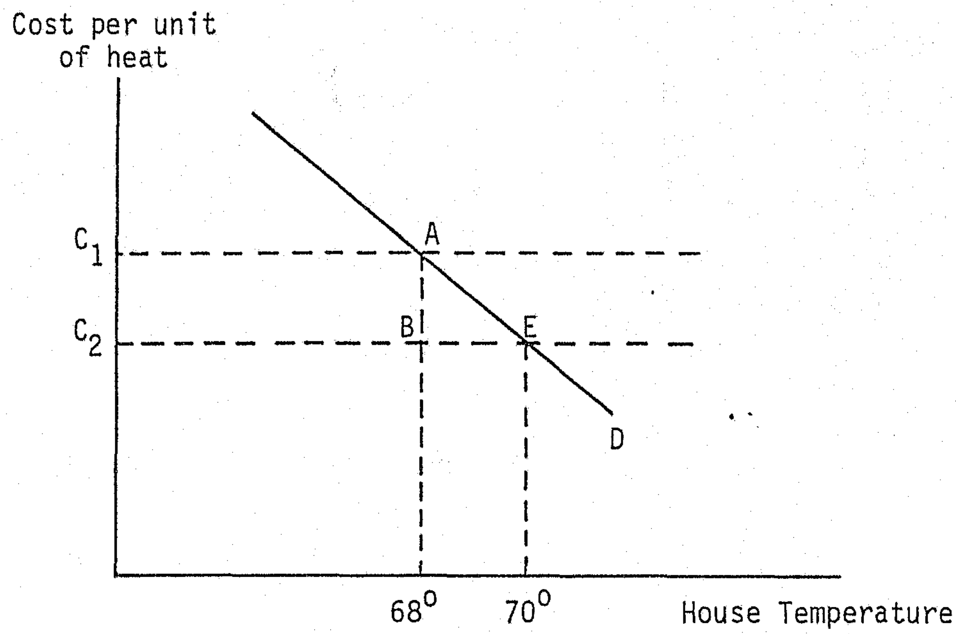

Figure 7

heating he had before, represented by the area C_1C_2BA in Figure 7 plus the consumer's surplus on the additional units of heat, represented by the area ABE. This is exactly the same as steps (1) and (2) of the four-step procedure outlined for the case where prices were set correctly.

Following that four-step procedure, we note that in the case of a regulated or administered price a reduction in demand resulting from conservation will not effect a reduction in price so that steps (3) and (4) can be omitted. However, a benefit to the producer must be taken into account. Consider Figure 6, and suppose that with the general introduction of insulation the demand curve for electricity shifted down to D' so the new amount of energy consumed was Q_C, i.e., a decrease of $(Q_R - Q_C)$ KWH. Because it cost P_E to produce each of the units saved and because the producer only received P_R per unit, decreasing production by $(Q_R - Q_C)$ will create a benefit for the producer of $(Q_R - Q_C)(P_E - P_R)$, i.e., equal to the reduction in energy used times the per unit loss. This loss averted is a benefit and must be added to the benefits computed in steps (1) and (2) discussed above.

The size of the benefit from this last source obviously depends on the amount by which electricity is priced below the marginal cost of producing it and on the total reduction in the use of energy resulting from conservation. Note that in this case, these benefits are directly related to the reduction in energy use. Because the benefits from such saving accrue to the producer, the individual home-owner won't take them into account in his own benefit-cost calculation and will, therefore, invest little in conservation. Therefore, a government program to subsidize conservation or some program of mandatory standards will be required to bring about the optimal level of conservation.

The second situation is that of natural gas where the quantity of natural gas supplied at the regulated price is far less than the amount demanded at that price. As a result, some buyers cannot get any gas and some get an amount less than they would buy at the regulated price. This situation was depicted previously in Figure 1. Again consider the individual who is heating his home, only this time with natural gas, and suppose again that Figure 7 represents his demand for heating, although it now depends on the price of natural gas. The analysis regarding the benefits from insulation to the individual home-owner follows just as before; he will save fuel costs on his original level of heating and he will buy more heating and receive a benefit equal to his additional consumer's surplus. In all but exceptional cases, his derived demand for natural gas will shift down and he will consume less gas, but not as much less as if he hadn't increased his level of heating. Thus, these benefits are computed exactly as before.

However, an additional benefit is associated directly with his decreased use of gas because the gas he doesn't use can be allocated to someone else. To the extent that its value to the person who receives it is greater than its cost at the regulated price, there is a net benefit. Consider in Figure 8 the demand of a consumer who will now be able to get the gas made available through conservation.

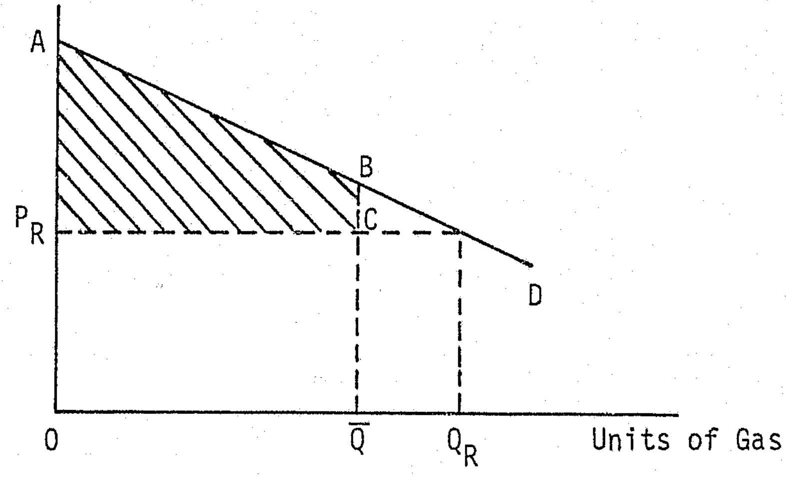

Figure 8

Suppose that $\overline{Q}$ units were made available to him, but that this amount is less than the Q_R units he would like to buy. The value of this additional gas is equal to the area under his demand curve up to point B, the amount he has to pay is represented by the rectangle $O\overline{Q}CP_R$, and the net benefit to him is the area of the shaded quadrilateral $ABCP_R$ which represents the difference in its total value to him and in its cost to him.

It is important to note that the benefits from conserving gas in this case come from putting it to new and higher value uses. Obviously, the higher the value of the alternative use, the greater the benefits will be. Further, the net benefit going to the homeowner contemplating insulation is less than the total benefit and therefore, as in the previous case, the consumer will not have an incentive to undertake conservation that will maximize net total benefits. He will be interested only in maximizing net benefits that accrue to him. The net benefits to him may, in fact, be zero and the result may be that without some other incentive, he will not invest or will under-invest in conservation.

It should also be noted that while the gas conserved in this example was reallocated to another consumer and, therefore, the total use of natural gas did not decrease, it does not mean there was not a significant reduction in energy use. The firm or household that was able to get natural gas as a result of conservation was in all likelihood previously using a substitute fuel, such as oil, which was less efficient. The opportunity to purchase gas makes it possible to reduce the use of that competitive fuel. This also points out one of the pitfalls of trying to measure the impact of conservation on total energy use by looking only at direct effects. More will be said, subsequently, on this point.

In summary, one initially computes the benefits from conservation using the first two steps outlined in the procedure for the case where energy is correctly priced; namely, one computes the value of the energy cost savings assuming no increase in final demand by the consumer and then adds to that one-half of the savings in energy costs on the additional energy that he consumes as a result of his increased demand for the final product. As a practical matter, one computes what energy would be saved as a result of conservation if the consumer's demand for the final product (heating) were held constant, and multiplies by the regulated price of the fuel. Then one computes how much more fuel will be used because of the increase in final demand that took place because of conservation, and one compares this with the increase in energy use that would have occurred with this increase in demand in the absence of conservation. Multiply this difference by one-half the regulated price of the fuel and add it to the first figure.

To illustrate this part of the procedure, consider the case of natural gas where if homes were insulated, the same level of heating could be obtained with a reduction of 100 million cubic feet of gas. Multiply this by the price of $500 per million cubic feet to get $50,000 as the benefits in step (1). Suppose, however, that the projected decrease in the use of natural gas is only 80 million cubic feet because 20 million cubic feet of gas will go into increased heating. Further, suppose that without insulation this increased heating would have taken 30 million cubic feet of gas and cost $15,000 rather than $10,000 as it does with insulation. Therefore, $5,000 is the savings in the cost of this additional heating as a result of the insulation and one takes one-half of this savings to get the benefit in step (2). The reason for going through this exercise is to show that the benefits in these two steps can be computed if you know the projected energy demanded with and without a conservation measure, the price of the fuel, and the decrease in energy use per unit of final product as a result of conservation.

One then adds to this total a third source of benefits that is directly related to the reduced demand for energy by the party who is conserving. In the first case where energy was assumed to be sold at below marginal cost, these benefits are simply the reduction in the loss incurred by the producing unit on the amount of energy that was saved. To compute this benefit, compute the reduction in the loss incurred by the producing unit on the amount of energy that was saved. The information needed is the reduction in energy output, the marginal cost of this output, and the regulated price. In this case, conservation is a way of reducing the economic inefficiency from over-production and over-consumption. The practical difficulty for measurement is correctly measuring the marginal costs of producing the energy saved.

In the second case, the third source of benefits, over and above what accrue to those who conserve, is the consumer surplus that goes to the firms or individuals who could not previously get natural gas. To compute this benefit one has to ascertain who will get the supplies of gas that have been made available by conservation and how much they will be willing to pay for it. One can approach this problem in several ways. First, one can study the involved industries from an engineering standpoint and compute what they have to pay to use the next best alternative fuel source. This provides a lower limit on what they will be willing to pay for natural gas. A second approach is to look at what the various types of firms are bidding for gas in the freely competitive intrastate markets. For example, contracts for natural gas at $2.00 per thousand cubic feet at the well head are now being signed in the Texas Panhandle. This is about four or five times the regulated interstate prices. This means that for some firms gas has a very high value. These intrastate data might be used to determine the value of natural gas to those users who are getting it. The bids of unsuccessful bidders, if available, might also be used to determine the value of gas to them.

A third approach is to use econometric models to estimate what would be the competitive or unregulated price of natural gas.[4] In our early discussion of Figure 1, it was demonstrated that some firms will always value supplies of natural gas at or above the competitive, equilibrium price P_E. One way of computing a minimum or lower bound value for the benefits to firms who can get gas because of conservation is to multiply the quantity of gas that is made available to them, i.e., the amount of the reduction in use by present users, by the difference between the regulated prices and the estimated competitive price.

It may turn out that at regulated prices the present consumers of natural gas will have little incentive to conserve. For them, conservation may even be a losing proposition with negative net discounted benefits. However, the total benefits from conservation may be enormous when the value of the gas in an alternative use is considered. This is likely to be the case if the regulated price is far below the competitive price. In such cases it will pay either to subsidize conservation or to make it mandatory. This assumes that price regulation will continue. Conservation in this case can be a major policy tool to effect a more efficient use of our scarce energy resources.

It is, however, important to point out that while government programs to promote greater energy conservation can contribute substantially to improving the allocation of our energy resources where energy is under-priced, it is still a "second best" solution because no amount of conservation can by itself bring about the optimal allocation that would be achieved if energy prices were allowed to reach competitive levels (i.e., where the price of each form of energy is equal to its marginal cost).

There are three reasons for this:

- Conservation cannot generate the optimal level of supply when the regulated price is too low and the amount supplied is determined by competitive market forces.

- In the case of a fuel like natural gas much of the reduction in use that would be effected by allowing the price to rise to competitive levels would come from the substitution of other fuels.

- Finally, even if one were to stimulate through subsidies or mandatory standards those conservation measures that would yield positive net benefits when valuing energy at the free market price, the individual user who is still paying the regulated price will consume more, given this price and conservation, than he would given the free market price and conservation.

However, while these points argue that conservation is not a substitute for rational energy pricing, it can be shown that energy conservation may substantially reduce the misallocation that occurs from our present pricing policies. Further, given this pricing policy it may follow that it is optimal to stimulate more conservation than would be optimal if our energy prices were consistent with efficient allocation. The reason for this is that increased levels of conservation may free supplies of, for example, natural gas to very high value uses that under deregulated prices would have been freed by interfuel substitution.

4.1 RATIONAL PRICING, INCOME REDISTRIBUTION, AND CONSERVATION

Why don't we simply establish a rational pricing system for energy by allowing energy produced under competitive conditions to be priced at competitive levels and by requiring that regulated utilities producing electricity price it at marginal cost including so-called peak load pricing? Without doubt this would achieve a dramatic improvement in the use of our energy resources. The reason we do not do it is because it would involve a significant redistribution of income. This problem has a number of aspects to consider. First, deregulation of natural gas would result in a significant redistribution from the consumers of natural gas and the consumers of products made with natural gas to the owners of existing supplies. To the extent that the former are many and the latter are few and are considered "fat cats" would create a significant political issue. It should be pointed out, however, that our present policy of regulating natural gas involves a significant redistribution of income to the people who at present can buy gas at low regulated prices from people who value it highly, but cannot get it.

Further, there is an expressed concern for the effect of higher energy prices on the poor. This is a worthy concern and an important policy issue; however, it must be pointed out that regulating the prices of selected energy products is perhaps one of the most costly and inefficient ways to help poor people. First, the subsidy goes only to those poor people who use the regulated fuel source, and many people who are not poor are also subsidized. Second, a program that produces a positive net benefit represents an increase in the value of goods and services produced and, thus, the potential for capturing and redirecting this gain to the poor. It is better to obtain benefits from efficient energy use and then address the problem of poverty and the effect of higher energy prices on the poor directly and separately. It does not make sense to distort our use of energy resources at a very high cost of misallocation in order to help the poor, when they can be helped more cheaply and more effectively through separate programs directed to their particular needs and problems.

Conservation can play a major role both in alleviating the problem of the poor and in limiting the impact of a higher more rational price structure for energy on the average citizen, thereby reducing the political opposition to such prices. To the extent that cost-effective conservation measures can offset the effect of energy price increases, it reduces or eliminates the impact of higher prices both on the amount of the final product (e.g., heating) consumed and on the amount paid for it. To this extent, the introduction of conservation can mean that higher energy prices will, at the very least, have a significantly smaller effect on the average consumer, including the poor consumer. Here again we see the role of conservation being primarily a means of mitigating the catastrophic effects of higher energy costs on the average man. To the extent that it reduces the opposition to a rational price structure and allows us to price and allocate our energy efficiently it can play a key role not only directly in promoting more efficient use of our energy resources, but also indirectly by softening the effects of higher energy prices and thereby reducing opposition to a sound energy pricing policy that will further promote efficient resource use.

For the poor that cannot afford cost-effective conservation measures, we can subsidize these measures directly. We may also want to subsidize cost-effective conservation for other sectors as well to promote acceptance by the public at large of higher energy prices. It is more economical and consistent with efficient resource allocation to subsidize the poor and others through cost-effective conservation than through price ceilings on energy.

From a benefit-cost point of view a subsidy does not represent a cost in benefit-cost analysis, but rather a transfer from the general tax-payer to the person who is subsidized. To the former it is a cost, to the latter a benefit; in total, the two net out. This is not to say that the item does not show up in the government's budget or that there will be no problems of financing this item. The subsidy does not, however, represent a resource cost, but simply a transfer of resources. It can be proved that if you wish to subsidize the energy consumer by some amount and if it is possible to provide this subsidy through a cost effective program of energy conservation, then it is cheaper to provide such conservation measures than to give him the cash. The basic idea is that if benefits exceed costs, then to provide equivalent cash benefits would require a cash outlay equal to these benefits which would exceed the cost of providing conservation.

Section 5

FURTHER ISSUES AND IMPLICATIONS FOR CONSERVATION PROGRAMS

5.1 DESIGNING INCENTIVES FOR CONSERVATION

One of the major roles of a conservation program is to accelerate the introduction of efficient conservation measures. The implications of this are that the major thrust of our conservation effort should be now and that incentives to promote conservation should be designed to differentially favor early adoption. This would entail, for example, making subsidies initially larger with progressively smaller payments in subsequent years. This problem is analogous to that of a firm introducing a new product and using a price discount to accelerate its market penetration. As such, it is amenable to analysis.[5] While an analysis of a full range of possible subsidy programs is beyond the scope of this report, it is important to point out that the optimal size and structure of incentive plans can and should be analyzed from a benefit-cost perspective.

Further, in the case where energy is underpriced, the government will have to create incentives for some conservation that are efficient for the economy as a whole, but not for the user of cheap energy. This will require determining which conservation measures have positive net benefits, and then, on the basis of the costs and benefits to the energy user, determining the subsidy needed to induce him to conserve. This report contains a methodology for performing these tasks. Benefit-cost analysis, therefore, is not only helpful in determining which conservation measures are efficient, but in designing incentives for individual users as well.

5.2 THE RATE OF DISCOUNT

The choice of a discount rate is important because programs which have large initial costs and benefits that accrue over a long period of time can critically affect whether net benefits are positive or negative. The subject of what rate the government should use in discounting the costs and benefits is complex and controversial, and a complete review of the issues and conclusions is beyond the scope of this report. However, there are two propositions which are both relevant and generally accepted as valid. First, to the extent that the benefits and costs of conservation accrue to individuals and firms, the discount rate used in discounting these costs and benefits should be the rate of discount appropriate for them. For example, if a firm has to borrow money at 12 percent to invest in conservation, then to compute the present value of benefits and costs to him, one has to use a discount rate of 12 percent. The implication of this is that whatever discount rate is used, it should be approximately the appropriate commercial rate.

Second, because there is almost never precise agreement on what the "correct" discount rate should be, it is useful to compute benefits and costs using different discount rates within the relative range. In this way one can test the sensitivity of the discounted benefits and costs to these changes to determine if small changes in the rate of discount will produce big changes in net benefits, and, in particular, whether the net benefits go from positive to negative.

This point also applies to many other areas of uncertainty in benefit-cost analysis. In any procedure for estimating benefits and costs, assumptions and parameters subject to error enter into the computation process. Since the role of benefit-cost analysis is not to produce a magic number but rather to illuminate policy choices for the decision-maker and to show him the magnitude of the totals under various assumptions and with various parameter values, it is useful to computerize the computation process so that he can quickly explore the effect of changes in parameter values and assumptions. More will be said on this in the appendix, where we present some preliminary benefit and cost estimates for different conservation options.

5.3 MEASURING CONSERVATION EFFECTIVENESS

The previous discussion has strongly argued that it is incorrect to judge the effectiveness of conservation on the basis of the amount of energy used and can lead to policies that seriously misallocate our energy resources. Further, if we limit our attention to the direct impact of conservation on energy consumption we do not get an accurate picture of the effect of that conservation on total energy consumption. As we have seen, a program to conserve natural gas that is allocated to another user may have an overall effect of reducing energy consumption through interfuel substitution. More importantly, however, the great contribution of conservation is that it allows us to maintain our level of national wealth in the face of increased energy scarcity and rising energy prices. In measuring how effective we have been in this regard, we need to look at the net contribution of conservation, and this is precisely what the benefit-cost framework allows us to do. In the final analysis we should look at the magnitude of the net benefits of conservation to this contribution.

At the same time, maximizing the contribution of energy conservation means implementing those conservation measures that produce positive net benefits. At any point in time we may wish to have indicators that tell us how we are doing with respect to implementing such measures. One approach is to study the major energy consuming sectors, determine what conservation measures are cost-effective, and then measure the degree to which efficient conservation has been adopted. For example, in judging conservation in space heating, it is more meaningful to look at the degree to which buildings are insulated, the heating efficiency of the equipment, etc., than it is just to measure energy consumed.

This approach can also be applied to the choice of fuels. For example, if it were determined that national economic efficiency were served by having industrial boilers fired by coal instead of by natural gas, one could measure the effectiveness of a program to get firms to conserve gas by the number of firms that had made the conversion, or by the percentage of firms that had done so. This example brings out an important point, namely that conservation can and should play a major role in promoting the efficient use of different fuels. To focus on the level of energy consumption in terms of some equivalent measure is to miss a significant part of the conservation opportunity.

Finally, by identifying efficient conservation by consuming sector, by type of firm, and by household, one can develop meaningful indicators that can be applied at the micro level. How much energy a plant consumes tells one less about whether that plant is using energy efficiently than does checking on whether it has adopted those conservation measures that are known to be cost-effective in such plants. While consumption data are critically important to energy policy analysis, they do not provide a ready indicator of conservation effectiveness.

5.4 CONSERVATION, ECONOMIC GROWTH AND PROSPERITY, AND THE EMBARGO

We have argued strongly that the most important contribution of energy conservation is that it provides a mechanism for maintaining greater economic growth and welfare in the face of rising energy costs than would otherwise be possible. Further, we have argued against the view that a reduction in energy consumption per se is a good thing, and that conservation measures are only beneficial if they are consistent with efficient resource use. Another way of putting this is to say that measures to conserve should only be undertaken if the benefits exceed the costs, and that the efficacy of conservation should be judged on the basis of net benefits and not on reduced consumption. Certainly, this line of argument is different than that frequently presented in support of conservation. Those who argue that the primary role of conservation is to reduce consumption might ask, but what about the embargo?

This question raises a number of complex issues that go to the heart of our national energy policy. Unfortunately, many of these issues have not been adequately studied, and many critical questions remain unanswered. While a definitive answer to the question raised by the threat of an embargo must await further analysis, we can sketch the issues and show why energy independence gained in large measure through demand restraint is not an obviously good objective.

An oil embargo, or any sudden supply interruption, can cause serious economic disruption and a corresponding reduction in national income. In the short-run, the possibilities for substituting other factors for energy, or one fuel for another, are limited so that the short-term effects of an energy cutback on the national product are likely to be greater than the long-term effects. Also, the larger the percentage of one's energy supply that is cut off, the greater the effect will be. The importance of this is that if we develop our economy in a way that requires us to use more energy, and therefore import a large proportion of it, we become more vulnerable in the sense that foreign supply interruptions will cause greater absolute reductions in our national product than if we had been using less imported oil.

It follows that we can reduce the loss of GNP from an embargo by reducing the amount of energy we import, and in the limit, where we have complete independence, we can reduce it to zero.

Further, under these circumstances, the threat of an embargo cannot be used as a political weapon, so energy independence clearly has many desirable aspects which have made it a much touted goal of energy policy. Unfortunately, the proponents of energy independence or of significant reductions in oil imports have not been as careful in analyzing the costs as they have the benefits. Any program for energy independence will, in normal times, reduce our national product so that the basic tradeoff is between a national product somewhat smaller most of the time, and drastically smaller in case of an embargo. It is this tradeoff that we must analyze.

First, consider the achievement of independence through demand restraint. This is in essence equivalent to a self-imposed total embargo. By adopting this policy we would have in effect done to ourselves on a permanent basis what we had feared a potential enemy might do temporarily. The only possible arguments for this can be:

(1) That the effect of such a policy on our long-run economic growth and welfare would be minimal because of both the potential for conservation and increased future domestic energy production, and

(2) That we need a policy that will direct us to this long-term economic path.

However, this brings out two further points. First, if a primary concern is mitigating the economic effect of relatively short-run supply interruptions, there are other ways of achieving this than by forcing our economy onto a long-term growth path that is restricted by our domestic energy supplies. Second, even if we do decide to pursue energy independence, in the long-run, as our production capacity increases, the problem will be more one of rising energy costs than absolute restrictions on our supplies. It will be the high cost of energy more than any physical limit on production that will limit the amount of energy consumed. Therefore, if we pursue energy independence the role of conservation in reducing the deleterious effects of high energy costs on our economic well-being will be more important than ever.

Returning to the first point it is clear that the short-run impact of an embargo can be greatly reduced by emergency preparedness such as storage, short-term demand curtailment, etc. How effective such plans might be will affect whether we should, as a matter of policy, accept a permanently lower GNP, thereby incurring immense costs as the price of lessening the severity of a short-term supply interruption. To make this point clear in the extreme, suppose our GNP would be 2 trillion in normal times if we did not attempt to limit oil imports, and 25 percent less, or 1 trillion 500 billion, if we pursued energy independence. Further, suppose that the effect of an embargo in the first situation would be to cut our GNP by 300 billion if it lasted one year. This would mean that even with the embargo our national product would be 200 billion greater than it would normally be with a policy of energy independence. This highlights the point that we should not focus just on the magnitude of the effect of a potential embargo, but on the magnitude of our GNP over time under various policy options.

One of the problems of determining what the optimal strategy is for our long-term energy policy in the face of a threatened embargo is that, to our knowledge, there is not complete analysis of what our short- and medium-term emergency preparedness options are, how effective they can be in reducing the impact of a supply reduction, and how much they will cost. Without such information it is difficult to analyze the tradeoffs among different projected time paths for GNP, given more or less dependence on imported energy. If we can reasonably cope with the potential of an embargo through a combination of measures such as storage, temporary demand restraint, etc., then permanent reductions in demand, over and above what cost-effective conservation will produce in any case, do not appear to be justified. The final answer awaits further analysis including that of different strategies for coping with short- and medium-term supply interruptions.

It is important that we distinguish between energy conservation designed to make better use of our resources and demand curtailment per se. While planned curtailment may be an important element in an emergency energy plan, at the same time it is antithetical to the efficient allocation of resources under normal conditions. As we move from the crisis environment of the embargo, from which our energy policy was born, and turn to the continuing problem of energy planning, it is extremely important that we separate the persistent long-term issues of policy from the issues of emergency preparedness and crisis management. This is particularly important for the case of conservation.

In summary, the long-term energy problem is one of increasing cost, and the role of conservation in the long-term is to mitigate the effects of these rising costs on our national wealth. This is true regardless of whether or not we strive for energy independence. We can achieve this goal by pursuing conservation that is consistent with efficient resource allocation. The benefit-cost framework provides a basis for evaluating which conservation measures are efficient, and this report provides procedures for benefit-cost measurement. Finally, it is extremely important to distinguish conservation from demand curtailment. While conservation may have a role to play in a strategy for coping with the threat of an embargo, it is by no means clear that it does, and it would be a serious mistake to base the case for conservation on this contention. Therefore, efficient energy use rather than reduced energy consumption should be conservation's objective, and net benefits rather than energy savings should be the measure of success.

FOOTNOTES

1. This assumes that the price of imported oil is given. If, however, there is a posibility of altering the import price by a bilateral or multilateral game with a foreign cartel, then the total amount that should be purchased at each price by the United States as part of a gaming strategy may not correspond with the amount that would be purchased under freely competitive conditions.

2. This is related to the basic concept of consumer's surplus which is discussed in most basic economics texts on price theory or public finance. For a discussion of the concept in the context of benefit measurement, see Robert C. Lind, "Benefit-Cost Analysis: A Criterion for Social Investment," in Water Resource Management and Public Policy, ed. by Thomas H. Campbell and Robert O. Sylvester, pp. 55-59, 1968.

3. If the demand for travel were not linear this formula would not give an exact measure of the consumer's surplus. As a practical matter, however, benefits can be approximated by using this formula without a significant loss of accuracy.

4. See P. W. MacAvoy and R. S. Pindyck, "Alternative Regulatory Policies for Dealing with the Natural Gas Shortage," The Bell Journal of Economics and Management Science, Vol. 4, No. 2, Autumn 1973.

5. For example, the choice of an optimal promotional campaign is examined by V. Rao and L. Joseph Thomas in "Dynamic Models for Sales and Promotional Policies," Operational Research Quarterly, Vol. 24, No. 3, pp. 454-497, Sept. 1973.

Appendix

METHODOLOGY APPLIED TO CONSERVATION OPTIONS

A.1 INTRODUCTION

The main body of this report develops a comprehensive methodology for measuring the benefits from energy conservation given a number of economic circumstances. We now apply this methodology to make benefit-cost estimates for two cases. The first is a 20 percent increase in the technical efficiency of automobile engines. The second is the installation of various kinds of home insulation. For the case of increased automobile efficiency, we estimate the benefits only. A fully developed analysis of the costs of developing and producing such engines was beyond the scope of work. However, the benefit estimates alone are extremely useful for policy purposes because they show what one can justify in the way of research and development costs for such an engine. For the case of home insulation we estimate both benefits and costs on a regional basis.

The primary limitation on the application of the methodology is the availability of good demand models for the final products; i.e., in this case automobile transportation services and home heating and cooling. Because the formulation and estimation of such models was beyond the scope of work under this contract, the preliminary benefit estimates had to be based on the application of existing demand models or on simplifying assumptions about demand. In the case of the benefits from a more efficient automobile engine, we adapted the benefit-cost methodology so that we could use the FEA Automobile Simulation Model to measure changes in the quantity of automobile transportation consumed. While one might have defined automobile transportation services differently from the way we have done it in order to use the FEA model, it appears that this definition is a good one in that it enables us to relate benefits to measurable cost savings for gasoline. This definition of automobile transportation services will be discussed in detail in Section A.2.

For the case of home heating and cooling, there are, to our knowledge, no good household demand models. This is an area that badly needs further work as it is critical to energy policy regarding household consumption and conservation. Because of the absence of a ready demand model, we made the simplifying assumption that household demands for heating and cooling are totally inelastic. Since we would expect such demands to be highly inelastic, this assumption probably will not have a significant effect on the measure of benefits. The bias of such an assumption is that benefits will be slightly understated by the amount of the consumer's surplus from increased heating and cooling that is excluded by the assumption of completely inelastic demand. At the same time the effect of this assumption may be to overstate significantly the fuel savings. Even with a relatively inelastic demand for the final product, much of the fuel savings resulting from conservation on the original quantity of heating and cooling consumed may go into increased consumption when the cost of heating and cooling is reduced by insulation. Therefore, while the estimates of benefits are likely to be slightly low, the estimates of fuel savings may be significantly high.

It must be emphasized that our task was to present rough, first-cut estimates of benefits and costs. While we feel we have done significantly better than that, further major improvements are still possible. Much of the improvement will come in the form of better demand estimates and better cost estimates. The benefit-cost estimates that we present show the order of magnitude of the benefits and in both cases the benefit potential is in the billions of dollars. The basic numerical results are presented in Sections A.2 and A.3 along with a discussion of how they were obtained and how they can be used in analyzing policy options.

In addition to the benefit estimates being interesting in themselves, they are interesting in that they demonstrate the methodology. In particular, in the case of increased automobile efficiency, the results demonstrate that if you compute benefits simply by multiplying the units of energy saved by the market price of energy, you significantly understate the value of the benefits. The difference between the benefits properly computed, and the benefits computed on the basis of the value of energy savings alone is displayed for this case. The difference is large. We also show separately the benefits in the form of the consumer's surplus from larger cars.

For the case of home insulation we show that if the net benefits from conserving natural gas are computed on the basis of the value of fuel savings alone, measured at the current regulated price of gas, they are relatively small, but when we add in an amount to reflect the value of the gas saved in some alternative use, the value of the benefits is considerably larger. To summarize, with these two examples we demonstrate the effects on the magnitude of the benefits of computing them correctly; taking consumer's surplus into account in the case of increased automobile efficiency and taking the value of the fuel saved in an alternative use into account in the case of home insulation where the fuel, natural gas, is under priced. Further, we demonstrate how such estimates might be used in analyzing tradeoffs associated with a number of policy options and give a number of alternative interpretations of the results.

A.2 MEASURING THE BENEFITS FROM A TWENTY PERCENT INCREASE IN THE TECHNICAL EFFICIENCY OF AUTOMOBILES

A.2.1 Review and Adaptation of the Methodology

This section describes in detail the procedure for measuring the benefits from a 20 percent increase in the efficiency of automobile engines. Benefits are computed for a ten-year period beginning in 1980 on the assumption that such engines would become available in new cars in 1980. A 20 percent increase in technical efficiency and a starting date of 1980 were chosen because 20 percent appeared to be a modest improvement that one might realistically hope to achieve in five years. Further, preliminary back of the envelope calculations lead us to believe that even such a modest increase in efficiency would produce yearly benefits of billions of dollars. The actual benefit estimates were of this magnitude.

The basic approach to the measurement of these benefits is outlined in Section 3 of the report. Given current levels of demand, we are in the range of the supply curve for gasoline where incremental increases or decreases in use will come from changes in oil imports for which the price is fixed. Therefore, we assume that, in the relevant range, the supply curve for gasoline is horizontal at fifty-five cents (55¢) per gallon in 1975 dollars and that the price for gasoline will be unaffected by any reduction in demand resulting from the more efficient engine. For this reason we need only carry out steps (1) and (2) of the four-step procedure for measuring benefits given in Section 3.1 of the report on page 25. Steps (3) and (4) can be omitted because there is no reduction in the price of gasoline.

The problem of benefit measurement is, therefore, reduced to measuring the area under the demand curve for the final product, transportation service or the increase in the consumer's surplus that results from a decrease in the cost of automobile transportation. This can be represented diagramatically as in Figure A-1.

On the vertical axis is measured the cost per unit of transportation service and on the horizontal axis is measured the quantity of transportation service. Given the demand for transportation at the cost of C_1 per unit corresponding to the unimproved engine, the consumer purchases T_1 units. Let C_2 represent the cost per unit of transportation given a car engine that is 20 percent more efficient. Then the consumer will demand T_2 units of transportation service. As before, his benefit, or the amount he would willingly pay to have the new, more efficient engine is the shaded area C_1 C_2 E B. The part C_1 C_2 A B

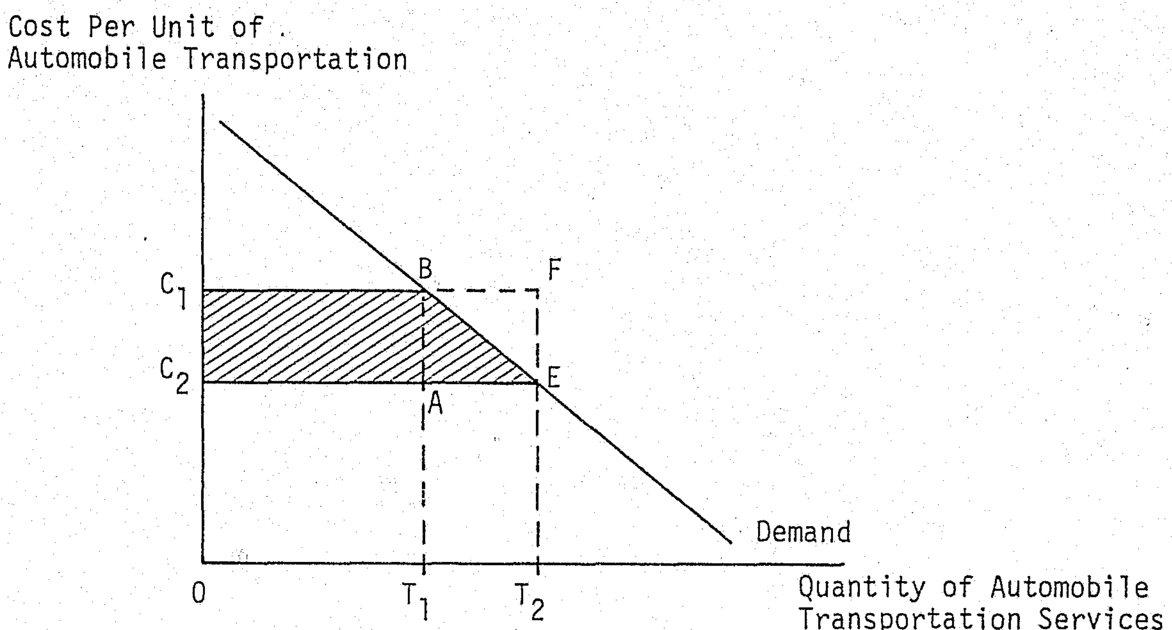

Figure A-1. Conceptual Demand Curve for Automobile Transportation

is simply his savings on the gasoline costs of the original amount of transportation and the part AEB is simply one-half the value of his savings on the gasoline costs of the additional T_2-T_1 units of transportation that he purchases.

To compute the benefits represented by the area AEB, first calculate the cost of the extra T_2-T_1 units of transportation given the old engine, and the old cost per unit of transportation. This is represented graphically by the rectangle T_1 T_2 F B. Second, compute the cost of the extra T_2-T_1 units, given the more efficient engine and the lower cost per unit of transportation. This is represented graphically by the rectangle T_1 T_2 E A. Then subtract this second computation from the first. This represents the savings in the cost of buying an additional T_2-T_1 unit of transportation as a result of an increase in automobile efficiency and is pictured graphically by the rectangle EFBA. To compute the consumer surplus which is represented by the triangle AEB, multiply by one and one-half.[1]

[1]When the demand or marginal cost curves are not linear this procedure gives an approximation, but not an exact measure of the consumer's surplus.

The only thing that is different between this presentation and the presentation in Section 3 of the main body of the report is that we have called the final output transportation services rather than miles traveled. The reason for this is that people value not only the number of miles that they travel but also the comfort of their travel. As a result, when the cost per mile of transportation goes down by 20 percent for cars of all sizes, people buy bigger, higher performance cars and they travel more miles. In fact, the FEA Auto Simulation Model estimates that a reduction in the cost per mile traveled affects more significantly the average size of cars than the number of miles traveled.

Therefore, in measuring benefits, we have to account for the part of consumer's surplus that arises both as a result of consumer's traveling more miles and as a result of buying more luxurious cars.

Section A.2.3 contains a detailed discussion of the conceptual basis for collapsing miles traveled and car size into a single measure of transportation services. It also contains a detailed description of the computation procedure including an explanation of the data requirements and of how the FEA Automobile Simulation Model can be used to obtain basic data inputs for benefit estimation. This, however, is of most interest to the analyst and can be omitted by those who simply want to understand the approach, the numerical results, and their potential use. Therefore, we turn first to the numerical results and how they can be interpreted for the purposes of energy policy

A.2.2 Benefit Estimates and Policy Interpretations

The basic numerical results are presented below in Table A-1. Each row shows the yearly magnitude of a particular benefit or savings

Table A-1. NUMERICAL RESULTS

Benefits or Savings $\$(10)^9$ \ Year	1980	81	82	83	84	85	86	87	88	89	Σ
B_1	1.40	2.60	3.73	4.69	5.57	6.39	7.1*	7.89	8.64	9.39	
PV B_1(10%)	1.27	2.15	2.80	3.20	3.46	3.60	3.66	3.69	3.66	3.63	31.12
PV B_1(5%)	1.33	2.36	3.22	3.86	4.37	4.77	5.08	5.34	5.57	5.77	41.6
B_2	.21	.41	.56	.75	.91	.98	1.05*	1.12	1.19	1.26	
PV B_2(10%)	.19	.34	.42	.51	.57	.55	.54	.52	.51	.49	4.64
PV B_2(5%)	.20	.37	.48	.62	.71	.73	.75	.76	.77	.77	6.16
B	1.6	3.01	4.29	5.44	6.48	7.37	8.19*	9.01	9.82	10.65	
PV B(10%)	1.46	2.49	3.22	3.72	4.02	4.16	4.20	4.21	4.16	4.11	35.75
PV B(5%)	1.53	2.73	3.71	4.48	5.08	5.50	5.82	6.10	6.33	6.54	47.82
VGS	.39	.72	1.04	1.29	1.57	1.82*	2.07	2.32	2.57	2.82	
PV GS(10%)	.36	.60	.78	.88	.98	1.03	1.06	1.08	1.09	1.09	8.95
PV GS(5%)	.37	.65	.90	1.06	1.23	1.33	1.47	1.57	1.66	1.73	11.97

* Because the FEA Automobile Simulation Model was not programmed to give output beyond 1985, the numbers beyond that point were obtained by adding a constant amount per year based on past increases.

measure from 1980-89 in terms of constant 1975 dollars. More specifically, B_1 represents the benefits corresponding to the value of the savings in gasoline that would result from a 20 percent increase in the technical efficiency of automobiles beginning in 1980, assuming people drove the same cars the same number of miles as they would have without the increase, i.e., B_1 represents the area C_1 C_2 A B in Figure A-1. PV B_1 (10%) and PV B_1 (5%) represent, respectively, the present value as of 1980 of this component of benefits in each year assuming a 10 percent and 5 percent rate of discount. The numbers in the column labeled $\sum$ are simply the sum of the numbers in the corresponding row, e.g., 31.12 is the present value of the benefits represented by B_1.

Proceeding down the rows, B_2 is the component of benefits corresponding to the consumer's surplus from consuming more transportation services, i.e., the benefits corresponding to the area AEB in Figure A-1. As before PV B_2 (10%) and PV B_2 (5%) are the present value of those benefits as of 1980 when discounted at 10 percent and 5 percent, respectively. B is simply the total of benefits, i.e., $B = B_1 + B_2$. VGS is the value of the actual gasoline that would be saved if a 20 percent increase in the technical efficiency of cars were introduced in new cars, beginning in 1980, that allowed people to respond by buying larger cars and driving more miles.

Before proceeding to interpret these results, a review of some of the basic assumptions will be helpful to understanding their meaning. First, B_1, B_2, B, and VGS are measured in billions of 1975 dollars assuming a price per gallon of $.55. Further, we assume that the technical advances in efficiency would be incorporated into new cars only. This explains why benefits rise over time as the conversion from old models to new ones occurs. This assumption could easily be changed, however. If for example, a new more efficient fleet could be obtained all at once, the yearly benefits and savings would be approximately equal to those shown for 1989 when the fleet has been converted. Finally, discount rates of 10 percent and 5 percent have been chosen arbitrarily to illustrate a range of values. However, since benefits are measured in constant 1975 dollars and therefore are in real terms, the appropriate interest rate is the real, inflation free rate. Therefore, the 5 percent rate, which corresponds to a 15 percent actual rate when 10 percent for inflation is included, is probably more appropriate when comparing the magnitude of discounted benefits and savings with costs at 1975 prices.

There are several striking results contained in the numbers in Table A-1. First, the magnitude of the discounted benefits over a ten-year period from a 20 percent increase in the technical efficiency of cars is large--almost 50 billion dollars when discounted at 5 percent. Second, the value of benefits correctly measured is over four times the value of the gasoline that is saved, i.e., the reduction in gasoline used multiplied by its price. Thus, using just the value of gasoline saved to measure benefits understates the benefits from conservation by a significant amount. Finally, B_2, the consumer surplus from increased transportation, is a relatively small fraction of the benefits comprising about 13 percent of the total. The significance of this, as will be seen, is that the loss of benefits, or the net social cost of instituting a gasoline tax in connection with an increase in efficiency, is relatively small.

It is clear from the magnitude of the estimated benefits that major investments in technologies and devices can be justified even if they will produce a rather modest increase in technical efficiency. However, before deciding in favor of any particular technology two further steps should be taken, namely, the costs of each alternative must be estimated and compared with the benefits and these data should then be arrayed for all options to determine which maxmizes net benefits.

It should be noted that while many technological options will produce increases in technical efficiency so that the benefits can be measured in the same way using the methodology that has been developed in this report, estimating the costs of various options must be done on a case-to-case basis and, therefore, will constitute a major effort. The next step in the use of this methodology is to program the benefit estimating procedure so that benefits can be computed quickly and easily given any set of assumptions about an increase or decrease in technical efficiency and then to estimate the costs of the major technological options. It is important to note that for the case of the automobile, research and development costs and increased maufacturing cost of a new automobile are accounted for on the cost side of the benefit-cost equation whereas the savings in operating costs are reflected on the benefit side. It should also be pointed out that, given cost estimates for each technical option, numbers used by the Office of Conservation and Environment, such as a cost per barrel saved, can be computed.

This raises a further point with regard to the difference between gasoline saved, and benefits, and also points out the need for using the concept of cost per barrel saved with some care. If one increases the technical efficiency of cars and allows consumers to respond, the result will not be a 20 percent savings in gasoline, but more like a 3 to 5 percent savings because people will drive bigger cars more miles. Therefore, the savings will be small and the cost per barrel saved might be relatively high depending on the cost. It is for this reason that some people have argued that technical efficiency alone is not the answer to our energy problems.

However, consider a 20 percent increase in the technical efficiency of cars accompanied by a 20 percent gas tax which just offsets the effect of the increase in technical efficiency leaving the cost per mile of automobile transportation to the consumer the same. In this case he will drive the same size car and the same number of miles as he would have with the old less efficient car in the absence of the tax. As a result there will be a 20 percent saving in gasoline and the value of gasoline saved will equal the benefits. Both are equal to B_1. By putting on the tax you have increased the gasoline savings, but lowered total benefits by the amount B_2, i.e., the consumer's surplus that is now foregone. Thus, in the case of a 20 percent increase in efficiency we lower the present value of net benefits (discounted at 5 percent) by $6.16 billion if we impose a 20 percent tax in conjunction with the increase in efficiency; but we increase the present value of gasoline savings from $11.97 billion to $41.66 billion, an increase of about $30 billion dollars. Note also that while the investment cost has not changed, the dollar per barrel saved figure will increase by about a factor of four in this case, whatever the costs are. This justifies some caution in the use of this concept despite its appealing and useful simplicity.

The previous discussion is a special case of a more general application. Return briefly to Figure A-1, and suppose for purposes of discussion that C_2 represents the present cost per unit of automobile transportation and that in order to meet objectives associated with vulnerability, we are considering a gasoline tax that will raise the cost to $\dot{C}$. As a result, consumers will drive smaller cars fewer miles. Automobile transportation services will be reduced from T_2 to T_1 with the result that there will be a net social loss equal to the area AEB which represents the consumer's surplus foregone. The area $C_1\ C_2\ A\ B$ is not a net cost to society as a whole but is simply money transferred from automobile drivers to the government by the tax. The point is that there has been a net cost to consumers, a very real cost even though it does not show up on any balance sheet or in any transaction, of achieving a reduction in gasoline consumption to reduce vulnerability. The methodology that has been developed allows us to estimate this cost.

Now suppose that one alternative to demand curtailment through a tax is storage. This involves real resource costs. Using the method outlined above it is possible to estimate the net social costs of the tax and compare it with the resource costs of other options to reduce vulnerability. If the numbers associated with B_2 are relatively small then the costs associated with the imposition of a tax are relatively small.

In general, this methodology can be used to compute the net social cost or benefit of any policy or action that affects the cost per unit of transportation or artificially changes the level of transportation services consumed, e.g., limits car size. It can be used, for example, to estimate the costs of environmental control programs that, in an attempt to reduce emissions, affect these factors. It therefore provides a basis for developing estimates of the relevant tradeoffs between environmental impacts, resource costs, and other costs borne by the transportation consumer.

A.2.3 The Definition of Automobile Transportation Services and the Method of Computing Benefits

We return now to the problem of defining a unit of automobile transportation services. Our definition is motivated by our desire to be able to use the FEA Automobile Simulation Model to estimate changes in demand. Because this model was originally developed to predict savings in gasoline resulting from various policy options for reducing demand, two key parameters of the model are the total miles driven by the fleet and the average miles per gallon of the fleet. These variables in turn measure two of the most important dimensions of automobile transportation, namely, the total distance traveled and the size and performance characteristics of the cars people drive.[2] Miles traveled obviously measures distance traveled; and miles per gallon, given any state of technology, reflects both the size of the car and the performance of its engine. Therefore, we can measure automobile transportation services as a composite good consisting of distance traveled and car comfort or performance, which is inversely related to gasoline mileage.

[2]We should note that this definition of automobile transportation services differs from that used in most econometric models of transportation demand where trips of differing characteristics are the units in which demand is measured.

When the cost of automobile transportation goes down the consumer will respond both by driving more miles and by driving bigger and higher performance cars. Both of these responses have to be taken into account in measuring benefits or costs associated with energy policies that affect the cost of automobile transportation. We therefore define a unit of transportation that reflects both miles driven and the quality characteristics of the cars in which these miles are driven. We solve this problem conceptually by defining a unit of transportation service[3] as a function of miles traveled, m, and car size, s, i.e., $T = f(m,s)$. Before the more efficient engine is introduced, the consumer will drive m_1 miles and drive a car of size s_1 and consume transportation services of T_1, i.e., $T_1 = f(m_1, s_1)$. When the new engine is introduced, he will drive m_2 miles, increase the size of his car to s_2, and consume $T_2 = f(m_2, s_2)$ of transportation services. Therefore, in order to compute the benefits from an increase in automobile efficiency, one must know the number of miles driven, the size of the car, and driving costs with and without the increase in efficiency. Since total benefits are simply the sum of individual benefits, one need only know this information for national totals, i.e., for the entire fleet of cars.

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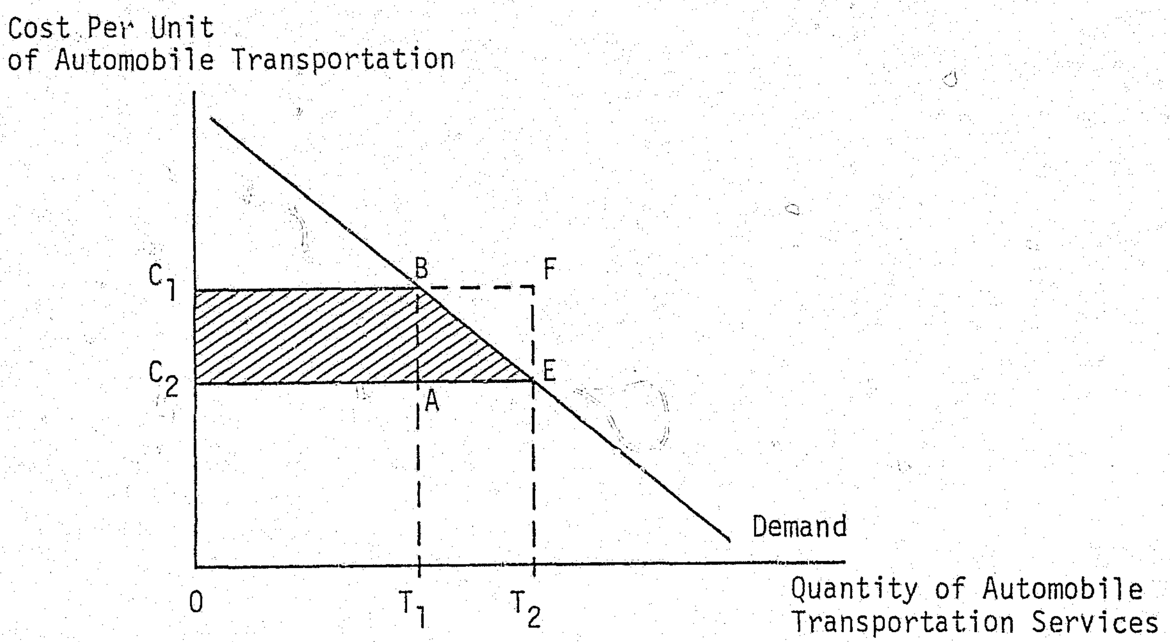
[3] In addition, we require f to satisfy the following condition. Given any two sets of values for m and s, say (m,s) and (m',s'), then if the combination (m,s) is preferred by the consumer to (m',s'), $f(m,s) > f(m',s')$, and if he is indifferent between (m,s) and (m',s'), $f(m,s) = f(m',s')$. In other words f has the properties of an ordinal utility function defined on pairs of transportation attributes, miles traveled, and size of car. Further, for every combination of m and s there will be some cost given by $C^*(m,s)$ and for any fixed value, $\bar{T}$, of T, the consumer will always choose that combination of (m,s) which minimizes $C^*(m,s)$ subject to $\bar{T} = f(m,s)$. Assuming that this minimum is unique, there is for each value of T one pair (m,s), with $\bar{T} = f(m,s)$ that the consumer will choose.

This can be clarified by reference to Figure A-1, which is reproduced below.



The cost curves C_1 and C_2 represent the sum of gasoline costs, maintenance costs, and depreciation. Maintenance and depreciation will depend both on car size and on miles traveled. If, (1) we assume that the new engine does not affect maintenance costs so that a car of the same size driven the same number of miles will require the same maintenance with the old or the new engine, and (2) we agree to account for any increase in the initial cost of a car that results from the introduction of the new engine by treating it as a capital cost and including it on the cost side of the benefit-cost equation, then the difference in the cost of driving a car of a given size a certain number of miles with the new engine is equal to the savings in gasoline costs alone. More specifically, the savings in the cost of driving m_1 miles in a car of size s_1, with and without the new engine, is the savings in gasoline costs and equals the area C_1C_2 AB. The reason for this is that when car size and mileage are held constant, maintenance and depreciation are the same in both cases.

Similarly, the difference in the cost of driving m_2 miles in a car of size s_2, with and without the new engine, is the difference in gasoline costs and is represented by the area C_1C_2 EF. Since the consumer's surplus AEB is one-half of the difference in the areas C_1C_2 EF and C_1C_2 AB, it too can be measured in terms of differences in gasoline costs.

We can now demonstrate the computation procedure for measuring both B_1, represented by the area C_1C_2 AB, and B_2, represented by the area AEB. We use the FEA Automobile Simulation Model to estimate the number of miles driven and the average miles per gallon of the fleet which, given engine efficiency, is a function of car size. Further, if we assume a price for gasoline then we can compute:

(1) The savings in gasoline costs as a result of a technically more efficient automobile if the numbers of miles driven and the size of cars remained constant at their initial level; i.e., the benefits represented by the area of C_1C_2 BA in Figure A-2.

(2) One-half the savings in the gasoline costs of driving more miles and driving bigger cars that results from an increase in technical efficiency; i.e., the benefits represented by the area of the triangle AEB in Figure A-2.

First, consider part (1) of the benefits. If car size and miles driven were held constant, then the effect of an increase of 20 percent in the technical efficiency of automobiles would be an increase of 20 percent in the average miles per gallon obtained by the fleet, and, therefore, a reduction of 20 percent in the amount of gasoline used. To compute this saving simply take 20 percent of the value of the gasoline previously consumed. Given the initial values for miles traveled, average miles per gallon of the fleet, and the price per gallon of gasoline, this computation is straightforward.

The second step is just slightly less straightforward. When automobile efficiency increases, people drive more miles and switch to bigger cars. The FEA Automobile Simulation Model estimates the increase in miles driven directly, but the increase in the size of automobiles is reflected through a change in the sales weighted average miles per gallon of the fleet. For example, if a 20 percent increase in the technical efficiency of automobiles is accompanied by only an actual 10 percent increase in the miles per gallon of new cars, then it can be inferred that there has been an increase in the size of new cars and that in the absence of the 20 percent more efficient engine these larger cars would have used 10 percent more gasoline than the average car in the initial fleet.

Because the procedure for computing the part of the benefits representing the consumer's surplus is somewhat complicated, it is useful to introduce some further notation. First, let m_1 be miles traveled before the introduction of a more efficient car and m_2 be miles traveled after its introduction. Let A be average miles per gallon of the fleet and further, let A be indexed by s_1 and s_2 denoting the size of cars before and after an increase in technical efficiency and by o and n denoting, respectively, the old and new technical efficiencies. For example, A_{s_2o} denotes the average miles per gallon of a fleet of larger cars that would have been adopted as a result of an increase in technical efficiency but on the assumption that these larger cars still have the old engines.[4]

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[4]It is important to note that A is the average miles per gallon of the fleet and not for new cars. Since new cars are introduced over time the two will not be equal until all cars in the fleet have the new engine. Thus, if a 20 percent more efficient car were put on the market in 1980, the value A_{s_2n} for 1982 would be the average miles per gallon of the fleet in 1982 given that the new engine had been introduced and larger but more efficient cars had been added to the fleet; the value A_{s_1n} would be the average miles per gallon of the fleet if the new cars introduced since 1980 had the new engine, but had not increased in size.

The expression for Part (1) of the benefits, or B_1 in Table A-1, is the area C_1C_2 AB in Figure A-2 and is given by

$$\left(\frac{m_1}{A_{s_1o}} P\right) - \left(\frac{m_1}{A_{s_1n}} P\right) \quad . \qquad \text{(A1)}$$

The expressions on the left and right of (A1) are respectively the gasoline costs without and with the new engine given car size and mileage of s_1 and m_1. Their difference is simply the difference in these gasoline costs and represents the area C_1C_2 AB.

The expression for Part (2) of the benefits, or B_2 in Table A-1, is

$$1/2 \left[\left(\frac{m_2}{A_{s_2o}} P - \frac{m_2}{A_{s_2o}} P\right) - \left(\frac{m_1}{A_{s_1o}} P - \frac{m_1}{A_{s_1n}} P\right)\right] \qquad \text{(A2)}$$

The term on the right inside the brackets is the expression for B_1 and represents the area C_1C_2 AB. The term on the left is the difference in gasoline costs of driving m_2 miles in a car of size s_2 and represents the area C_1C_2 EF. Therefore, the difference of the two terms within the brackets represents the area of the rectangle AEFB. Multiplying by 1/2 gives the area of the triangle AEB, which is the amount of the consumer's surplus.

Using (A1), (A2) can be rewritten as

$$B_2 = 1/2 \left[\left(\frac{m_2}{A_{s_2o}} - \frac{m_2}{A_{s_2n}}\right)\right] P - B_1 \quad . \qquad \text{(A3)}$$

Therefore, once B_1 has been computed, it can be used in computing B_2.

To summarize, one uses the FEA Automobile Simulation Model to get the vehicle miles and average miles per gallon of the fleet with and without an increase in technical efficiency. More specifically, one needs the parameters m_1, m_2, A_{s10}, A_{s20}, A_{s1n}, A_{s2n}. Given these parameters, the benefit calculations are straightforward. The numbers presented in Table A-1 were computed using this procedure. The basic computer run using the FEA Automobile Simulation Model was performed by Dr. Mark Rodekohr and his computations and the supporting computer printout are contained in a Memorandum for the Record, dated June 10, 1975, entitled, "Analysis of Consumer Surplus Associated With Energy Conservation Policies Utilizing the FEA Automobile Simulation Model."[5]

If we were performing a full blown benefit-cost analysis of a new technology that would produce a 20 percent increase in the technical efficiency of cars, then on the cost side we would include the research and development costs of the new technology plus any increase in the resource or manufacturing cost of producing cars incorporating this new technology. If, upon analysis, we found that the new technology had a significant impact on maintenance costs, then one would have to modify the benefit calculation to take these changes into account; i.e., benefits could no longer be measured in terms of potential gasoline savings alone. However, accounting for changes of maintenance costs could be handled within the general framework that has been developed for benefit measurement.

[5]We are indebted to the Office of Energy Systems, and its director, Dr. James L. Sweeney, for able assistance and critical review, and, in particular, to Mark Rodekohr who executed the computer work at a time when he had no time.

A.3 MEASUREMENTS OF THE BENEFITS AND COSTS OF A SET OF INSULATION RETROFIT MEASURES TO REDUCE ANNUAL HOME HEATING AND AIR CONDITIONING COSTS

A.3.1 Review and Adoption of the Methodology

For the case of insulation retrofiting, we use a simple version of the methodology. In the absence of reliable demand models showing the response of consumer demand for heating and cooling as a function of cost, we have made the simplifying assumption that the demand is totally inelastic. In this special case, the benefits to the homeowner from reduced heating costs are just equal to his savings in fuel cost. This simplifying assumption will bias the estimates of benefits and fuel savings. Benefits will be understated because the consumer's surplus that is generated when lower heating and cooling costs result in an increase in the level of heating is not included. In terms of Figure 7 of the report, we are measuring only the part of the benefits represented by the area C_1C_2 BA and omitting those represented by the area ABE. Our estimate of fuel savings will be high because we have ignored the consumer's increased demand for heating and cooling that results from a decrease in its cost as a result of insulation. As first order approximations, the benefit estimates are likely to be reasonably good. As we saw in the case of automobile transporation, only about thirteen percent of the benefits were accounted for by the consumer's surplus. However, the estimates of the fuel savings may significantly overstate these savings.

Because we are considering specific technologies to achieve these benefits, unlike the previous case of a general increase of 20 percent in the technical efficiency of cars, we compute both the present value of costs and benefits. Further, one of the fuels conserved is natural gas, and we demonstrate, for this case, the methodology developed in Section 4 of the report to be used where an energy source is underpriced. In this case, however, the probable overestimation of fuel savings is a problem as one component of benefits is the value of fuel saved in an alternative use. If fuel savings are overestimated, this component of benefits will also be overstated.

The costs and benefits have been estimated on a regional basis taking into account regional differences in climate, mix of fuels, and fuel prices. The calculations are based on information and data on materials and insulation cost, heat loss equations, and targeted insulation standards that were found in previous reports and documents that were furnished to us by the Office of Energy Conservation and Environment of FEA. Because our task was to make a first cut at estimating benefits and costs using existing data no attempt was made to verify the accuracy of these data inputs.

There are, however, so many simplifying assumptions necessary to estimate benefits and costs, these tend to overshadow the possible errors in the basic engineering calculations. As a note on computing the potential benefits, costs, and fuel savings from retrofit measures, three developments are badly needed. The first is to program the entire computation process so as to be able to test the sensitivity of the results to various parameter changes. The second is to develop a better data base, and to include, in particular, more data on the housing types and size by region, the age distribution and current state of insulation, and the efficiencies of the heating and cooling systems employed. The third is to develop household demand models for heating and cooling.

The basic results of the benefit-cost calculation are presented and discussed next in Section A.3.2. A more detailed description of the assumptions and computation procedure is contained in Section A.3.3.

A.3.2 Benefit-Cost Estimates and Policy Interpretations

The basic benefit-cost estimates per household are presented on a regional basis by fuel type in Tables A-2a through A-2d. These benefit-cost estimates are given for four to six separate insulation measures depending on the region. The first column specifies the retrofit measure and its estimated cost. The second column specifies the combination of fuel types used for heating and cooling; o-e, g-e, e-e represent, respectively, the combinations oil for heating and electricity for cooling, gas for heating and electricity for cooling, and electricity for both heating and cooling. The third and fourth columns show the fuel savings and dollar savings for each retrofit measure and fuel type combination. The first of the two numbers displayed for each fuel type combination represents the savings associated with heating; the second represents the savings associated with cooling.

The fifth column shows the breakeven period given on interest rates of 10 percent. In other words, it is the length of time that it will take the investor to recapture his initial investment plus his interest at 10 percent. At the end of the breakeven period the investment in insulation has just paid for inself.

The sixth, seventh, and eighth columns show the basic data in benefit-cost terms. Column six displays the present value of yearly benefits over a 20 year period discounted at 10 percent. Column seven displays the present value of net benefits, i.e., discounted benefits minus costs, and column eight displays the benefit-cost ratio.

The benefits and costs displayed in these tables are the benefits and costs to the individual homeowner. They will equal the net social benefits of insulating a home provided that the price of fuel accurately reflects the opportunity cost of the fuel. If fuel is underpriced, as is clearly the case with natural gas, the benefits to the homeowner will be less than the total social benefit. This case will be discussed, subsequently, in terms of an example.

Table A-2a. Benefits and Fuel Saving Per Household in Each Region of the Country for Each Retrofit Measure and Heating Fuel Type - SOUTH

Measure	Fuel Types	Fuel Savings/Yr	Dollar Savings/Yr	Breakeven Period	Discounted Benefits (10%)	B-C	B/C
R-11 Walls (Cost $490)	o-e	121 gal. 1080 KWH	$45.10 33.50	11	669	179	1.37
	q-e	171 therms 1080 KWH	$21.00 $33.50	Never	468	-22	.96
	e-e	2500 KWH 1080 KWH	$78.00 33.50	6	924	434	1.89
R-20 Ceilings (Cost $250)	o-e	87.5 gal. 800 KWH	$32.40 24.80	6	486	236	1.94
	q-e	123 therms 800 KWH	$15.00 24.80	11	339	89	1.36
	e-e	1800 KWH 800 KWH	$55.70 24.80	4	685	435	2.74
Storm Windows (Cost $105)	o-e	30.5 gal. 304 KWH	$11.20 9.40	8	175	70	1.67
	q-e	62.8 therms 304 KWH	$ 7.70 9.40	10	146	41	1.39
	e-e	920 KWH 304 KWH	$28.50 9.40	3	323	218	3.08
Weather Stripping (Cost $10)	o-e	10 gal. 66 KWH	$ 3.70 2.04	2	49	39	4.9
	q-e	13.8 therms 66 KWH	$ 1.68 2.04	3	32	22	3.2
	e-e	202 KWH 66 KWH	$ 6.26 2.04	1	71	61	7.1

Table A-2b. Benefits and Fuel Savings Per Household in Each Region of the Country for Each Retrofit Measure and Heating Fuel Type - WEST

Measure	Fuel Types	Fuel Savings/Yr	Dollar Savings/Yr	Breakeven Period	Discounted Benefits (10%)	B-C	B/C
R-11 Wall (Cost $490)	o-e	153 gal. 620 KWH	$61.30 18.05	10	676	186	1.38
	q-e	215 therms 620 KWH	$29.20 18.05	Never	402	-88	.82
	e-e	3140 KWH 620 KWH	$91.20 18.05	6	930	440	1.90
R-20 Ceiling (Cost $250)	o-e	108 gal. 460 KWH	$43.40 13.30	6	483	233	1.93
	q-e	152 therms 460 KWH	$20.60 13.30	14	289	39	1.16
	e-e	2220 KWH 460 KWH	$64.50 13.30	4	662	412	2.65
Storm Doors (Cost $75)	o-e	14.7 gal. ---	$ 5.88 ---	Never	50	-25	.67
	q-e	20.6 therms ---	$ 2.92 ---	Never	25	-50	.33
	e-e	301 KWH ---	$ 8.75 ---	18	74	- 1	.99
Storm Windows (Cost $210)	o-e	109 gal. 350 KWH	$43.40 10.10	5	455	245	2.17
	q-e	152 therms 350 KWH	$20.70 10.10	12	262	52	1.25
	e-e	2230 KWH 350 KWH	$64.70 10.10	3	631	427	3.03
Weather Stripping (Cost $25)	o-e	25 gal. 75 KWH	$10.00 2.20	3	104	79	3.16
	q-e	35 therms 75 KWH	$ 4.70 2.20	5	59	34	2.36
	e-e	510 KWH 75 KWH	$14.80 2.20	2	145	120	5.80

Table A-2c. Benefits and Fuel Savings Per Household in Each Region of the Country for Each Retrofit Measure and Heating Fuel Type - NORTHEAST

Measure	Fuel Types	Fuel Savings/Yr	Dollar Savings/Yr	Breakeven Period	Discounted Benefits (10%)	B-C	B/C
R-11 Wall (Cost $490)	o-e	237 gal. 210 KWH	$92.60 12.00	7	891	401	1.82
	q-e	392 therms 210 KWH	$71.50 12.00	9	711	221	1.45
	e-e	4870 KWH 210 KWH	$277.60 12.00	2	2,460	1,970	5.02
R-20 Ceiling (Cost $250)	o-e	170 gal. 240 KWH	$66.40 13.70	4	682	432	2.73
	q-e	238 therms 240 KWH	$51.30 13.70	5	553	303	2.21
	e-e	3495 KWH 240 KWH	$199.00 13.70	1	1,810	1,560	7.24
Storm Doors (Cost $150)	o-e	34.20 gal. ---	$13.30 ---	Never	113	-37	.75
	q-e	48.8 therms ---	$10.30 ---	Never	88	-62	.59
	e-e	700 KWH ---	$39.90 ---	5	340	190	2.27
Storm Windows (Cost $320)	o-e	252 gal. 164 KWH	$98.30 9.40	4	917	597	2.87
	q-e	354 therms 164 KWH	$76.20 9.40	5	729	409	2.28
	e-e	5190 KWH 164 KWH	$295.80 9.40	1	2,598	2.278	7.12
Weather Stripping (Cost $35)	o-e	63 gal. 12 KWH	$24.60 0.70	1	215	180	6.14
	q-e	88.4 therms 12.0 KWH	$15.00 0.70	2	134	99	3.83
	e-e	1300 KWH 12 KWH	$73.80 0.70	<1	634	599	18.11

Table A-2d. Benefits and Fuel Savings per Household in Each Region of the Country for Each Retrofit Measure and Heating Fuel Type - NORTHCENTRAL

Measure	Fuel Types	Fuel Savings/Yr	Dollar Savings/Yr	Breakeven Period	Discounted Benefits (10%)	B-C	B/C
R-11 Wall (Cost $490)	o-e	274 gal.	$96.00				
		173 KWH	6.80	7	875	385	1.79
	q-e	384 therms	$54.50				
		173 KWH	6.80	16	522	32	1.07
	e-e	5620 KWH	$219.00				
		364	6.80	3	1,922	1,432	3.92
R-20 Ceiling (Cost $250)	o-e	203 gal.	$71.10				
		200 KWH	7.80	4	672	422	2.69
	q-e	285 therms	$40.50				
		200 KWH	7.80	8	411	161	1.64
	e-e	4175 KWH	$162.80				
		200 KWH	7.80	2	1,452	1,202	5.81
R-11 Floors (Cost $180)	o-e	140 gal.	$49.00				
		---	---	5	417	237	2.32
	q-e	196 therms	$27.90				
		---	---	11	238	58	1.32
	e-e	2880 KWH	$112.30				
		---	---	2	956	776	5.31
Storm Doors (Cost $225)	o-e	53 gal.	$18.50				
		---	---	Never	158	-67	.70
	q-e	74.2 therms	$10.50				
		---	---	Never	89	-136	.40
	e-e	1087 KWH	$42.40				
		---	---	8	361	136	1.60
Storm Windows (Cost $425)	o-e	380 gal.	$132.00				
		181 KWH	7.10	4	1,184	759	2.79
	q-e	530 therms	$72.30				
		181 KWH	7.10	8	676	251	1.59
	e-e	7764 KWH	$302.80				
		181 KWH	7.10	2	2,638	2,213	6.21

Table A-2d. Continued

Measure	Fuel Types	Fuel Savings/Yr	Dollar Savings/Yr	Breakeven Period	Discounted Benefits (10%)	B-C	B/C
Weather Stripping	o-e	90 gal	$31.40				
(Cost $50)		13 KWH	0.50	2	272	222	5.44
	q-e	126 therms	$17.90				
		13 KWH	0.50	3	157	107	3.14
	e-e	1840 KWH	$62.40				
		13 KWH	0.50	<1	595	545	11.90

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1 OF 2

There are a number of obvious but important conclusions that can be drawn from these data. First, insulation is a good investment in almost all cases. Second, if one looks at the data by fuel type the highest net benefits by far from insulation accrue to homes which heat with electricity, the next highest to homes that heat with oil, and the lowest to homes using natural gas. This reflects two things, the exceptionally high cost of electric heating and regulation of natural gas prices at levels far below the market clearing price.

The third observation is that the net benefits from retrofitting are significantly higher in the Northeast and Northcentral regions. This is mostly a function of climate, but in part a function of higher energy costs in these regions. In particular, energy prices are significantly higher in the Northeast.

This, at first blush, might lead one to conclude that one should concentrate on retrofitting homes in cold climates that heat with electricity or oil. However, there are several reasons why this is not necessarily the best strategy. First, the success of a government program to promote energy conservation through retrofitting must be measured in terms of the amount of conservation that occurs over and above what would have occurred given private economic incentives. Where there are large financial gains from insulating, one would expect a higher percentage of homes to be insulated. We know, for example, that almost all electrically heated homes are insulated. Therefore, we would expect the percentage of uninsulated homes to be smaller where, as a result of climatic conditions and fuel costs, the net benefits from insulation are higher.

In calculating the net benefits from insulation to the nation as a whole one has to consider how many houses are uninsulated and how many might be induced to insulate that would not do so otherwise. This is a difficult task because our data on the number of homes that are insulated is not good. Further, we have very little information about the effect of various incentive programs on the adoption of insulation. Tables A-3 and A-4 give the total energy savings and dollar savings per year that would result from insulating all homes assuming that no homes were insulated initially. This gives a very high upper bound on the potential fuel saving and benefits to homeowners from installing insulation.

We have not tried to estimate the penetration rate for various measures to stimulate retrofitting simply because the data are inadequate. However, we have developed a strategy for estimating changes in penetration as a result of financial incentives. It would involve collecting data on the precentage of insulated homes using various fuel mixes in different parts of the country. For each subgroup we would compute the payback period, the value of net benefits, and the benefit-cost ratio. We would then regress percentage of homes insulated against these variables one at a time to see if one could establish a consistent relationship between the percentage of homes that are insulated and the economics of an investment in insulation. If this could be done then we could analyze the impact of various tax credits, etc., on these economic parameters and then relate them to the percentage of homes that have insulation. It should be noted that if we could predict the number of homes that will be insulated by region and fuel types over time (or if we are willing to make assumptions about this) then the data in Tables A-2a through A-2d provide the basic information for computing the net benefits by region and for the nation.

The second problem with concluding one should focus on homes heated with electricity and oil as opposed to natural gas is that natural gas is underpriced and, therefore, the fuel savings to the homeowner do not reflect the potential value of that gas in some alternative use. From information about prices at the well head in intrastate markets and from econometric studies such as that by MacAvoy and Pindyke, it appears that the value of natural gas in alternative

Table A-3. Total Annual Dollar Savings for Retrofit Measures in Different Regions of the Country at Saturation

Heating x $\$10^9$					
	S	W	NE	NC	Nation
R-11 Wall	0.780	1.450	1.040	1.350	3.600
R-20 Ceiling	0.560	0.315	0.745	0.990	2.600
R-11 Floors	---	---	---	0.580	0.580
Storm Door	---	0.043	0.149	0.260	0.450
Storm Windows	0.290	0.315	1.110	1.850	3.600
Weather Stripping	0.063	0.073	0.275	0.440	0.850
Cooling x $\$10^9$					
R-11 Wall	0.480	0.130	0.090	0.080	0.800
R-20 Ceiling	0.350	0.100	0.100	0.100	0.650
R-11 Floors	---	---	---	---	---
Storm Doors	---	---	---	---	---
Storm Windows	0.130	0.080	0.060	0.080	0.380
Weather Stripping	0.030	0.020	---	---	0.050

Table A-4. Total Fuel Saved in Different Regions of the Country at Saturation for Retrofit Measures

Measure	Fuel*	S	W	NE	NC	Nation
R-11 Wall	oil	0.283	0.092	0.818	0.548	1.741
	gas	0.643	0.789	0.573	2.304	4.309
	elec.	32.220	15.740	11.790	23.260	83.010
R-20 Ceiling	oil	0.203	0.065	0.588	0.407	1.263
	gas	0.462	0.557	0.411	0.710	3.140
	elec.	22.670	11.290	9.140	18.170	61.270
R-11 Floor	oil	----	----	----	0.280	0.280
	gas	----	----	----	1.178	1.178
	elec.	----	----	----	10.790	10.790
Storm Doors	oil	----	0.010	0.117	0.105	0.231
	gas	----	0.080	0.080	0.450	0.600
	elec.	----	1.060	1.470	4.080	6.610
Storm Windows	oil	0.104	0.070	0.870	0.760	1.800
	gas	0.240	0.560	0.610	3.180	4.590
	elec.	11.600	10.500	12.100	31.400	65.600
Weather Stripping	oil	0.020	0.020	0.220	0.180	0.430
	gas	0.050	0.130	0.150	0.750	1.090
	elec.	2.500	2.300	2.800	8.550	16.150

*Oil in gallons x 10^9
Gas in therms x 10^9
Elec. in KWH x 10^9

uses is between $.50 and $1.50 per thousand cubic feet greater than the regulated price. Translated into price per hundred therms, which is the unit of measure in this report, it comes to an increase of from $4.85 to $14.55 per hundred therms.

For purposes of illustration let us assume that the average value of gas in an alternative use is $9.30 per hundred therms above the market price. Then consider the case of the benefits from saving natural gas in a household in the Northcentral region as shown in Table A-2d. Take for example the first retrofit measure, R-11 wall insulation. The gross social benefits are now increased from $522 to $864, or by 65 percent. The net benefits are increased from $32 to $374, or by a factor of almost 12, and the benefit-cost ratio has increased from 1.07 to 1.76. Note that the benefits now become almost identical to those from conservation in homes which heat with oil. However, because natural gas is underpriced there is much less incentive for the individual home owner to conserve by investing in insulation. Therefore, you would expect to find many more homes that heat with natural gas that are candidates for retrofitting than you would among homes that heat with oil. Further, financial incentives either in the form of a subsidy for insulation or a tax on gas are more likely to have a significant effect. As we have suggested, one way to analyze this impact is to analyze the difference between the fraction of insulated homes that use natural gas and those that use oil in the same region. If we found there were no difference, this would cast doubt on the efficacy of financial incentives, alone, for retrofitting. We would, however, expect to find a significant difference and this could be used to evaluate the amount of the impact of different financial incentive plans.

One final point of caution. The benefits associated with the value of natural gas in an alternative use are only realized on gas that is saved. To the extent that the elasticity of demand for heating as a function of price is not zero, the potential fuel savings estimates will be high and, therefore, these benefits will be overstated.

In summary the net benefits from insulation appear to be large, homes using natural gas are a prime target for retrofitting, and better benefit estimates require better demand models for home heating and cooling and better data on the number of types of homes by region and the degree to which they are insulated.

A.3.3 Basic Assumptions, Equations, and Computations

The retrofit measures considered are the installation of:

Wall insulation
Ceiling insulation
Floor insulation
Storm windows and doors
Weather stripping and/or caulking.

While the recommended degree of the particular measure to be installed varies according to housing construction type, size of house and style, and climatic conditions present, in order to make the maximum use of the available data and to limit the complexity of the calculations, we have utilized the notion of a "typical" dwelling with the following characteristics:

Frame dwelling	
One story	
Ceiling (floor) area	1400 sq ft
Wall area (exclusive of windows and doors)	900 sq ft
Numbers of windows, size 3' x 5'	17
Numbers of doors, size 3' x 7'	3
Linear feet requiring caulking and/or weather stripping.	270'

This typical dwelling corresponds approximately in size and characteristics to that employed in previous calculations.

In order to take into consideration the variations in weather conditions in different parts of the U.S., we have assumed the typical house above to be located in four separate regions of the country--South, West, Northeast, and Northcentral (these correspond to the regional breakdown used in the Project Independence reports). Within each of these regions the figures for weighted average degree days, outside average temperatures, etc., are shown in Table A-5.

Table A-5. Data Used in Heat Loss Calculation for Different Regions of the Country*

Region	Weighted Average D.D.	Heating Design Δt	Cooling Hours	Cooling Design Δt
South	2795	50^0	2000	15^0
West	3515	55^0	1150	25^0
Northeast	5470	70^0	600	15^0
Northcentral	6345	75^0	500	15^0

*Source: Project Independence Report: Conservation Residential and Commercial Buildings

The National Bureau of Standards report on "Retrofitting Existing Housing for Energy Conservation, In Economic Analysis," by Stephen R. Petersen, includes an analysis of "optimum" insulation for different areas of the country. These results confirm that there is a wide variation in what is "optimal" from one area to another. On the other hand, labor is a major cost in retrofitting in ceilings, walls, and floors; therefore, one can reasonably assume standard thickness insulation will be employed. The targeted insulation standards in the typical dwelling in the various regions of the country shown in Table A-6 take both of these factors into consideration. The particular R values assumed for the targeted ceiling, wall, and floor insulations are based on reports of Hittman Associates, A.D. Little, and NBS, and on other information dealing with customary usage, availability of standard size insulation materials, and compatibility with existing structures.

Table A-6. Targeted Insulation and Percentage of Total Windows, Doors, and Weather Stripping Area Covered

Region	Ceiling	Walls	Floors	Storm Windows	Storm Doors	Weather Stripping
South	R-20*	R-11	----	25%	----	25%
Western	R-20	R-11	----	50%	50%	50%
Northeast	R-20	R-11		75%	75%	75%
Northcentral	R-20	R-11	R-11	100%	100%	100%

*The R value is a measure of the thermal resistance to heat flow through the boundary between inside ⊖ outside of the surface.

There are a variety of materials to choose from in installing insulation in existing structures. These vary in cost and in insulating characteristics. The costs of storm windows and doors, and weather stripping and caulking vary even more widely depending on materials, quality of construction, and ease of installation. Again, in order to restrict the complexity of our calculations, we have assumed the use of the materials and installation costs listed below.

Ceilings	6" fibre glass batts	$.18/sq ft*
Walls	3-1/2" blown in cellulose	$.50/sq ft
Floors	2" fibre glass batts	$.13/sq ft
Storm Windows		@ $25 ea.
Storm Doors		@ $75 ea.
Weather Stripping and/or Caulking		$.15/ft

Table A-7 gives the total capital costs associated with materials and installation for the targeted retrofit measures defined in Table A-6.

Table A-7. Total Capital Costs of Materials and Installation of Targeted Retrofit Measures

	S	W	NE	NC
Ceiling	$250	$250	$250	$250
Wall	$490	$490	$490	$490
Floors	----	----	----	$180
Storm Windows	$105	$210	$320	$425
Storm Doors	----	$ 75	$150	$225
Weather Stripping	$ 10	$ 25	$ 35	$ 50

The assumed lifetime for all of these retrofit measures is taken to be 20 years. The calculations of national energy savings make use of several other pieces of information data. These are given in Tables A-8 and A-9. They also assume the following space heat efficiencies: Gas=50%; Oil≥50%; Electricity=100%. The coefficient of performance for air conditioners is assumed to be 2. In calculating the total

*Source: NBS Report Building Science Series 64.

monetary savings stream, we assume prices of fuel remained fixed in terms of 1975 dollars and a discount rate of 10 percent.

The calculations that are presented are based on the following definitions and equations:

Definitions

Index i = the specific measure

Index j = the fuel type used to provide the space heating

Index k = the region in which "typical" house is located

Index C_i = cost of materials and installation of retrofit measure i

E^h_{ik} = annual BTU heating savings produced by measure i in region k

E^c_{ik} = annual BTU cooling savings produced by measure i in region k

F^h_{ijk} & F^c_{ijk} = equivalent annual fuel savings

S_{ijk} = annual dollar savings from measure i using fuel type j in region k

S = total yearly dollar savings

E_j = efficiency of heating by fuel type

P_{ij} = price of fuel type j in region k

N_k = number of single detached dwellings

f_{jk} = fraction of homes in region k heated by fuel type j*

Equations

$$F^h_{ijk} = \frac{E^h_{ik}}{\frac{BTU}{unit} \times E_j} \qquad F^c_{ijk} = \frac{E^c_{ik}}{\frac{BTU}{unit} \times (cop)}$$

*We assume the fuel for all cooling is electricity.

$$S_{ijk} = N_k f_{ijk} \left[F^h_{ijk} P_{jk} + F^c_{ijk} P_{jk}\right]$$

$$S_k = \sum_{ij} S_{ijk}$$

Tables A-8, A-9, and A-10 present additional basic data used in preparing the results presented in Tables A-2 and A-3 in Section A.3.2.

Table A-8. Fraction of Single Detached Dwellings in Each Region of the Country Heated by Gas, Oil, or Electricity*

Region	Gas	Oil	Elec.	Number of Single Detached Dwellings**
South	26	16	54	14.5×10^6
West	49	8	47	7.5×10^6
Northeast	23	46	28	7.5×10^6
Northcentral	48	16	30	12.5×10^6

* Source: A.D. Little Report "Residential and Commercial Use Patterns," November, 1974.

**Source: Project Independence Report

Table A-9. Prices for Fuel Types in Each Region of the Country*

Region	Gas/100 therms	Oil/100 gal.	Elec./100 KWH**
South	$12.20	$37	$3.10
West	$13.60	$40	$2.90
Northeast	$21.50	$39	$5.70
Northcentral	$14.20	$35	$3.90

* Source: U.S. Bureau of Labor Statistics, Dec. 1974

**Calculated on basis of 500 KWH monthly usage.

Table A-10. Energy Savings from Retrofitting Target Insulation Measures

Heating: x 10^6 BTU				
Measure	S	W	NE	NC
R-11 Wall	8.53	10.73	16.62	19.20
R-20 Ceiling	6.13	7.59	11.93	14.25
R-11 Floor	---	---	---	9.82
Storm Windows	3.14 (25%)	7.61 (50%)	17.71 (75%)	26.50 (100%)
Storm Doors	---	1.03 (33%)	2.39 (66%)	3.71 (100%)
Weather Stripping	0.69 (25%)	1.75 (50%)	4.42 (75%)	6.29 (100%)

Cooling: x 10^6 BTU				
Measure	S	W	NE	NC
R-11 Wall	7.37	4.24	1.43	1.18
R-20 Ceiling	5.46	3.14	1.64	1.37
R-11 Floor	---	---	---	---
Storm Windows	2.07 (25%)	2.39 (50%)	1.12 (75%)	1.24 (100%)
Storm Doors	---	---	---	---
Weather Stripping	0.45 (25%)	0.52 (50%)	0.08 (75%)	0.09 (100%)

END