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A NATIONAL INDEX FOR ENERGY PRODUCTIVITY

A STUDY

PREPARED FOR THE USE OF THE

JOINT ECONOMIC COMMITTEE
CONGRESS OF THE UNITED STATES

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LETTERS OF TRANSMITTAL

MAY 6, 1981.

To the Members of the Joint Economic Committee:

I am pleased to transmit to the members of the Joint Economic Committee, other Members of Congress, and the general public a study by the Energy Productivity Center of the Mellon Institute entitled "A National Index for Energy Productivity."

This study has two purposes. First, to determine whether the publication by the Federal Government on a regular basis of an index measuring changes in the energy productivity of the economy would help focus national attention on this critical element of our energy programs. The second objective was to determine how a sound energy productivity index would be structured.

I commend this study to you and to my other colleagues in Congress. The conclusions of this study represent the opinions of the authors and not necessarily the opinions of the members of the Joint Economic Committee.

Sincerely,

HENRY S. REUSS,
Chairman, Joint Economic Committee.

APRIL 30, 1981.

Hon. HENRY S. REUSS,
Chairman, Joint Economic Committee,
Congress of the United States,
Washington, D.C.

DEAR MR. CHAIRMAN: Since 1975, the Energy Subcommittee of the Joint Economic Committee has focused its attention on the importance of increasing the efficiency of the American economy.

The Subcommittee's recent study, "Energy Conservation, Emerging Consensus, Diverging Commitment," concluded that energy conservation will have an enormous positive impact on America's energy situation, but is not receiving the level of Federal support that is absolutely essential. One of the reasons that energy conservation is not receiving the support that it deserves is that readily available indices of the efficiency or productivity with which we use energy are not available.

Thus, last year, as chairman of the Energy Subcommittee, I asked the Energy Productivity Center to examine carefully what indices could be used to measure energy productivity. The publication of a sound index would be a crucial indicator of the importance that our government attaches to the goal of increasing our energy efficiency. It would sustain and focus our national efforts in this critical energy area. The attached study by the Center examines several specific ways to measure energy productivity and recommends the adoption of an Energy Consumer Savings Index as the primary aggregate energy productivity index. I agree with the study's conclusion that the adoption and dissemination of an energy productivity index will significantly enhance public understanding of energy productivity and contribute to the full realization of the benefits of increased energy efficiency in the United States.

Sincerely,

EDWARD M. KENNEDY,
Member, Joint Economic Committee.

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A NATIONAL INDEX FOR ENERGY PRODUCTIVITY

By Alton Penz and Dennis Bakke*

EXECUTIVE SUMMARY

The increasing vulnerability of the United States to energy supply interruptions and rising energy prices has forced energy issues into the consciousness of the American public. For a variety of economic, political, and environmental reasons, the United States has been on an energy course that has led to wasteful use of energy supplies and energy technologies to provide the nation's energy services. As a result, U.S. consumers are paying higher prices for energy services than is necessary. Increasing energy productivity—using less energy to obtain equivalent energy services—is an essential means of ending this waste of vital energy resources. This paper explores possible indices to measure changes in energy productivity. These indices could provide the nation with better information about how it uses energy. The study recommends that certain uses of these indices be adopted and widely disseminated by government.

The widespread use of an energy productivity index by our government and in the media could provide many significant benefits. First, it would signal the importance that our government attaches to increasing our energy efficiency. Just as the Personal Consumption Expenditure deflator highlights our anti-inflation efforts and the unemployment index focuses on our efforts on job creation, a regularly published energy productivity index, would become a public symbol of the nation's commitment and progress towards wise and effective use of energy.

Second, it would focus and sustain national attention on this critical energy strategy. Periodic reporting of an energy productivity index would provide a periodic reminder to the public and to government officials of this ongoing effort.

Third, an energy productivity index would motivate and challenge the nation just as periodic exams motivate and challenge college students. Our efforts at improving energy productivity would be confirmed in a national "report card" on energy efficiency efforts. Energy productivity measures can stimulate pride in achievement and lead toward even more productive behavior.

Fourth, such an index would serve as an early warning system that current approaches are not working and new approaches are called for.

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*The authors are with the Energy Productivity Center, Mellon Institute, Arlington, Va. We wish to thank Roger Sant, Steve Carhart, Marc Ross, and Richard Shackson, Energy Productivity Center, and Robert Whorf, Robert Whorf Associates, for their generous assistance.

Fifth, it is a useful tool for public planners and policymakers for predicting future energy productivity trends. The development of a reliable index that reports energy requirements per unit of output, coupled with predictions of future output levels, allows estimation of future energy costs and resource needs. This capability is of obvious interest for anticipating conditions of energy demand and supply that will in turn affect subsequent economic productivity.

And finally, energy productivity indices increase the public's understanding of energy services, and stimulate study and the discussion on how the nation's energy productivity can be improved.

No one index is available that clearly identifies and measures energy productivity for all purposes. We first consider aggregate measures that reflect overall national energy performance. This survey includes potential measures such as Btu's per dollar of GNP. International comparisons of the GNP/BTU index have provided considerable insight. A major concern regarding a single aggregate energy index is whether total energy consumption should be measured in dollars or physical units (Btu's). This question recognizes tradeoffs in emphasis between economic and technical issues of energy productivity.

Our discussion of dollars spent on energy, and the output derived from those expenditures, leads to a discussion of the total cost of energy services. Ultimately, we are not as concerned with the cost of fuels per se that provide energy services, such as heating a home or moving an automobile; but rather, we should focus on the total cost of all resources—land, labor, capital, and energy—that are required.

One measure that we propose is an Energy Consumer Savings Index (ECSI). This involves the difference between energy/GNP ratios for alternative time periods, so that we can estimate how much we would be spending on energy at current output levels had we not achieved greater levels of energy efficiency.

The ECSI has significant advantages over alternative indices. First, it provides a measure that is easily recognized by American families: dollar savings. Second, it provides a useful yardstick by which households can seek energy savings opportunities. Third, it can educate consumers about the relative advantages of long-term investments in energy productivity versus short-term consumption spending. Finally, it permits us to relate previous accomplishments to the potential for savings from new investments.

According to this measure, energy productivity has increased 12 percent since 1973, which implies that the nation would have spent $31 billion more to achieve 1978 GNP levels had energy productivity levels not changed since 1973. Thus, national productivity gains since 1973 were worth $31 billion per year in 1978.

We recommend the adoption of the Energy Consumer Savings Index as the primary aggregate energy productivity index, and that it be prepared and publicized at least quarterly.

In addition to aggregate indices, we examine sector indices, where sectors of the economy are established on the basis of both energy allocations and types of activities. We adopted the commonly accepted demarcation of residential/commercial buildings, transportation, and industry. Such a distinction also permits us to recognize the productivity with which specific energy services are provided.

In the buildings sector, energy productivity can be measured approximately by Btu's per square foot, adjusted for degree days. This measure recognizes that space heating and cooling require most of the energy consumed in buildings, and that space heating/cooling services are heavily influenced by weather conditions. An analysis of energy consumption in the residential/commercial sector (which is mostly buildings), suggests that this sector has improved energy productivity by 14 percent between 1973 and 1978. This gain represents a drop in annual energy fuel costs of $13 billion in 1978.

In the transportation sector, we discuss why energy productivity varies substantially according to the mode of transport. We suggest, accordingly, that the energy productivity concept is acceptably measured as Btu/ton-mile for freight. For automobiles, the fleet fuel economy is recommended.

These indices communicate clearly the basic objectives of transportation activities. In contrast to buildings, transportation energy indices reflect a more rapid turnover of vehicular stock and an ability to reduce the level of transportation service provided with drops in economic growth. While energy productivity in this sector dropped in 1975–76, transportation gained energy productivity overall between 1973 and 1978, so that the annual savings in energy expenditures in 1978 (relative to 1973 technology) were $7 billion, or 8 percent of the 1978 consumption expenditures.

Finally, the adoption of energy productivity measures in the industrial sector can take two paths. We can rely on a sectorial version of Btu/GNP, since data collection on industrial contribution to GNP (value added) is highly organized and collected systematically. On the other hand, a few industries (e.g., steel, chemicals, aluminum, petroleum refining) are responsible for most of the industrial energy use. This condition suggests that measures of industrial energy productivity such as Btu's per ton of product would be useful also. In fact, the Industrial Energy Efficiency Improvement Program of DOE, which addresses energy consumed by a limited number of industries that consume large quantities of energy, uses this index to measure energy productivity. Overall, the industrial sector realized energy consumption gains of $10 billion/year in 1978 relative to 1973 technology. This reduction represented a 14 percent reduction in 1978 energy expenditures.

In conclusion, we believe the adoption and systematic dissemination of these indices will significantly enhance public understanding of energy productivity and contribute to maximizing energy efficiency in the United States.

INTRODUCTION

The rising prices of energy and the frequency of energy supply interruptions have generated much public awareness of the nation's dependency on energy services. Many households, businesses, and public institutions are seeking alternative means of obtaining the energy services needed to maintain the quality of their lives. Households are adding insulation to their homes and tuning their furnaces. Industry is exploring better ways to utilize energy resources in their operations, and governments are seeking new ways to provide public services that are less costly. All of these efforts lead us to ask whether we can identify indices that measure our national progress toward a more energy productive economy. The use of such measures by public officials and in public media can in turn both stimulate public pride from achievement of gains in energy productivity and lead the public toward more productive behavior.

In this paper we explore the usefulness and feasibility of energy productivity indices. We first identify some of the causes of energy supply/demand imbalances that have arisen in the last decade, and then we turn to the task of defining energy productivity. In particular, we distinguish between energy conservation, which emphasizes a reduction of energy consumption, and the provision of energy services at the least total cost. We identify some of the ways that measures of energy productivity could be useful in our society and describe some criteria for evaluating energy productivity measures. The paper then assesses the merits of a variety of potential indices, including national measures based on GNP and energy consumption, where energy is measured in either physical units or dollars. In addition to national measures, we also examine individual sectorial measures for the residential/commercial, transportation, and industry sectors. Finally, the paper's conclusion recommends the establishment of both a national aggregate index and a series of sectorial indices that would assist the nation in tracking its changes in energy productivity.

THE CHANGING ECONOMICS OF ENERGY

In the last decade the United States economy has encountered a fundamental shift in the supply and demand relationships for energy resources. After many years of declining real energy fuel prices as a result of readily available supplies and regulatory practices, the market has changed. Whereas fuel demand has grown in response to earlier low prices, these supplies are no longer available at the same low cost. The reasons for higher costs and lower supplies are many (Sander [16]). Increasing relative scarcity of domestic oil has dictated higher costs to assure adequate supplies. Increasing costs of construction have raised the price for nuclear power. Stringent environmental codes have raised the cost of energy procured from coal. Government regulation of utilities has discouraged efficient production and pricing. Foreign oil prices have risen, and production has not risen substantially.

The changing economics of energy has created an imbalance in the delivery of energy services (e.g., heat, light, steam, mechanical power) to the nation. Because of the rapid rise in the cost of energy fuels relative to other productive inputs such as capital and labor, the opportunity exists to provide the same quality of energy services with reduced conumption of energy fuels and at lower total cost. From an individual household perspective, this transition is already underway. Households are adopting alternative means to heat a house or commute to work that are more capital- and labor-intensive (e.g., additional home insulation, a more fuel efficient automobile). These efforts are but a few examples that illustrate how the economy is shifting toward greater energy productivity.

Many opportunities exist to alter the means of providing energy services so that they become available at the least total cost (Sant [17]. These opportunities arise from differences among the costs of capital, labor, and energy resources, and their relative contributions to such activities as the heating of homes, the propulsion of automobiles, and melting iron. Furthermore, because energy fuel costs have risen faster than initial capital acquisition costs, many opportunities for enhanced productivity have surfaced as awareness of lifecycle costs increases.

DEFINING ENERGY PRODUCTIVITY

A basic tenet of economics is that the optimal national economy maximizes the productivity of all its resources. An essentially equivalent concept is that a given productivity level should be achieved at a minimum total cost for all input resources, including labor, capital, materials, and energy. Both of these statements suggest that the mix of input resources that maximizes output is related to individual resource costs. For example, the currently rising costs of energy sources relative to capital and labor costs suggests that the economy should shift to processes that employ more labor, material, and capital relative to energy.

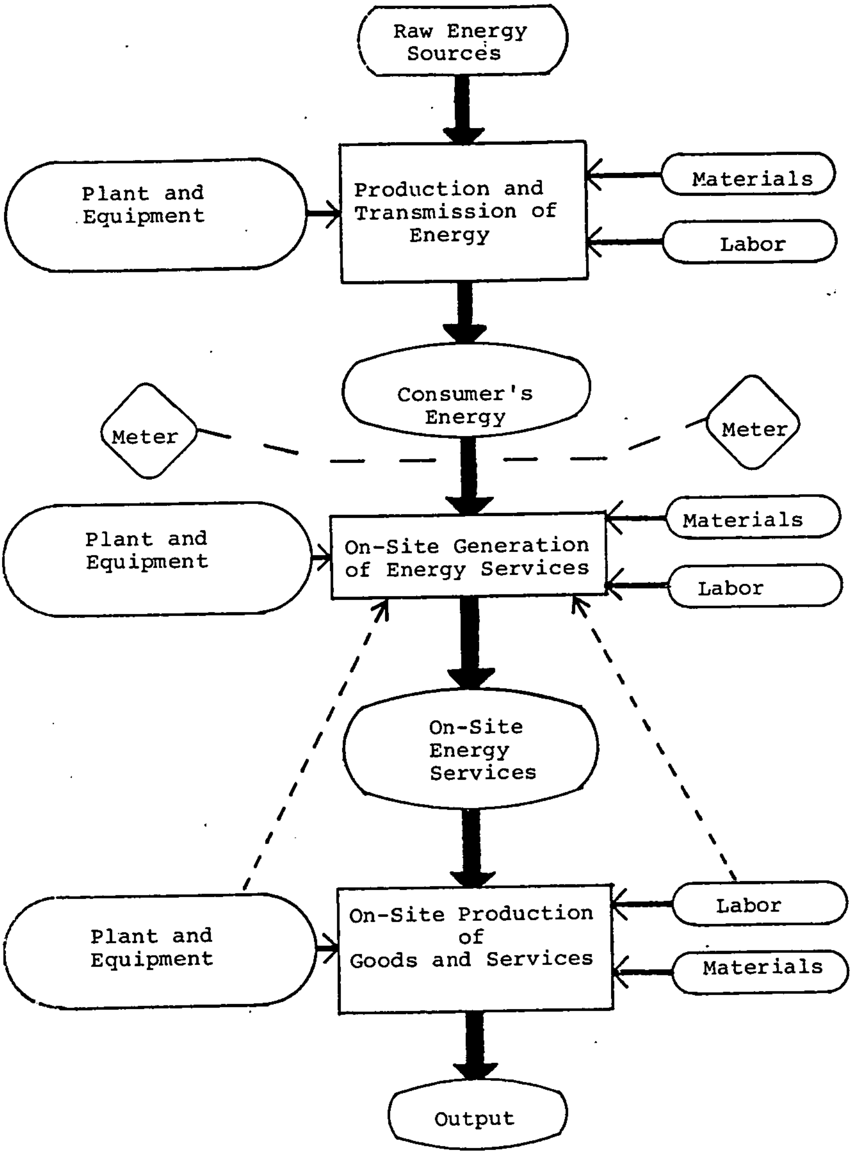
Figure 1 illustrates some of the concepts just described. The energy that is purchased from a utility company, gasoline service station, or a heating fuel oil company is the result of an often elaborate production system. Few forms of consumer's energy closely resemble the raw energy sources from which they have been derived. Rather, through mining, pumping, shipping, refining, processing and distribution, raw energy sources are transformed into the goods we know as automobile gasoline, heating fuel oil, and site delivered natural gas. The price of consumer's energy, as monitored at the gas meter or the gasoline pump, reflects all of the downstream costs of producing it (assuming, for the moment, perfect economic markets).

But the price of consumers' energy does not represent the total cost of consuming energy services. A building requires a furnace, air duct system, and thermostat control system to provide its occupants with the energy service, temperature and humidity regulated air. Lighting requires not only electricity but also light bulbs, fixtures, and wiring. Hot water service implies not only the consumption of a heating fuel, but also the use of a hot water heater, distribution pipes, faucetts and sinks. Thus the cost of energy services is greater than the cost (price) of consumers energy.

The consumption of energy services in a business or home is but one activity involved in providing the final output, of course. In 1976, on a national basis, the cost of raw energy expenditures constituted only 5 percent of GNP, the total cost of producing final goods and services (Schurr et al. [18], pp. 79–80). The cost of providing energy to consumers, i.e., the raw energy plus processing and distribution costs, was approximately 12 percent of 1976 GNP. Yet the identification of the cost of energy services is not always obvious. Are the walls and roof of a building a part of the energy system because they control the circulation of conditioned air? Are curtains in a home part of the energy system, because they slow heat losses through windows when they are closed?

We also recognize that the classification of many activities as energy services can be misleading, at least in an absolute sense. The trucking industry involves freight, which requires more labor and

FIGURE 1



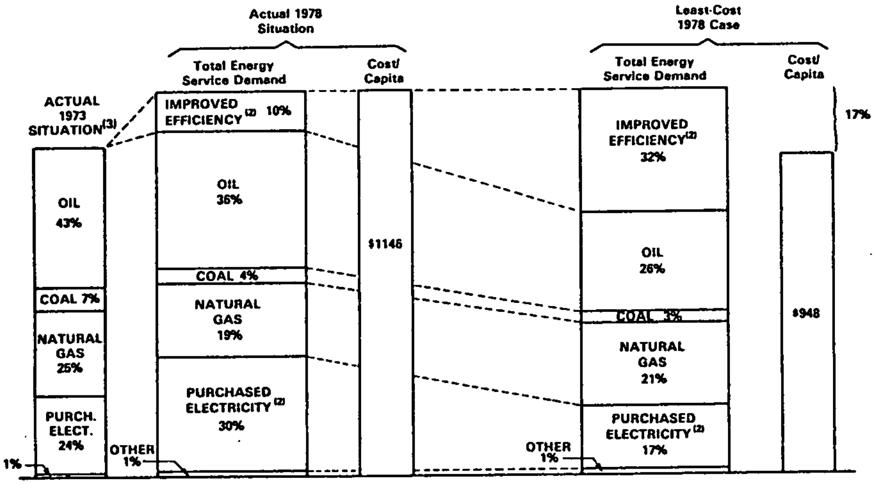
capital cost than it does energy costs. Yet our concern with energy consumption tempts us to refer to trucking as an energy service. In Figure 1, we recognize the ambiguity of the energy service definition via the strippled flows of labor, plant and equipment.

Much of the conventional thought on energy utilization focuses not on the total cost of activities but on the motivation to changing the costs. The addition of storm windows contributes to a building's energy system, as does the acquisition of additional insulation. But is a decision to paint a building with a different color paint to reflect (or absorb) sunlight an energy decision or a maintenance decision? Undoubtedly the exact demarcation of activities involved in producing energy services will always elude identification.

The concepts illustrated in Figure 1 suggest that although the nation's objective should be to minimize the total cost of all resources for a given level of output, some of the nation's attention should now focus on *energy productivity*—the efficient provision of energy services. A preliminary analysis of the potential gains to be realized from enhancing energy productivity are illustrated in Figure 2 and presented in detail in Sant [17]. The Energy Productivity Center of Mellon Institute suggests that currently provided energy services can be achieved at a lower total cost by a more efficient allocation of not only energy but also the labor, capital, and materials required to provide *energy services*.

FIGURE 2

ENERGY SERVICE MARKET SHARES(1)
OF VARIOUS TECHNOLOGIES



(1) THE PRIMARY FUEL EQUIVALENT OF SERVICE DEMAND IN 1978 WAS 79.0 QUADS, PLUS 9.2 QUADS OF IMPROVED EFFICIENCY (CALCULATED AGAINST A BASE OF STOCK AND EQUIPMENT IN PLACE IN 1973), OR A TOTAL OF 88.2 QUADS. ACTUAL SERVICE DEMAND DEPENDS ON THE CONVERSION EFFICIENCY OF THE FUELS AND EQUIPMENT UTILIZED.
(2) IN TERMS OF PRIMARY FUEL
(3) PRIMARY FUEL DEMAND IN 1973 WAS 74.6 QUADS.

We do not assert that any ideal measures of energy productivity are readily available. In fact, we can easily identify several conditions that impede the acceptance of many of the more obvious measures. Berndt [2] has provided an excellent discussion of many of these points, and we will review some of them in a later section of this paper. First, however, we should reflect on why we want energy productivity measures and how they are likely to be used.

POTENTIAL GOALS OF MEASURING ENERGY PRODUCTIVITY

The widespread use of an energy productivity index by our government and in the media could provide many significant benefits. First, it would signal the importance that our government attaches to increasing our energy efficiency. Just as the Personal Consumption Expenditure deflator highlights our anti-inflation efforts and the unemployment index focuses on our efforts on job creation, a regularly published energy productivity index would become a public symbol of the nation's commitment and progress towards wise and effective use of energy.

Second, it would focus and sustain national attention on this critical energy strategy. Periodic reporting of an energy productivity index would provide a periodic reminder to the public and to government officials of this ongoing effort.

Third, an energy productivity index would motivate and challenge the nation just as periodic exams motivate and challenge college students. Our efforts at improving energy productivity would be confirmed in a national "report card" on energy efficiency efforts. Energy productivity measures can stimulate pride in achievement and lead toward even more productive behavior.

Fourth, such an index would serve as an early warning system that current approaches are not working and new approaches are called for.

Fifth, it is a useful tool for public planners and policymakers for predicting future productivity trends. The development of a reliable index that reports energy requirements per unit of output, coupled with predictions of future output levels, allows estimation of future energy costs and resource needs. This capability is of obvious interest for anticipating conditions of energy demand and supply that will in turn affect subsequent economic productivity.

And, finally, energy productivity indices increase the public's understanding of energy services, and stimulate study and the discussion on how the nation's energy productivity can be improved.

Whether any simple set of indices could be developed that would satisfactorily meet all of the objectives discussed above is questionable. Each index considered will have flaws and will reflect only crudely the productivity issues of the economic activities it measures. Hopefully, concerned leaders as well as lay citizens will debate vigorously the implications of any measure adopted. How well does the measure truly reflect changes occurring in the economy? Do these changes relate to energy productivity? Are the changes appropriate for providing the most end use energy services at the least total cost? If an index can stimulate this kind of debate and self-examination, the resulting understanding of energy productivity may by itself justify the adoption of an index.

CRITERIA FOR SELECTING INDICES

The criteria for establishing an energy productivity index are many and conflicting. The ideal index should be easily understood by all American citizens, yet it should reflect sophisticated relationships among costs and availabilities of not only energy but also labor, material, and capital. It should provide historical perspectives on the U.S. energy consumption experience, yet it should be timely. It should reflect the intrinsic structure of the American economy, yet it should also facilitate international comparisons. It should measure national progress toward a more energy efficient economy, and yet individual and institutions should learn how the sectors in which they operate—residental, commercial, industrial, transport—are progressing on specific energy goals.

For the purposes of the paper we have selected six criteria to use in evaluating energy productivity indices. These criteria include the clarity of the index, or its ability to communicate with the American people, how it reflects the quality of energy services provided, how it distinguishes the quality differences among alternative energy sources, the timeliness and reliability of the index, its preparation cost and feasibility, and, finally, how well it relates energy productivity to national economic productivity.

(1) Clarity of the Index Message

An important criterion that any energy productivity index must satisfy is that the American people must understand it. In labor, rises in the unemployment rate are "bad," drops are "good." As a result of rising relative energy prices, however, we can expect a measure of energy productivity per se (e.g., Btu/output) to continually drop for the next decade or more. But what is a good (versus bad) drop in the index?

We are aware, of course, that an abstract index may influence public behavior in contradiction to the intended effect. An index that always (or often) suggests that we are doing well may encourage the public to relax its vigilence concerning increased energy productivity. Thus an index should be structured so that it encourages appropriate behavior by the American public.

(2) Refleting the Quality of Energy Services

One of the most difficult problems that will be encountered by alternative measure of energy productivity is the distinction between changes in the level of goods and services consumed (per capita) and the energy efficiency with which those services are provided. A frequently quoted example is home space heating: if the quantity of energy consumed for space heating drops, have households lowered their thermostats or have they insulated their homes? What we would like is an index that can differentiate between reductions in the quality of and increases in productivity.

Some changes in the consumption of energy services may be interpreted as changes in lifestyle without a significant alteration in the "quality of life," or standard of living. Schurr et al [18], who clearly distinguish end consumption of energy from energy consumed in production (although not without reservations pp. 100–101), take a liberal view that changes in end consumption of energy do not affect productivity. We suggest that a more conservative position may be appropriate. Whereas some changes in the quality of life may surface in a diminution of, e.g., labor productivity, the goal is to maintain the quality of life as it incorporates energy consuming services, yet with diminished consumption of energy fuels.

Many issues associated with the quality of energy services surface in the intensity concept. Americans drive heavier and less fuel economic automobiles than do Europeans, for example. As Americans switch to smaller and lighter cars that are more fuel economic, the question arises as to whether such gains reflect increased energy productivity or a change in services consumed. Dunkerley and others [5] suggest that as much as 40 percent of international differences in energy consumption are associated with structural characteristics of national economies. Most obviously, structural characteristics reflect fundamental differences in the use of land, labor, energy, and capital. For example, the American custom of occupying large, single family detached homes in low density suburbs dictates that Americans drive more miles than do European households. This difference will disappear if Americans adopt more dense living patterns; yet would such a change signify enhanced productivity or diminished services?

(3) The Quality of Energy

Berndt [2] has pointed out, as have others [19], [21], that energy sources differ in several characteristics other than energy content as measured in, say, Btu's. Different fuels impose varying social costs on the user or the public, such as shale oil operations. If the economy operated with a completely free and open market system, and public externalities did not exist, then price differentials among fuel sources would reflect the true cost of consuming alternative fuels. Measurement of energy consumed in monetary terms would then accurately reflect its production value. Although some public externalities, such as air pollution attributable to burning coal, have been internalized (via pollution controls) so that the price of the fuel resource has responded to the ultimate cost of consuming it, other externalities still exist. Furthermore, public regulation of energy market prices distorts their value as well (Sander [16]).

Fuels also possess characteristics that are not necessarily reflected in prices directly. The transportability of fuels, their rate of releasing energy and their storage requirements all influence which sources are used to provide various energy services. The ability of an index to reflect total energy consumption yet distinguish barriers to substitu-

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tion (of either other fuels or non-energy resources) is important (Berndt [2]).

The issues of energy resource quality and cost measures of energy consumption often raise a conceptually different but no less important point. The ideal measure of energy productivity should not only reflect how we utilize energy now but also what potential we have for utilizing it more effectively. Technologically, this issue relates to the First Law of Thermodynamics which identifies the amount of work performed per unit of energy consumed. The Second Law identifies a relationship between the minimum amount of work necessary to perform a task and the maximum amount of work achievable with the fuel consumed. Thus the Second Law focuses on the potential for accomplishing work with a fuel, or the energy services available from an energy source. Most measures of energy consumed ignore this latter perspective of energy productivity potential. Yet measurement of energy production potential as reflected in the Second Law requires a description of the processes in which energy is used. Furthermore, energy productivity issues ultimately involve the economics of labor and capital; the Second Law, a physical relationship, ignores input prices and marginal productivities, as Berndt [2] and Landsberg et al. [10] (p. 120) point out.

(4) Timeliness, Detail, and Reliability

One of the primary objectives of reporting energy productivity measures is to maintain a high level of awareness and concern among the population. This goal dictates that productivity indices be timely, and the currency of the measures is paramount. Furthermore, the productivity measures must be sensitive to productivity changes (and insensitive to inconsequential changes).

The frequency with which data is reported is further complicated because of the relationships between production capacity and levels of production. In the short term, changes in production reflect changes in the percent of capacity that is utilized. Yet energy productivity is not constant for different levels of production, so that short term changes in energy productivity are most likely the result of changing production levels rather than a fundamental change in the production process itself.

In addition, the reflection of structural changes in the economy poses serious problems for development of an energy productivity index. An index that reasonably accounts for structural changes requires information at an extraordinary level of detail. Such extensive and in depth data collection is expensive and therefore infrequently collected. As Wood [34] points out, information on interindustry goods flows is collected only every 4 or 5 years, and the resulting data becomes available after 4 or more years of processing.

The solution to these questions of timeliness and reliability lies in the adoption of indices that one based on data whose frequency of collection reflects the rate of changes in the economy. Changes in the underlying structure and capacity of the economy occur only slowly, so that in-depth studies of structure need only occur relatively infrequently. In contrast, the levels of intensity, load factors and proportions of capacity utilized must be monitored closely to capture rapid changes in their values. Fortunately, much information that is currently gathered by a variety of government agencies and trade associations reflect these conditions. Nevertheless, some serious gaps remain in some industries.

(5) Cost and Feasibility

Certainly an important criterion for determining what index to use is its cost of preparation and the feasibility of obtaining the necessary data. Much of the following discussion of alternatives focuses on the inadequacy of data according to at least one of the criteria we have identified. Correction of these deficiencies may require the commitment of substantial resources on the part of the agency assigned to prepare an index. The question naturally rises as to how much this additional effort will cost. More fundamentally, we must ask how valuable a productivity index is likely to be relative to this additional cost.

(6) Energy Productivity and National Productivity

We have identified the energy crisis as being the result of a rapid rise in the cost of energy sources or, in the case of price controls, as a rise in the occurence of shortage attributable to excess energy demands. The suggested remedy to this situation to substitute labor, material, and capital for energy in the economy. Yet several caveats must accompany this suggestion. Whereas labor and energy are substitutable in many economic activities, shifts toward labor and away from energy should not occur if the cost of labor and shortages escalate as rapidly as the cost of energy. Similarly, if the cost of capital rises, then energy will not be replaced by more extensive use of capital. Furthermore, even if the interest rate on money drops, the aggregate consumption of energy may rise: historical evidence (Berndt [27]) suggests that capital and energy have been complementary for many economic activities. How much energy-capital complementarity reflects on intrinsic relationship versus the effect of historically rising labor costs (and hence joint substitution of capital and energy for labor) remains to be seen.

This awareness of marginal productivity and factor substitution conditions suggests that an index of energy productivity. Our emphasis on the efficient us of energy should not obscure the ultimate goal of higher total productivity.

The obvious conclusion to be drawn from this description of evaluation criterion is that no one index of energy productivity can satisfy all the demands placed on it. Too many of the criteria conflict. Any one index can satisfy some criteria only at the expense of other needs. At the same time, the adoption of multiple indices to satisfy specific goals are likely to dilute the impact on the public of a single index. In the following sections, we turn to a consideration of how well alternative energy productivity indices meet the criteria we have identified.

NATIONAL, AGGREGATE MEASURES

Many energy specialists contend that few indices are known that reflect the opportunities available for enhancing energy productivity. Schurr et al. [18], in a recently released study of America's energy future, stress their dissatisfaction with indices for guiding the technological resolution of America's energy problems, as does Berndt [2] in an earlier study. In the studies of international comparisons edited by Dunkerley [5], on the other hand, the ability to compare energy productivity among nations yielded much insight, in spite of (or because of) inconsistencies and uncertainties in the data. In this section we consider a variety of macro-economic, aggregate measures of energy productivity. These measures include energy consumed per unit of economic output (Btu/GNP), the expenditures on energy per unit of output, a Btu per capita measure, the construction of an index using macro-models, and a consumer survey methodology.

Btu/GNP

The most obvious macro-economic measure of national productivity in the United States today is Gross National Product, or GNP. GNP is an estimate of the total value of goods and services produced by the United States, including all energy services. Although for discussion purposes we will continue to refer to GNP, a more effective measure of national production may be Gross Domestic Product, or GDP. GDP was used in the international studies conducted by the Resources for the Future [5] because it adjusts for imports, i.e., goods produced by other nations that do not involve U.S. energy consumption.

The popularity of GNP as a measure of production is at least partially based on the extensive effort by the government to maintain current estimates of GNP. The Bureau of Economic Analysis, in the Department of Commerce, continually monitors production in the economy according to the Value-Added concept as applied to a detailed break down of the Standard Industrial Classification (SIC) code. This effort is a well established one, with extensive work involved to adjust the raw data for seasonality, inflation, scale, and changes in consumption patterns. Meadows [12] discusses this process in some detail.

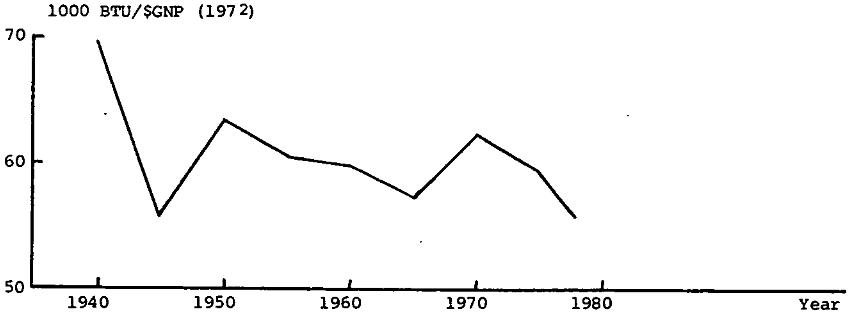
The popularity of GNP and GNP/capita as measures of national welfare have inevitably led to discussions of the measure Btu/GNP (Schurr et al. [18], Wood [34], Dunkerley et al. [5]).

The implication of examining Btu/GNP is that some relationship exists between productivity and energy consumption, so that the ratio is a measure of performance. Starr et al. [22], for example, explore the relationship quite extensively in the context of U.S. regions, industrial concentrations, and labor. As previously cited, the Resources for the Future [5] study involves international comparisons. The RFF study by Schurr et al. [18] examines the Btu/GNP issue, as well as the practicality of adopting any single measure of change in the energy productivity relationship. The concensus seems to be that no trend in the Btu/GNP ratio is inherent in any society; rather, the ratio varies over extended periods of time (decades) in response to fundamental shifts in both the price and availability of energy relative to other resources and technological/social structure of the economy (Sant [17]). This property, of course, is desirable for an energy productivity index.

The Btu/GNP measure is probably the best currently available index for reporting national energy productivity. In fact the Energy Information Administration reports a value for Btu/GNP on an annual and quarterly basis in the *Monthly Energy Review* [29]. The ratio reported by EIA is calculated from the BEA's estimate of GNP and EIA's measure of energy consumed. The latter ratio is derived from estimates of fuel consumed by sector (Residential/Commercial, Transport, and Industry), where fuel refers to consumer's energy in Figure 1.

Figure 3 illustrates how the Btu/GNP ratio has changed in the United States over the last 30 years. Although the interval for which we have illustrated the ratio is limited, the general trend has been a gradual decline in the ratio since the 1920's (Schurr et al. [18]. In fact over the last 50 years the consumption of energy has grown at only 80 percent of the rate of growth of GNP in real terms. The fact that the Btu/GNP index has been declining consistently does not imply that we are using energy more rationally or that we are consciously conserving energy, however. But it does suggest that, as an energy productivity index, we must focus on drops in Btu/GNP beyond the rates experienced historically when awareness of energy economics was considerably lower.

FIGURE 3



Source: U.S. Dept. Commerce, Bureau of Census, Statistical Abstract (1978).

The reporting of Btu/GNP is not without problems however. One of these problems is that the most recent estimates of current GNP are subject to much error (Meadows [12]), so that reliability in GNP is achieved at the expense of timeliness. Furthermore, the estimate of Btu/GNP must be performed at the aggregate level, i.e., total Btu's of fuel consumed divided by total GNP. Sectoral ratios of Btu per dollar of contribution to GNP from specific sectors can not be calculated because energy consumption is not classified in as great detail as the Standard Industrial Classification (SIC) code.

From the point of view of relating energy consumption to GNP, the availability of data on inter-industry accounts is not updated as frequently as would be desirable (Wood [34]). The BEA's Census of Manufactures is the principal source of this information which would allow adjustments to GNP (or energy consumption) to recognize shifts in the mix of production. Yet the frequency of collection, lags in data analysis, and price/cost basis changes impede the timeliness and accuracy of updates (Myers [15], Wood [34]).

An aggregate measure of energy in Btu's ignores all of the quality differences that exist among actual sources of energy, and yet such a measure actually implies that different sources of energy are perfectly substitutable at an equal cost per Btu (Berndt [2]). This condition is not true, of course. Similarly, GNP does not reflect quality changes in the goods and services produced by a nation, except if the changes are reflected in prices.

Finally, we must remind ourselves that the measure Btu/GNP may emphasize energy productivity at the expense of overall economic productivity. Reducing the Btu/GNP measure may be appropriate on the average for the nation as a whole, but pushing energy productivity for some sectors or specific activities may not be justifiable.

Energy Dollars/GNP

A little economic reflection leads to the realization that the measure Btu/GNP is a hybrid productivity measure. Whereas GNP represents the economic value of output (market price of output times amount of output), Btu is a physical measure of energy resources consumed. One alternative to this, Btu per physical output, is not practical at the national level because the measurement of national output in physical units creates an "apples and oranges" problem. We will consider technical measures of output in our assessment of sectorial indices later.

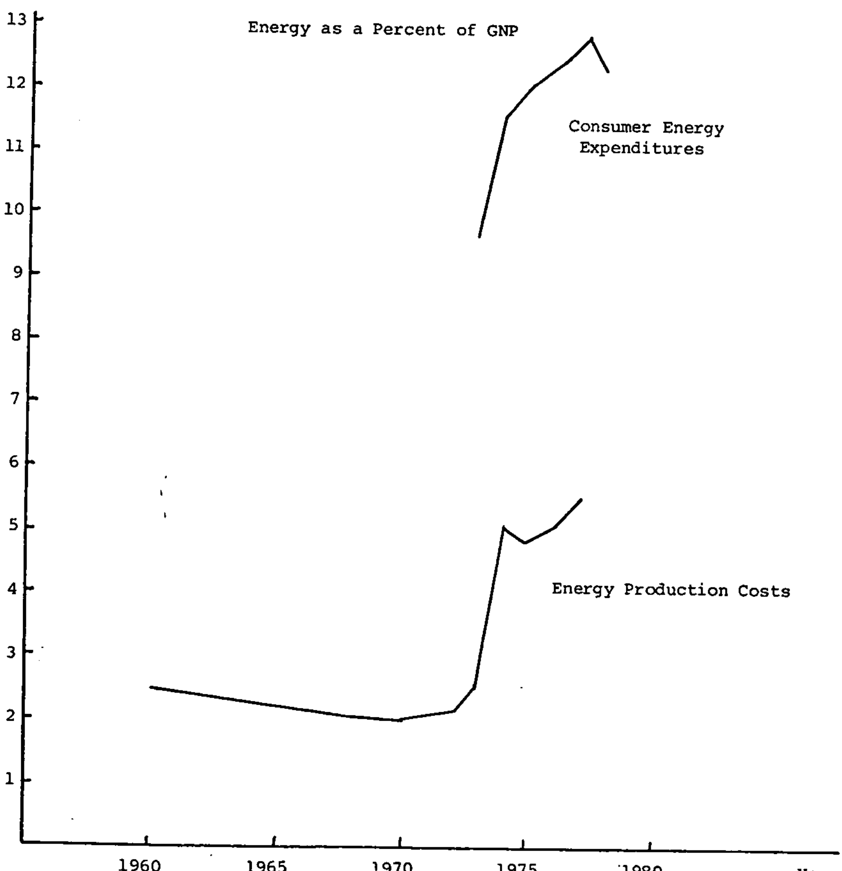
One could argue that energy productivity should be measured in purely economic terms, however. Instead of reporting aggregate national energy consumption in Btu's or some similar physical measure, energy dollars/GNP would reflect the economic value of energy resources consumed. The price of energy as sold at the consumer's meter reflects not only the value of the original energy fuel source but also the cost of capital and labor required to provide energy. Thus energy dollars/GNP reflects the economic value of energy consumed per dollar of economic output.

The ratio of energy dollars/GNP contains both strengths and weaknesses as a measure of energy productivity. Although we may expect the measure of Btu/GNP to continue to drop over the next few years, it may not drop as rapidly as energy sources become scarce. In other words, energy dollars may rise (for constant GNP) because the price of energy increases more rapidly than Btu's per GNP decreases. Hence energy dollars/GNP is a more accurate reflection of the economic productivity of energy, provided that energy prices reflect the energy supply and demand forces.

How well energy prices reflect the supply of and demand for energy has not been resolved. Clearly, energy prices reflect some of the non-Btu quality characteristics identified earlier, if energy prices are measured at the customer's meter. On the supply side, the price should indicate the costs of capital, labor, and energy resources to provide energy at the meter. On the demand side, the price at the meter should relate to the costs of the consumer to utilize the energy, along with internal capital and labor, to provide energy services.

The catch is that energy prices are distorted and do not reflect supply/demand conditions very well (Sander [16]. In the case of domestic energy supplies, prices are regulated. In the case of foreign oil supplies, rapid price rises reflect a short term disequilibrium between supply and demand. On the demand side, the lack of perfect substantiality among energy resources prevents demand from immediately responding to changing supply conditions. Thus changes in a ratio of energy dollars per dollar of GNP may reflect not so much a change in productivity but instead a deregulation of prices, a transition to greater market freedom, and/or substitution effects, as Figure 4 illustrates.

FIGURE 4



Source: Statistical Abstract (1978), EIA Monthly Energy Review.

A Divisia Index

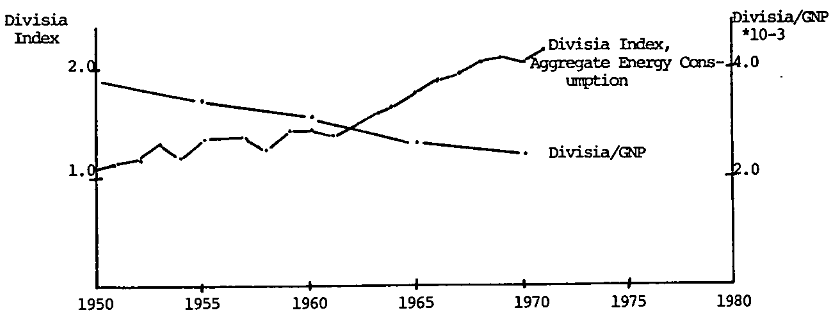
Many of the issues we have raised in generating an aggregate index of consumer's energy are satisfied by the use of a Divisia Index (Berndt [2]). Although such an index may assume several alternative forms, the basic idea is to identify a relative change in aggregate energy consumption from time period t–1 to period t as

$$E_t/E_{t-1} = (p_i e_{it})/(p_i e_{it-1})$$

where p_i is an appropriate time averaged price for energy resource i, and e_{it} is the physical quantity of energy i consumed in period t. With the calculation of a measure of output such as GNP, then changes in the nation's production level can be compared with relative changes in energy consumption to establish gains or losses in productivity.

We should point out that Divisia indices are used heavily by economists because of their computational features. They are a significant improvement over a simple Btu aggregate measure or even an energy dollars aggregate measure, in part because it reflects substitution among alternative energy sources. On the negative side, Divisia indices still assume that substitution between energy sources and non-energy inputs are the same for each energy source. As with the aggregate energy dollar measures, they depend on the rather strong assumption that market prices reflecting the market value for energy sources. Less technically, a problem with Divisia indices of aggregate energy consumption is that their meaning is not easily conveyed to the general public. Figure 5 illustrates two possible representations of Berndt's Divisia index.

Figure 5

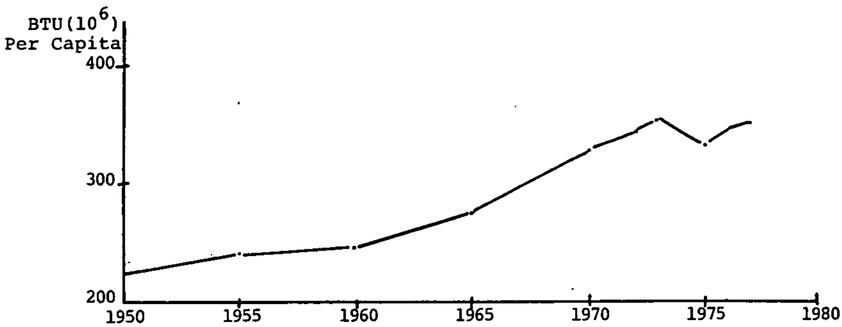


Source: Berndt (2), and Statistical Abstract (1978)

Btu/Capita

Figure 6 illustrates another potential index, Btu per capita, a measure suggested by some staff in DOE [27]. Although it is perhaps more direct in its focus on energy saved per person, the ratio contains several weaknesses from our perspective. First, it measures energy consumed without identifying or recognizing the output achieved. An improvement in the energy performance for the nation could imply an increase or decrease in this measure, since it does not recognize changes in per capita production. A reasonable basis for adjustment might be Btu/capita-GNP, or Btu/GNP-capita, but this ratio suggests a measure of labor productivity as well as energy productivity.

FIGURE 6



Source: Statistical Abstract, 1978

Second, Btu/capita does not distinguish direct energy consumed by, e.g., a household, versus the indirect energy component of final goods and services consumed. Yet a Btu/capita measure suggests that a household could match its direct energy consumption (gasoline, electric, and gas bills) with its "national allocation," with the usual conclusion that the household is not getting its "share". In short, Btu per capita dots not communicate to an individual how well the economy as a whole is performing. Most people do not have a sense for Btu's as a measure of energy, nor do they know how much energy is justifiable for them to consume.

A Macro-Economic Modeling Approach

The use of macro-economic models is another alternative for developing an energy productivity index. Typically these models incorporate a description of the structure of the economy as their foundation. Information on historical productivity levels are provided as input data, and models extrapolate economic performance for future time periods. By varying the input data to reflect changes in government energy programs or hypothesized changes in the supply of resources, the models can be employed to project alternative development scenarios. Manne et al. [11] provide an excellent survey of energy modeling.

In recent publications, the Energy Information Administration of DOE ([25], [27], esp. Vol. III of [26]), suggests that macro models can be employed to measure energy conservation or productivity gains in the current time period. If a model is provided with current production level data and information on the percent of productive capacity is utilized, then projections of current energy consumption can be composed with actual energy consumption.

A macro-modeling approach promises to provide much insight into how the economy's use of energy is changing. Since input data is provided by sector, identification of sectorial changes should be possible and helpful. Many such studies are currently underway (Manne et al. [11]).

Yet we believe that incorporating elaborate macro-models into formulation of a productivity index probably contains too many disadvantages to be commendable at this time. As we have already mentioned, the timeliness of the input data is already questionable, especially if detailed sectoral data is required. Withholding an index until this data is collected and prepared for a model, the model is executed, and the output is analyzed will diminish timeliness even further.

A second difficulty with using macro-models is that the measure of performance is the difference between two estimates of energy consumption—the model's and actuality. Neither estimate is accurate, and the correlation between the two indices is not sufficiently high that the difference is likely to be a reliable indicator.

Finally, the selection of a specific model is likely to cause problems. Each model contains its own idiosyncratic strengths, weaknesses, and biases which are often related to the objectives of the model. Selecting one model to provide a national index is probably not possible, and the use of sectorial models to generate a single index would introduce conflicts in basic model assumptions and the frame of reference for integrating output.

Consumer Surveys

Another approach to formulation of a macro-economic measure of productivity involves measuring the intensity of use of, e.g., home appliances. This approach, again suggested by the DOE [27] study and used in Vol. III of [26], would rely on statistical sampling of American households and institutions and their utilization of selective energy services. In a manner analogous to field work for the Consumer Price Index (CPI), households could be surveyed to determine the frequency, duration, and efficiency with which they consume a "market basket" of energy services. Some of the surveys would contain subjective rather than (or in addition to) objective questions. In any case, the information is expensive to collect and time consuming to process. Furthermore, the information collected tends to focus on specific actions, e.g., number of homeowners installing storm windows, which may not be recommended for all people or all geographical locations; the "market basket" varies greatly by region as well as by socio-economic class.

Then what we seek is a means to measure the cost of all inputs to on-site energy services. We haven't identified a clear procedure for defining energy service inputs, for many reasons given previously.

The benefit of measuring changes in energy service productivity is not straightforward, either. Although we can measure changes in GNP reasonably well, we can not identify changes energy service inputs as readily. We can monitor changes in energy consumption, and we can measure sales of caulking, insulation, and flow restrictors, measurements of other potential energy saving tasks such as repainting a building, planting shade trees, and turning furnaces are not possible. Furthermore, the substitution of capital and installation labor for annual energy consumption dictates that we establish a proper capitalization rate for capital improvements. Finally, the ratio of changes in energy service inputs per dollar change in GNP does not clearly distinguish good from bad performance.

AGGREGATE ENERGY CONSUMER COSTS

Most of the energy productivity measures suggested so far have emphasized, in one way or another, the technical issues of energy consumed per unit of output, where energy is usually measured in physical units. Invariably, too, the indices are just that: i.e., a somewhat abstract measure of an equally confusing concept, consumption of energy to obtain energy services. Yet none of these measures attempts to reflect a concept familiar to almost all American consumers, namely, dollars saved by performing more productively.

TABLE 1.—ENERGY CONSUMER COST SAVINGS

[1978 prices]

	1973	1974	1975	1976	1977	1978
Gross energy consumption (10^{15} Btu)*	74.5	72.6	70.6	74.4	76.5	78.2
Net energy consumption (10^{15} Btu)†	60.7	58.5	56.3	59.2	60.7	61.3
Energy consumption cost (billions)	$167.1	$198.6	$205.5	$224.2	$243.8	$252.6
Energy cost per net million Btu	$2.75	$3.39	$3.65	$3.79	$4.02	$4.12
GNP (trillions)	$1.878	$1.851	$1.829	$1.935	$2.038	$2.128
Implied 1978 energy requirements (10^{15} Btu)††	68.8	67.5	65.6	65.2	63.2	61.3
Implied 1978 energy costs (billions)**	$283.4	$278.1	$270.3	$268.6	$260.4	$252.6
1978 value of implied savings (billions)	$30.8	$25.5	$17.7	$16.0	$7.8	0
Implied 1978 energy savings (10^{15} Btu)	7.5	6.2	4.3	3.9	1.9	0

*Includes losses in transmission of electric power.
†Metered consumer energy.
††The energy required to achieve 1978 output at current year Btu/$GNP ratios.
**Valued at $4.12/MMBtu.

One measurement of dollar reductions achieved by increased energy productivity is illustrated by the data in Table 1. This table shows how much the nation spent for energy consumption as experienced by the end user (as measured at the meter in Figure 1). The data in this table emphasizes an important achievement: although GNP increased by 12 percent in real terms over the 5-year interval 1973–78, energy consumption (as measured in physical units) rose by only 5 percent. Almost the entire rise in energy consumption expenditures of $85 billion is attributable to a rise in energy prices, from $2.75/MMBtu to $4.12/MMBtu. Stated differently, the United States would have spent $30.8 billion more for energy in 1978 had the nation's energy productivity not improved by 12 percent since 1973. This saving represents approximately a $400 reduction in annual energy consumption per household in 1978.[1]

The recognition of energy cost savings from a consumer's view contains several significant advantages. First, it provides a measure that the typical American household can recognize easily: dollar savings. Admittedly, much of these dollar savings are not the result of a household's own decisions, since they originate from energy productivity gains achieved in industry, the commercial sector, and com-

[1] The authors acknowledge that this measure of energy was suggested by Roger Sant, director, Energy Productivity Center.

mercial transportation. But a second advantage is that households can adopt this measure as a yardstick by which they can seek energy saving opportunities. In the residential sector, for example, current research suggests that the energy consumption of an owner-occupied single family house (73 percent of the total housing stock) can be reduced by $120/year with an initial expenditure of approximately $400. At a real capital cost of 5 percent, the net annual savings are approximately $80. Individual households thus can use this energy consumer savings index (ECSI) to relate opportunities available to them.

A somewhat subtle but extremely important advantage of the energy consumer savings index is that it should educate consumers about energy productivity investments. Almost all current consumer behavior focuses on purchasing consumer goals now in order to avoid higher, inflated prices later. Paradoxically, households are not spending now for, e.g., insulation or storm windows, in order to achieve the same energy comforts later at reduced real costs. The energy consumer savings index should teach this lesson: the average household spent $400 less, directly or indirectly, for energy fuels in 1978 because of the investments made since 1973 in all sectors of the economy.

The ECSI permits us to relate previous accomplishments with the potentials that current research suggests are possible. One of those potentials, $120/year fuel reduction for $400 investment in home thermal improvements, was just cited. In another work, Sant [17] has suggested that, if available and economical technologies for providing energy services had been implemented in 1978 in all sectors of the economy, the reduction in energy consumption would have been 32 percent instead of 12 percent.

An interesting and telling observation is that the calculations presented in Table 1 required extensive searching through numerous references to identify the prices charged to end-use energy consumers. Whereas the EIA [29] reports energy consumption in physical units by end-use sector, the cost of energy to consumers is not presented as extensively. Instead the price of energy at the production end (raw energy sources in Figure 1) is emphasized. (This situation is even more obvious in the *Statistical Abstracts* published by the Department of Commerce.) Recent issues of *Monthly Energy Review* contain several aggregate (as well as sectional) measures of energy productivity that focus on energy consumed as measured in Btu's and Gross National Product as measured in dollars. Aggregate measures of energy costs to the consumer (e.g., $4.12 per MMBtu in 1978) are not presented, however.

The ECSI can be calculated readily from conventional information as it becomes available. Because it relies on a ratio for its determination (i.e., Btu/GNP), it will be no more reliable than the data available for the associated energy consumption and GNP output levels. Monthly reporting of the index is not advisable for this reason, but quarterly updates accompanying GNP estimates may be appropriate. According to the EIA's *Monthly Energy Review*, energy consumption levels and energy consumer price data become available more readily than do estimates of GNP.

The ECSI is not without fault, of course. Perhaps the most fundamental weakness is that it does not reflect the cost of capital expended to achieve energy productivity gains. Whereas energy consumption dropped by 12 percent from 1973 to 1978 (relative to 1978 output levels), the cost of the capital investments is not measured. The $120 reduction in energy expenditures for home energy improvements, for example, requires an initial capital expenditure of $400. If the improvements last 20 years, then the annual capital consumption cost is $20. The annual capital carrying charge is an additional $20, if the real cost of capital is 5 percent. Thus the net energy savings are $80 per year.

The ECSI is clearly not an appropriate measure of energy productivity gains for professional use. In addition to the capital cost problem, the ECSI does not reflect how the quality of output has changed. The household that drives a smaller automobile will contribute to reductions in automobile fuel consumption, but the cost of riding in a smaller automobile, whether psychic, foregone opportunities, or real, is not measured.

Furthermore, the ECSI makes no pretense of relating energy productivity accomplishments to what could have been achieved or what should have been achieved. Historically, energy consumption has risen at a rate that is approximately 80 percent of the growth rate for GNP. Thus the 7.5 quad implied energy savings as a result of productivity gains from 1973 to 1978 should be 5.9 quads: from historical levels, the 13 percent growth in GNP implies a "normal" increase in energy consumption of 6.5 quads. Since energy consumption did rise by 0.6 quads, the net gain, exclusive of capital costs, is 5.9 quads, equivalent to $24.3 billion at 1978 prices.

The Energy Consumer Savings Index is very clearly an index rather than an estimate of actual savings realized. One condition that supports this distinction is the difficulty of predicting how much energy consumption would have grown without unusual efforts to achieve energy productivity. Should the normal growth rate of energy consumption be defined as equal to the growth rate of total production, 80 percent of it, or some other proportion? This problem becomes more evident when the ECSI concept is applied to sectors of the economy. If the ECSI were a measure of energy fuels saved, the sum of the sectorial savings should equal the aggregate savings. This equality does not hold, except under trivial conditions, because the ECSI is an index; it reflects an extrapolation that is derived from a ratio.

Finally, the value of the ECSI obviously varies for any specific years as a result of the base year selected. This characteristic also holds true for most other indices, of course, but they tend not to be so explicit on first approach. For example, the Consumer Price Index is a somewhat abstract number that measures the change in cost of a basket of goods in one time period relative to another period. The dollar cost implications of this shift are made clear only after translation into a measure of additional dollars spent to acquire the same quantity of goods. The ECSI, in contrast, emphasizes the implied dollar savings realized in acquiring the same energy services in successive time periods. Perhaps the primary energy efficiency measure should be an index like the Divisia index, or simply Btu per dollar of GNP.

Recommendations—Aggregate Measures

We have explored briefly several measures for reporting aggregate energy productivity. The preferable index is one that reflects net productivity gains in providing services, rather than measures of energy consumption, as the latter relates to total national production. The measure that appears most promising is an Energy Consumer Savings Index which, while based on a technical measure of energy consumed per dollar of output achieved, emphasizes the dollars of energy consumption avoided by achieving greater energy productivity. As indicated earlier, this measure suggests that energy productivity improved by 12 percent between 1973 and 1978. This improvement saved the nation $31 billion in energy expenditures in 1978.

Sectorial Indices

Our assessment of aggregate measures of energy productivity has led us toward the conclusion that the Energy Consumer Savings Index is, from a practical viewpoint, one of the better measures of national energy productivity. Yet the aggregate indices we have identified stress the relationship between energy resources and total output. They do not indicate in any clear or obvious manner how energy is being used, and thus they do not contribute to an understanding of energy productivity or to identification of opportunities for improving productivity. To address these goals of productivity indices, we turn to a review of energy use by economic sector. Since the energy accounts are the least detailed and the most restrictive on sectorial analyses, the discussion proceeds with an examination of the energy classifications of sectors: Residential/commercial, transport, and industrial.

We should keep in mind, of course, that sectorial measurements of energy productivity are correlated, at least weakly. If the prediction of households returning from the suburbs to inner city apartments occurs, then we can expect aggregate energy performance to reflect not only increased occupancy of multi-unit dwellings, but also a drop in automobile passenger miles due to shorter commutes and a shift to public transportation. The relationship between sectors need not be positive, however. A drop in truck ton-miles may be related to a rise in rail ton-miles with net productivity gains (losses) corresponding to the difference between the marginal energy productivity rates of each mode. Our point here is not to discuss or even hypothesize intersectorial transitions, but to emphasize that a strict focus on sectorial indices may overlook important interactions.

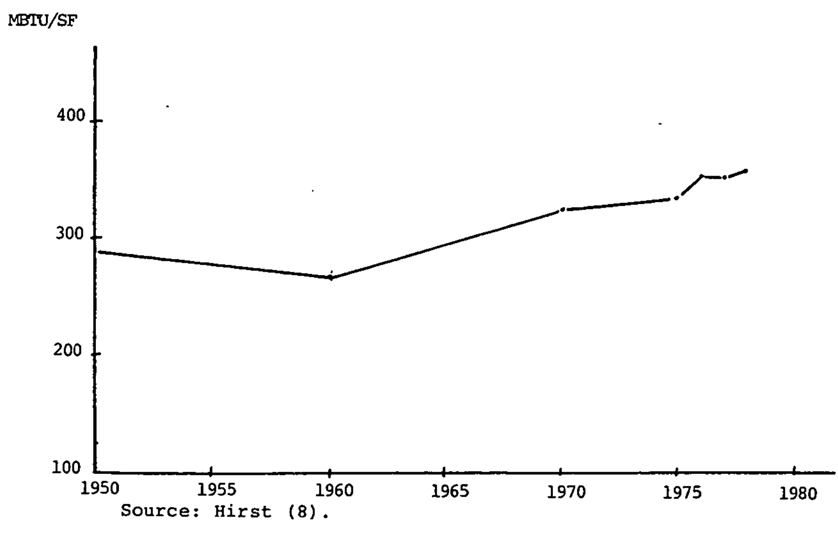
Residential/Commercial

The residential/commercial sector accounts for approximately 35 percent of national energy consumption, primarily for use in buildings (transportation is excluded). Within buildings, energy is consumed to provide several types of energy services. Although priorities shift for different types of buildings and according to geographical location, the dominant categories of energy use—space heating/cooling, lighting, and domestic hot water—account for over 80 percent of the residential/commercial sector's energy consumption (Hirst and Jackson [7]). In most climate conditions, space conditioning and domestic hot water dominate in residences. Contrary to popular belief, energy for domestic hot water in residences can be large relative to space heating or cooling (Socolow et al. [21]). Except for schools and hospitals, equipment and process energy generally play a lesser role in buildings.

The question of how to measure the productivity of energy services in buildings is not an easy one to answer. On the energy supply side, any attempt to measure energy supplied for hot water versus space conditioning will be difficult because the basis for energy monitoring is meter readings. In commercial buildings, some equipment is monitored separately, but the amount of energy that is used for, e.g., lighting and office machinery, is sizeable and not metered separately. In fact, many utility companies include large residential building accounts in their commercial records, so that disaggregating residential and commercial building energy consumption is a problem. Recent efforts by the EIA to distinguish residential from commercial usage will help in the future.

The measurement of productivity in buildings is a no less serious problem. Since the greater proportion of building energy is usually allocated to space conditioning, the logical measure of productivity should be Btu/square foot or Btu/cubic foot. Data on building stock cubic footage is essentially non-existent. Whereas square footage of construction is reported quite frequently, square footage measures of total building stock are not available in general. Recent efforts by the Oak Ridge National Laboratory have attempted to establish the amount of commercial space that is available (and presumably occupied). In Figure 7 we illustrate a measure of energy/square foot as estimated from Oak Ridge data (Hirst [8]).

FIGURE 7.—Commercial energy consumption per square foot



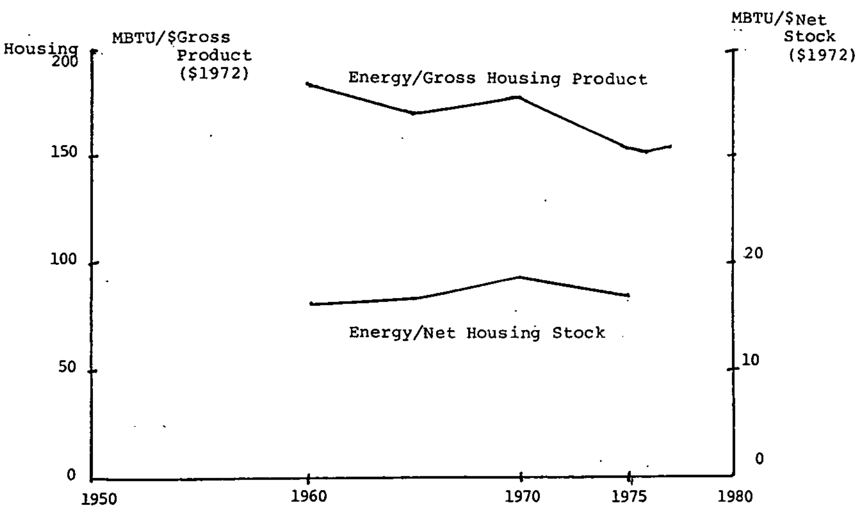
Source: Hirst (8).

The general consensus is that buildings have become increasingly energy consumptive over the last 20 years; Figure 7 supports this view for commercial stock. As a result of many energy productivity studies for the building industry, however, we can expect this ratio to drop as new buildings are designed with energy productivity in mind. We should expect this ratio to drop also because of on-going efforts by the building industry to improve the operating efficiency of existing commercial and residential buildings.

The measure of Btu/square foot is a familiar one to energy professionals in the building field; it is frequently used to evaluate individual buildings, especially their air handling equipment. Yet, it does present several problems if it is used as an aggregate measure of building performance. First, it must be adjusted for degree days, since most energy production in buildings involves space heating/cooling to compensate for differentials between outside and indoor temperatures. Second, hot water use is related more directed to the number of building occupants than to square footage; hopefully, square feet is a suitable surrogate for the number of occupants.

In the residential sector of the economy, square footage measures of the housing stock are not available. Alternatively, however, the Bureau of the Census and HUD maintain more accurate data on the amount of housing in use as measured in household units. Furthermore, from the national accounts, we have measures of housing consumption expenditures. Figure 8 illustrates an index that is derived from this data. Housing product, which is derived from household consumption expenditures for housing and is reported here in 1972 dollars, mav be biased because of large inflation in housing markets in the 1970's.

FIGURE 8.—Residential energy consumption



Source: Hirst (8), and U.S. Dept. of Commerce, Bureau of the Census, Statistical Abstract

Any measure of aggregate building energy productivity must be adjusted for demographic shifts, of course. The obvious issue is the movement of households from the north to the south and southeast. A less obvious point is intra-urban shifts, especially as the proportion of multi-family units increases with the return to the city of many households.

Collection and Analysis of Building Information

The reporting of energy productivity in the residential/commercial sector on a Btu/SF or Btu/dwelling unit basis requires timely and accurate data. In the Energy Information Administration within DOE, energy consumption data on the residential/commercial sector is collected monthly from utility companies. This data, which identifies energy consumption by fuel type, is reported initially in the *Monthly Energy Review* with a lag of approximately two months. Subsequent *Reviews* contain adjusted values as previously published data is revised. At the present time a value of building energy productivity, such as Btu/SF, is not reported in the *Review*.

In the residential sector, the number of housing units as well as some information on their characteristics is collected extensively every decade in the Census of Population. Each year the Annual Survey of Housing updates this information, based on a more limited sampling of households. In addition, the housing construction industry is monitored by the Department of Commerce as well as by trade organizations (e.g., McGraw-Hill Information Systems). The data collected is typically the number of housing unit starts and dollar value of housing constructed rather than square footage constructed. Square footage must be estimated from figures on the total dollar volume of construction and per square foot construction costs.

In the commercial sector, which accounts for approximately one third of the energy attributable to residential/commercial, relatively little is known about the amount, location, and quality of space. Whereas the construction industry monitors the amount of building space constructed, a census of commercial buildings does not exist (Hirst [8]). Because demolition rates and building conversion rates are not known for many cities, the determination of cumulative construction or total square footage in place cannot be established for the nation as a whole.

One can think of several remedies for estimating commercial square footage for the nation. Some of the SIC categories essentially represent only buildings and probably account for a very large proportion of all commercial space. Data on rent or building operating costs might be extrapolated to imply occupied square footage. "Trade" information for some types of commercial buildings, such as schools, hospitals, government, or retail, may provide the basis for an index. Most large SMSAs maintain information on retail and office building space through trade organizations, which could account for a large proportion of all such space. Relating these measures to energy consumption data will be difficult, however.

Energy Consumer Savings

For a variety of reasons just presented, measuring energy productivity in the residential/commercial sector on the basis of energy consumed per square foot of building space is not a practical procedure at this time. Since most of the energy consumed in this sector is associated with providing building space, however, examination of how energy consumed relates to total sector productivity should provide some measure of building energy productivity. To take this approach, the procedures used previously to calculate the value of energy consumer savings are adopted.

Table 2 presents data that is available from either the EIA's *Monthly Energy Review* or the U.S. Department of Commerce's Bureau of Economic Analysis. The energy consumption data covers fuel consumed by businesses that are classified as communications, wholesale and retail trade, finance, insurance, and real estate, services, or government. In addition, residential energy consumption is included. The measure of production which corresponds to the GNP measure used for the aggregate measure previously is gross product (for the non-residential institutions), a measure of value added. For the residential sector, the measure used is household expenditures for housing space, exclusive of housing services (furniture, utilities, appliances, etc.). This measure cannot be compared with GNP, however, because it includes both production and consumption accounts.

TABLE 2.—RESIDENTIAL/COMMERCIAL ENERGY CONSUMER COST SAVINGS

[1978 prices]

	1973	1974	1975	1976	1977	1978
Gross energy consumption (10^{15} Btu)*	26.5	25.9	26.0	27.2	27.5	28.6
Net energy consumption (10^{15} Btu)	18.2	17.5	17.2	18.1	17.9	18.5
Energy consumption cost (billions)†	$62.8	$70.8	$74.1	$80.6	$87.6	$91.7
Energy cost per million Btu	$3.45	$4.04	$4.31	$4.45	$4.89	$4.96
Residential/commercial product (billions)††	$1,265	$1,281	$1,294	$1,355	$1,413	$1,465
Implied 1978 net energy requirements (10^{15} Btu)**	21.1	20.0	19.5	19.6	18.6	18.5
Implied 1978 energy costs (billions)	$104.6	$99.2	$96.7	$97.2	$92.2	$91.7
1978 value of implied savings (billions)	$12.9	$7.5	$5.0	$5.5	$0.5	0
1978 implied primary energy savings (10^{15} Btu)	4.2	1.0	0.8	0.8	0.3	0
1978 implied net energy savings	2.6	1.5	1.0	1.1	0.1	0

*As reported by EIA (29) to be residential/commercial energy consumption, including electricity transmission losses.
†See appendix for discussion of data.
††Actually, the total of gross product accounts for communication, wholesale and retail trade, finance, insurance, real estate, services, and government, plus household consumption of housing space from ORNL (35).
** Energy required to achieve 1978 output at current year energy/output ratio.

The analysis shown in Table 2 suggests that, had no energy productivity gains been made since 1973, residential/commercial consumers would have required 4.2 quads more primary energy in 1978 to achieve 1978 levels of production. This reduction in energy consumption represents a cost savings of approximately $13 billion, or 14 percent of the total 1978 expenditures for energy.

Recommendation

The calculation of aggregate energy productivity measure in the residential/commercial sector is not straightforward. Although EIA collects data on energy consumption for this sector, the production of this sector is not easily measured. Shipper [20] argues that general indices such as Btu/square foot are inadequate, and that, at least for professional assessment of energy productivity in buildings, individual measures of, e.g., lighting, space heating and hot water heating efficiency, may be more appropriate. For a lay audience, however, at the present time a Btu/square foot measure may be appropriate for the residential and commercial sectors combined. If utility companies revise their billing procedures to separate residential and commercial accounts, then a housing index of Btu/dwelling unit, adjusted for degree days, would be more effective. EIA [25] [26] is currently undertaking numerous studies to learn more about energy use in the buildings sector; a periodic survey to monitor energy productivity may evolve from these efforts. Until any of these measures are available in a reliable form and reported frequently, the best measure available is probably a sectorial version of the Energy Consumer Savings Index introduced previously. According to this measure, the nation spent $13 billion less in 1978 for energy than it would have to achieve the same output levels but at 1973 energy productivity levels.

TRANSPORTATION

The transportation sector encompasses both passenger and freight movement via automobiles, truck, rail, water, pipeline, and air traffic. This sector accounts for roughly 25 percent of all energy consumption and 5 percent of GNP. Unlike the residential sector, the transportation sector relies heavily on petroleum for fuel, and the transportation services provided are extremely diverse. The typical units of production are passenger-miles or, for freight, ton-miles, so that measures of Btu's per passenger-mile or ton-mile are widely accepted indicators of transportation energy efficiency.

From a broad perspective, the transportation sector is structurally constrained by the size of the nation, its relatively low population density, and the relatively low density of urban areas. In comparison with European nations, U.S. automobile traffic is less effective for both structural and intensity reasons; American households drive more miles and consume more fuel per mile. Freight traffic, in contrast, is less intensive than European operations, but is still less efficient for structural reasons (Ayres and Ayres [1], Dunkerley et al. [5]).

Some obvious measures of transportation productivity that are worth observing include passenger car energy (Btu) per dollar of GNP, freight energy per GNP, etc. These measures include both features of transport energy efficiency (Btu/mile) and transport productivity (passenger- or ton-miles/GNP). An emphasis here on energy services suggests that we focus on transport energy efficiency rather than overall productivity.

Whereas some structural conditions that would improve energy efficiency are not likely to change rapidly, the turnover rate of rolling stock, especially automobiles, holds much promise for improving the fleet fuel economy in the next decade. Btu's per passenger- or ton-mile are the most clear and readily available measures of energy productivity in the transport sector. Yet the reliability and completeness of data on the transportation sector is as varied as the modes of transport.

Productivity and Measurement Problems

The collection of data on energy consumption by the transportation sector does not always coincide with the basis for measuring production. The DOE measures of energy allocated to the Transport sector are sometimes residuals, based on allocations to other sectors that are more easily measured [29]. These allocations are necessarily distinguished by subsector allocations, or alternatively, they are allocated on a fixed, proportional basis. Thus energy productivity gains in one subsector would be attributed to all sectors. In the automobile subsector, miles driven is derived from a fleet average mileage and total fuel consumed, so productivity gains are by definition unmeasurable. Of course, studies by specific industries, or the Departments of Commerce, Energy, or Transportation are providing insight into select transportation operations.

We can conclude from the discussion so far that the data on transportation energy productivity is uneven in both availability and timeliness. In addition, the measures themselves will not reflect all sources of energy productivity gains, and they will report productivity changes that do not involve long-term trends. One of these major difficulties is that changes in the load factor can alter productivity substantially, since most of the energy cost of operating a transportation vehicle involves movement of the vehicle; the load itself adds little to the energy cost. In automobiles, a shift to car pooling can thus affect productivity, and a change in regulation of trucking that influences the amount of empty backhauls would also alter productivity. In airlines, rapid shifts in passenger load factors attributable to economic as well as seasonal conditions are notorious for their influence on corporate performance via total operating efficiency, including energy productivity. The rail industry reflects a contrast: because of specialization in rail cars, the empty backhauls are inherent in the operation. As a result of all of these conditions, productivity measures of individual transportation modes may be misleading, especially if they are analyzed separately and inter-modal shifts are ignored.

A comparison of transport modes also reveals characteristics of mode operations that do not surface in comparing loads. Rail operations consume energy in yard switching and idling, and trucks must often take circuitous routes; both conditions represent sources of inefficiency, yet they are not reflected in changes in yearly energy operating ratios.

As one might expect, the intra-mode variance in transportation is quite high and weakens the link an individual or organization can make between their performance and average productivity measures. Some of the variance is attributable to local operating conditions: urban versus inter-city, over-the-road hauls, hilly versus flat terrain, deep versus shallow channels. Speed, of course, plays a major role; operating efficiency drops exponentially with increases in speed and air/water resistance.

Another issue in transportation productivity is quality characteristics of the services provided. Much freight moves by air, rail, water, pipeline, or road because of speed, volume, weight, or distribution requirements. Coal moves by rail or boat, whereas packaged goods move by truck or by air. Some goods require refrigeration. Many of these considerations involve the intensity criterion raised earlier: given a need to move people or cargo between two locations, the nature of the load often dictates the mode of travel. Many automobile trips, even private auto trips, are initiated to move goods rather than people. Much air freight travels on passenger aircraft. Thus auto passenger miles should be freight-miles, and air passenger-miles should be freight-miles, at least when energy is associated with the services.

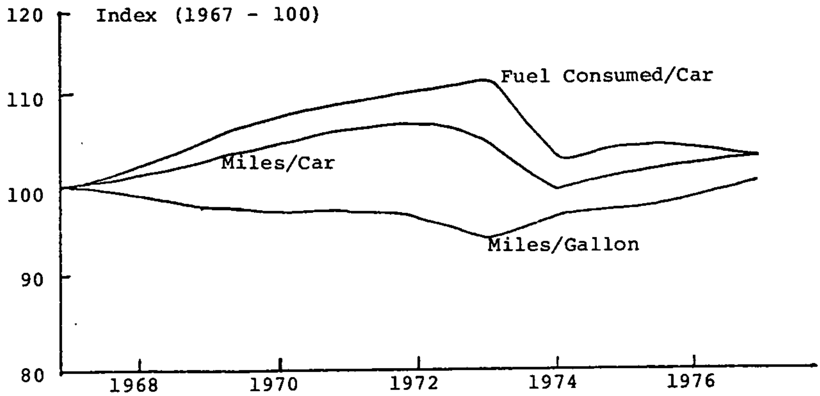
For many transport operations, the objective is not ton miles or passenger miles but rather ton miles or passenger miles per unit of time. Speed, and the necessity to minimize transport time for commodities, is the essence of much freight and passenger movement. (We can remind ourselves that the bicycle is the most energy efficient means for moving a person.) Yet energy consumption increases roughly as the cube power of an increase in speed. As a result, huge gains in energy productivity, as measured in Btu per ton mile, for example, may reflect drops in transport productivity rather than increases in energy productivity.

Automobiles

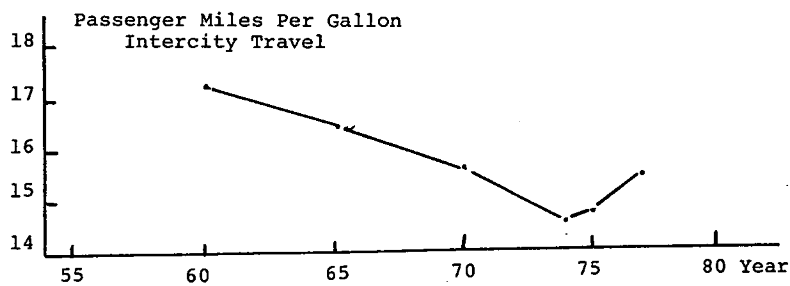
In the automobile sector, which accounts for 55 percent of all energy use in transportation, data on private automobile usage is primarily collected by the Bureau of Census each decade. The Federal Highway Administration prepares the "Highway Statistics" (VM–1) report each year [30]. This report extrapolates miles driven from the state fuel tax revenues. The big assumption in these reports is the average fleet economy, which is estimated from less frequently executed studies such as the National Travel Survey [31]. The average fleet economy calculation requires estimates of the mix of cars in the fleet by age and type, the number of miles driven by each type and age car, and the fuel economy of each car by type and age. As should be obvious, so much of the passenger-miles/Btu calculation depends on presumptions about automobile fuel economy that the calculation is a tautology. An independent periodic measure of automobile energy productivity does not exist, unless one simply considers fleet fuel economy. Some of these difficulties are illustrated for the automotive industries in Figures 9 and 10. Fuel consumed per car, for example, is affected more in the short term by changes in the level of transport services realized (e.g., vehicular miles) rather than performance per mile.

As Figure 9 suggests, some improvement has been noted in the automobile sector of transportation, which accounts for approximately 80 percent of the energy consumed in transportation. Table 3, for example, presents the automobile fleet fuel economy as estimated by data from the VMI report. This data suggests that an 8.4 percent improvement has been achieved from 1973 to 1978.

FIGURE 9.—U.S. passenger car efficiency



Source: U. S. Department of Transportation, Federal Highway Administration, Federal Highway Statistics Division "Highway Statistics", Table VM-1, as published in the Monthly Energy Review, U. S. Department of Energy, Energy Information Administration (October, 1979).



Source: Transportation Facts and Trends

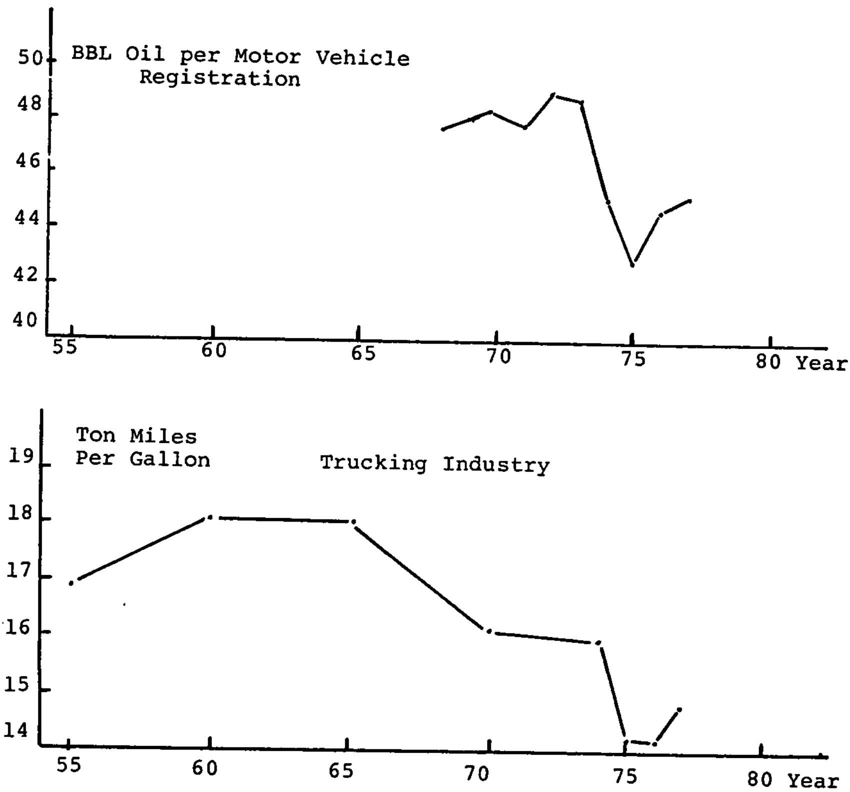
TABLE 3.—U.S. AUTOMOTIVE FLEET FUEL ECONOMY

	Miles per gallon	Index
1955	14.5	110.7
1960	14.3	109.2
1965	14.1	106.9
1970	13.6	103.8
1973	13.1	100.0
1974	13.4	102.2
1975	13.5	103.0
1976	13.7	104.6
1977	13.9	106.1
1978	14.2	108.4

Freight Transport

Most of the information on freight transportation is provided by the Bureau of the Census, the Interstate Commerce Commission and the Transportation Association of America. Some government contributions originate from the Census of Transportation: a truck inventory and use survey is conducted every 5 years and made available several years later. The ICC's "Transport Economics" provides data on regulated transportation modes on a quarterly basis. Although several trade associations collect data periodically on various transportation subsectors (e.g., American Association of Railroads, American Trucking Association), much of their data surfaces in a quarterly publication, *Transportation Facts and Trends*, which is published by the Transportation Association of America. This publication provides ton-mile data on regulated common carrier trucking, rail, air, and shipping. The time lag in obtaining the latest data is generally one quarter, although some reported data has not been updated for 5 or more years. Figure 10 illustrates one of the transport productivity measures, ton miles per gallon for the regulated common carrier trucking industry. This index suggests that performance has deteriorated since 1970, although the change in the index has reversed direction: energy productivity of common carrier trucking is improving.

FIGURE 10



Source: Transportation Facts and Trends

The freight data for the air, rail, and shipping modes is generally complete with respect to breadth of coverage. These subsectors account for approximately 12 percent of transportation energy (Schurr [18]). Unfortunately, the data on trucking accounts for only regulated common carriers, who represent approximately 40 percent of the trucking volume. The other 60 percent—private carriers, contract carriers and special agricultural freight—is not covered systematically on a periodic basis, except via Bureau of Economic Analysis and Federal Reserve Board monitoring of industry. An assessment on how frequently various measures become available and/or are updated is provided in the Appendix to the TAA's *Transportation Facts and Trends* [23].

Transportation Consumer Savings

The approach taken earlier to measure aggregate energy savings to consumers can be applied to the transportation sector. Table 4 illustrates the appropriate data, as taken from the *Statistical Abstracts* and the EIA's Monthly Energy Review. Because automobile use accounts for such a high proportion of total transportation, the effects of rising fuel prices, a recession, and fuel shortages as illustrated in Figure 9 are identified in Table 4. Fluctuations in energy efficiencies attributable to load levels are readily apparent in the amount of energy saved in 1978 relative to different years. The low load levels and total volumes realized in 1975, for example, led to unusually poor energy efficiencies in that year. Overall, of course, the improvement in energy productivity was 8 percent between 1973 and 1978, which implies a savings to the consumer of $7 billion in 1978 relative to 1973 productivity levels.

TABLE 4.—TRANSPORTATION ENERGY CONSUMER SAVINGS

[1978 prices]

	1973	1974	1975	1976	1977	1978
Energy consumption (10^{15} Btu) *	18.9	18.3	18.5	19.3	20.0	20.5
Energy consumption cost (billions)	$68.5	$82.2	$83.4	$87.8	$91.3	$92.0
Cost per million Btu	$3.62	$4.49	$4.51	$4.55	$4.56	$4.49
Transportation output (billions)†	$394.1	$384.1	$372.2	$409.1	$440.7	$460.4
Implied 1978 energy requirements (10^{15} Btu)	22.2	21.9	22.9	21.7	20.9	20.5
Implied 1978 energy costs (billions)	$99.2	$98.3	$102.8	$97.4	$93.8	$92.0
1978 value of implied savings (billions)	$7.2	$6.3	$10.8	$5.4	$1.8	0
Implied energy savings (10^{15} Btu)	1.6	1.4	2.4	1.2	0.4	0

*As reported by the EIA (29) and others: see appendix. Energy consumption attributed to transportation may not coincide with the measure of transportation output.

†Based on "Transportation Facts and Trends" (23), output includes both commercial and private transportation.

Recommendations

We conclude this section on transportation by noting that, at the current time, no one measure of productivity could suffice for the entire sector. For some subsectors, the Interstate Commerce Commission and trade associations routinely collect data on production and/or energy consumption, so that energy productivity indices can be calculated, however infrequently. We suggest that Btu/ton mile is an appropriate measure of energy productivity for freight traffic, because it is widely accepted and does capture many of the energy productivity issues in this sector. For air traffic, a measure of fleet fuel economy such as Btu per passenger mile is probably the best readily available measure. The fleet fuel economy measure—average miles per gallon—has become a widely accepted measure of overall productivity improvement for automobiles, and this measure is popular for evaluating individual model performance as well. This measure indicates that the automobile fleet, which accounts for approximately 80 percent of the transportation sector's energy consumption, improved by 8.4 percent between 1973 and 1978. The Energy Consumer Savings Index, when applied to the transportation sector, suggests that overall energy productivity gains in transportation were approximately 8 percent between 1973 and 1978, and saved the nation $7 billion in fuel costs.

INDUSTRY

The industrial sector of the economy accounts for approximately 35 percent of domestic energy consumption and roughly 35 percent of GNP. These figures are based on different classifications of industry, however, so they may not be comparable with great accuracy. Whereas the energy proportion comes from DOE, the GNP proportion is derived from Department of Commerce accounting for GNP.

In several respects our ability to account for energy productivity in the industrial sector is much improved in comparison with the residential/commercial or transportation sectors. First, the industrial sector is extensively monitored by the Department of Commerce for determining the nation's economic performance. This monitoring is highly organized, systematic, and provides data which is consistent over a significant period of time. Second, relatively few industries consume the bulk of energy allocated to all industry: chemicals, iron and steel, petroleum refining, paper, aluminum and cement account for over 60 percent of total industrial consumption (EIA [28]). Furthermore, the number of large companies in these industries is usually small, so that much industrial energy consumption can be monitored via observation of a few firms.

The data collection efforts on industrial performance still obey the seemingly inevitable relation that greater levels of detail imply infrequent updating, substantial time lags, and/or unreliability. The prominent measures of industrial production (which in fact include commercial activities, grouped in this paper with residential) are the Federal Reserve Board Production Index, the Bureau of Economic Analysis estimates of GNP by SIC code, the Census of Manufacturers, and select trade associations (e.g., American Paper Institute, American Petroleum Institute). The FRB Index is similar to the BEA's measurement of GNP in terms of frequency of updating and reliability of early estimates. We discussed the GNP efforts earlier; a rather extensive if somewhat dated comparison of the two measures is contained in Gottsegan [6].

Many of the data collection and performance measurement problems raised earlier apply to analysis of the industrial sector. Myers and Nakumura ([15], Chapters 1–2) cite many of these issues in a recent publication. They have relied heavily on the Census of Manufacturers Survey data from 1974–76. As we have pointed out before and Wood [34] discusses in depth, information on the structural relationships among industries, notably inter-industry accounts, are not updated frequently or integrated with energy consumption data. Nevertheless, Figure 11 illustrates the energy performance of a few energy intensive industries, albeit without recent data because of time lags.

One of the bright spots in the industrial energy productivity picture is the Industrial Energy Efficiency Improvement Program of DOE [28]. This program has begun reporting gains in energy productivity with the 1976 year. It is an extensive effort to involve the leading corporations in the most energy intensive industries in a program of energy conservation and improved energy productivity. Thus, this effort emphasizes both development of energy productivity programs and the monitoring of energy consumption and production. The results are reported semi-annually, expressed as a percent gain in energy productivity.

As should be evident from the diversity of output attributable to the industrial sector, no one measure of productivity in physical units is appropriate for this sector. If the productivity of specific industries is the issue, then specific indices can be adopted, e.g., Btu's per ton of steel or ton of paper, Btu per barrel of fuel or per pound of chemical. These measures require the identification of energy allocations by industry, of course. Interestingly, the first annual report on the Industrial Energy Efficiency Improvement Program [28] does not identify the measures of productivity.

Consumer Energy Savings

The reporting of net value added by all firms in the Agricultural, Mining, Construction, and Manufacturing sectors by the U.S. Bureau of Economic Analysis facilitates the computation of savings realized by energy consumers in the industrial sector. This measure is analogous to the national ECSI proposed earlier; data is presented in Table 5 to illustrate this approach. The evidence suggests that between 1973 and 1978 industry improved energy productivity, as measured in Btu per dollar of value added to GNP, by 14 percent. This improvement represents a $10 billion reduction in energy consumption in 1978 relative to the energy required of productivity had not changed since 1973.

TABLE 5.—INDUSTRIAL ENERGY CONSUMER SAVINGS

[1978 prices]

	1973	1974	1975	1976	1977	1970
Gross energy consumption (10^{15} Btu)*	29.1	28.3	26.2	27.9	28.9	29.1
Net energy consumption (10^{15} Btu)	23.6	22.7	20.6	21.7	22.7	22.3
Energy expenditures (billions)	$35.8	$45.6	$48.0	$55.8	$64.9	$68.9
Energy cost per net million Btu	$1.52	$2.01	$2.33	$2.57	$2.86	$3.09
Industrial output (billions)†	$575.3	$547.4	$520.6	$558.4	$591.7	$628.3
Implied 1978 net energy requirements (10^{15} Btu)††	25.7	26.0	24.9	24.4	24.1	22.3
Implied 1978 energy costs (billions)	$79.4	$80.3	$76.9	$75.4	$74.5	$68.9
Implied energy savings (billions)	$10.5	$11.4	$8.0	$6.5	$5.6	0
Implied net energy savings (10^{15} Btu)	3.4	3.7	2.6	2.1	1.8	8

*Source: See appendix.

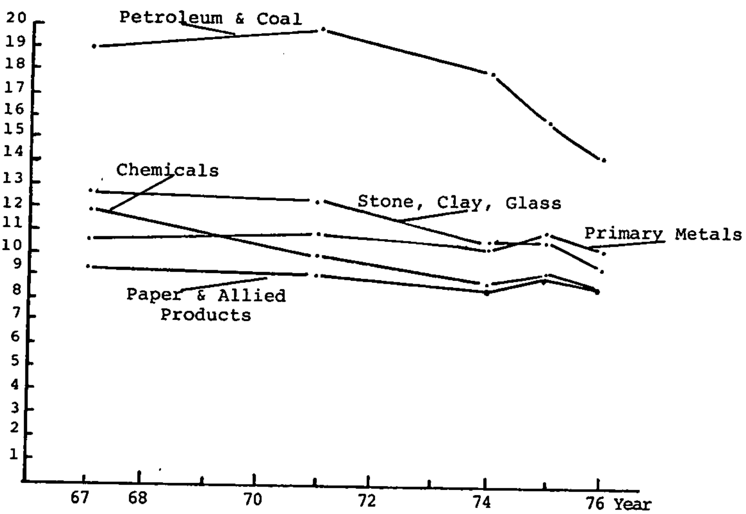
†Source: Gross product for the agriculture, forestry, fisheries, mining, construction, and manufacturing industries ("Statistical Abstracts," 1979).

††Energy requirements implied to be required to achieve 1978 output levels with current year energy/output ratios.

Recommendations

For the industrial sector as a whole, a measure such as Btu per dollar of sales leads to double counting because of the cost of energy contained implicitly in the industry's input materials, which is also recognized in another industry's sales of output. Yet a dollar value of output such as contribution to GNP can be used, and hence the best overall index may be Btu's of energy consumed per dollar of value added to GNP by the industrial sector. We have illustrated this measure for select industries in Figure 11, which suggests that these industries are achieving some gains in energy productivity. Whether these gains reflect simply the long term trend of growth in energy and GNP or specific efforts by these industries is not clear. For more detailed and technical analyses of energy productivity in some industries, measures provided by the Industrial Energy Efficiency Improvement Program will probably provide greater insight in the coming years. For the industrial sector as a whole, however, analysis of energy consumer savings indicates that industry has achieved a 14 percent gain in energy productivity between 1973 and 1978. This gain implies a reduction in consumer energy expenditures of $10 billion.

FIGURE 11.—Gross energy purchased per 1974 dollar of value added: Select industries



From Myers, John and Leonard Nakamura, Saving Energy in Manufacturing, derived from Census of Manufacturers, Annual Survey of Manufacturers, and Federal Reserve Board Bulletin.

THE ENERGY INFORMATION ADMINISTRATION

Throughout this paper we have quoted a variety of sources of data on productivity, the consumption of energy and energy productivity. Although much of the productivity data is provided by the Department of Commerce, the greatest source of data on energy consumption is the Department of Energy. Within DOE, the Energy Information Administration is very heavily involved in the collection and analysis of energy supply and demand. Yet, as the 1978 Annual Report to Congress by EIA [25], [26] indicates, the preponderance of available data focuses on the supply of energy and its consumption by fuel type rather than by end use or by economic sector. The EIA's *Quarterly Energy Indicators*, a brief fact sheet reporting the latest energy consumption/production figures, fails to mention any measures of economy production levels and/or energy productivity. Clearly, the monitoring of energy productivity according to end use energy services—the ultimate goal of energy consumption, is in relatively primitive stages.

The EIA Annual Report also indicates that many efforts are underway to improve our understanding of energy consumption and efficiency. Some of these efforts are singular studies of select energy markets, whereas others are initiating new periodic surveys and reports. Most of these projects could not be identified individually here, of course, but many of them will help define and refine practical measures of energy productivity.

CONCLUSIONS

The discussion in this paper has made clear that the consumption of energy is deeply imbedded in all the activities of our economy. More importantly, the evaluation of how effectively energy is utilized cannot be established by any one index, or even a handful of indices. For almost every index proposed to measure energy productivity, one can easily identify numerous characteristics which weaken any conclusions drawn from it.

An important criterion for advocating an index is the purpose which it will satisfy. If an index is to be proposed as a national goal and is to be reinforced by the adoption of laws and other mandates, then much more data must be collected to assure that this additional regulation will be effective. Alternatively, indices can be utilized now to monitor, however inexactly, how the economy adjusts its productivity to higher energy prices.

The use of indices to monitor progress toward greater energy efficiency contains considerable merit. Although all such indices contain weaknesses from an analytical perspective, promotion of them is quite likely to stimulate much debate about their meaning and ultimately, the value of energy productivity. The value of this debate, while immeasureable, is extremely high. The fact that no energy productivity goals exist, in the most general sense of economics, dictates that the nation be guided by free and open debate on how it should utilize its resources.

Pragmatically, we can foresee two directions that should be pursued. At the present time a measure of Btu/GNP probably is the most readily adopted index. It can be calculated with reasonable timeliness, it is readily recognizable, it can be determined historically, and it is the most practical method for international comparisons. For publicity purposes, the Energy Consumer Savings Index defined in this paper could help to communicate to the public how well the nation is progressing on energy productivity.

Undoubtedly many singular studies of specific economic sectors will become available in the next few years; many have been done already. Numerous efforts are underway in EIA and elsewhere to improve the collection and reporting of economic/energy relationships on a frequent and periodic basis. We suggest that government financed efforts to inform the public of the results of singular studies could be very beneficial, e.g., TV documentaries on energy productivity in the steel industry. Many such efforts are currently provided by the EIA.

A direction which should be explored is the potential for formulating an aggregate measure of energy productivity that is based on sectoral indices. The appropriate adjustments to these indices for seasonal, load factor, or scale changes that are intrinsic to specific industries would increase the reliability of the aggregate measure. At the present time, probably 80–85 percent of all energy can be identified with sufficiently specific economic activities that proper adjustments can be made.

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APPENDIX

ENERGY CONSUMPTION/EXPENDITURE DATA

[1978 prices, energy in quads—10^{15} Btu]

	1973	1974	1975	1976	1977	1978
Residential/commercial:						
Coal	0.293	0.292	0.248	0.239	0.234	0.265
Gas	7.626	7.516	7.581	7.866	7.462	7.692
Petrol No. 2	6.831	6.214	5.839	6.290	6.327	6.423
Electricity	3.489	3.469	3.584	3.725	3.932	4.087
Electricity loss	8.295	8.419	8.729	9.060	9.589	10.114
Total	26.534	25.912	25.981	27.180	27.544	28.581
Total net	18.329	17.493	17.252	18.120	17.955	18.467
Expenditures (billions)	$62.8	$70.8	$74.1	$80.6	$87.6	$91.7
Industrial:						
Coal	4.377	4.047	3.786	3.773	3.612	3.433
Gas	10.397	10.012	8.532	8.768	8.641	8.504
Petrol No. 2	6.441	6.277	5.929	6.682	7.552	7.666
Electricity	2.341	2.337	2.304	2.525	2.635	2.726
Electricity loss	5.564	5.668	5.613	6.144	6.431	6.752
Total	29.120	28.341	26.164	27.892	28.871	29.081
Total net	23.556	22.673	20.551	21.748	22.727	22.329
Expenditures (billions)	$35.8	$45.6	$48.0	$55.8	$64.9	$68.9
Transportation:						
Coal	.003	.002	.001	0	0	0
Gas	.743	.685	.595	.559	.543	.546
Auto gasoline [1]	14.5	14.1	14.3	15.0	15.6	16.0
Jet fuel [1]	1.45	1.41	1.43	1.50	1.56	1.6
Diesel [1]	2.17	2.12	2.14	2.25	2.34	2.40
Total	18.866	18.317	18.466	19.309	20.043	20.546
Expenditures (billions)	$68.5	$82.2	$83.4	$87.8	$91.3	$92.0
	Prices (1978 constant dollars per million)					
Residential/commercial:						
Coal [2]	0.54	1.03	1.32	1.38	1.36	1.54
Gas [3]	1.65	1.70	1.91	2.16	2.41	2.45
Heating oil No. 2 [4]	2.36	3.23	3.23	3.25	3.52	3.72
Electricity	9.75	10.86	11.29	11.50	11.95	11.89
Industrial:						
Coal	.36	.69	.88	.92	.91	1.02
Gas	.72	.86	1.18	1.50	1.82	1.91
No. 2 distillate	2.36	3.23	3.23	3.25	3.52	3.72
Electricity	4.93	5.95	6.73	6.90	7.32	7.59
Transportation:						
Coal	.36	.69	.88	.92	.91	1.02
Gas	.72	.86	1.18	1.50	1.82	1.91
Gasoline [5]	4.06	4.93	4.94	4.94	4.89	4.78
Jet fuel (kerosene) [6]	1.90	2.60	2.58	2.63	2.84	2.88
Diesel [7]	2.91	3.98	3.89	3.95	4.11	4.11

[1] Transportation petroleum consumption is reported by the EIA in aggregate. The disaggregation adopted here—80 percent gasoline, 8 percent jet fuel, 12 percent diesel—is estimated from traffic volume and operating efficiencies reported in "Transportation Facts and Trends" [23].

[2] Base consumer prices for coal were obtained from the ORNL data book [36]. This price schedule is the same as the one reported in the "Statistical Abstracts" for coal production costs. Residential retail prices were assumed to be 1.5 times higher. Prices for 1973–74 are estimated. Energy content is assumed to be 22×10^{6} Btu per short ton, the EIA [29] rating for bituminous coal, average consumption.

[3] Gas prices are based on "Statistical Abstracts" (1979), reported for gas utility revenue per million Btu sold. Residential and commercial prices were averaged in the proportion of 66 percent/33 percent, respectively.

[4] Heating oil prices were obtained from ORNL [35], for 1974–78. Price for 1973 was extrapolated on basis of 1973–74 transportation diesel prices. Energy content is assumed to be 5.8×10^{6} Btu/bbl, and 42 gal/bbl.

[5] Gasoline prices reported in "National Petroleum News," McGraw-Hill Publication (mid-June 1979). Energy content is assumed to be 5.2×10^{6} Btu/bbl.

[6] Jet fuel prices for 1976–78 are reported by EIA [29]. Price for 1975 was obtained by personal communication from the CAB. Prices for 1973–74 are extrapolated on the basis of 1973–75 diesel fuel prices. Energy content assumed to be 5.67×10^{6} Btu/bbl.

[7] Diesel fuel prices are reported in "National Petroleum News" (mid-June 1979). Energy content assumed to be 5.2×10^{6} Btu/bbl.

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