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DISCLAIMER

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A MODEL FOR LONG-TERM INDUSTRIAL ENERGY FORECASTING (LIEF)

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EXECUTIVE SUMMARY

The Long-term Industrial Energy Forecasting (LIEF) model described in this report was created by Marc Ross, Physics Department, University of Michigan and developed in collaboration with the Energy Analysis Program, Lawrence Berkeley Laboratory. The purpose of this report is to establish the content and structural validity of the model, and to provide estimates for the model's parameters. The model is intended to provide decision makers with a relatively simple, yet credible tool to forecast the impacts of policies which affect long-term energy demand in the manufacturing sector.* Particular strengths of this model are its relative simplicity which facilitates both ease of use and understanding of results, and the inclusion of relevant causal relationships which provide useful policy handles.

The modeling approach of LIEF is intermediate between top-down econometric modeling and bottom-up technology models. It relies on the following simple concept, that trends in aggregate energy demand are dependent upon the factors: 1) trends in *total production*; 2) *sectoral or structural shift,* that is, changes in the mix of industrial output from energy-intensive to energy non-intensive sectors; and 3) changes in *real energy intensity* due to technical change and energy-price effects as measured by the amount of energy used per unit of manufacturing output (KBtu per constant $ of output). The manufacturing sector is first disaggregated according to their historic output growth rates, energy intensities and recycling opportunities. Exogenous, macroeconomic forecasts of individual subsector growth rates and energy prices can then be combined with endogenous forecasts of real energy intensity trends to yield forecasts of overall energy demand.

Proper description of production activities is a key to reasonable forecasting of industrial energy use. Sectoral shifts and changes in real energy intensity can only be properly characterized if careful attention is paid to the kind of *sectoral disaggregation* (Section II) as well as to *data series* (Section IV). It is often more important to the forecast than the description of efficiency improvement. Disaggregation into 2-digit Standard Industrial Classifications (SICs) is not satisfactory for long-term forecasting, neither for energy-intensive industries nor for energy-non-intensive industries. Section II describes a new approach. This requires, of course, some additional information or assumptions, beyond that for the 2-digit sectors.

The long-term, *real energy intensity* forecasting technique proposed here rests on the concept of a *hierarchy of industrial decision making*: 1) choice of fundamental production process, which is autonomous in the sense that it is not sensitive to energy prices, 2) choice of energy-related technologies which is sensitive to energy price, and 3) operational decisions. It is assumed for long-term forecasts that operational decisions, for example the important choices made during recessions, are not of interest. Thus, the modeling effort

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* The model covers the manufacturing portion of the industrial sector. Not included are the agriculture, mining and construction subsectors.

focuses on (1) and (2), as discussed in Section III. For (2), the conservation supply curve (CSC) is adopted as the basic analytical tool. This enables introduction into the model of variables aside from energy prices, which provides useful policy-analysis handles. It is proposed here not to build CSCs up from a list of technologies, but instead to estimate CSCs in the spirit of econometrics, i.e., by statistical techniques using aggregate historical data. While realism is important, detail is not that relevant to a long-term forecast. Results from econometric fitting of aggregate historical data, presented in Section V, are consistent with data from engineering and case-studies.

A brief description of policy analysis using the model is presented in Section VI. This model, with microeconomic-based CSC and interfuel-competition relationships, provides handles for forecasting the effect of policies which affect energy prices, implicit discount rate, penetration rate of conservation investments, recycling rate and recycling energy intensity. To illustrate how analysts can use LIEF in analyzing policy scenarios, two forecasts are presented using a Lotus 1-2-3, Release 3.0, spreadsheet version of the model. One scenario is "business-as-usual" and the other assumes strong conservation policies. These sample forecasts are not especially sophisticated, and we intend to develop more realistic forecasts in the future.

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I. INTRODUCTION

A. Why Long-Term Forecasting?

Organizations involved in long-term or strategic planning, such as government agencies, oil companies and utilities, need models to assist them in decision making. These organizations, as well as environmental organization and other interveners in the planning process, need to understand forecasting models and the spirit of long-term forecasting. By its very nature, demand forecasting beyond 5 to 10 years is rife with uncertainty and should not be viewed as an attempt to produce quantitatively exact predictions. Instead, when grounded in the understanding of the important, underlying mechanisms that drive energy demand and based on explicit assumptions about future policies and other future conditions, long-term forecasting models provide important inputs into the planning process by providing decision makers with illustrative, alternative scenarios.

Future energy consumption is a critical area for long-term planning because of the large costs and long lead times involved in building new capacity and in conducting R&D connected with energy supply and use. Furthermore, we are now faced with increasing marginal costs of replacing or increasing existing supply capacity. Government has many policy tools, many of which were tried in the energy crisis of the 1970s and early 1980s, which can affect energy consumption in the long, as well as short, term.

The purpose for which long-term energy forecasting is used does not involve accurate prediction of energy use several decades in the future. A misforecast by, say, 50% would spoil the usefulness of such a prediction. Instead, one wants to raise issues, to make rough judgments among options, to illustrate. A suitable question to ask of a long-term forecasting model might be: How sensitive would the roles of two competing energy technologies be to variations in their capital costs? Or, how sensitive is energy savings to the discount rate of the investor in conservation equipment? For such questions, a misforecast by a factor of two might not spoil the usefulness of the forecasts. It is not that the forecast is more accurate in these latter cases, but that the questions may be more appropriate. Long-term forecasts can be used to help create alternative scenarios, which in turn might help in the design of robust policies (Davis 1988). They might be used to help identify insurance measures that would be useful in case the main policy thrust proved less than successful. They might be used to help systematize a process of periodic policy review. A valuable role for long-term forecasting can thus be as a tool in an ongoing planning process.

The model discussed in this paper has been developed with the needs of decision makers in mind. It is intended to provide the user with a relatively simple, yet credible, long-term forecasting tool. To establish credibility in the eyes of decision makers, a forecasting model must be both valid and understandable (Kaya 1990, Lipinksi 1990). Besides having statistical validity, a valid model should include relevant and reasonable causal relationships (content validity) within a legitimate structural relationship (structural validity). An understandable model is important because users are reluctant to trust model results when they cannot grasp the underlying mechanisms driving the output. For this reason, highly detailed, complex models are often given less credibility than simpler models that may or may not be less accurate (Baker and Finizza 1990). A long-term model should also be readily amenable to modifications by the analyst (NEMS 1991), and the model described here is designed with this in mind. Furthermore, the structural equations of the model described here incorporate relevant causal relationships which provide the user with several policy-related handles, enabling the forecasting of policy-induced changes in energy consumption and other descriptors, relative to a base case. Significant modeling capability for several, but not all, potential policies is provided, as will be discussed in Section VI.

The purpose of this report is to establish the content and structural validity of the model, and to provide estimates for the model's parameters. This model is critically dependent on the proper disaggregation of the manufacturing sector and on keen insight into the determinants of changes in real energy intensity. Section II discusses the disaggregation scheme and how the model's equations account for the shifts in the structure of the manufacturing industry. Section III discusses the important sources of change in energy intensity and how the model incorporates the effects of these factors. Section IV discusses the general difficulties in determining the appropriate data for energy analysis, and the reasoning behind the data used here. Section V explains how we estimated the necessary parameters using a variety of techniques including econometric analysis and engineering studies. Finally, Section VI discusses how the model can be used to analyze various policies. We begin with background on previously developed industrial demand models and a brief overview of this model.

B. Other Models

The proposed modeling approach is intermediate between top-down econometric modeling and bottom-up technology models. Econometric models forecast energy use on the basis of parameters statistically estimated using historical data. These models primarily describe price sensitivity. Their principal strengths are that they reflect actual historical behavior, and that they can be relatively simple. Their principal limitations are that the policy handles are essentially limited to prices and that they may be much less reliable.

The current industrial spreadsheet model of the Energy Information Administration is an example of this approach, involving, essentially, elasticities associated with energy price and production in each of several sectors (EIA 1990, Werbos 1983). The Electric Power Research Institute (EPRI) has developed the INDEPTH level 1 econometric model, which incorporates four alternative mathematical formulations for statistical analysis. Three of these accommodate economic theory by relating energy consumption to capital, labor and materials prices, as well as to energy price and production (EPRI 1990). From the point of view of economic theory, it is quite important whether capital stock and the cost of capital are incorporated in a model; in that way, the dynamics of change can be modeled (Berndt 1981, Watkins 1991). However, the available deflated series for capital (and materials) for the separate industrial sectors are rather inaccurate for these purposes, so it is not clear that there is much practical benefit from this approach. The INDEPTH analysis is for each two-digit Standard Industrial Classification (SIC) sector of manufacturing. The INRAD model of Argonne is similar to one of the INDEPTH econometric formulations (Boyd 1991). It disaggregates metals, chemicals, and pulp and paper below the 2-digit level. INRAD also experiments with the inclusion of major process innovations in the historical period, including data on their level of implementation, to explore the impact on estimated parameters.

A different econometric approach enables deep analysis of the effects of changing industrial structure and changing structure of international trade: input-output analysis (Herendeen 1974, Roop 1987, OTA 1990). Perhaps the earliest indication of industrial shift away from basic materials manufacturing was found by this method (Carter 1966).

In all these econometric approaches, at least three important characteristics (parameters) of energy intensity are estimated: production (and/or time) dependence, own-price dependence, and electricity-fuel substitution (and, in some cases, interfuel substitution). The different formulations lead to rather different parameter values, as should be expected. For example, the own-price elasticities for electricity, in three INDEPTH formulations for the various sectors, range from -0.01 to -1.3 with two-thirds of the values in the range -0.2 to -0.7. The elasticities vary strongly and irregularly with both sector and formulation. These variations may be the result of problems with excessive or inappropriate aggregation, and/or inadequacies of the approach for dealing with the varied conditions in the period 1958 to 1985.

The bottom-up or technology models describe a large number of energy-use technologies in the context of production processes which may be described in detail (process models) or perfunctorily. All important technologies, or at least a complete list of representative technologies, should be included. The principal drawbacks to technology models are their voracious data requirements (if they are realistic). Data requirements are huge, both to establish the model and to update it. For example, the creation in the late 1970s of ISTUM-2, with a $2 million budget, provided for a good technology description for pulp and paper mills and an interesting approach for industrial chemicals, but funding was inadequate for an interesting analysis of other industries (EEA 1982). Furthermore, some decision makers show a distrust for these large complex models, and instead prefer small models which can be more easily understood (Baker and Finizza 1990).

Process models have been created for specific industries. At least three were created for DOE in the late 1970s and early 1980s (Pierce 1983, Pilati and Rosen 1978, Reister 1979) and are now beginning to see some use by electric utilities and regulatory commissions. In these models, generic plants are modeled by stage of production, including process units, materials and energy flows, and costs. Changes in variables associated with different major kinds of products and different major process choices are modeled. Technological options for conserving energy are included. Since the models are highly complex but do not describe particular mills accurately, they are hard to evaluate. In addition, they are costly to keep current.

The key difficulty is that industry uses hundreds of different processes, dozens of which are important for energy analysis. One approach to avoiding this heterogeneity is to model generic functions like motors, lights, electrolysis, and low-and high-temperature heating.

This generic or functional approach can at best provide a seriously incomplete analysis, however. It is not adequate to analyze a function like steam production (focusing on improved boiler efficiency), or like motors, or even more specific functions such as pumping and air handling. An example of the problem is provided by compressed air in SIC 3465, stamping of metal sheets into auto body panels. While the efficiency of the large compressor motors might be improved 1% or 2%, and that of the compressors by a few percent, a 50% reduction in plant-wide compressed air requirements is being achieved by changing the compressed air cushions in stamping presses from pistons which leak, to a new technology based on coated air bags which do not leak (Price and Ross 1989). Thus, the major part of the long-term potential savings in this sector is not associated with modifications to motors or compressors, but is process-specific.

The concept, borrowed from analysis of the buildings sector, that generic energy services (like motor drive and lighting) would provide a useful basis for analysis of industrial energy use is therefore incorrect for industry. Truly generic technologies describe less than half the conservation opportunities. Other technologies which may appear generic are not. For example, variable speed motor controls are custom designed for most process-related applications, and the engineering costs are often higher than the equipment costs. Rather than generic functions, most energy services must be narrowly process-specific in a good technology model.

The Oak Ridge Industrial Model (ORIM 1982) is an example of a hybrid model with some features of both top-down and bottom-up models. It deals with four energy services: steam, other process heat, machine drive, and other electrical services. Nine manufacturing services are modeled econometrically using production functions with fuel, material, labor and capital as the factor inputs. Although the technologies are not described explicitly, the model is data intensive. A strength of the model is explicit representation of the vintage of facilities in each sector (although the vintage data is merely based on the age of the building). A weakness is that by relying on highly generic services, process change (altering the role of generic service per unit of intensity) receives little attention in the modeling.

C. Overview of This Model

Like the hybrid models, the model proposed here incorporates some features of both top-down and bottom-up models. Unlike ORIM, this model does not explicitly model energy services. Instead, it relies on the concept that trends in aggregate energy demand are dependent upon the factors: 1) trends in *total production*; 2) *sectoral or structural shift,* that is, changes in the mix of industrial output from energy-intensive to energy non-intensive sectors; and 3) changes in *real energy intensity* due to technical change and energy-price effects as measured by the amount of energy used per unit of manufacturing output (Marlay 1984, Boyd 1987, Doblin 1988, Howarth 1991). The model's approach is to first properly disaggregate the manufacturing sector according to output growth rates and energy intensities. Real energy intensity trends can then combine with exogenous, macroeconomic forecasts of individual subsector growth rates and energy prices to yield forecasts of overall energy demand. Figure 1.1 provides a schematic overview of this model.

The model calculates aggregate electricity and fossil fuel demands using the following simple formula:

$$E_j(t) = \sum EI_{ij}(t)\ Q_i(t) \qquad (1.1)$$

where i = manufacturing sector;

j = energy form;

$E_j(t)$ = total energy demand for energy type j;

$EI_{ij}(t)$ = energy intensity by sector i of energy type j;

$Q_i(t)$ = production value by sector i.

The effect of trends in total production is accounted for through summing the production values, $Q_i(t)$, across all sectors. The effect of sectoral shift is accounted for by the differing rates of change in sector production shares, $Q_i/\sum Q_i$. Finally, changes in real energy intensity are associated with the term $EI_{ij}(t)$.

Proper description of production activities is a key to reasonable forecasting of industrial energy use. Sectoral shifts and changes in real energy intensity can only be properly characterized if careful attention is paid to the kind of sectoral disaggregation (Section II) as well as to data series (Section IV). The choice of disaggregation can be more important to the forecast than the description of efficiency improvement. Disaggregation into 2-digit Standard Industrial Classifications (SICs) is not satisfactory for long-term forecasting, neither for energy-intensive industries nor for energy-non-intensive industries. Section II describes a new approach. This requires, of course, some additional information or assumptions, beyond that for the 2-digit sectors.

The long-term, real energy intensity forecasting technique proposed here rests on the concept of a hierarchy of industrial decision making: 1) choice of fundamental production processes, which is autonomous in the sense that it is not sensitive to energy prices, 2) choice of energy-related technologies which is sensitive to energy price, and 3) operational decisions. It is assumed for long-term forecasts that operational decisions, for example the important choices made during recessions, are not of interest. Thus, the modeling effort focuses on (1) and (2), as discussed in Section III. For (2), the conservation supply curve (CSC) is adopted as the basic analytical tool. This enables introduction into the model of variables aside from price, which provide useful policy-analysis handles. Figure 1.1 illustrates how these factors relate to the forecast of energy intensity.

For the building sectors, CSCs have been constructed on the basis of detailed lists of technologies (Meier 1983, Koomey 1991, McMahon 1986). It is suggested here instead, that less-restricted procedures be used to estimate and describe CSCs. While realism is important, detail is not that relevant to a long-term forecast. Case studies of a few representative processes and use of cross-sectional comparisons should enable one to generate representative CSC parameters (Ross 1990). Moreover, it is proposed to consider the CSC partly in the spirit of econometrics, i.e., by statistical estimation using aggregate historical data.

The principal model variables which affect sectoral energy intensities are autonomous (or price-independent) time trends, energy prices, implicit capital recovery factors, slope and intercept parameters for the conservation supply curves, and the rate of penetration of conservation technologies. Two important groups of variables are not included in the model: 1) variables directly representing capital investment in basic process facilities and vintage of facilities, and 2) variables describing short-term phenomena, especially response to changes in capacity utilization. Capital-related behavior is important. It is indirectly incorporated in the model by providing for sectoral dependence of the autonomous time trend.[1] Capital investment in conservation measures is addressed by use of conservation supply curves with explicit capital recovery factors. This limited treatment of capital is justified, in part, by the strong desire for simplicity, especially in data requirements and, in part, by the poor quality of information about real capital prices, expenditures and retirement of facilities. In addition, although there are great differences in the energy intensity of new and old facilities, the opportunities for conservation improvement are not as different in retrofit and new facilities as might be imagined. In particular, high implicit discount rates for investment in conservation equipment tend to apply to both old facilities and facilities about to be built; the same kinds of budgetary constraints often apply to discretionary investments in the two situations.

Perhaps the main characteristic of the model, besides that it has policy handles in addition to prices, is its simplicity and brevity. A model run with all output tables is computed on a typical PC in about one second. *All* 130 parameters in the current 4-sector model can be thoughtfully changed in roughly half an hour. And all these parameters (except perhaps the fuel switching parameter) have familiar interpretations. It is planned for a future version to enable changes in functional forms such as those for expected price and conservation supply curve.

[1] In a later version of the model, we will consider relating autonomous change to long-term trends in growth of output.

II. THE STRUCTURE OF INDUSTRIAL ENERGY USE

A. Introduction

The total consumption of a particular form of energy by industry is analyzed as a sum over the subsectors of the production activity times energy intensity as shown in equation 1.1 where $Q_i(t)$ is a measure of the annual production in sector i and $EI_{ij}(t)$ is the energy consumption per unit of that measure. For example, for electricity in cement manufacture, $Q_i(t)$ could be tons of cement produced in a particular year and $EI_{ij}(t)$ the average kWh/ton for electricity used that year. If one has a measure of total industrial production $Q(t)$, then,

$$EI_j(t) = \frac{E_j(t)}{Q(t)}$$

where $EI_j(t)$ is the aggregate intensity, the overall measure of industrial performance for each energy form, j.

As mentioned in Section I C, trends in the aggregate energy demand depend on total production, the changing mix or structure of production (sectoral shift) and the changing intensity in each sector. The latter is summarized by the real intensity, i.e., the energy-weighted average of the individual-sector intensities. Although changes in the real energy intensity are of great importance, structural change is of comparable importance in overall efficiency. The reason structural effects are large is the great range in energy intensities across sectors, e.g., from the manufacturers of primary aluminum to the manufacturers of computers, and the rapid growth in production in some low-energy-intensity sectors and slow growth in essentially all the energy-intensive sectors.

B. The Energy-Intensive Industries

The most energy-intensive sectors are the industries in which bulk materials are manufactured: metals from ore and scrap, pulp and paper, industrial chemicals including refined petroleum products, and cement, concrete, pottery and glass. The energy-intensive parts of these industries typically do not extend to shaping and assembly of these materials.

The key fact is the decline in consumption of bulk materials relative to industrial activity as a whole (Williams 1987). Printing papers, plastics and industrial gases like oxygen and nitrogen are the only important materials whose consumption is still rising roughly with the economy; the consumption of others, measured in tons, is declining. The phenomenon is called *dematerialization* (Herman 1989). While the statistical trends for any short period may not provide compelling evidence for the phenomenon, long-term statistics and analysis of product design and markets are compelling. They strongly suggest that dematerialization will continue as a long-term trend.

Dematerialization is not caused by increasing imports of some materials. It is an issue of consumption, not production. On the other hand, production forecasts must take net exports into account. Net exports of some bulk materials like paper, steel and cement have good long-term prospects for the U.S. Other bulk materials, like those based on petroleum, may in the long term see production move overseas. In addition, the relative lack of growth in U.S. markets for bulk materials (as distinguished from fabricated products or engineering materials) will tend to make U.S.-based production of these materials less competitive in the long term.

The effects of the changing mix of production can be summarized as a structural shift, the rate of change in aggregate energy intensity due to the changing composition of production. For the period 1971-1985, the sectoral shift averaged -1.6% per year for fossil fuel, about -0.9% per year associated with changes in consumption and the rest with the decline in net exports (largely confined to the early 1980s). Results for electricity are similar (Boyd 1989).

C. The High-Growth Sectors

An important structural phenomenon is also taking place among some of the low-energy-intensity sectors. Statistical information and case histories support the concept that high-technology product sectors will play an important role in reducing the aggregate energy intensity of industry in the long term (Ross 1991). During the 1970s and 1980s, the fastest growing sectors, especially electronic equipment, drugs and instruments (such as measuring devices), have been the main sources of growth in overall industrial production. It seems likely that these and other research-intensive, innovative sectors will continue to propel growth in U.S. industry as it matures.

In Figure 2.1, growth in output is compared with energy intensity for the 71 manufacturing sectors in the National Energy Accounts. The distribution is shaped like the Greek letter L (in the xy-plane) with all the big energy users having low growth and high energy intensity (left-hand arm of the L, with energy intensity decreasing moving to the right on the log energy intensity axis), and all the high-growth sectors having low energy intensity (right-hand arm of the L). The sectors (and SICs) with real gross output growing roughly 4% per year and faster for 1971-1985 are:

- furniture and fixtures excluding household furniture (25, excluding 251)
- printing and publishing (27)
- drugs and toiletries (283 & 284)
- rubber and miscellaneous plastics products (30)
- computer and office equipment, and miscellaneous industrial machinery (357 & 359)
- electronic equipment and components, communication equipment, and miscellaneous electrical equipment (365 & 369)
- selected military equipment (3761 & 3795)
- instruments (38)

If one could disaggregate some of these sectors even more, the real gross output growth rate would be even greater. For instance, inclusion of the slow-growing tire sector with plastic products and the slow-growing typewriter sector with computing machines reduces the real gross output growth rates of these sectors. The key energy behavior is the low and declining energy intensity of these high-growth sectors.[2] The decline in the energy intensity of these sectors is extremely rapid. This decline is not due to energy conservation

[2] Here, energy intensity can be measured as energy consumption per unit of value added in a base year. Relative changes in energy intensity are, however, much better measured in terms of the ratio of energy to deflated gross output.

efforts. It is largely due to continuing product innovation embodying design improvements which have a major impact on the value of the products but relatively little on the use of materials and energy. In addition, new plants and efficient processes are rapidly being introduced. If such sectors continue to become more important in the economy, they may strongly dampen the aggregate energy intensity of industry.

D. Categorizing Industry for Energy Analysis

The categorization of the standard industrial classifications (SICs) has been troublesome for energy analysis. The twenty 2-digit level categories within manufacturing were created many decades ago and do not adequately reflect modern industry. The problem is not that there are too few 2-digit sectors, but that they are badly aggregated. The main difficulties are that: 1) some energy-intensive 2-digit industries, like chemicals and allied products, contain a heterogeneous mix of highly energy-intensive and energy-non-intensive sectors, and 2) some energy non-intensive 2-digit sectors, like non-electrical machinery, contain a heterogeneous mix of very fast-growing sectors (that drive economic growth as a whole) along with slow-growing sectors of low, but significantly greater, energy intensity. It is these differences in economic growth and energy intensity between subsectors of a given 2-digit sector which call for further disaggregation. It is not proposed here that one should carry out analyses at the 3-digit SIC level with its 100-plus sectors. That would be inappropriate for long-term forecasting. It is proposed to organize the manufacturing subsectors into 4 to 10 sectors, as shown in Figure 2.2 for four sectors. This four-sector structure can be used whether one is investigating a single 2-digit sector like chemicals or all of industry. The structure will be seen to enable analysis of the growth and energy intensity variations just discussed, and of recycling.

There are two sectors of energy non-intensive subsectors in Fig. 2.2: (1) slow growing and (2) fast growing. The SIC subsectors which are regrouped are roughly at the 3-digit level. As discussed above, the typical fast-growing sector (e.g., computers, drugs and medical instruments) has innovative products and is research intensive, although there are some moderately fast-growing sectors which are not research intensive (e.g., plastics products) and do not have the extraordinarily low-energy intensities of the very fast growing sectors.

Returning to the group structure of Figure 2.2, one sees that there are two energy-intensive sectors: (3) materials processing where recycling is not an option and (4) processing where recycling is an option. Thus, recycling is an alternative within (4). The materials processes where recycling is an option are:

iron and steel (leading to liquid iron or steel)
non-ferrous metals (e.g., aluminum)
glass (to molten glass)
some organic chemicals (leading, e.g., to plastics)
pulping (preparing fiber for papermaking)

Not all products in these general categories can be made from recycled material, so limits on substitution by recycled material are needed in a model because of such technological restrictions, as well as perhaps, because of materials availability or price. Major material areas without recycling potential are cement and clay, most chemicals, and all fuels. In principle, the division of an industry between sectors (3) and (4), for example, between the processes leading to liquid steel and those which follow (casting, shaping and treating), should be more disaggregated than the 4-digit level. Detailed analysis is needed to determine the best approach for an adequate analysis of recycling; at present, disaggregation essentially at the 3-digit level is adopted.

For many purposes, the grouping of all energy-intensive sectors into two sectors is too aggregate for energy analysis. A suitable level of disaggregation within sectors (3) and (4) would be:

Sector 3	**Sector 4**
non-recyclable industrial organic chemicals	paper products
industrial inorganic chemicals	plastics and other recyclable organics
cement, clay products	glass
	iron & steel
	non-ferrous metals

Since aggregation of the energy non-intensive sectors (1) and (2) is probably adequate, this disaggregation scheme would yield a 10-sector model of manufacturing.

Where all industry is the subject, rather than manufacturing or a part of it, the non-manufacturing industries, except for construction, could be grouped with the sectors just discussed. Thus, agriculture and fisheries could be associated with food processing (SIC 20 in sector (1), forestry with SICs 24 and 26, oil and gas extraction with SIC 29, metal mining, and perhaps metallurgical coal mining, with SIC 33, etc). The largest non-manufacturing subsectors in terms of energy use are food and feed crops, and oil and gas extraction. Unfortunately, energy-use data for all these non-manufacturing subsectors are highly uncertain, and consequently are not included in the current spreadsheet model.

III. THREE SOURCES OF CHANGE IN ENERGY INTENSITY

A. Introduction

The approach to describing changes in real-energy intensity developed here rests on the assumption that most investments affecting energy intensity can be classified as either *energy-price sensitive* or *energy-price insensitive* (autonomous technical change). While many decisions by manufacturers involve consideration of energy, energy cost is a secondary consideration in most decisions. Other concerns occupy management such as: marketing, product quality, reliability and rate of production, labor productivity, employee morale and contracts, safety, environmental regulations and concerns, materials and parts supply, financial arrangements, acquisitions, technological style and capabilities, product development, and special stockholder concerns. Even in the few industries where energy costs are a considerable fraction of total costs, energy costs are usually a secondary concern. There are some exceptions like the industrial gas sector and the primary aluminum sector.

This means that, for almost all manufacturing, the selection of a production process is not at all sensitive to energy price, i.e., it is *autonomous* of changes in energy price. For example, steel firms do not choose electric-arc furnace technology with a primary concern for electricity prices, but because the scrap-based process involves lower capital costs than ore-based processes, scrap is available in the region, the scale of production can be kept relatively small and product markets look promising. To model the choice of the electric-arc based process from an energy cost perspective would be misleading. Empirical study supports this conclusion: electricity price has not had a substantial effect on this process choice, although it has influenced the particular arc-furnace parameters (Karlson 1990). This general conclusion is even stronger for less-energy-intensive sectors than steel.

Although it plays a secondary role in most investment decisions, energy price is of primary concern for certain investments, such as energy conservation and fuel choice project by industry. These investments, in turn, do have major impacts on energy use, i.e., these investments are *energy price sensitive*. For example, choice of boiler or heater including fuel capabilities, add-on equipment such as automatic controls, and thickness of insulation, strongly influence energy use and the decisions are strongly influenced by energy prices. Many investments have multiple benefits, but energy prices receive special emphasis because the energy benefits tend to be predictable and quantifiable, while other benefits may not be. It is reasonable to classify such investments as energy-price related.

The proposal then, is to recognize this heterogeneity and divide investments into two categories: *energy-price sensitive* and *energy-price insensitive*. The former category tends to involve projects small and medium in size, up to the order of tens of millions of dollars. These choices only rarely determine the fundamental production process. The latter category involves projects of all sizes, including the very large. They include fundamental process choice. There are, of course, important examples which are not easily categorized. In the early 1980s, for instance, it was disputed whether continuous casters for steel were energy-conservation technologies and thus eligible for the energy investment tax credit. It is assumed here, however, that if the analyst makes reasonable allocations, the two categories effectively separate the great majority of investment projects.

B. Autonomous Technical Change

Substantial evidence shows that general progress in production technology tends to reduce all inputs roughly to the same extent: 1) The energy costs associated with established types of processes are reduced along with other costs (Berg 1978). The energy intensity of energy-intensive industries fell in the 1950s and 1960s when energy prices, including electricity prices, were low and often falling (Williams 1987); 2) New applications of electricity continue to occur, where surface treatment and specific heating (as contrasted with general volume heating in a typical oven) are two currently important areas (Berg 1989, Schmidt 1984, Resource Dynamics 1988). In addition, some electricity consumption is associated with added environmental controls. Thus, most electrification is based on markedly superior production technology, not energy price; and 3) Learning or experience curve studies of particular processes like high-pressure production of low-density polyethylene, show fairly steady and remarkably large cost reductions over long periods (Argote 1990, Joyce 1991).[3] Energy costs decline along with total costs, although less rapidly in many cases.

For modeling purposes, it is necessary to quantify these autonomous trends. The paucity of good data and the mixing of effects in an analysis, such as autonomous change and output elasticity, prevent meaningful specification of complex relationships. In other words, we typically have enough data to enable determination of, at best, only one parameter to represent the effect. Some economists are not even convinced of the phenomenon of autonomous change because it is difficult to pull it out from general statistical data. Case studies make it clear that the phenomenon exists and is important; but how should the relationship be specified? Quantitative data on manufacturing costs for specific processes have been developed for many "learning curve" studies. Starting at low levels of production, unit costs are found to decline about 20% for every doubling of cumulative production. This implies, for typical manufacturing, a 0.5% to 1.0% per year decline in total costs per unit of production. (See Appendix B.) Unit energy costs may decrease less rapidly. Moreover, the unit energy cost typically consists of an increasing unit electricity component and a decreasing unit fuel component. In any case, this type of analysis suggests the introduction of a factor in the determination of energy intensities for fuel and electricity separately:

$$EI_j = EI_{jo} \left(\frac{q(t)}{q(0)}\right)^{-B'j}$$

where $q(t)$ is cumulative production corresponding to a particular product or process. Similarly, for an entire sector, the relationship is better correlated with time,

$$EI_j = EI_{jo}\, e^{-B_j t} \qquad (3.1)$$

Typically, $|B|$ is of the order of 1% per year, or $B' \approx 0.3$. One may also want to assume maturation of this dependence in long-term forecasts; that is, a function $B(t)$ which decreases over time. (See Section III E.)

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[3] The reductions actually correlate better with cumulative production rather than time.

C. Conservation Supply Curves

1. General Formalism

Conservation supply curves (CSCs) are adopted as the basic tool to analyze energy-price sensitive changes in energy intensity. Incorporation of CSCs in one's model creates useful policy handles by including microeconomic considerations of capital cost, discount rate and energy savings of conservation projects. For example, the impact of capital subsidies, such as tax credits, can be estimated since capital requirements for conservation can be deduced from the CSC.

Energy analysts often construct conservation supply curves (CSC) in order to illustrate the cost-effective energy conservation potential in a given sector (Koomey 1991), i.e., they are used for normative purposes. Energy analysts also use CSCs to forecast the impact of energy conservation programs on energy demand (McMahon 1986). For a given sector, these two CSCs should contain the same technical information, but different assumed discount rates. The former assumes a social discount rate or the utilities' weighted average cost of capital[4], an average of 5% to 7% real (Koomey 1990). CSC used in forecasts, however, must use the estimates of the implicit discount rate that the relevant market as a whole displays for the particular energy conservation measure, typically much higher than utilities' weighted average cost of capital. In this report, we will refer to CSC designed to illustrate cost-effective energy conservation potential as *engineering* CSCs, and the CSCs used to forecast energy demand as *investor* CSCs.[5]

The initial form of the CSC which we consider is illustrated in Figure 3.1. It is commonly constructed from the "bottom-up" using a list of specific measures.[6] The y-axis, K/S, is the unit capital cost of a project, the cost divided by the rate of energy saving, K/S, (e.g., $ per average kW or $ per bbl/day saved). The x-axis shows the cumulative energy savings capacity, expressed either as an absolute rate (e.g., average kW or kWh/yr) or as a percent (e.g., of annual energy use). The CSC is a *capacity* supply curve, which is slightly different from supply curves usually discussed by economists. The actual supply ranges up to the capacity, depending on the fraction of capacity used. It is analogous to an oil and gas supply curve: as money is spent to develop facilities, the capacity to deliver energy (here saved energy) increases. And as the opportunities are exploited, developing further capacity becomes more expensive.

Alternatively, in order to facilitate comparison to the cost of purchasing, energy analysts often convert the project's capital and operating costs into a stream of annual payments divided by the annual energy savings. In this form, the project's costs are known as the

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[4] Since utilities are regulated, the weighted average cost of capital should be about the same as utilities' rate of return on capital.

[5] Note that the term *investor* refers to the consumer investor and not the utility investor.

[6] For industrial sector examples, see Heidell and King 1990 and Miller, et al. 1989.

"cost of conserved energy" (CCE) (Meier 1983) which is calculated using the following formula:

$$CCE = \frac{((K_k\, CRF) + R)}{S_k} \qquad (3.2)$$

where CCE = cost of conserved energy, e.g., in units of \$/kWh;
K_k = capital cost of project k, \$;
CRF = capital recovery factor, yr^{-1};
R = any annual, non-energy costs associated with the project k, \$/yr;
S_k = expected annual amount of energy saved, kWh/yr.

The formula for the capital recovery factor (*CRF*) is simply a standard financial formula to convert an initial capital outlay into a stream of annual payments with equivalent present (i.e., discounted) values:

$$CRF = \frac{d}{(1-(1+d)^{-n})}$$

where d = annual discount rate;
n = amortization period or expected lifetime of project.

The discount rate is the social discount rate or the utility's average rate-of-return on investments when constructing an engineering CSC and the implicit or market discount rate when constructing an investor CSC.

When the CSC is expressed in terms of CCE, the assumption of different discount rates with the same technical information creates a family of CSCs (Figure 3.2). For example, with a discount rate of 30% per year and an expected project life of 10 years, $CRF = 0.32$; while changing the discount rate to 10% per year yields $CRF = 0.16$. With these two discount rates, two CSCs are obtained. The upper curve (d.r. = 30%) describes actual investment behavior which yields a lower energy savings for a given price than the lower curve (d.r. = 10%).

Note that the lower curve describes a phenomenon of great interest to many conservation analysts. Some economists believe that high implicit discount rates can be explained by theories of rational investment behavior and well functioning markets.[7] However, we believe that these theories can only partially account for implicit high discount rates and that the residual represents a market failure. (See Section VI A.) One can further imagine mechanisms for correcting this failure. For example, another organization, like a utility, might be able to make the investments, using its own discount rate and other criteria, without injuring the financial position of the firm that operates the facility. With the lower discount rate, there would be a "societal surplus" (hatched area of Figure 3.2) involving the projects which would be done with the lower discount rate but at the same energy price.

2. *Drawbacks of Bottom-Up CSCs for Forecasting in the Industrial Sector*

The industrial sector has extraordinarily difficult data problems which prevent realistic, long-term bottom-up CSCs from being constructed, necessitating the adoption of a different technique in long-term industrial energy forecasting. In this model, information

[7] See for example Sutherland 1991.

from several sources is used: technology characterizations for sample subsectors, technology adoption behavior, and econometric analyses.

The major data problems are due to the inability to characterize the end-use demand of the hundreds of industrial processes and the inability to characterize industrial investment behavior. As discussed in Section I, compiling a list of technologies that could provide reasonable coverage to the industrial sector is a formidable, not to mention expensive, task. Furthermore, only a fraction of the sites where a technology in principle is applicable is actually suitable. Since CSCs are often displayed with the y-axis as energy price rather than as amortized unit capital cost (or *p/CRF*), one must adopt the discount rates appropriate to the behavior one believes will exist. As a consequence, the cost of energy conservation may be misleading if the *CRF* is mis-specified.

Finally, perhaps the most troubling data problem is the analyst's inability to forecast future innovations. In constructing engineering CSCs for the industrial sector, Heidell and King (1990) point out the following:

> The estimates are for *short term* supply curves based upon programs and conservation measures that a utility can implement in the short term (next five years). The technologies are proven and thus have a relatively high likelihood of being acceptable to the industrial customer. On the other hand, *the development and acceptance of new technologies can make the current estimates obsolete.* (emphasis added)

Curve A in Figure 3.3 shows a typical CSC that rises rapidly at some energy intensity limit as the better known and less expensive energy conservation capacity becomes exhausted. Data from high-energy-price environments suggests instead that this positive limit is usually the result of lack of knowledge or imagination on the part of the analyst. In fact, new conservation opportunities and technologies will be found if prices rise and stay up for a while. The correct relationship usually has the form of curve B, Figure 3.3. Whatever information is available to determine the long term CSC shape is, however, highly approximate. Not only is detailed cost data missing for most cases, especially for technologies which would be important at high prices, but there is great variability from plant to plant and from industry to industry.

3. *The CSC Concept in LIEF*

If some simplifying assumptions are made, CSCs can also be constructed from the "top down," that is, without a comprehensive list of projects. In this manner, we essentially establish a relationship between the *long-run price elasticity of energy consumption* and the technical possibilities incorporated in a CSC. We begin by assuming that a firm's investment decision in an energy conservation project, k, can be characterized by the following simplified, "break-even" microeconomic criterion:

$$S_k p_k = K_k \, CRF + R \qquad (3.3)$$

{annual energy cost savings} = {annual cost of measure}

S_k is the annual energy savings associated with the project, K_k is the installed capital cost, and R is any residual operating cost or benefit ($/year). p_k is the levelized energy price or price expectation of the decision maker. From this perspective, the *CRF* characterizes the firm's actual investment behavior in energy efficiency.

Of course, equation 3.3 is simplification of the actual decision process a firm undergoes when it is considering an energy efficiency investment. The firm may have investment criteria other than just to break-even, such as payback time or rate of return. Alternative models of investment behavior range from the simple such as satisficing and capital rationing (Ross 1986) to the more financially sophisticated such as capital asset pricing model (Herbst 1990). Furthermore, firms have investment objectives other than just cost minimization, such as market share. Firms are concerned with cost minimization as only one way to increase profits. Additionally, there are market barriers to energy efficiency investments (see Section VI A). Barriers would include limited access to capital, uncertainty in energy prices, perceived riskiness of energy-efficiency investments, and information costs. Hence, even when the goal is cost minimization, the typical *CRF* associated with an individual firm's energy investment behavior is higher than its average rate of return on capital. By subsuming all these factors into a single *implicit CRF,* equation 3.3 characterizes the decisions of the firms that have decided to invest in energy efficiency.[8] Like *implicit discount rates*, an implicit *CRF* is defined as the *CRF* which would make actual investment behavior *appear* economically rational in terms of a break-even criterion (Stern 1986).

An investor CSC is related to the technical possibilities displayed in an engineering CSC through the implicit *CRF*. Hence, the investor CSC determines the *long-run price elasticities*. On the other hand, the *short-run price elasticity* observed is dictated in large part by the penetration rate of energy conservation or the *adoption* behavior of industry.

By inspection, one can see that the equation for an investor CSC (equation 3.2) is functionally equivalent to the equation for a break-even investment (equation 3.3). Hence, project k provides one segment on the investor CSC, Figure 3.1. The remainder of the curve can be established using the standard, bottom-up method by ordering a series of projects according to their break-even price. Since this curve uses behavioral discount rates, it would describe the investment and energy savings which would eventually occur at increased energy prices (while maintaining the same implicit discount rate).

In order to eliminate the need for a comprehensive list of projects, we note that the CSC shown in Figure 3.1 as a series of discrete projects can be approximately represented by a smoothed curve. Let us assume that, for the average project, R can be neglected in equation 3.2. Then in the neighborhood of project k, the sequence of ordered projects establishes the slope of the curve b, the increase in unit capital cost associated with the annual energy savings due to a set of projects:

$$\Delta\frac{K}{S} = b\Delta E$$

[8] To characterize the entire market by equation 3.3 (as opposed to a single firm's decision), one would need to estimate a *market CRF*, that is, the *CRF* that would describe the overall performance of the energy efficiency market *as if* the market in the whole acted in a life-cycle cost minimizing manner. Ruderman, Levine and McMahon (1987) used an analogous concept, *market discount rate*, to characterize aggregate investment behavior in energy efficiency in residential appliances. A *market CRF* would be even higher than an *implicit CRF* due to the diffusion rate of energy efficiency technology, i.e., the rate at which it penetrates the market. Of course, slow adoption of cost-effective technology can also be viewed as a market barrier. In this model, since we have knowledge of the *investor CRFs* and not of *market CRFs*, we explicitly account for penetration effects in the model (see Equation 3.10 or 3.11). Furthermore, explicitly including a penetration term in the model incorporates an additional policy handle into the model.

where E is total energy use. In other words, in the neighborhood of project k, the smoothed result of the sequence of projects is the straight line (see Figure 3.1):

$$\frac{K}{S} = a+b(E_O-E) \qquad (3.4)$$

where K is the capital cost of the project ($), S is the rate of energy savings of the project (average kW or kWh/yr), E is the rate of energy use and $\sum S_i = E_O-E$ is the cumulative rate of energy savings (average kW or kWh/yr). The form is approximately correct even though there is no list of technologies.

If we assume the same CRF for all projects in the industry under consideration, then the left-hand-side of equation 3.3 can be reformulated to contain the CRF:

$$\frac{p_k}{CRF} = \frac{K_k}{S_k} \qquad (3.3a)$$

So that equation 3.4 now becomes,

$$\frac{p_k}{CRF} = a+b(E_O-E) \qquad (3.4a)$$

Price appears now in the combination *p/CRF* and the y-axis of the conventional CSC is simply rescaled (Figure 3.4). In other words, the CCE has been rescaled to reflect the behavioral *CRF* or the industry's perceived opportunity cost of capital. For a given point on the curve, a low *CRF* implies a lower price of energy is needed to break-even than if one assumes a higher *CRF*. Note that the y-axis now has the same units as the left hand axis of Figure 3.1, which is the most fundamental form of the CSC.

If the ratio of price to the behavioral or implicit *CRF* has its base-year value (p_O/CRF_O), then $E = E_O$ (rate of energy savings = 0) at equilibrium. As shown in Figure 3.4, if the ratio (p/CRF) increases to (p_1/CRF_1), then at the new equilibrium (and same level of production activity) energy use would be reduced to E_1 (*rate of energy savings* = E_O - E_1). Energy savings can be induced through changes in energy price, *CRF* or both. The annual capital cost of the changes is the area under the CSC (hatched).

Hence, in principal, if we temporarily ignore the time lags due to slow adoption of cost-effective energy conservation technologies, time series data on energy intensities and ratio-of-price change can be used to construct an investor CSC from the top down. If the *CRF* can be assumed not to change, then one does not need knowledge of the appropriate *CRF*, although of course, it would still be needed to predict the value of the investments in energy conservation. Section III E discusses how this model accounts for penetration rates. In practice, available macroeconomic data alone may not be good enough to be able to construct CSCs in this manner, necessitating the use of additional sources of information, as discussed below.

4. *Choice of Functional Form*

It has been thought that a CSC has at least three main attributes: an intercept, a slope, and a limit to savings (an energy intensity floor greater than zero), as shown by curve A, Figure 3.3. As noted before, data suggest the upper limit on savings is due to the inability of the analyst to predict future innovations. In this situation, a two-parameter form popular in economics can be adopted:[9]

$$EI = EI_0 \, (P/P_0)^{-A} \qquad (3.5)$$

Here, P is the energy price divided by the capital recovery rate which applies in the same time period:

$$P = \frac{p}{CRF} \qquad (3.6)$$

When (P/P_0) is small, equation 3.5 is approximately linear:

$$EI = EI_0 \, (1 - A \, (P - P_0)/P_0)$$

which is the form of equation 3.4a. This form has the undesirable property, however, of changing sign at high prices, so it is preferable to adopt equation 3.5.

Keep in mind that although equation 3.5 involves price and *CRF*, the form of the CSC and its shape parameter A describe the engineering-economic opportunities as indicated by Figure 3.1 and equation 3.4, and not investment behavior. On the basis of recent analysis, $A \approx 0.3$ for energy intensive sectors and $A \approx 0.5$ for energy non-intensive sectors. (See Section IV D.) The correct values are probably somewhat larger, but not larger than 1.0. In addition, $CRF \approx 0.3$ represents average behavior, e.g., an implicit discount rate of about 30% combined with an economic life of 10 years. These numbers are highly uncertain; their accuracy, however, could be substantially improved with a moderate research effort.

A check on CSCs derived from engineering data is obtained by comparing them with own-price elasticity estimates where, for example (with some time lag)

$$EI = EI_0 \, (p/p_0)^{-x} \qquad (3.7)$$

Comparing equation 3.7 with equations 3.5 and 3.6 we thus have that

$$x \approx A \qquad (3.8)$$

or slightly larger. Because of the way it occurs in the model, the parameter A corresponds to a *long-run price elasticity* of energy consumption. Long-run price elasticities tend to be larger in magnitude than short-run price elasticities since the short-run price elasticity is dictated by the penetration rate as well as by the long-run price elasticity. The long-run price elasticity is mainly determined by the *technical possibilities* described in CSCs, whereas the short-run price elasticity is governed by industrial *behavior.* Typical long-run, own-price elasticities are $x \approx 0.5$, with a wide scatter of values roughly between 0.1 and 1.0 and more. (See Section I B and Bohi and Zimmerman 1984). This is consistent with the CSC parameter values just listed.

D. Price-Sensitive Interfuel Competition

Several sources have indicated that industry has invested in major fuel-switching capabilities, e.g., to switch residual oil and gas in boilers (AGA, EIA 1987, EIA 1988). However, the focus of discussion here is not switching capability, but long-term substitution: the change from fuel to electricity (or vice versa) associated with investment in

[9] Recall as discussed in Section I C, that the CSC is an average of opportunities for conservation in retrofit and new facility situations.

process equipment *and* associated with changes in relative energy prices. There is less such substitution than one might imagine. Good insights can be obtained by comparing specific industries in Scandinavia (where electricity prices have been roughly half those here), the U.S., and Japan (where electricity prices have been roughly twice those here). On the basis of a preliminary investigation of this issue, we first note that the same processes are used in the three regions (supporting the claim above that fundamental process choice is not sensitive to energy price). In addition, even detailed choices of energy use are not that different. Where does the interfuel competition occur? The more important cases are:

motors vs fuel-driven prime movers
metal melting and heating
high temperature furnaces, e.g., for glassmaking
electrical-resistance boilers and ovens

In modern plants, except where an excess of high pressure steam is available, electric motors dominate over turbines, in Japan as well as elsewhere. In the U.S. there is competition between electricity and gas in several high-temperature-furnace areas, but often production considerations favor one type of furnace or the other. Industrial electrical resistance heating does occur in Scandinavia, but is rare in the U.S. Quantitative data on these specific technology competitions is needed. The tentative conclusion, however, is that the scope of substitution over a price-ratio range of about 4 to 1, is significant (i.e., detectable), but small. One must be careful to distinguish this substitution from conservation (efficiency improvement within the separate energy forms) and most electrification, which is autonomous, i.e., not sensitive to energy prices.

In its details, this discussion is limited to the switch from fossil fuel to electricity and vice-versa, associated with new investments. The investments are associated with neither non-price-sensitive technological developments nor on-site generation. As mentioned above, there is some engineering data but little analysis in this area.

Let us define the electricity share:

$$S_e = \frac{E_e}{E_T}$$

where E_e is the electrical energy consumption and E_T is an appropriately defined total energy consumption.[10] We adopt the form:

$$EI_e = EI_{eo} (P_r / P_{ro})^{C'} \qquad (3.9)$$

where $C' \approx C/S_{eo}$. Here, P_r is the generalized price ratio

$$P_r = \frac{(p_f/p_e)}{CRF}$$

where p_f and p_e are the fuel and electricity prices, respectively.

In analogy with the discussion of the CSC relationship, we note that by approximating the change in electricity share by,

[10] In the spreadsheet model (see Appendix C), although input electrical energy is quoted as such: 1 kWh = 3413 Btu, the fuel-electricity substitution involves E_T = (HRATE)E_e + E_f where HRATE = 3.3.

$$\Delta S_e = C\frac{(P_r - P_{ro})}{P_{ro}}$$

we can derive the linear form of equation 3.9 when (P_r / P_{ro}) is small:

$$EI_e = EI_{eo}\left\{1 + \frac{C}{S_{eo}}\frac{(P_r - P_{ro})}{P_{ro}}\right\}$$

Analyses have not been carried out that would provide an estimate of C. Roughly, we may expect for electricity versus all fossil fuels $0 < C \leq 0.05$. Assuming a typical historical value of $S_{eo} \approx 0.4$, if the fuel-to-electricity price ratio doubled, the effect would be an additive change in electrical intensity of

$$(EIe/EIo) = (P_r / P_{ro})^{C'} = (2)^{0.05/0.4} = 1.09$$

i.e., a 9% increase in electricity intensity. The effect of such a price-ratio change would probably not be larger than this and might be substantially smaller. In the historic model runs reported in Section V, we use $C = 0.02$, corresponding to a 4% increase in electricity intensity for a doubling in fuel-to-electricity price ratio. This value is consistent with an econometric analysis using the same general data as we use here. It indicates that C = 0.02 for the steel industry (Boyd 1991). While this is a representative value, a variety of estimates are obtained in econometric studies, depending on assumptions. Admittedly, the value of C is crudely defined and deserves further refinement.

E. Structure of Model

Aggregate electricity and fuel demands, $E_j(t)$, are calculated by combining knowledge of each sector's base year output and trends in growth rate with forecasts of each sector's energy intensity:

$$E_j(t) = \sum EI_{ij}(t)\ Q_i(t_o)\ PI_i(t)$$

where i = manufacturing sector;
j = energy form (only two forms are incorporated in the present version: fossil fuel and electricity);
$E_j(t)$ = total energy demand for fuel type j;
$EI_{ij}(t)$ = energy intensity by sector i of energy type type j;
$Q_i(t_o)$ = production value in base year;
$PI_i(t)$ = index of production value relative to base year.

For each sector, the model calculates electricity and fuel energy intensities. The energy intensity equation steps through time, e.g., from time n-1 to time n. Neglecting, for the moment, price-induced fuel switching, and assuming a constant growth rate describes the autonomous change, then the general structure of the calculation for the sectors without recycling is simply:[11]

$$EI_{ij}(t) = (1 - Pen)\,EI_{ij}(t\text{-}T)\exp(-B_{ij}\ T) + (Pen)(IEI_{ij}(p_{ij},t)) \qquad (3.10)$$

where Pen = penetration rate per period T of cost-effective, energy-price sensitive conservation;

[11] See Appendix C for a more detailed discussion of the model's equations and parameters.

B_{ij} = autonomous trend coefficient;
$IEI_{ij}(p_{ij},t)$ = ideal energy intensity or conservation supply curve for sector i of energy form j;
T = length of 1 period for which forecasts are made.

Fuel-switching complicates the iteration only slightly:

$$EI_{ij}(t) = (1 - Pen)\, EI_{ij}(t-T)\, F_1(p_{ij}/p_{ij'})\, f_1(t) + (Pen)\,(IEI_{ij}(p_{ij},t))\, F_2(p_{ij}/p_{ij'}) \quad (3.11)$$

where $f_1(t)$ = function for the autonomous trend;
$F_k(p_{ij}/p_{ij'})$ = functions for energy-price sensitive fuel switching.

As discussed in Section IV C, the form of the CSC is as follows:

$$IEI_{ij}(p_{ij},t) = IEI_{ij}(t_o)\left[\frac{EP_{ij}(t)/CRF(t-T)}{p_{ij}(t_o)/CRF(t_o)}\right]^{-A_{ij}} (f_2(t)) \quad (3.12)$$

where $IEI_{ij}(t_o) = (1-Gap0)\, EI_{ij}(t_o)$;
$Gap0$ = the percent gap between the actual energy intensity and the ideal, cost-effective aggregate energy intensity in year zero;
$f_2(t)$ = function for the autonomous trend.

$IEI(t)$ represents the investment climate during the period t-T to t. It depends on $CRF(t)$ and on $EP_{ij}(t)$, the expected price appropriate to investments at the time of decision. That is, investors deciding to install projects in the period t-T to t ask what energy price they expect a few years into the projects' lives. In the model runs reported here, the expected price is taken to be:

$$EP_{ij}(t) = m\,t + b$$

where m is the slope and b is the y-intercept of a line (using the least squares method) determined by the energy prices from t-2 to t-7 years. That is, the typical project is assumed to be in use two years from the time it is evaluated.

The f_k 's show the autonomous technological trend (price independent), and its form, as discussed in Section III D, is exponential:

$$f_1(t) = \exp(-B_{ij}(t)T)$$

where $B_{ij}(t) = B_{ij}(0)\ [1-(t-t_o)/(T\,Bpr)]$;
Bpr = saturation period for autonomous trend;

and

$$f_2(t) = f_1\, f_2(t-T) \text{ with } f_2(t_o) = 1.$$

The F_k 's show the price-induced switching between fuel and electricity. Its form, as discussed in Section III B, is:

$$F_1(p_{ij}/p_{ij'}) = \left[\frac{p_{ij}(t-T)\,/p_{ij'}(t-T)}{p_{ij}(t-2T)\,/p_{ij'}(t-2T)}\right]^{C/S_{ie}(t)}$$

where p_{ij} = energy price energy form j;
$p_{ij'}$= energy price energy form other than j;

$S_{ie}(t)$ = electricity share;
C = fuel switching coefficient;

and

$$F2(t) = F1 \; F2(t\text{-}T) \text{ with } F2(t_o) = 1.$$

Anecdotal evidence supports the assertion that the penetration rate, *Pen,* during a long period of stable real energy prices, such as for fuel prices prior to 1970, is likely to be near zero and that the penetration rate became positive after the first oil shock in 1973. The period following was marked by heightened awareness by industry of the need to cut its energy costs, with many companies creating energy consumption reporting procedures, goals for energy efficiency improvements and positions for "energy managers" (Steinmeyer 1990). With zero penetration in a period such as the 1950's and 1960's, the model predicts that the actual energy intensity and the idealized energy intensity would change together because of the autonomous trends, so that the relationship between them would remain unchanged. Similarly, in a period of energy prices falling gradually, such as for electricity prior to about 1970, the penetration rate is likely to be near zero, since although new conservations investments are not being made, the status quo is likely to be maintained (e.g., electric motors are unlikely to be replaced by less efficient ones). In a period of rapidly rising energy prices, the penetration is a single year might be as high as 15%. At this level, half of all eligible sites would be retrofitted in only four years, rapid implementation indeed. With annual penetration of 10% per year, half of all sites would be retrofitted in 6.5 years.

For sector 4 which includes recycling, the iteration is modified as follows:

$$EI_{4j}(t) = (1\text{-}R(t))\, EI'_{4j}(t) + R(t)\; EI''_{4j}(t)$$

where $EI'_{4j}(t)$ is the energy intensity of the non-recycling portion of sector 4 and is calculated as in equation 3.10. $EI''_{4j}(t)$ is the energy intensity of the recycling portion of sector 4 and is calculated as $EI''_{4j}(t) = REI(t)\, EI'_{4j}(t)$. $R(t)$ is the fraction of sector 4 inputs which are recycled material. In the historical exercises in Section V C, the values of $REI(t)$ and $R(t)$ are determined from historical knowledge.

Figures 3.5 and 3.6 schematically illustrate how equation 3.11 works. For simplicity, the subscripts i and j are dropped in the figures. As illustrated in Figure 3.5, the energy intensity at the end of period n, EI_n, is first adjusted for fuel switching and then for autonomous change. It moves toward the target energy intensity, as dictated by the penetration rate, *Pen*. The target energy intensity is the ideal energy intensity at time $n+1$ (IEI_{n+1}) adjusted for fuel switching. IEI_{n+1} is determined by equation 3.12 and is illustrated in Figure 3.6. At time n, the ideal energy intensity, IEI_n, is established by the conservation supply curve, CSC_n, and the energy price, p_n. At time $n+1$ the autonomous time trend, $f2(t)$, shifts the conservation supply curve inward, in this case, to CSC_{n+1}. An inward shift corresponds to an energy intensity autonomously decreasing with time (the case of fuel). The cost-effective energy intensity level, IEI_{n+1}, is then determined by the new price, p_{n+1}.

IV. DATA

Historical information is needed on actual production, energy consumption, and energy prices. Such data enables statistical study of energy intensities by subsector, price and time, or cross-sectionally by subsector and energy price. Case-study information from engineering and micro-economic perspectives is also very valuable, enabling independent analysis of the responses to energy-price developments. Autonomous change can also be studied using a case study approach.

A. General Statistical Data: Production

It might seem that acquiring good information on production would be easy. Unfortunately, there are serious pitfalls. Inconsistencies that sometimes occur between energy consumption and production data have demonstrated that production series based on Federal Reserve Board Industrial Production Indices are not useful for energy analysis. What one wants, at best, for energy analysis are physical measures of production. Paradoxically, the FRB index is constructed from selected physical series. Unfortunately for long-term trend analysis, the FRB has selected time series data on the basis of its rapid availability (FRB 1986). They are not good series for energy analysis. In one important example, the FRB index for SIC 28 (chemicals) has been growing about 2% per year faster than series based on the tonnage of chemical products (Ross 1983).

Another potential production series, deflated value added, is also severely flawed for two reasons: First, the relation between value added and physical production has been changing because of changes in industrial organization, such as the outsourcing of services and the decline of returns to capital in mature industries. Second, the deflations involve two quantities, the value of output and value of products bought from others. Not only is the value of products bought from others unlikely to be deflated accurately, because the products are typically heterogeneous, but the value added is typically the difference between two numbers of similar size, magnifying errors.

Physical (tonnage) production data is available for a few energy-intensive sector and is excellent data for energy analysis. In general, however, the best complete production data is the deflated value of output. For the U.S., real output series are available from the Bureau of Labor Statistics (BLS) and from the Office of Business Analysis, Department of Commerce. Both series are based on the nominal value of output from the Annual Survey of Manufacturers (ASM). An attractive approach, which is variant on the FRB index approach, is to represent the production in the base year by value added and to describe the growth in each sector by the growth in real output.

B. General Statistical Data: Energy Consumption and Price

Energy data also has particular pitfalls. Accounting conventions need to be adopted. The primary issues are captive fuels (fuels made from materials owned by the manufacturer, which are often not recorded in Census data), feedstock use of fuel (i.e., as material in the final product), and self-generation of electricity. In Table 4.1, estimates of energy use in these categories are shown. The list includes biomass wastes burned as fuels, which are important at paper mills and to a lesser extent in the food processing and lumbering sectors. These wastes cannot be converted to useful energy as efficiently as standard fuels, and so can be omitted, or included at a fraction of their energy value. It is clearly important to include consumption of metallurgical coal by the steel industry to make coke and the subsequent use of that coke in reducing iron ore, and of the coke by-products as fuels. Likewise, it is important to include combustion of by-products of petroleum refining and petrochemical manufacturing. The major fuels are "still gas" (the light products of distillation at refineries) and petroleum coke.

Feedstocks, especially petroleum products and natural gas used in manufacturing organic chemicals and ammonia, and asphalt (if the construction sector is being modeled) are also a major contributor to total fuel use. Feedstock use needs to be analyzed but is not governed by the same considerations (discussed in Section III) as fuel burned for heat and power. Different assumptions are needed.

On-site generation and use of electricity is of interest if one wants to sort out causes of growth in demand for purchased (utility) electricity. A source of concern for forecasting is that the long-term decline in self-generation reversed in the early 1980s, roughly at the boundary between past and future.

The National Energy Accounts is a consistent energy consumption data set with considerable (roughly 3-digit SIC) detail in the manufacturing sector (NEA 1988). It is based primarily on the Annual Survey (and Census) of Manufactures (ASM) and the Manufacturing Energy Consumption Survey (MECS). The former currently provides annual data at the 4-digit level on electricity consumption (kWh) and electricity expenditures and fuel expenditures. (Data on captive fuel use are not included.) The latter has appeared for 1985 and 1988. It has "other" fuel uses and feedstock uses shown separately. Unfortunately, little information is provided below the 2-digit level. The National Energy Accounts, presently available for 1958-85, are constructed using interpolations and extrapolations. NEA also includes estimates for the three non-manufacturing sectors, which are probably inaccurate.

C. Statistical Data for Cross-sectional Analysis

Some regional production and energy data are provided by the surveys mentioned above. However, there is little useful standard statistical data directly enabling the comparison of energy intensities in disaggregated sectors at sites with substantially different energy prices. Special studies, based on special data, are needed. One potential source of cross-sectional data is the Longitudinal Establishment Database at the Census, the records for the individual establishments surveyed for ASM and MECS. These data can only be analyzed by Census employees but general results are publishable. Such data would be especially valuable in homogeneous 4-digit sectors. For example, the cement industry has plants in all regions of the country because there are markets in all regions and cement is costly to ship. If the data could be collected, the dependence of energy intensity on fuel and electricity price variations could be effectively analyzed.

International data is also of interest because industrial processes tend to be the same in all industrial countries, while energy prices, especially electricity prices, differ substantially. Unfortunately, great care is needed to insure that comparable quantities are being compared. An example of careful work is the comparisons by Kahane (1986).

D. Engineering and Case-Study Data and the CSCs

There are several sources of information about CSC parameters. Consider three: 1) a study of electricity savings opportunities in the auto industry in which initial implementation of technologies is studied as a function of the local electricity price, 2) plant-level conservation investment proposals, and 3) engineering-economic analysis of major conservation opportunities in particular industries. Care is needed in interpreting observations in terms of the parameter *A*, because *A* is associated with the comprehensive opportunity for energy savings. Thus, *A* would tend to be larger (more savings for a given price increase) than indicated by studies such as these.

1. Electricity Conservation in Auto Manufacturing

A survey of recently implemented electricity-conservation projects in auto plants showed opportunities to save about 30% under U.S. conditions (Price and Ross 1989). It was possible to roughly convert this information to a useful CSC by examining the electricity prices at which these projects were initially being adopted, and by extending the curve to higher electricity prices using Japanese data roughly corrected to U.S. financial conditions (Bloyd 1989). This analysis provides relatively direct evidence on the model's CSC parameters, *A* and *Gap0* for sector 1. (See Table 4.2.) Undoubtedly, the proper values of *A* (which would be revealed during a long period at higher prices) would be higher.

2. Energy Conservation Plans at a Steel Mill and a Petroleum Refinery

In the early 1980s, ambitious plant engineers at two sites developed comprehensive energy-conservation plans for their sites. These plans remain largely unimplemented except at short payback. Both plants, though hardly new, are continuing in production and appear to have long futures. The steel mill plan showed 20% savings up to a simple payback period of 3.5 years (Ross 1987). (The price of the base fuel, natural gas, was $4 per million Btu at the time.) The refinery plan showed 28% savings up to a simple payback of five years (based on prices of $4.70 per million Btu for gas and 6¢ per kWh for electricity) (Larsen 1990). These two plants, correcting for estimated implementation of some projects, provide sample values for the model CSC parameter *A* for sectors 3 and 4. (See Table 4.2.)

3. Major Electricity-conservation Technologies in Various Sectors

Separate studies of 1) major process improvements for aluminum cells and of 2) improvements in electrical processes in chlor-alkali, glass melting, steel melting and electricity use in cement making provide three further examples of the *A* parameter drawn from engineering analysis (Bloyd 1989). (See Table 4.2.) These examples apply to sectors 3 or 4, and in the chlor-alkali and aluminum cases, to processes where thermodynamics strongly limits the potential for conservation.

As discussed above, a serious problem for creation of CSCs is identifying an adequate list of technologies. Conservation technologies specific to each production process are needed. The best way to determine CSCs may be case studies of a few representative subsectors or processes.

E. Data for Analysis of Interfuel Competition

There have been several EPRI studies from an engineering perspective of the concept of substituting electricity for fuel through new electrotechnologies (Schmidt, EPRI). This somewhat academic work could be combined with data from the field to define the potential for substitution and associated costs, thus converting examples or anecdotes in the EPRI studies into descriptions of industrial opportunities and decision making.

A promising source of information for cross-sectional analysis of interfuel substitution, which we intend to pursue in the future, is electricity and fuel intensities for some well-defined (homogeneous) and appropriate sectors, roughly at the 4-digit SIC level, for the U.S., Scandinavian countries and Japan. Unfortunately, the most recent year for which extensive information at the 4-digit level is available for the U.S. is 1981, because MECS has so far included only 16 4-digit sectors, and many of these sectors would be too heterogeneous for this purpose.

V. PARAMETER ESTIMATION AND HISTORICAL SIMULATION

A. Methodology

1. General

As indicated in Table 5.1, equation 3.10 contains a number of parameters. As discussed in Section IV D and presented in Table 4.2, engineering and case-study data yields insight into the values of A_{ij} and B_{ij}, particularly the former. In this section, we demonstrate that this insight is consistent with the results of statistically fitting the model to the historical data series. Furthermore, by combining the econometric results with information from engineering and case-study data, we are able to gain some insight into the values of *Pen* and *Gap0*, particularly the former.

Two main groups of parameters are needed as inputs to the model for the econometric estimation and historical forecasting that follows: *historical data* and *forecast parameters.* The input historical data (Table 5.2 and Appendix D) are the time series for fuel and electricity prices, the time series for growth rates in outputs, recycling characteristics, and base year outputs and energy consumption, all for the period 1960-1985. The forecast parameters, shown in Table 5.1, are the CSC characteristics, autonomous time trends and time series for the penetration rates.

Table 5.1 shows the forecast parameters and the techniques used to produce estimates. By using historical data and other sources of information about the forecast parameters, we are able to estimate the most important forecast parameters: A_{ij}, the technogical constraints or the "slope" of the conservation supply curve; and B_{ij}, the autonomous time trend coefficient. For a four-sector model of manufacturing, this involves estimating a total of eight parameters, two fuel types (fuel and electricity) per sector.

For the forecast parameters *CRF(t)/CRFo, C* and *Bpr,* plausible values could be established, and although they merit future investigation, they are not critical parameters for model validation at this stage. For instance, it is reasonable to assume that industrial investment behavior did not change dramatically over the historical period, so that the behavior is represented by the parameter $CRF(t)/CRFo \approx 1$. Similarly, a value is simply specified for the fuel-switching behavior, *C*. *Bpr* is a coefficient which reduces the effect of the autonomous time trend coefficient over time. Although it is not well characterized, it is important to include such a coefficient. For instance, over the past 30 years, manufacturing as a whole has seen an increase in the electricity energy intensity. It would, however, be unreasonable to believe that this trend would continue indefinitely. Again, the estimations of A_{ij} and B_{ij} are not overly sensitive to reasonable estimates of this parameter.

On the other hand, the model results are sensitive to the forecasts parameters *Pen* and *Gap0*; hence, we specify ranges of values for these parameters. Here, *Pen* is the penetration rate per year associated with conservation investments.[12] As explained in Section III E, we assume that $Pen \approx 0$ for periods when the energy price was constant or falling gradually, e.g., prior to the first oil embargo. Anecdotal evidence suggests that most industries began to give energy conservation a high priority in planning and

[12] Note that in the current spreadsheet model, PEN = PENYR.

organization only after the first oil embargo of 1973. Our upper range for the post-oil shock penetration rate (t >1973) is approximately 14% corresponding to about 50% cumulative penetration over five years. Higher values are unlikely because of delays in adopting new projects and because some firms where the projects are applicable may choose not to invest at all.

Gap0 represents the gap between the cost-effective energy intensity and the actual energy intensity in the base year. This parameter is difficult to characterize due to problems estimating the amount of conservation potential available to the manufacturing sector in 1958 or at any specified date. Anecdotal evidence of individual processes and plants suggest that this parameter may have been about 20%. (See Section IV D.)

B. Econometric Estimations

1. *Econometric Estimation Method*

Equation 3.10 is nonlinear with a lagged endogenous variable, $EI(t-1)$. To statistically estimate the coefficients A_{ij} and B_{ij}, we use a non-linear least-squares estimation technique, NLIN, contained in a packaged program, SAS. We use a five-year prediction period since the model is intended to predict long-term energy intensities and not yearly fluctuations. Five-year rolling averages of the data series for energy intensities and energy prices were calculated for each sector and fuel type (see Table 5.2 and Appendix D for the un-averaged data). Five-year rolling averages conveniently smooth out the effects of recession years, a determinant of energy intensity not included in this model. An undesirable side-effect of taking five-year steps is that it reduces the number of data points (increasing the uncertainty of the estimate) that are being fitted. In order to increase the number of data points being fitted, we stagger the base years from 1958 to 1962 and normalize the data to their respective base years.

2. *Results of Econometric Fitting*

Tables 5.3a, 5.3b and 5.3c present the regression results with the values of *Gap0* which yield the best historical forecast fit. Section V C (which follows) will discuss how we measured the "best fit" for the forecasts of the historical period.

The price elasticities, A_{ij}, are positive and less than or of the order of one; that is, as energy prices increase, energy intensity decreases and energy expenditures do not decline. For the autonomous time trend coefficient B_{ij}, the signs are negative for electricity, corresponding to increasing electrification, and positive for fuel, corresponding to a decreasing fuel energy intensity.

Note that we separate the steel industry (SIC 331,332, 339) from sector 4 and replace the steel value output with physical output data. Inclusion of the steel industry in sector 4 results in negative values of the parameter A_{4j}. An important reason for separating steel is that the pattern of energy use in processing recycled material is qualitatively different for steel than for paper and aluminum, i.e., $REI_{steel,e} > 1$ rather than less than 1 for paper and aluminum. Since A_{ij} can be interpreted as the long-run price elasticity, it should be positive for all cases. When steel is separated, the values of A_{ij} and B_{ij} for all the sectors display the correct signs (except for a few cases in the steel industry), and with the exception of post-embargo values of Pen = 0.02, are within the expected range.

3. *Conclusions from Econometric Analysis*

The results suggest that *Pen* = 0.02 is an unreasonably low penetration rate for the period following the first oil embargo. Note that the estimate for A_{ij} is consistently too high, ranging from 1.8 to 34. As shown by the asymptotic standard error and the range of the 95% confidence interval, the confidence level of the prediction is low for *Pen* = 0.02 and dramatically improves for the next lowest penetration rate, 0.05. It is justifiable to conclude then, that *Pen* = 0.02 is not valid for the period after the first oil embargo.

In general, the econometric fit, as indicated by a reduction in the standard error, improves slightly as the value of *Pen* increases. The amount of improvement as the value of *Pen* varies from 0.05 to 0.14 differs for each sector. However, we believe the trend in fit does not enable a "best" estimate for *Pen* . On the basis of econometric analysis alone, we must be satisfied with the range from 0.05 to 0.14 for *Pen*.

For sector 2 (fast growing industries), we do not believe that the parameter estimates truly reflect the structure of decision making. Rather than being controlled by large price elasticities of demand for energy-conservation-related investment (i.e., $A_{ij} \approx 1.0$), we suspect that the electricity intensity should display less of an autonomous increase (i.e., a more positive value of B_{ij}). We also suspect that the analysis is flawed for this sector because the NEA subsectors are not sufficiently disaggregated to properly describe the effect of changing product mix in the high-growth industries in the 1960s. For example, slow-growing tire sector is included with plastic products, and the slow-growing typewriter sector is included with computing machines.

The results for the steel sector with value output data which are not shown demonstrate the sensitivity of any model to input data. The negative values for $A_{steel,e}$ using value output are due to a trend that the BLS output data exhibits: steadily increasing electricity energy intensity from 1970 to 1985 (except for a slight decrease in rate in 1984-1985) despite the constantly increasing electricity prices. This behavior caused the estimate of $A_{steel,e}$ to be negative, suggesting that the steel industry has become more electricity intensive in response to rising electricity prices, clearly an incorrect inference. This result is attributable to data problems that are particularly severe in the steel sector. In this case, the physical production data in tons (shipments of steel mill products corrected for inventory change) displays a distinctly different trend: for 1980-85 the real value per ton of mill products plummeted dramatically from \$87 billion to \$58 billion (constant 1982 \$s) according to BLS, whereas production in tons fell relatively slightly from 81.3 mm tons to 73.3 mm tons. Using the physical series as the denominator in the energy intensity, we obtained reasonable values, in terms of sign and magnitude, for the coefficients $A_{steel,j}$ and $B_{steel,j}$, except for $A_{steel,e}$ when $Pen \geq 0.10$ and $Gap0 = 0.2$. The results point out that using value output series as a proxy for physical output can be a problem for certain industries, especially one which has undergone significant structural change over the period of interest.

C. Historical Simulation

1. *Method*

To test the model's predictive capabilities and gain further insight into the parameters, we ran historical simulations of energy intensities for the period 1958-1985. Since the equation forecasts energy intensity based upon the previous time periods energy intensity, the only historical data required are the base year's energy intensity and energy price series. We used estimates of the forecast parameters A_{ij} and B_{ij} from the econometric estimates discussed above and did not attempt to vary these parameters to produce the "best" historical forecasts.

As a measure of the predictive capabilities of the model, we calculated a R^2-coefficient as an indicator of "best" fit. Note that this is not the same as the standard R^2-coefficient for a regression, although it is calculated in the same manner. The regression fitted equation uses energy intensity data from every time step, whereas the historical simulation uses information on energy intensity from only one year, the base year. Hence, one would expect a worse fit from the historical simulation than the regression because the errors tend to accumulate as the forecasts moves through time (Werbos 1990). The formulas used to calculate R^2 is:

$$R^2 = \frac{\text{(ESS, sum of squared errors explained by all regressors)}}{\text{(TSS, total sum of the squared errors)}}$$

$$ESS = \sum_{t=1960}^{1983} (\widehat{EI_{ij}}(t) - \overline{EI_{ij}})^2$$

$$TSS = \sum_{t=1960}^{1983} (EI_{ij}(t) - \overline{EI_{ij}})^2$$

where $EI_{ij}(t)$ = actual 5-year rolling average of energy intensity
$\overline{EI_{ij}}$ = average of all actual 5-year rolling averages of energy intensity
$\widehat{EI_{ij}}(t)$ = estimated 5-year rolling average of energy intensity

2. *Results of Historical Simulations*

Historic energy price trends are an important part of this model. The behavior of the price series was similar for all four sectors, differing only in the magnitude of the variation. Figure 5.1 shows the energy prices for sector 3 (energy intensive) where the changes in energy prices where most pronounced. Price behavior was steady up until early 1970s with fuel prices changing very little and electricity prices declining gradually. Energy prices had already begun to rise in the early 1970s when the first oil embargo in 1973 served notice that this was not to be a short-term trend.

Figures 5.2 through 5.6 show historical forecasts for the four sectors plus the steel. For sectors 1 through 3, a *Gap0* = 0.2 and *Pen* = 0.10 are shown. For sector 4 (excluding steel) and steel, a combination of *Gap0* = 0.1 and *Pen* = 0.05 are shown. The solid points are the estimates of the year-year rolling averages of energy intensity starting in a base year of 1960. The single, open point is the last point which can be estimated using year-year rolling averages of the unaveraged data from 1958-1985. Note this point uses a different base year, 1963, and that for clarity other estimates using this base year are not shown.

3. Conclusions from Historical Simulations

As shown in Table 5.4, the fit for the electricity intensity forecasts, as measured by increasing values of the R^2-coefficient, improves for higher values of *Gap0* and *Pen* in the cases of sectors 1, 2 and 3. Figure 5.7 illustrates how the fit improves for increasing *Gap0* and *Pen* in sector 2.

On the other hand, the goodness of fit for the electricity intensity forecasts in sector 4 and the steel industry improves as the values of *Pen* and *Gap0* decrease. (Although the goodness of fit for the fuel intensity forecasts decreases for higher *Pen* and in some cases *Gap0,* it changes only slightly in comparison to electricity.) Intuition supports these results for *Pen*. Since the primary processing industries in sector 4, dominated by metals, have lower capital stock turnover and have had poorer earnings over the later part of the period under consideration, they are more constrained in ability to adopt energy conservation technologies. Hence, one would expect their penetration rates to be lower than in the other sectors. Sector 3 may behave differently because it is dominated by the relatively profitable chemical industries.

D. Comparison of Results to Other Sources of Data

By comparing Table 4.2 with Tables 5.3 and 5.4, one can conclude that the results of the econometric fitting and historical forecasts are generally consistent with engineering and case-study data. By combining the information from these sources and making some reasonable assumptions, we are able to gain further inferences into the best parameter estimates for *Pen*, *Gap0*, A_{ij} and B_{ij}.

First, we begin by assuming that *Gap0* = 0.2 for sectors 1, 2 and 3 and *Gap0* = 0.1 for sector 4 and steel. As noted in the conclusions from the above section, the fit of the historical forecasts improves significantly for these values of *Gap0*. With this assumption, the econometrically estimated values of A_{ij} and B_{ij} are those that are listed in Table 5.3. We choose to present the range of the values to be one standard error from the estimate, rather than the 95% confidence interval.

Second, we require that the parameter A_{ij} fall in the range

$$Ao_{ij} \leq A_{ij} \leq \sim 1.0$$

where Ao_{ij} is based on engineering information (Table 4.2). We adopt the values Ao_{ij} = 0.3 and 0.2 for electricity and fuel, respectively, in all sectors. These are lower limits because the engineering evidence analyzed is likely to underestimate the value of A_{ij} that would characterize a CSC based on full knowledge of the opportunities. While elasticities can be larger than 1.0, the expectation is that it is of the order of 1.0. A larger value would imply that firms increase their demand for energy conservation in a greater proportion than the price rises so that the expenditures for energy decline as the price rises.

Applying these constraints to the estimates in Table 5.3 narrows the ranges for A_{ij} as shown in Table 5.5. Furthermore, these constraints eliminate certain values of *Pen*. For example in sector 4 for *Pen* = 0.10, the range of values for A_{4f} is 0.17 to 0.26 (0.22±0.4) which lies entirely outside the assumed constraint. Table 5.5 lists the results of eliminating values of *Pen* in this manner. For sector 1, no values of of *Pen* can be eliminated. Low values of *Pen* are eliminated in sector 2, whereas in the remaining sectors, higher values of

Pen are eliminated. Note that *Pen* characterizes investment behavior in a sector which, for example, depends on earnings. Thus, *Pen* can differ by sector.[13] However, we assume it does not differ by fuel type within a sector. Finally, eliminating values of *Pen* narrows the range of possible B_{ij}'s, also shown in Table 5.5.

If these results are accepted, there are implications. First, there is a hint that A_{ie}, which is related to the long-run price elasticity for electricity, is larger in magnitude than that for fuel. If correct, this conclusion could be associated with any of three factors: 1) Most electricity use is in motors, which effect physical changes and where there is little, if any, thermodynamic minimum energy requirement; 2) The rapidly evolving control technologies tend to be more effective for electricity than for fuel; and 3) Finally, the electricity used in this historical simulation has been for purchased electricity only, and therefore the opportunity to cogenerate tends to increase the electricity elasticity.

The second implication concerns the autonomous time trends. The increase in electricity intensity (negative B_{ie}) is strong, as is well known. Electrification (the implementation of new uses of electricity) continues. The autonomous decrease in fuel intensity is more controversial. The 0.5% to 1.0% per year decline in fuel intensity determined here is associated with the factor-neutral improvement of production technology mentioned in Section III B.

[13] In the current spreadsheet model, *Pen* depends on time but not on sector.

VI. POLICY ANALYSIS

A. Barriers to Adoption of Conservation Measures

Available anecdotal information strongly suggests that in U.S. industry in the 1970s and 1980s, implicit discount rates have been high, approximately 30%, compared to real interest rates of perhaps 5% and returns on stocks of perhaps 15%. In a study in which Marc Ross participated with the Alliance to Save Energy, we found that this behavior is primarily associated with capital availability problems, in particular the practice at many firms of rationing capital for all projects except the large projects specifically analyzed in detail by top management (Alliance to Save Energy 1983, Ross 1986). Such capital rationing is widely practiced to enable top management to easily control capital requirements and thus the corporation's external financial arrangements (van Horne 1980).

Analysts have identified a variety of general market barriers to adoption of cost-effective conservation measures (Carlsmith 1990, Koomey 1990, Fisher 1989, Blumstein 1980). The industrial sector is similar in behavior to the residential and commercial sector, but, in general, is more cost conscious, has a tendency to follow "rational" models of investment evaluation and has more constraints on timing (Peters 1988). We have chosen to categorize the barriers relevant to the industrial sector in terms of effects, as shown in Table 6.1: high implicit discount rates, the failure of many applications to receive serious consideration and delay.

Let us consider only three of the barriers, those marked with an asterisk in Table 6.1. In addition to failure to identify projects, these appear to be the most important barriers.

a) *Capital funds are limited for conservation projects*, or, more generally, for small- and medium-sized cost-cutting projects. Firms rely on internal cash flow to finance discretionary investments like these projects. Funds are raised from outside primarily for large strategic investments, e.g., in connection with new markets. These large projects are in the purview of the Board and CEO. In principle, top management could follow textbook rules, encouraging divisions and plants to propose as many good projects as they can, with top management raising the funds for all those that are likely to return more than the cost of capital. Instead, in most firms, capital is severely rationed to divisions and plants for the medium and small projects for which they have primary responsibility, regardless of the investment opportunities which might exist. Under capital rationing, top management has great control over corporate finance and, as mentioned, reserves the often arduous task of raising outside funds for its own strategic projects. Capital rationing is widely practiced by marginal firms with poor cash flow. It is also practiced by some firms with good cash flow where top management has a financial strategy that strongly limits the availability of capital for internal investments and by many firms that have highly centralized management.

Because of capital rationing, funds are very limited for most small and medium projects, including energy conservation projects. Under this limitation, little effort is made to identify conservation projects. One should not misunderstand the rate of return criterion met by projects undertaken in this context. It is not that all good projects with a better rate of return are done, but that the projects being done have a return at least that high. If more opportunities were identified, the minimum return on investment would tend to increase since the total capital allocation is fixed. This is awkward for analysis, since it is convenient to describe a firm's behavior in terms of a discount rate, assuming that the firm undertakes all investments which meet the discount rate criterion. As indicated, behavior under capital rationing is fundamentally different, so that the effects of policies to encourage conservation projects may be difficult to analyze properly.

b) *Some sites for a conservation technology are unsuitable.* Although a technology is, in principle, applicable at a site, the application at that site may be disqualified by decision makers at the firm for several reasons: the product being made there has poor market prospects; the production process is expected to be changed; the plant is likely to be closed or sold in the next few years; the equipment which would be retrofitted is expected to be replaced; or management doesn't trust the people responsible for the project at the site. A substantial fraction of nominally applicable sites will be in this category at any time. This phenomenon does not, however, explain high implicit discount rates at sites which are suitable.

c) *Smaller projects are discounted because they tend to return less than projected.* This perceived riskiness is more speculative as a reason for limited investment in conservation projects. There are two arguments: One involves the risk that the physical performance of smaller projects may tend to be poorer than project designs predict. This is probably not a major concern, both because project design is usually carried out by technical experts and because manufacturers are highly risk averse with respect to installing technologies which are not essential to the production process. The other argument is that engineering and management costs are likely not to be fully considered in the financial evaluation of smaller projects; and those costs are likely to be relatively large for smaller projects. For very small projects (e.g., under $100,000), this may be an important issue. For medium-sized projects, costing one or several million dollars, this argument does not explain the observed implicit discount rates of 30% or 50% per year.

B. Policies to Improve Industrial Energy Efficiency

Public policies aimed at improving industrial energy efficiency or at reduced CO_2 emissions can be categorized by government action or by their impact. Generic policies available to governments are *regulation, fiscal incentives, information* and *technology policies* (EPA 1989, DOE 1989). For each generic policy type, government has a variety of specific policy options or instruments available. Although the listing in Table 6.2 is not complete, it does include examples of all the types of policies which are being widely discussed.

For evaluation of forecasting models, it is more useful to categorize policies by type of impact and to identify the policy handles incorporated in a model. Goverment policies may affect *energy prices, financial criteria for equipment investment, rate of adoption of energy efficient equipment, rate of technical innovation, criteria for investment other than financial and recycling behavior*. As shown in Table 6.3, the model presented here can forecast the effect of some, but not all, of the policy instruments. This model, with microeconomic-based CSC and interfuel-competition relationships, provides handles for forecasting the effect of policies which modify:

- energy prices (P_e and P_f),
- implicit discount rate[14],
- penetration rate of conservation investments (*Pen*),
- conservation supply curve shape(*A* and *B*),
- recycling rate (*R*) and
- recycling energy intensity *(REI)*.

As just discussed, energy prices are not the only factor affecting the level of energy conservation investment. The inclusion of other factors, especially the effect of alleviating capital constraints, is a major advantage of the approach in LIEF over econometric models. Of course, it cannot be claimed that the forecast responses to changes in any of these inputs are exact. The hope would be, with reasonable parameters, that the forecast responses are accurate enough to not be misleading. A brief discussion of a few of the policy instruments other than manipulation of energy prices follows.

Equipment Subsidies by Utilities or Government. This model is particularly suited to analyzing DSM programs and government subsidy programs due to the explicit inclusion of the CRF and the penetration rate. A preliminary exercise to study the effect of utility demand-side management (DSM) programs has been conducted with the analysis based on reducing the CRF and increasing the penetration rate (Boyd 1991). To improve such analyses, one would need experience with actual programs in order to determine how effective such programs are and how to describe a program in terms of the model parameters.

Research and Development Programs and Demonstration Programs. Here the issue is: If a new technology is brought to market because of a government program, can the forecasting model provide a reasonable estimate of industry energy savings, including, perhaps other information like timing and capital expenditure? The type of model being proposed here does not involve a description of the specific energy-use technologies, some of which compete in each energy-service market. Nevertheless, the desired estimation of the benefits of a particular technology could be accomplished at a later stage of model development by modifying the corresponding conservation or fuel-switching relationship. Although specific procedures will not be discussed here, a method exogenous to the model could be developed to determine the effect on the model's parameters and relationships. (If the technology were instead a fundamental new production process, the model might still provide a useful accounting framework.) If it is a conservation technology, for example, a shift in the CSC curve could be built in at the price, or price range, where the technology would be adopted. Clearly the credibility of such a forecast would depend on the detail in the model with which production and energy use are described for the sector/process where the technology would be applied. In addition, the detailed forecast would depend on whether and how lags in adoption are modeled, if new plant versus retrofit devices are modeled separately, etc.

Recycling Content and Deposit-refund Systems. The model enables evaluation of exogenously assumed increases in the rate of use of recycled materials by manufacturers.

[14] Through *CRF* which is a function of discount rate. See Section III C 1.

The credibility of forecast effects would depend on the level of disaggregation in the model (e.g., whether there are separate descriptions of steel and aluminum), and the sophistication with which limitations to the extent of recycling are considered in the assumed increases in recycling rates. For deposit-refund systems, the analyst needs to exogenously determine the program's effectiveness in increasing the recycling rate.

Technological Standards. Since the type of model proposed here does not explicitly represent equipment like lights or motors, the impact of specific technological standards could not be readily obtained. Obviously, modifications to the approach could be made that would generate accounts of energy use by such functions. There is little knowledge that would enable realistic forecasting of functional uses, however. Moreover, direct regulation of performance, while it has had success with mass-produced products for transportation and buildings, is not an important policy area for industrial energy efficiency.

Behavior Modification. This is a potentially important policy area where a model of the type described here could at best provide an accounting framework.

C. Sample Scenarios

We present two forecasts in order to illustrate how analysts can use LIEF in analyzing policy scenarios. These scenarios, presented in Tables 6.4a,b,c and 6.5a,b,c, are for the entire U.S. manufacturing sector. It is relatively straightforward, if data are available, to analyze a specific region or manufacturing subsector.

The first forecast, presented in Tables 6.4a,b,c, is a "business as usual" scenario. Real energy prices are adopted from the National Energy Strategy analysis. The forecast growth rates are based on selected historical trends. Overall production growth is based on a GNP growth scenario from the National Energy Strategy combined with extension of the historical trend that output of manufacturing is growing 1.0% per year slower than GNP. The assumed sectoral growth rates are: sector 3, constant production per capita, or 0.5% per year long-term growth (Williams 1987); sector 2, production gradually growing more slowly than the 1971-85 rate of 6% per year. Sector 1 is the residual. The 1971-85 growth rate for sector 1 output was 1.4% per year.

The engineering parameters, A_{ij} and B_{ij}, are assigned central values from the analysis of Section V (Table 5.5). The parameter *Pen(t)* is assigned the value of 2% per year[15] which we consider reasonable for a climate of moderately rising prices, but no energy crises or strong programs to encourage conservation. The scenario is somewhat sensitive, however, to the uncertainty in *Pen(t)* and *Gap0*. Tables 6.4a,b,c are copies of the printout from the LOTUS spreadsheet version of LIEF. A wide variety of tables and graphs can be selected, combined energy summary, and the electricity and fuel intensities, being shown. In addition, all the input parameters are printed with each output table or graph as shown in Tables 6.4a and 6.5a.

This business as usual scenario is not intended as the last word in analytical sophistication. It is merely an example. In a more careful analysis, we would probably use: 1) production indices based upon detailed value-added weights and real output trends; 2) value-added

[15] Note that in the present spreadsheet version of LIEF (LIEF.Wk3), the user does not have the option of varying Pen(t) by sector. Hence, the value of *Pen(t)* represents an average for all sectors.

production price trends, with less growth for fuel and more growth for electricity; 3) a more careful evaluation of the future autonomous trends in sector 2 involving autonomously declining energy intensities with little or low price sensitivity (i.e., low penetration); and 4) different penetration rates in the different sectors which the current spreadsheet version does not allow.

Tables 6.5a,b,c show an alternative scenario, "conservation," in which it is assumed that energy prices are the same, but strong conservation policies involving capital incentives cause the implicit *CRF* to drop from 0.33 to 0.19 and annual penetration rates to rise from 2% to 10% during a 15-year period. Of course, further analysis is needed to establish parameter values that might realistically describe an ambitious conservation program. The engineering context as represented by A_{ij} and B_{ij} is assumed to remain the same as for the first scenario. It would be influenced by all the conservation activity and by technology policies, although more slowly than the investment stimulus modeled here; but we felt it more important to make the point that the engineering context should be largely the same in different scenarios. The impact of the conservation effort shown in the second scenario is seen, for example, to be a 20% reduction in electricity consumption.

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TABLE 4.1
Fuel Consumption by Industry by General Category of Use, 1985, Quads

	Direct Fuel Use	Purchased Electricity	Electrical Losses [b]	Total (EIA)
Heat and Power				
Manufacturing	9.6	2.27	5.4	17.3
Non-manufacturing[a]	3.7	0.54	1.3	5.5
Total	13.3	2.81	6.7	22.8
Oil and gas feedstocks	4.3			
Grand Total	17.6	2.81	6.7	27.1
Captive fossil fuels [c]	2.4			
Biomass waste fuels (not included above)	~2.5			
Fuels used for self-generation (included above)	~0.6			

Notes:
a) Agriculture, mining and construction.
b) Calculated at fossil fuel rate, as per EIA accounting.
c) Primarily still gas and petroleum coke used in refining, metallurgical coal in steel mills.
d) Assumed heat rate of 8000 Btu/kWh.

TABLE 4.2
CSC Parameters from Case Studies and Engineering Analysis

Case and Sector	Energy Form	CSC Parameter	
		A	*Gap0*[a]
auto manufacturing, S1	electricity	0.3 0.45[b]	~0.2
steel mill, S4	natural gas	0.2	-
petroleum refining, S3	natural gas and electricity	0.3	-
aluminum cell retrofit, S4	electricity	0.2	-
energy-intensive sectors[c], S3 and S4	electricity	0.25	-

Notes:
a) Typically the Gap0 estimate is too uncertain. In the case of fuel, conditions at the time were not stable and had departed strongly from 1978.
b) With Japanese data.
c) Chlor-alkali, cement, glass and electric arc steelmaking.

TABLE 5.1
Forecast Parameters

Parameter	Field Size	Estimate
Not Econometrically Estimated		
Pen	1*	2-14% per year
Gap0	1†	10 and 20%
Bpr	1†	75 years
CRF(t)/CRF(to)	1*	1
C	1†	0.02
Econometrically Estimated		
A_{ij}	8	(see Table 5.3)
B_{ij}	8	

Notes:

* *Possibly 4 if assume sector dependent.*

† *Possibly 8 if assume sector and energy type dependent.*

Explanation of Parameters:

Pen = penetration rate of conservation technologies per year
Gap0 = gap between cost-effective EI and actual EI in base year.
Bpr = time until autonmous trend goes to zero.
CRF(t)/CRF(to) = ratio of capital recovery factors.
C = fuel-switching coefficients
Aij = slope of CSC, "price elasticity"
Bij = autonomous time trend coefficient.

TABLE 5.2
Historical Data Series Used in Econometric Fitting of Forecast Parameters

Data Series	Method for Calculating
Energy Intensity, EI_{ij}	$\frac{[\text{energy use}]_{ij}{}^{a}}{[\text{output value}]_{i}{}^{b}}$, $\frac{\text{Btu}}{82\$}$
Energy Price, p_{ij}	$\frac{[\text{producer energy value}]_{ij}{}^{ac}}{[\text{energy use}]_{i}{}^{a}}$, $\frac{82\$}{\text{Btu}}$
REI_4	~50%
R_4 [d]	~25% for yrs 1980-85, ~20% for all others.
$REI_{steel,e}$ [e]	1.8
$REI_{steel,f}$ [e]	0.24
R_{steel} [f]	36% for yrs 1980-85, 29% for all others.

Notes:

i = sector number
j = energy type

Sources:

a) *National Energy Accounts 1958-1985, U.S. Department of Commerce, Office of Business Analysis.*

b) *Bureau of Labor Statistics 1958-1985, U.S. Department of Labor.*

c) *Current value from NEA deflated by the authors using the producer price index for total manufacturing production, BLS.*

d) *American Paper Institute, "Statistics of Paper, Paperboard and Wood Pulp", and Aluminum Association, "Statistical Review" (various years).*

e) Ross, M. (1987). "Industrial Energy Conservation and the Steel Industry of the U.S." *Energy* **12**: 1135-1152.

f) *Author's analysis based on American Iron and Steel Institute "Annual Statistical Report".*

Explanation of Parameters:

EI_{ij} = *Energy Intensity*

P_{ij} = *Energy Price*

REI = recycle EI as fraction of that for primary process.

R = recycling fraction. It is the material from sources external to the industry that is input to downstream processes compared to the sum of that material and the material from the primary process. For steel, the external scrap is not directly reported, and it is referred to as, essentially, total scrap input to steelmaking less the difference between raw steel production and production of rolled products.

TABLE 5.3a
Results of Econometric Estimation of Parameters A_{ij} and B_{ij}

Sector	Fuel Type	Para-meter	Gap0	Pen (1/yr)	Estimate	Asymp-totic Std. Error	Asymptotic 95% Confidence Interval Lower	Upper
1	Elec	A	0.20	0.02	2.13	2.55	-3.25	7.51
		B			-0.0196	0.0043	-0.0287	-0.0106
		A		0.05	0.93	0.87	-0.91	2.78
		B			-0.0247	0.0031	-0.0313	-0.0181
		A		0.07	0.71	0.57	-0.48	1.90
		B			-0.0274	0.0026	-0.0330	-0.0218
		A		0.10	0.58	0.36	-0.17	1.33
		B			-0.0307	0.0021	-0.0352	-0.0263
		A		0.14	0.54	0.24	0.03	1.04
		B			-0.0341	0.0017	-0.0378	-0.0305
1	Fuel	A	0.20	0.02	34.44	426.99	-866.44	935.31
		B			0.0086	0.0035	0.0013	0.0159
		A		0.05	1.01	0.38	0.21	1.81
		B			0.0056	0.0038	-0.0025	0.0137
		A		0.07	0.56	0.19	0.16	0.97
		B			0.0055	0.0035	-0.0019	0.0130
		A		0.10	0.35	0.11	0.12	0.59
		B			0.0047	0.0031	-0.0019	0.0113
		A		0.14	0.25	0.07	0.09	0.41
		B			0.0035	0.0027	-0.0022	0.0092
2	Elec	A	0.20	0.02	4.76	3.20	-1.99	11.51
		B			-0.0122	0.0063	-0.0256	0.0011
		A		0.05	2.63	1.22	0.06	5.20
		B			-0.0185	0.0043	-0.0275	-0.0094
		A		0.07	2.04	0.77	0.42	3.67
		B			-0.0218	0.0035	-0.0291	-0.0145
		A		0.10	1.58	0.45	0.63	2.53
		B			-0.0258	0.0026	-0.0313	-0.0203
		A		0.14	1.30	0.26	0.74	1.86
		B			-0.0299	0.0019	-0.0338	-0.0260
2	Fuel	A	0.20	0.02	7.66	52.96	-104.09	119.40
		B			0.0186	0.0061	0.0057	0.0315
		A		0.05	4.54	3.11	-2.02	11.11
		B			0.0066	0.0031	0.0000	0.0132
		A		0.07	1.76	0.35	1.02	2.51
		B			0.0056	0.0028	-0.0004	0.0116
		A		0.10	0.96	0.14	0.66	1.26
		B			0.0052	0.0028	-0.0007	0.0112
		A		0.14	0.64	0.10	0.44	0.85
		B			0.0045	0.0030	-0.0019	0.0108

TABLE 5.3b
Results of Econometric Estimation of Parameters A_{ij} and B_{ij}

Sector	Fuel Type	Para-meter	Gap0	Pen (1/yr)	Estimate	Asymp-totic Std. Error	Asymptotic 95% Confidence Interval Lower	Upper
3	Elec	A	0.20	0.02	7.45	7.14	-7.61	22.51
		B			-0.0205	0.0045	-0.0299	-0.0110
		A		0.05	0.40	0.53	-0.71	1.51
		B			-0.0214	0.0046	-0.0310	-0.0118
		A		0.07	0.20	0.33	-0.49	0.90
		B			-0.0233	0.0040	-0.0316	-0.0149
		A		0.10	0.12	0.20	-0.31	0.55
		B			-0.0260	0.0032	-0.0329	-0.0192
		A		0.14	0.11	0.13	-0.16	0.39
		B			-0.0294	0.0025	-0.0347	-0.0240
3	Fuel	A	0.20	0.02	1.79	0.73	0.25	3.33
		B			0.0130	0.0014	0.0100	0.0159
		A		0.05	0.36	0.06	0.24	0.48
		B			0.0118	0.0012	0.0093	0.0143
		A		0.07	0.22	0.04	0.13	0.30
		B			0.0114	0.0013	0.0088	0.0141
		A		0.10	0.13	0.03	0.05	0.20
		B			0.0109	0.0015	0.0078	0.0140
		A		0.14	0.07	0.03	0.01	0.14
		B			0.0103	0.0018	0.0066	0.0140
4 *	Elec	A	0.10	0.02	2.11	1.16	-0.34	4.55
		B			-0.0252	0.0025	-0.0305	-0.0199
		A		0.05	0.64	0.32	-0.03	1.30
		B			-0.0274	0.0025	-0.0327	-0.0222
		A		0.07	0.40	0.23	-0.09	0.90
		B			-0.0284	0.0025	-0.0337	-0.0230
		A		0.10	0.25	0.18	-0.13	0.64
		B			-0.0296	0.0026	-0.0351	-0.0241
		A		0.14	0.17	0.15	-0.16	0.49
		B			-0.0309	0.0027	-0.0365	-0.0253
4 *	Fuel	A	0.10	0.02	2.64	1.50	-0.51	5.80
		B			0.0102	0.0018	0.0064	0.0140
		A		0.05	0.48	0.09	0.29	0.68
		B			0.0101	0.0017	0.0066	0.0136
		A		0.07	0.32	0.06	0.19	0.45
		B			0.0100	0.0016	0.0065	0.0134
		A		0.10	0.22	0.04	0.13	0.31
		B			0.0097	0.0016	0.0063	0.0132
		A		0.14	0.16	0.04	0.08	0.23
		B			0.0094	0.0017	0.0059	0.0129

Note:
** Does not include steel industy (SIC 331, 332, and 339).*

TABLE 5.3c
Results of Econometric Estimation of Parameters A_{ij} and B_{ij} for the Steel Industry Using Physical Output Data

Sector	Fuel Type	Parameter	Gap0	Pen (1/yr)	Estimate	Asymptotic Std. Error	Asymptotic 95% Confidence Interval *Lower*	*Upper*
4, Steel* Phy. out	Elec	A	0.10	0.02	1.05	0.72	-0.47	2.56
		B			-0.0349	0.0023	-0.0397	-0.0300
		A		0.05	0.29	0.21	-0.16	0.74
		B			-0.0370	0.0019	-0.0410	-0.0330
		A		0.07	0.20	0.15	-0.12	0.51
		B			-0.0383	0.0017	-0.0420	-0.0346
		A		0.10	0.15	0.11	-0.09	0.39
		B			-0.0401	0.0017	-0.0436	-0.0366
		A		0.14	0.14	0.10	-0.06	0.35
		B			-0.0421	0.0017	-0.0456	-0.0386
4, Steel* Phy. out	Fuel	A	0.10	0.02	3.46	2.65	-2.13	9.05
		B			0.0053	0.0025	0.0000	0.0105
		A		0.05	0.33	0.13	0.05	0.61
		B			0.0081	0.0023	0.0031	0.0130
		A		0.07	0.19	0.09	0.00	0.38
		B			0.0082	0.0022	0.0035	0.0130
		A		0.10	0.10	0.06	-0.04	0.23
		B			0.0083	0.0021	0.0039	0.0128
		A		0.14	0.04	0.05	-0.06	0.15
		B			0.0083	0.0020	0.0041	0.0125

Note:
**Steel industy includes SIC 331, 332, and 339.*

TABLE 5.4a
Results of Historical Simulations

Sector	Fuel Type	GapO	Pen (1/yr)	"R^2"- (goodness of fit*)
1	Electricity	0.1	0.05	0.598
			0.07	0.682
			0.10	0.729
			0.14	0.814
	Fuel	0.1	0.05	0.917
			0.07	0.920
			0.10	0.926
			0.14	0.931
1	Electricity	0.2	0.05	0.709
			0.07	0.791
			0.10	0.847
			0.14	0.858
	Fuel	0.2	0.05	0.921
			0.07	0.926
			0.10	0.932
			0.14	0.937
2	Electricity	0.1	0.05	-0.410
			0.07	-0.120
			0.10	0.172
			0.14	0.408
	Fuel	0.1	0.05	0.965
			0.07	0.966
			0.10	0.965
			0.14	0.962
2	Electricity	0.2	0.05	-0.146
			0.07	0.178
			0.10	0.483
			0.14	0.706
	Fuel	0.2	0.05	0.965
			0.07	0.964
			0.10	0.962
			0.14	0.956

Note:
**See text, Section V C 1.*

TABLE 5.4b
Results of Historical Simulations

Sector	Fuel Type	GapO	Pen (1/yr)	"R2"- (goodness of fit*)
3	Electricity	0.1	0.05	-0.048
			0.07	0.045
			0.10	0.179
			0.14	0.329
	Fuel	0.1	0.05	0.993
			0.07	0.992
			0.10	0.990
			0.14	0.986
3	Electricity	0.2	0.05	0.089
			0.07	0.225
			0.10	0.403
			0.14	0.577
	Fuel	0.2	0.05	0.991
			0.07	0.988
			0.10	0.983
			0.14	0.972
4 (excluding steel industry)	Electricity	0.1	0.05	0.938
			0.07	0.905
			0.10	0.867
			0.14	0.833
	Fuel	0.1	0.05	0.800
			0.07	0.759
			0.10	0.711
			0.14	0.668
4 (excluding steel industry)	Electricity	0.2	0.05	0.830
			0.07	0.702
			0.10	0.531
			0.14	0.374
	Fuel	0.2	0.05	0.732
			0.07	0.636
			0.10	0.510
			0.14	0.375

Note:
**See text, Section V C 1.*

TABLE 5.4c
Results of Historical Simulations

Sector	Fuel Type	GapO	Pen (1/yr)	"R^2" (goodness of fit*)
Steel Industry	Electricity	0.1	0.05	0.938
			0.07	0.905
			0.10	0.867
			0.14	0.833
	Fuel	0.1	0.05	0.800
			0.07	0.759
			0.10	0.711
			0.14	0.668
Steel Industry	Electricity	0.2	0.05	0.814
			0.07	0.716
			0.10	†
			0.14	†
	Fuel	0.2	0.05	0.518
			0.07	0.352
			0.10	†
			0.14	†

Notes:
**See text, Section V C 1*
† Not calculated because A< 0.

TABLE 5.5
Final Range of Parameter Estimates

Sector	*Gap0*	*Pen*, $t \geq 1974$ (1/yr)	A_{ij} electricity	A_{ij} fuel	$B_{ij}(1960)^{a} \times 10^{-2}$ electricity	$B_{ij}(1960)^{a} \times 10^{-2}$ fuel
1	0.2	0.05-0.14	0.3-1.0	0.2-0.8	-(3.6-2.2)	0.1-1.0
2	0.2	~0.10[c]-0.14	~1.0	0.5-1.0	-(3.2-2.3)	0.2-0.8
3	0.2	0.05-0.07[d]	0.3-0.9	0.2-0.4	-(2.7-1.7)	1.0-1.3
4[b]	0.1	0.05-0.10[e]	0.3-1.0	0.2-0.6	-(3.2-2.5)	0.8-1.2
Steel	0.1	0.05-0.10	0.3-0.5	0.2-0.5	-(4.2-3.5)	0.6-1.1

Notes:
a) $B_{ij}(1985) = 0.67 B_{ij}(1960)$
b) Excluding steel industry.
c) If A_{ij} allowed to be slightly higher than 1.0, A_{ij} = 1.1
d) Although historical fit improves as Pen increase.
e) Historical fit improves as Pen decreases.

TABLE 6.1
Some Barriers to Adoption of Conservation Measures Categorized by Effect

High Discount Rate
- Capital Rationing, internal investments restricted *
- Limited Access to Capital, financial market failure
- Split Incentives, disconnect between investor and user †
- Bias against small projects, poor evaluation technique and/or perceived riskiness of energy-efficiency investments *
- Bias against energy-efficiency investments, favor market-share or other strategic investments

Limited Application (Low Penetration)
- Unsuitability of some sites *
- Information gap, slow diffusion of knowledge

Delay in Adoptions
- Scheduling Considerations
- Investor's financial position

Notes:

**. Discussed in text.*

†. Probably not as important in industrial sector as in residential and/or commercial sectors.

TABLE 6.2
Policies Categorized by Type of Government Action

Generic Policy	Policy Instrument

REGULATION	Technology Standards
	  equipment and design standards
	  process standards
	  performance standards
	Recycle Content Standards
	Controls on CO_2 emissions, end-user

FISCAL INCENTIVES (MARKET-ORIENTED)	Energy Prices
	  energy taxes
	  carbon tax
	  tradeable CO_2 emission rights, utilities
	  greenhouse gas emission limits, utilities
	Equipment Subsidies by Utility (via Rate-of-Return Regulation)
	  rebates
	  low-interest loans
	  installation at utility cost
	  audits
	Equipment Subsidies by Government
	  depreciation and investment tax allowances
	  direct government purchases
	Recycling, Deposit-refund Systems

INFORMATION	Data Collection
	Information Dissemination
	  audit programs
	  extension services
	  advertising and labeling
	Behavior Modification
	  goal setting and reporting of performance
	  training and education
	  moral suasion
	  signalling

TECHNOLOGY POLICIES	Research and Development Programs Demonstration Programs Patent Law

TABLE 6.3
Policies Categorized by Area of Impact

Area of Impact	Policy Handle in LIEF
ENERGY PRICES	Electricity and Fuel Prices,
Taxes	P_e and P_f
energy taxes	
carbon tax	
Emission of Greenhouse Gases	
greenhouse gas emission limits	
tradeable CO_2 emission rights	
FINANCIAL CRITERIA FOR EQUIPMENT INVESTMENT	Capital Recovery Factor, *CRF*
Equipment Subsidies by Utility (via Rate-of-Return Regulation)	
rebates	
low-interest loans	
installation at utility cost	
audits	
Equipment Subsidies by Government	
performance based tax rebates	
investment tax credits	
direct government purchases	
RATE OF ADOPTION OF ENERGY EFFICIENT EQUIPMENT	Penetration Rate, *Pen*
Equipment Subsidies by Utility (via Rate-of-Return Regulation)	
Equipment Subsidies by Government	
Technology Standards	
equipment and design standards	
process standards	
performance standards	
Data Collection	
Information Dissemination	
audit programs	
extension services	
advertising and labeling	
training	
Patent Law	
RATE OF TECHNICAL INNOVATION	Conservation Supply Curve Parameters, A_{ij}
Research and Development Programs	and B_{ij}
Demonstration Programs	
Patent Law	
CRITERIA FOR INVESTMENT OTHER THAN FINANCIAL	Possibly Capital Recovery Factor, *CRF*, or Penetration Rate, *Pen*
Behavior Modification	
goal setting and reporting of performance	
training and education	
moral suasion	
signalling	
RECYCLING BEHAVIOR	Recycling Rate, *R*
Recycle Content Standards	Recycling Energy Intensity, *REI*
Deposit-refund systems	

TABLE 6.4a
Sample Printout: "Business as Usual" Scenario

Simplified Energy Forecasting Model of the Industrial Sector

Date of analysis: 16-Dec 04:24 PM.

Energy Intensity and Consumption
(incl generation + distrib losses)

Year	EI(e)	EI(f)	EI	E(e)	E(f)	E
1985	7.21	9.67	16.88	7.21	9.67	16.9
1990	7.22	8.77	15.99	7.90	9.59	17.5
1995	7.30	8.23	15.53	8.98	10.13	19.1
2000	7.38	7.50	14.88	10.17	10.35	20.5
2005	7.42	6.75	14.17	11.24	10.23	21.5
2010	7.34	6.04	13.38	12.16	10.00	22.2
2015	7.21	5.41	12.62	12.93	9.70	22.6
2020	7.02	4.87	11.89	13.56	9.41	23.0
2025	6.82	4.42	11.24	13.58	8.80	22.4
2030	6.59	4.03	10.62	13.51	8.27	21.8
2035	6.57	3.88	10.45	13.89	8.19	22.1

0.02	C
0.2	Gap0
0.5	REIelec
0.5	REIfuel
5	Period
1985	Base
10	Bpr(periods)

year	Ref Price Elec (*)	Ref Price Fuel (*)	CRR %	R %	G %	P %
1980	10.70	3.06	33			
1985	13.10	3.41	33	25		
1990	11.00	2.40	33	25	1.80	2
1995	10.88	2.65	33	28	2.40	2
2000	11.31	3.47	33	30	2.30	2
2005	11.79	4.31	33	30	1.90	2
2010	12.28	5.15	33	32	1.80	2
2015	12.33	5.48	33	32	1.60	2
2020	12.38	5.82	33	35	1.50	2
2025	12.43	6.04	33	35	0.60	2
2030	12.47	6.25	33	35	0.60	2
2035	12.50	6.50	33	35	0.60	2

* $/million BTU

secto		E(0)	DP	A	B
S1	el	0.729	2.53	0.60	-0.018
	fu	1.815	0.26	0.50	0.004
S2	el	0.306	3.19	0.60	-0.005
	fu	0.436	0.37	0.50	0.004
S3	el	0.455	-1.6	0.50	-0.015
	fu	4.255	-0.0	0.40	0.006
S4	el	0.674	-1.8	0.50	-0.015
	fu	3.167	0.1	0.40	0.006
TotEl		2.164			
TotFu		9.673			

year	<--- Growth Rate ----> Sec1	Sec2	Sec3	Sec4
1990	1	5	0.5	0.5
1995	1	5	0.5	0.5
2000	1	4	0.5	0.5
2005	1	4	0.5	0.5
2010	1	4	0.5	0.5
2015	1	4	0.5	0.5
2020	1	3	0	0
2025	1	3	0	0
2030	1	3	0	0
2035	1	3	0	0

	<-- Production Rate --> Sec1	Sec2	Sec3	Sec4
1985	1181	551	331	178

Table 6.4b
Electricity Summary Output: "Business as Usual" Scenario

Summary (Electricity)

Year	EI	Q	E	P
1985	2.164	1.00	2.164	13.10
1990	2.169	1.09	2.371	11.00
1995	2.192	1.23	2.698	10.88
2000	2.215	1..38	3.055	11.31
2005	2.227	1.52	3.375	11.79
2010	2.205	1.66	3.652	12.28
2015	2.165	1.79	3.884	12.33
2020	2.108	1.93	4.073	12.38
2025	2.048	1.99	4.078	12.43
2030	1.978	2.05	4.058	12.47
2035	1.974	2.11	4.172	12.50

Table 6.4c
Fuel Summary Output: "Business as Usual" Scenario

Summary (Fuel)

Year	EI	Q	E	P
1985	9.673	1.00	9.673	3.41
1990	8.772	1.09	9.591	2.40
1995	8.228	1.23	10.128	2.65
2000	7.503	1.38	10.348	3.47
2005	6.750	1.52	10.229	4.31
2010	6.037	1.66	10.001	5.15
2015	5.408	1.79	9.700	5.48
2020	4.873	1.93	9.415	5.82
2025	4.422	1.99	8.803	6.04
2030	4.031	2.05	8.269	6.25

TABLE 6.5a
Sample Printout: "Conservation" Scenario

Simplified Energy Forecasting Model of the Industrial Sector

Date of analysis: 16-Dec 04:21 PM

Energy Intensity and Consumption
(incl generation + distrib losses)

Year	EI(e)	EI(f)	EI	E(e)	E(f)	E
1985	7.21	9.67	16.88	7.21	9.67	16.9
1990	7.22	8.77	15.99	7.90	9.59	17.5
1995	7.30	8.23	15.53	8.98	10.13	19.1
2000	7.11	7.19	14.30	9.80	9.92	19.7
2005	6.22	5.59	11.81	9.42	8.47	17.9
2010	5.59	4.46	10.05	9.25	7.39	16.6
2015	5.47	4.01	9.48	9.81	7.19	17.0
2020	5.46	3.70	9.16	10.56	7.15	17.7
2025	5.44	3.43	8.87	10.82	6.83	17.6
2030	5.36	3.19	8.55	11.00	6.54	17.5
2035	5.46	3.13	8.58	11.54	6.61	18.1

0.02	C
0.2	Gap0
0.5	REIelec
0.5	REIfuel
5	Period
1985	Base
10	Bpr(periods)

	Ref Price					
	Elec	Fuel	CRR	R	G	P
year	(*)	(*)	%	%	%	%
1980	10.70	3.06	33			
1985	13.10	3.41	33	25		
1990	11.00	2.40	33	25	1.80	2
1995	10.88	2.65	33	28	2.40	2
2000	11.31	3.47	19	30	2.30	10
2005	11.79	4.31	19	30	1.90	10
2010	12.28	5.15	19	32	1.80	10
2015	12.33	5.48	33	32	1.60	2
2020	12.38	5.82	33	35	1.50	2
2025	12.43	6.04	33	35	0.60	2
2030	12.47	6.25	33	35	0.60	2
2035	12.50	6.50	33	35	0.60	2

* $/million BTU

secto		E(0)	DP	A	B
S1	el	0.729	2.53	0.60	-0.018
	fu	1.815	0.26	0.50	0.004
S2	el	0.306	3.19	0.60	-0.005
	fu	0.436	0.37	0.50	0.004
S3	el	0.455	-1.6	0.50	-0.015
	fu	4.255	-0.0	0.40	0.006
S4	el	0.674	-1.8	0.50	-0.015
	fu	3.167	0.1	0.40	0.006
TotEl		2.164			
TotFu		9.673			

	<--- Growth Rate ---->			
year	Sec1	Sec2	Sec3	Sec4
1990	1	5	0.5	0.5
1995	1	5	0.5	0.5
2000	1	4	0.5	0.5
2005	1	4	0.5	0.5
2010	1	4	0.5	0.5
2015	1	4	0.5	0.5
2020	1	3	0	0
2025	1	3	0	0
2030	1	3	0	0
2035	1	3	0	0

	<-- Production Rate -->			
	Sec1	Sec2	Sec3	Sec4
1985	1181	551	331	178

Table 6.5b
Electricity Summary Output: "Conservation" Scenario

Summary (Electricity)

Year	EI	Q	E	P
1985	2.164	1.00	2.164	13.10
1990	2.169	1.09	2.371	11.00
1995	2.192	1.23	2.698	10.88
2000	2.134	1.38	2.943	11.31
2005	1.867	1.52	2.829	11.79
2010	1.678	1.66	2.779	12.28
2015	1.642	1.79	2.945	12.33
2020	1.641	1.93	3.170	12.38
2025	1.632	1.99	3.250	12.43
2030	1.611	2.05	3.304	12.47
2035	1.639	2.11	3.465	12.50

Table 6.5c
Fuel Summary Output: "Conservation" Scenario

Summary (Fuel)

Year	EI	Q	E	P
1985	9.673	1.00	9.673	3.41
1990	8.772	1.09	9.591	2.40
1995	8.228	1.23	10.128	2.65
2000	7.193	1.38	9.920	3.47
2005	5.589	1.52	8.470	4.31
2010	4.459	1.66	7.387	5.15
2015	4.010	1.79	7.192	5.48
2020	3.699	1.93	7.146	5.82
2025	3.429	1.99	6.826	6.04
2030	3.189	2.05	6.541	6.25

FIGURE 1.1
Factors Affecting Energy Demand in LIEF, and External Considerations to the Model

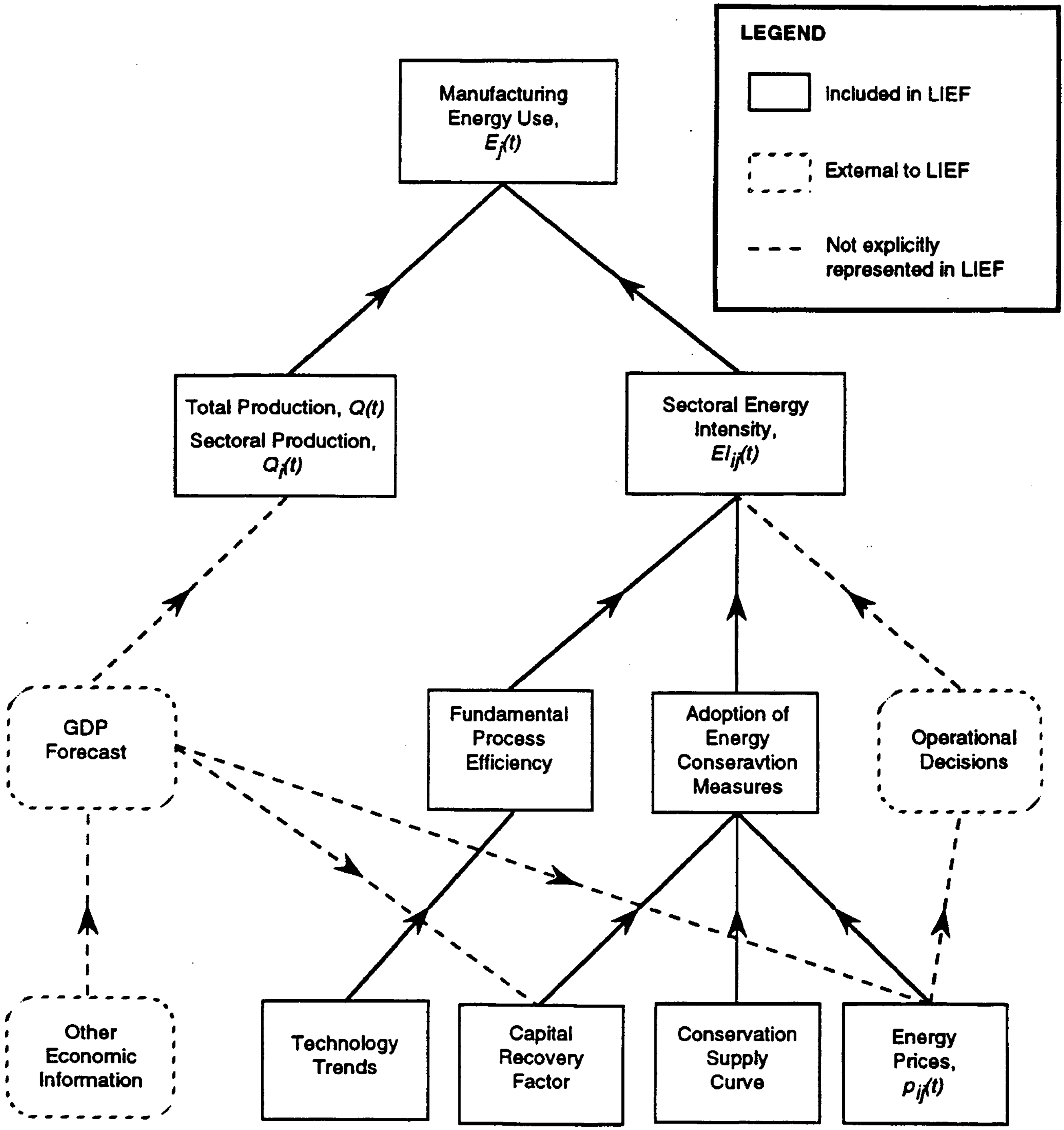


FIGURE 2.1
Scatter Plot of Total Fuels

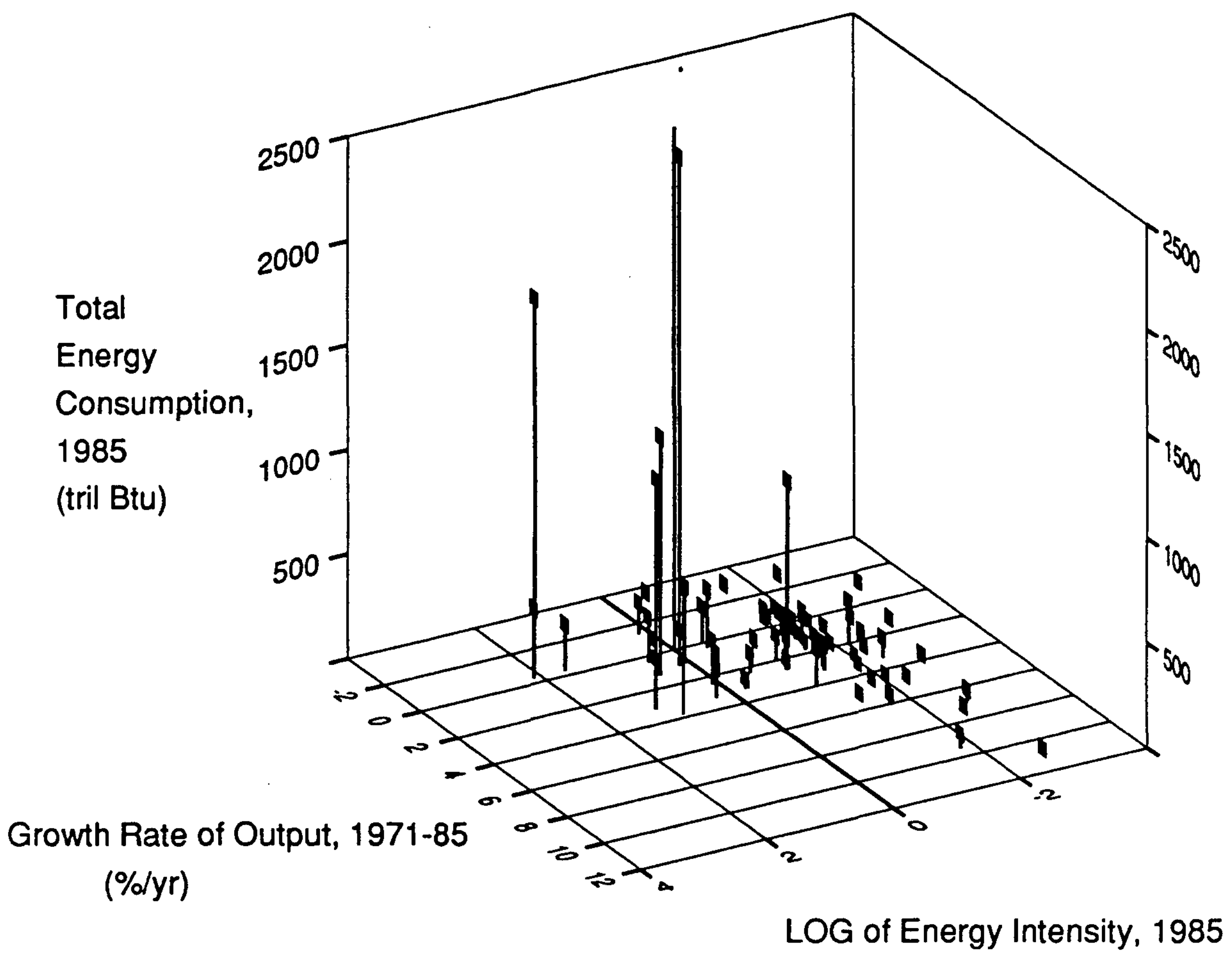


FIGURE 2.2
Grouping of Industry Subsectors for Modeling

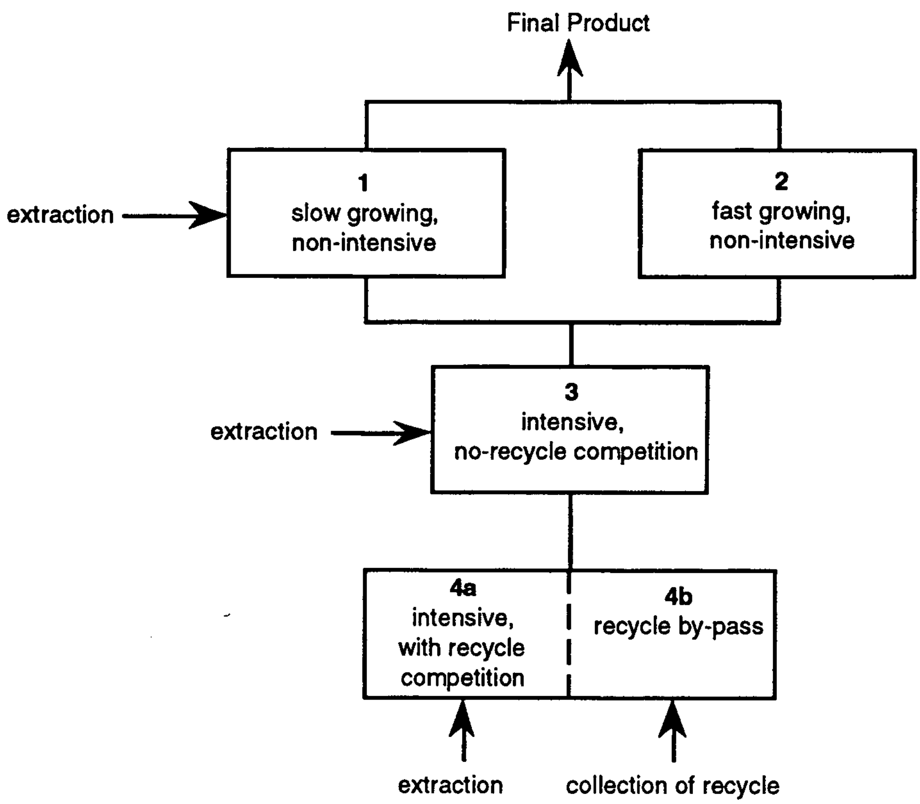
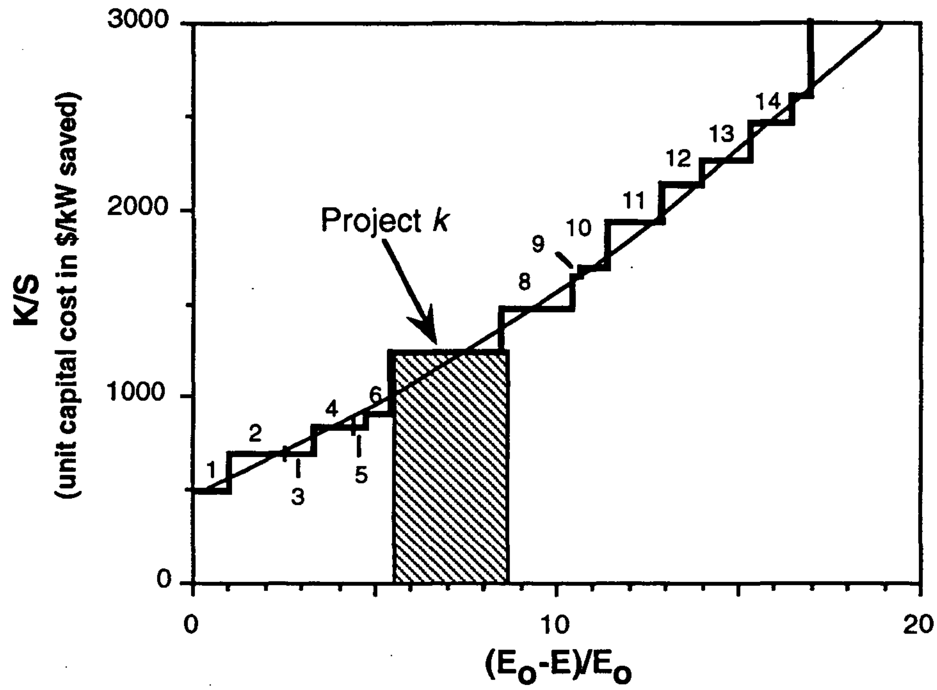


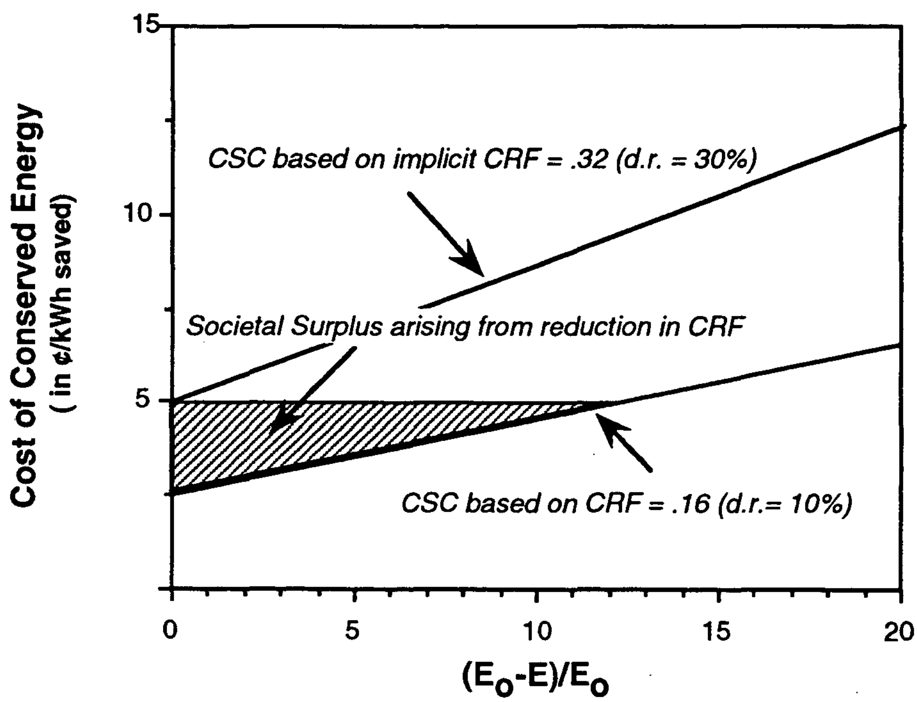
FIGURE 3.1
Conservation Supply Curve



(Cumulative Annual Energy Savings in % of base)

Note: Numbers on curve correspond to hypothetical project number.

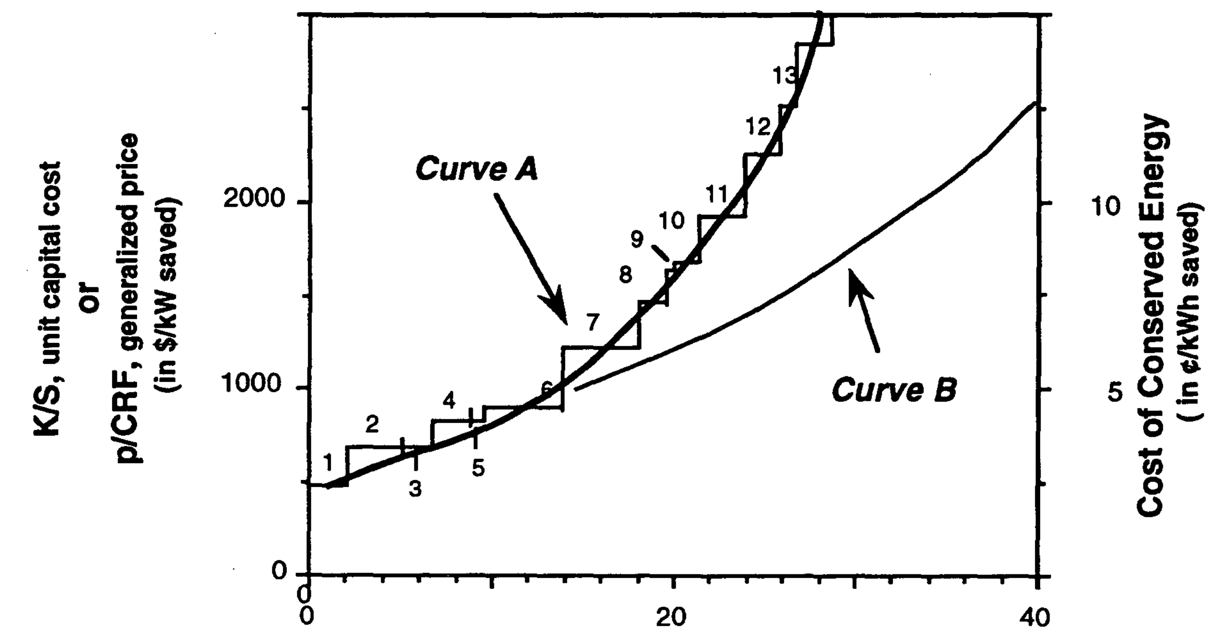
FIGURE 3.2
Dependence of Conservation Supply Curve on Capital Recovery Factor



(Cumulative Annual Energy Savings in % of base)

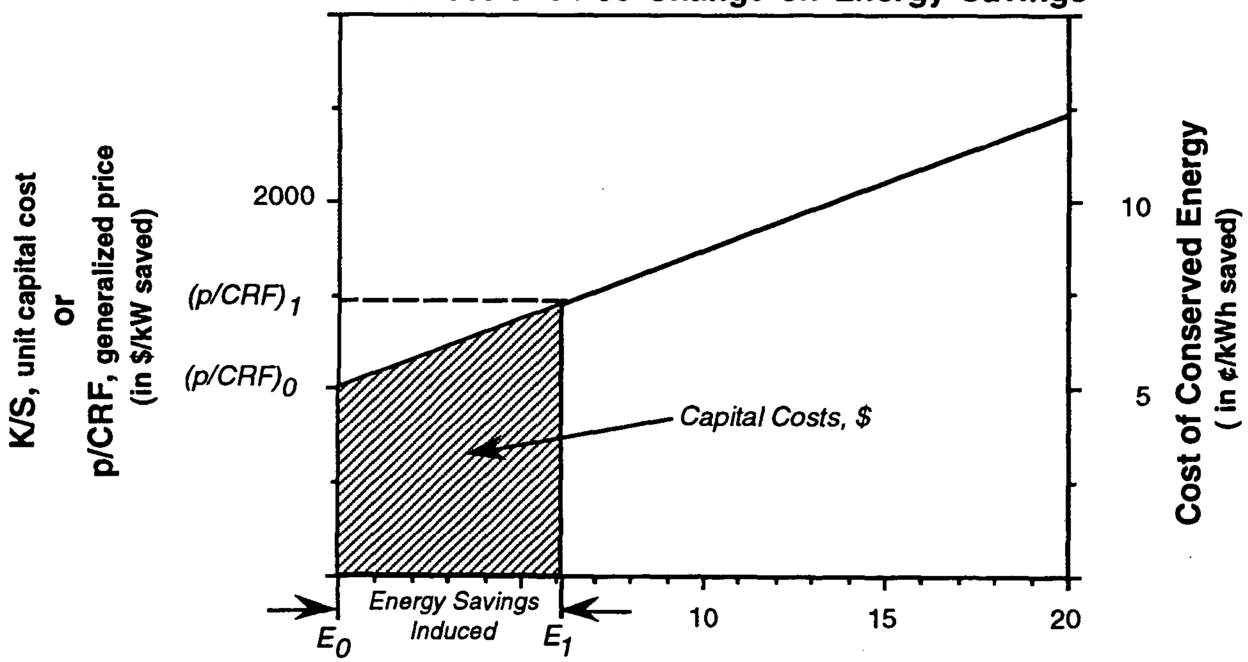
Note: CCE calculated assuming project life = 10 yrs

FIGURE 3.3
Effect of Innovation on the Shape of CSCs



(Cumulative Annual Energy Savings in % of base)
Curve A: Based on cost analysis of a short list of generic technologies.
Curve B: Based on a fairly complete list of technologies including those at plants in higher priced environments.
CCE calculated using CRF = 0.32

FIGURE 3.4
Effect of Price Change on Energy Savings



(Cumulative Annual Energy Savings in % of base)
CCE colculated using CRF = 0.32

Figure 3.5
Illustration of Energy Intensity Calculation

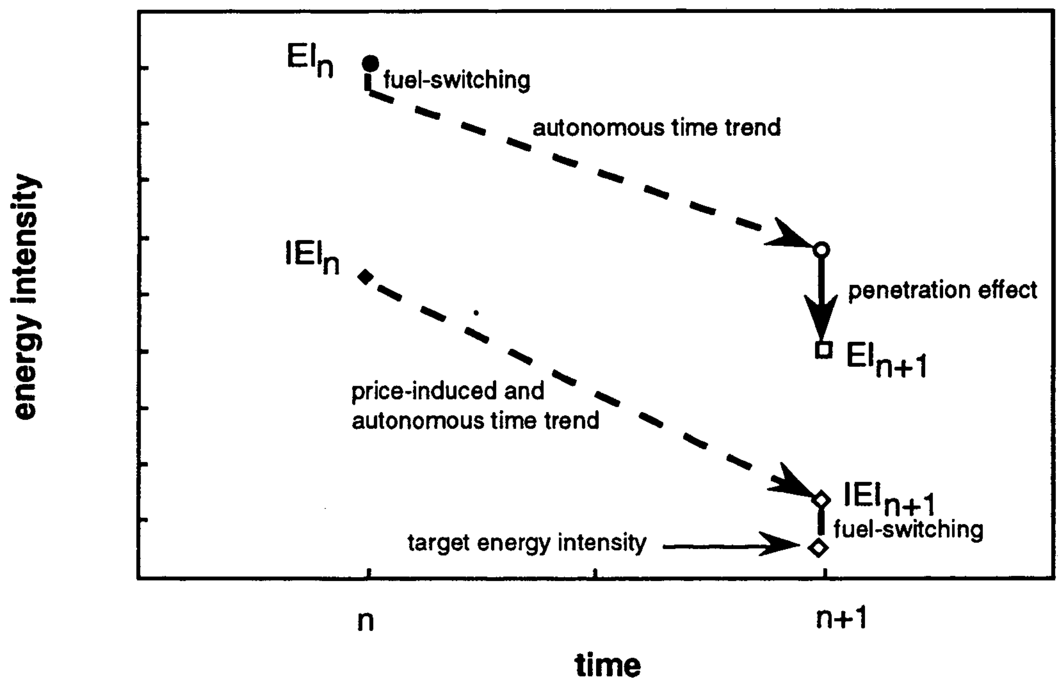


Figure 3.6
Illustration of Conservation Supply Curve Equation

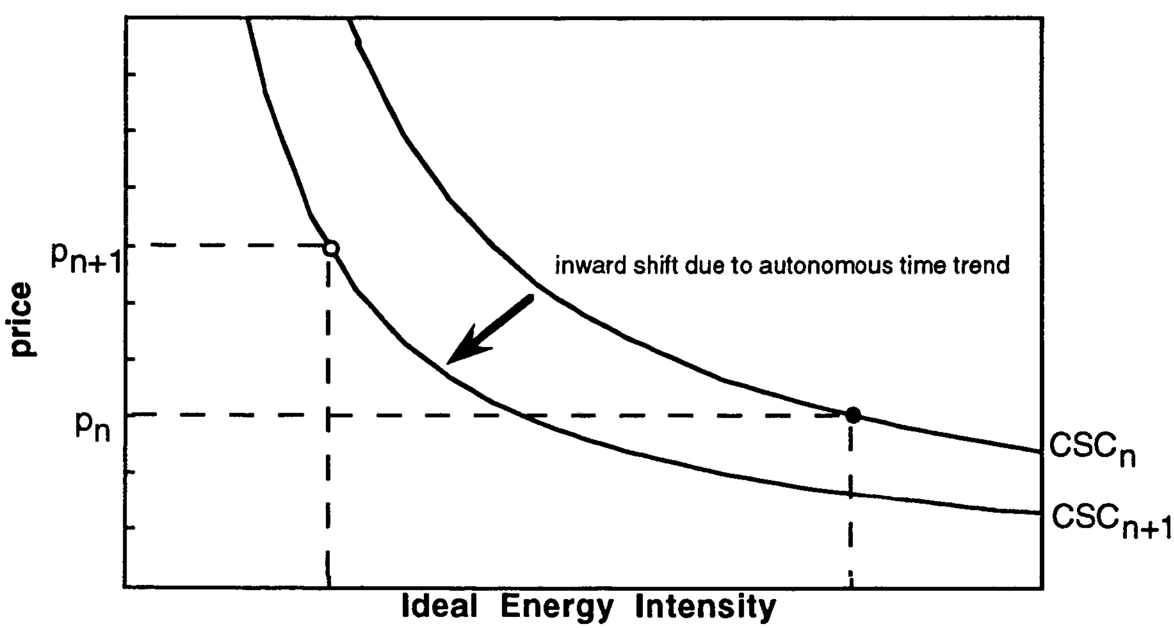
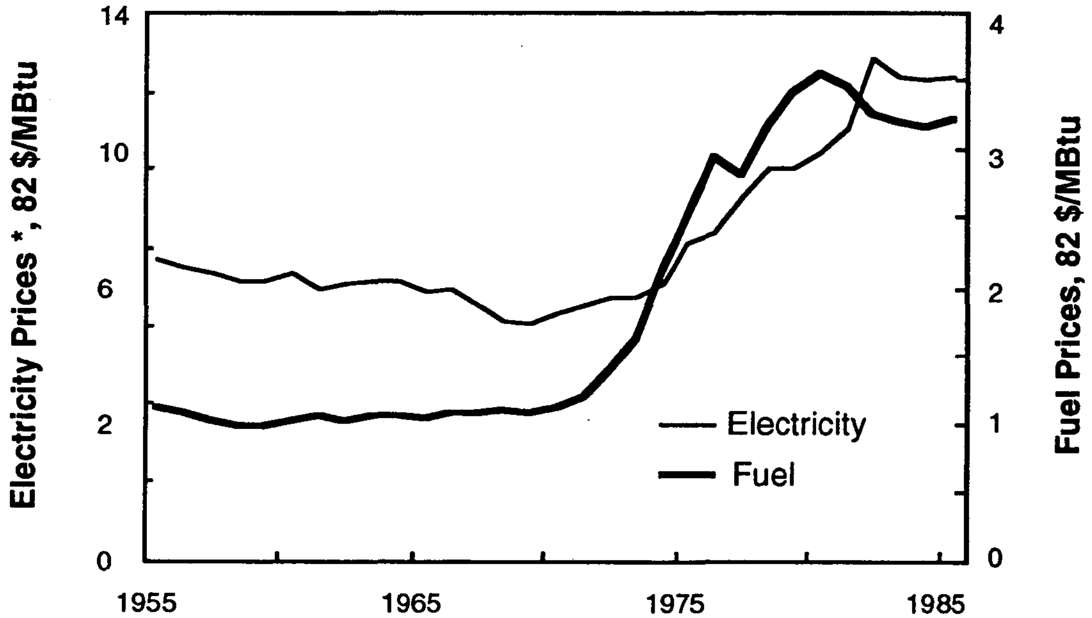


FIGURE 5.1
Sector 3, Electricity and Fuel Prices, 1955-1985



* *Based on 1kWh = 3413 Btu*

Figure 5.2a
Sector 1, Actual and Estimated Energy Intensity, Electricity, 1958-1985
***Gap0* = 0.2 *Pen* = 0.10**

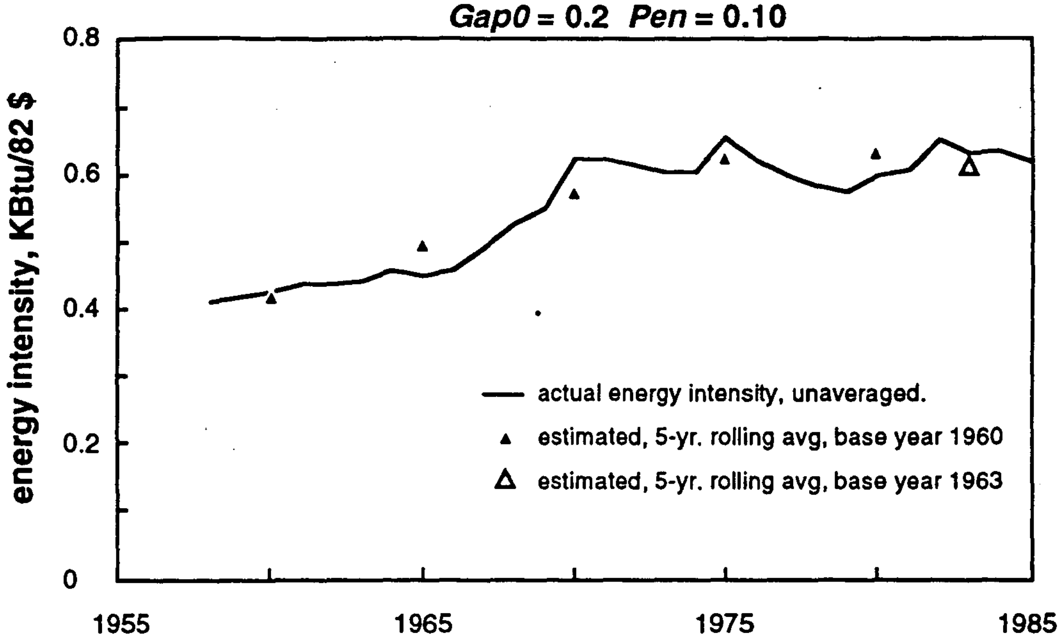


Figure 5.2b
Sector 1, Actual and Estimated Energy Intensity, Fuel, 1958-1985
***Gap0* = 0.2 *Pen* = 0.10**

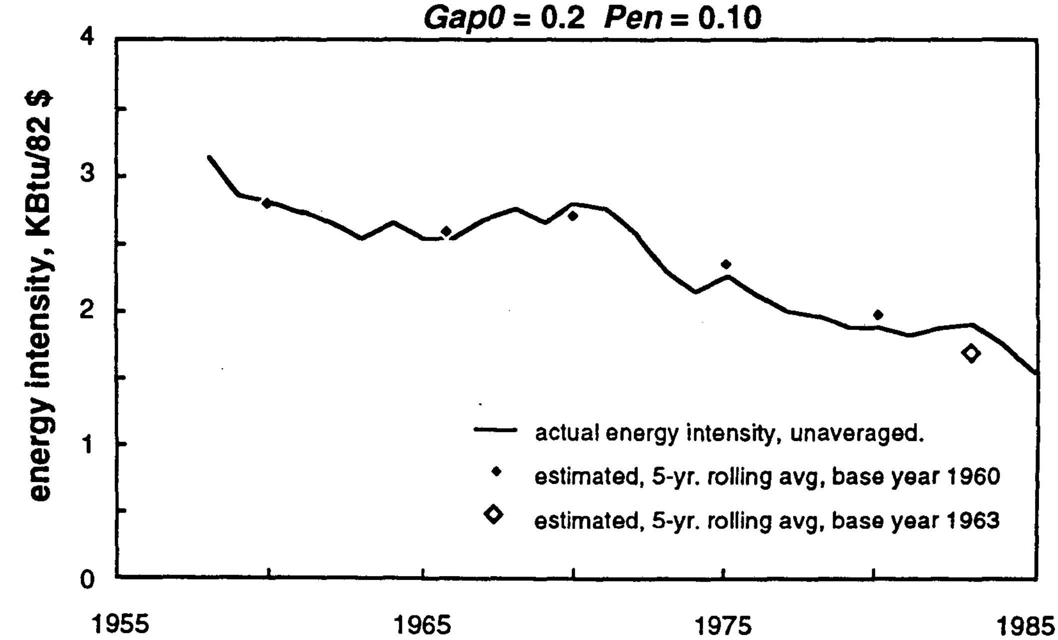


Figure 5.3a
Sector 2, Actual and Estimated Energy Intensity, Electricity, 1958-1985
***Gap0* = 0.2 *Pen* = 0.10**

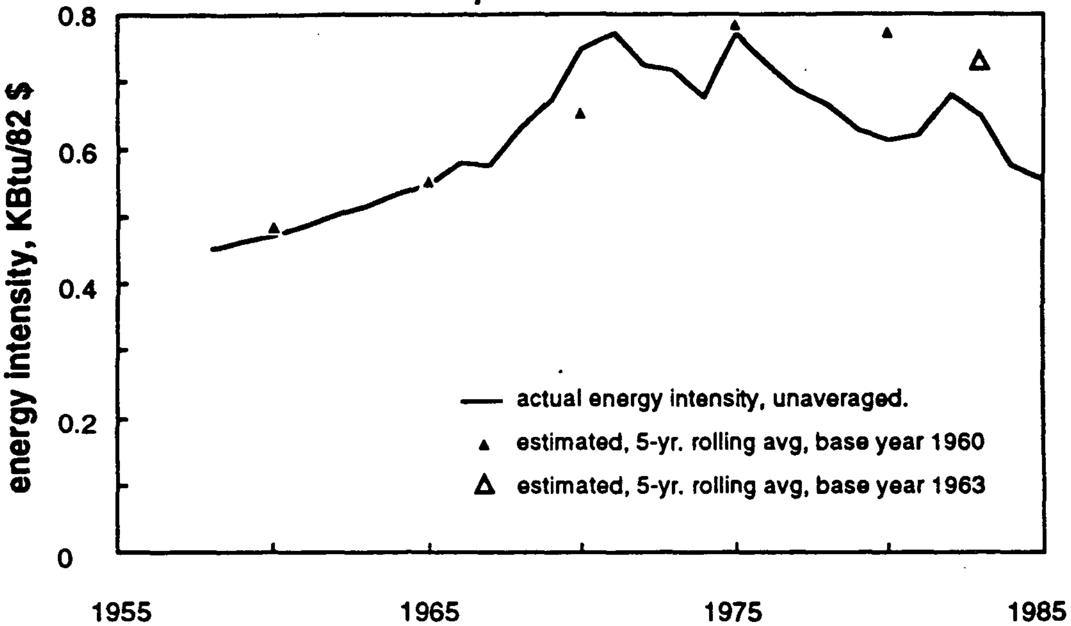


Figure 5.3b
Sector 2, Actual and Estimated Energy Intensity, Fuel, 1958-1985
***Gap0* = 0.2 *Pen* = 0.10**

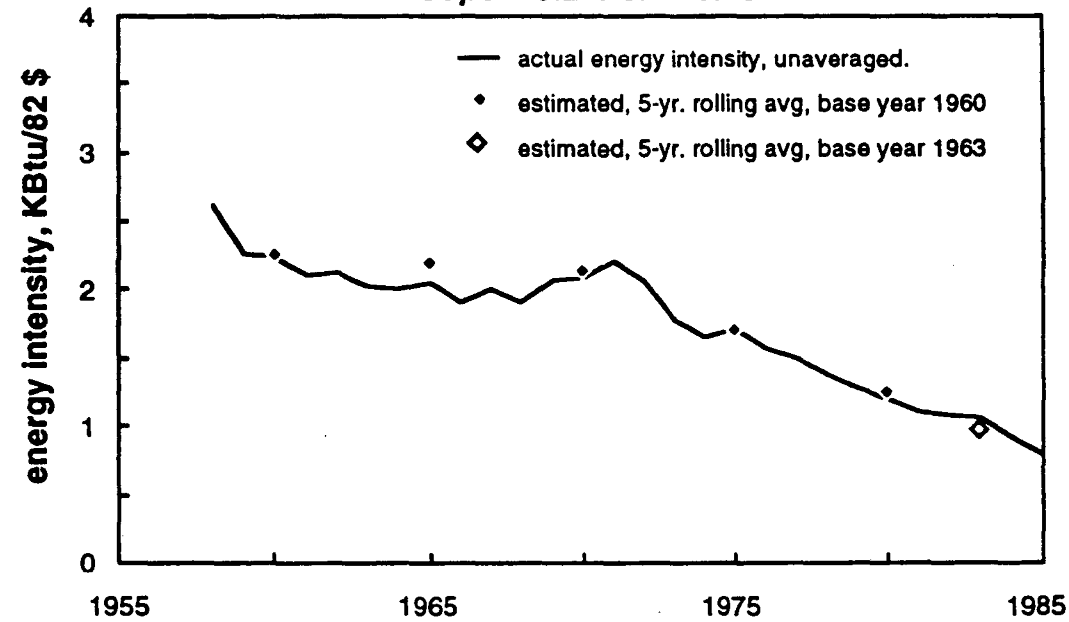


Figure 5.4a
Sector 3, Actual and Estimated Energy Intensity, Electricity, 1958-1985
***Gap0* = 0.2 *Pen* = 0.10**

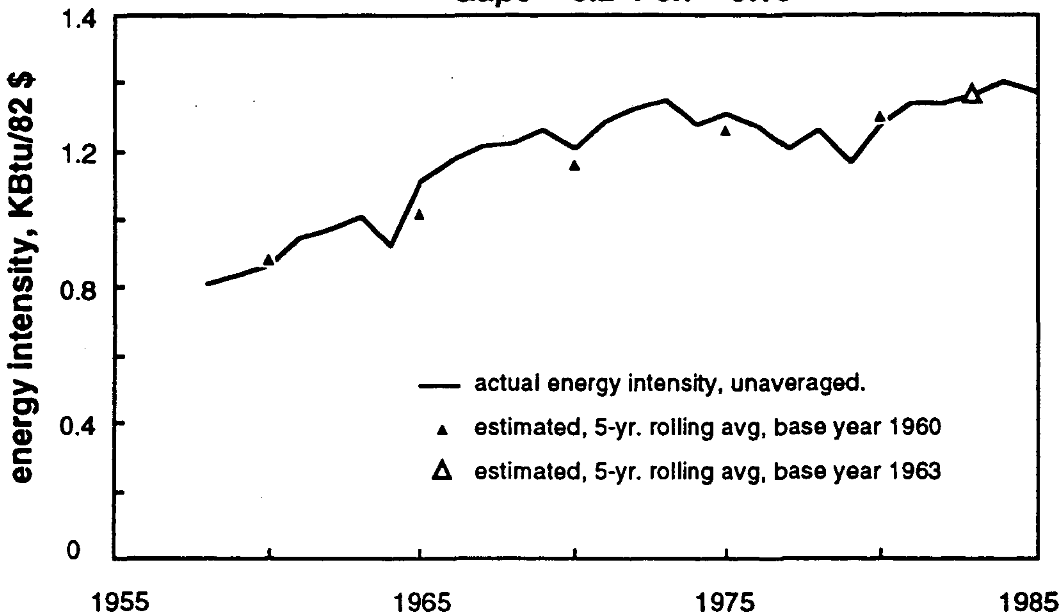


Figure 5.4b
Sector 3, Actual and Estimated Energy Intensity, Fuel, 1958-1985
***Gap0* = 0.2 *Pen* = 0.10**

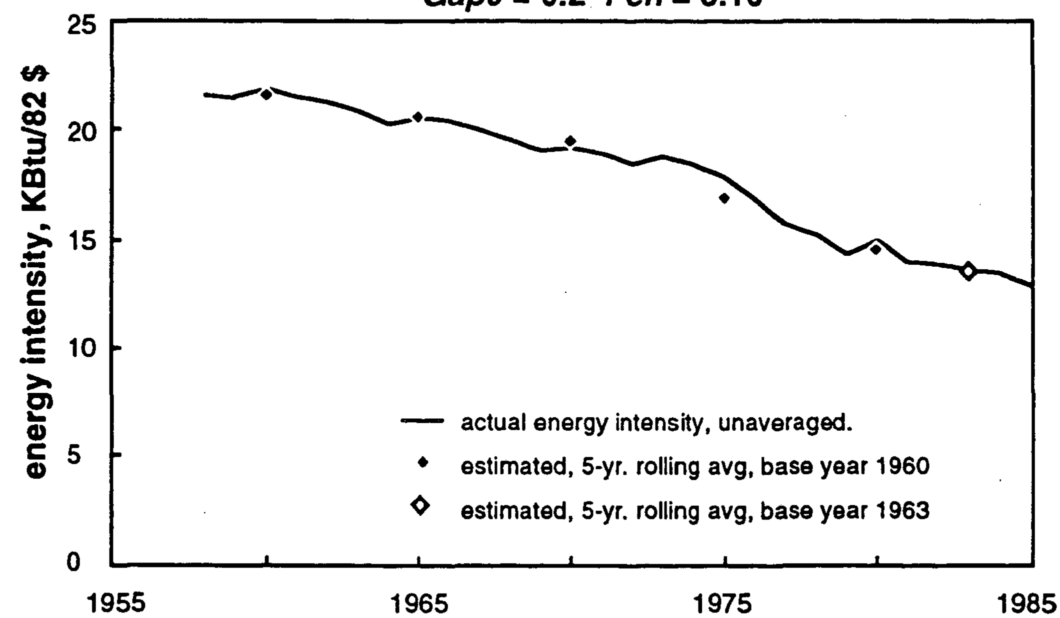


Figure 5.5a
Sector 4 *, Actual and Estimated Energy Intensity, Electricity, 1958-1985
(* excluding steel industry)
***Gap0* = 0.1 *Pen* = 0.05**

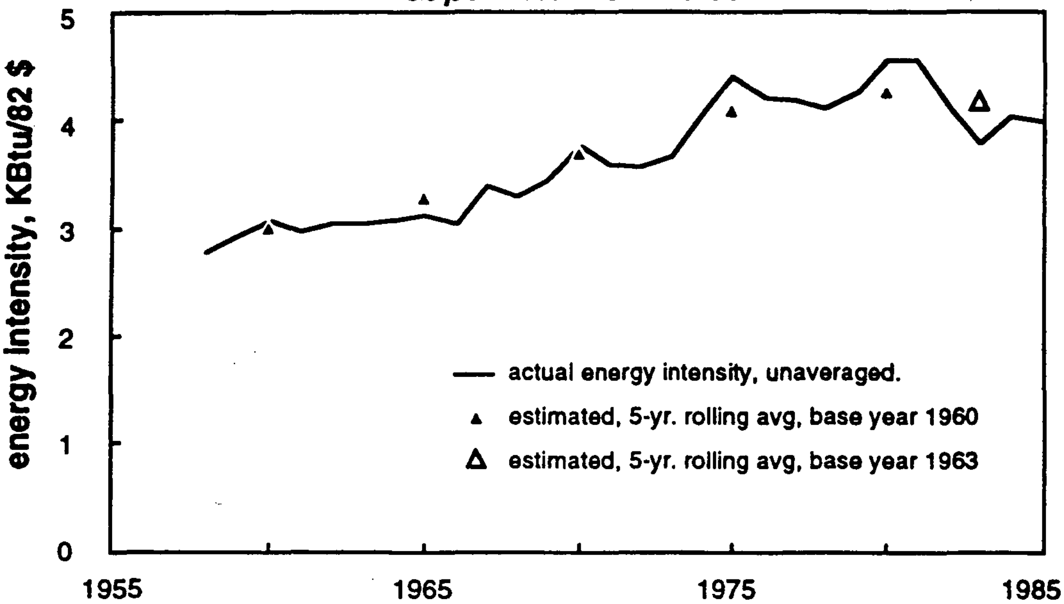


Figure 5.5b
Sector 4 *, Actual and Estimated Energy Intensity, Fuel, 1958-1985
(* excluding steel industry)
***Gap0* = 0.1 *Pen* = 0.05**

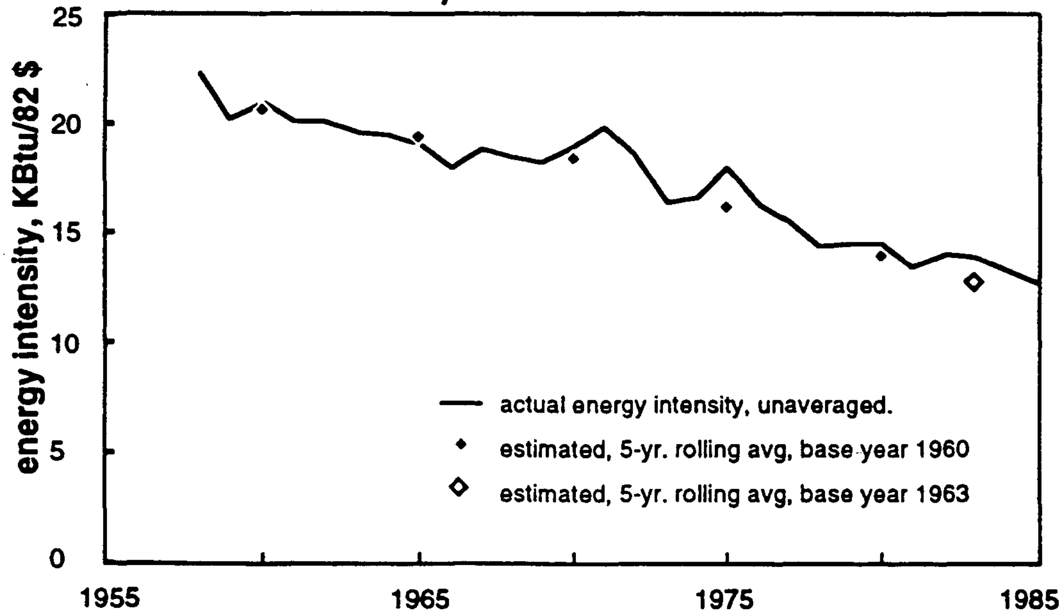


FIGURE 5.6a
Steel Industry, Actual and Estimated Energy Intensity
Electricity, 1958-1985

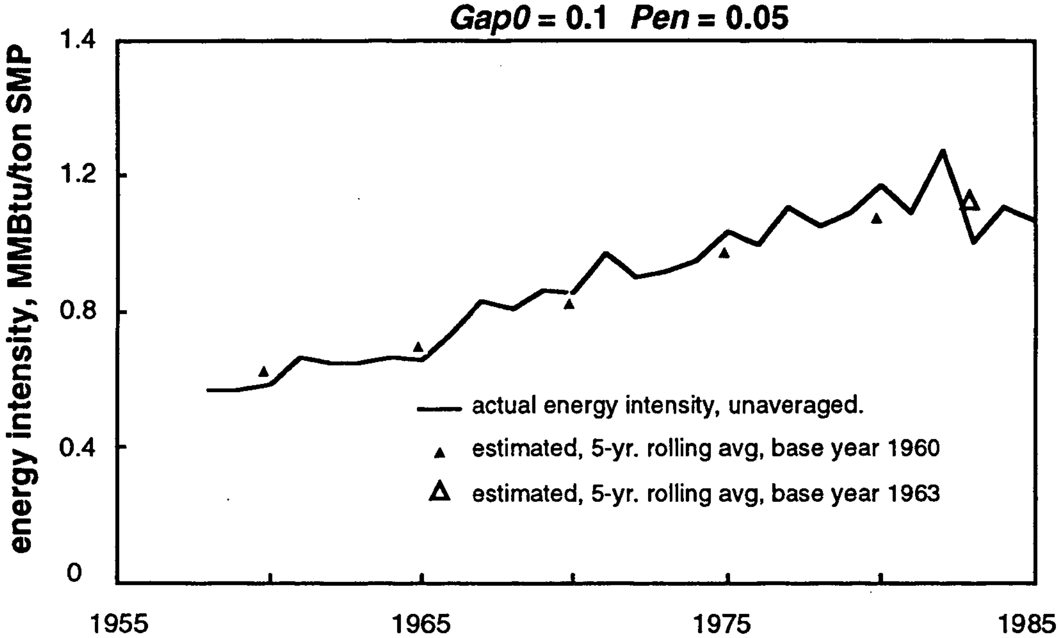


FIGURE 5.6b
Steel Industry, Actual and Estimated Energy Intensity
Fuel, 1958-1985

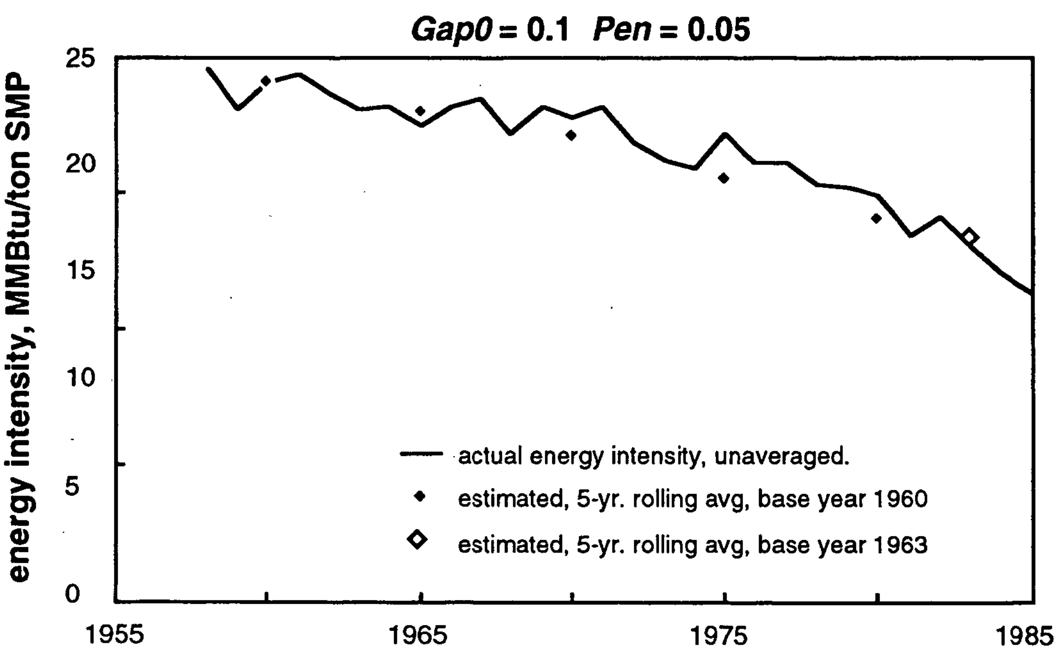
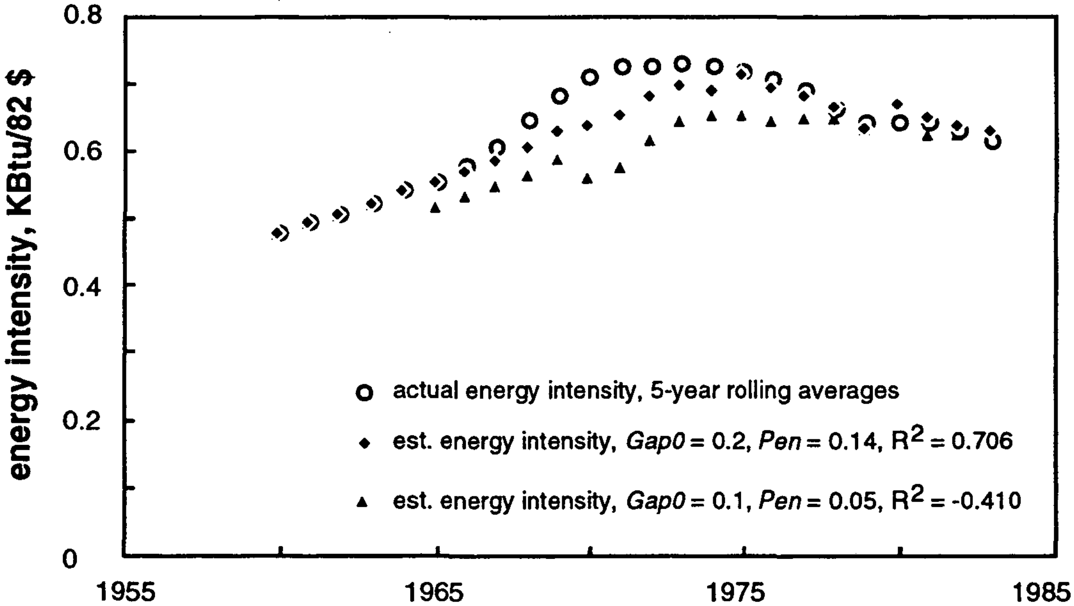


Figure 5.7
Affect of Changing *Gap0* and *Pen*, Sector 2, Electricity, 1958-1985



Note: Estimates use five different values base years from 1960-1964. Hence, each series of points can be viewed as five separate forecasts using the same value of *Gap0* and *Pen*.

APPENDIX A
RELATIONSHIP BETWEEN LIEF, NEA AND SIC SECTORS

TAXONOMY E: INDUSTRY SECTORS

LIEF Sector	NEA CODE	INDUSTRY TITLE	SIC CODES	BIE CODE
		AGRICULTURE		
Sectors not included	01000	Livestock and livestock products	02 (ex. 0254, pt.0219, pt. 0259, pt.0291), pt.0191	pt. 62
	02000	Other agricultural products	01 (ex. pt.0191), pt.0219, pt.0259, pt.0291	pt. 62
	03000	Forestry and fishery products	08 (ex. 085), 09 (ex. 092)	pt. 62
	04000	Agricultural, forestry, and fishery services	0254, 07 (ex. 074), 085, 092	pt. 62
		MINING		
	05000	Iron and ferroalloy ores mining	101, 106	63
	06001	Uranium - radium - vanadium ores mining	1094	pt. 64
	06002	Nonferrous metal ores mining	102, 103, 104, 105, pt. 108, 109 (ex. 1094)	pt. 64
	07010	Anthracite coal mining	pt. 11	pt. 65
	07020	Bituminous and lignite coal mining	pt. 12	pt. 65
	08001	Crude petroleum	pt. 131	pt. 66
	08002	Natural gas	pt. 131	pt. 66
	08003	Natural gas liquids	132	pt. 66
	09000	Stone and clay mining and quarrying	141, 142, 144, 145, pt. 148, 149	67
	10000	Chemical and fertilizer mineral mining	147	68
		CONSTRUCTION		
	11001	Oil and gas well drilling	pt. 138	pt. 69
	11002	New construction	pt.15, pt.16, pt.17, pt.108, pt.11, pt.12, pt.148	pt. 69
	12000	Maintenance and repair construction	pt.15, pt.16, pt.17, pt.138	pt. 69
(Sector = 1 unless otherwise labeled)		MANUFACTURING		
	13990	Ordnance and accessories	348	39
	13010	Guided missiles and space vehicles	3761	pt. 57
2	13030	Tanks and tank components	3795	pt. 42
	14000	Food and kindred products	20	1
	15000	Tobacco manufactures	21	2
	16000	Broad and narrow fabrics, yarn and thread mills	221, 222, 223, 224, 226, 228	3
	17000	Miscellaneous textile goods and floor coverings	227, 229	4
	18990	Knitting mills	225	5
	18040	Apparel made from purchased materials	231, 232, 233, 234, 235, 236, 237, 238, 39996	6[a]
	19000	Miscellaneous fabricated textile products	239	7
	20990	Lumber and wood products	241, 242, 243, 249, 2448	8[b]
	20070	Prefabricated wood buildings	2452	pt. 9
	21000	Wood containers	244 (ex. 2448)	10[b]
	22000	Household furniture	251	11
2	23000	Other furniture and fixtures	252, 253, 254, 259	12
4	24020	Paper mills, except building paper	262	14
4 (except for	24990	Paper and allied products, ex. containers, boxes, paper mills	261, 263, 264, 266	13
SIC 264 = S1)	25000	Paperboard containers and boxes	265	15
2	26000	Printing and publishing	27	16
3	27010	Industrial chemicals	281 (ex. 28195), 2865, 2869	pt. 17[c]
3	27020	Fertilizers	2873, 2874, 2875	pt. 18
	27030	Pesticides and agricultural chemicals, n.e.c.	2879	pt. 18
	27040	Miscellaneous chemical products	2861, 289	pt. 17
4	28010	Plastic materials and resins	2821	pt. 19
4	28020	Synthetic rubber	2822	pt. 19
3	28990	Cellulosic man made fibers and organic fibers	2823, 2824	pt. 19
2	29000	Drugs, cleaning and toilet preparations	283, 284	20
	30000	Paints and allied products	285	21
3	31011	Petroleum refining	291	22
3	31012	Miscellaneous products of petroleum and coal	299	23

APPENDIX A
RELATIONSHIP BETWEEN LIEF, NEA AND SIC SECTORS

LIEF Sector	NEA CODE	INDUSTRY TITLE	SIC CODES	BIE CODE
		MANUFACTURING (cont.)		
3	31990	Paving mixtures, blocks, asphalt felts and coatings	295	24
2	32000	Rubber and miscellaneous plastics products	30	25
	33000	Leather tanning and finishing	311	26
	34000	Footwear and other leather products	313, 314, 315, 316, 317 319	27
4	35000	Glass and glass products	321, 322, 323	28
3	36010	Cement, hydraulic	324	29
3	36990	Stone and clay products, ex. cement hydraulic	325, 326, 327, 328, 329	30
4	37011	Coke oven products	pt. 3312	pt. 31
4	37012	Blast furnaces and basic steel ex. coke oven products	331 (ex. pt. 3312)	pt. 31
4	37990	Primary iron and steel ex. blast furnaces and basic steel	332, 339	32
	37999	Forgings	3462, 3463	pt. 37[d]
4	38040	Primary aluminum	3334, 28195	pt. 33[c]
4	38990	Primary nonferrous metals, ex. primary aluminum	333 (ex. 3334), 334, 335 336	pt. 33
	39000	Metal containers	341	34
	40000	Heating, plumbing, and fabricated structural metal products	343, 344	35
	41010	Screw machine products	345	36
	41990	Metal stampings	346 (ex. 3462, 3463)	pt. 37
	42000	Other fabricated metal products	342, 347, 349	38
	43000	Engines and turbines	351	40
	44000	Farm and garden machinery	352	41
	45000	Construction and mining machinery	3531, 3532, 3533	pt. 42
	46000	Materials handling machinery and equipment	3534, 3535, 3536, 3537	43
	47000	Metalworking machinery and equipment	354	44
	48000	Special industry machinery and equipment	355	45
	49000	General industrial machinery and equipment	356	46
2	50000	Miscellaneous machinery except electrical	359	47
2	51000	Office, computing, and accounting machines	357	48
	52000	Service industry machines	358	49
	53990	Electrical transmission and distribution equipment	361, 362	50
2	53010	Instruments to measure electricity and industrial apparatus	3825	pt. 59
	54000	Household appliances	363	51
	55000	Electric lighting and wiring equipment	364	52
2	56000	Radio, television and communication equipment	365, 366	53
2	57000	Electronic components and accessories	367	54
2	58000	Miscellaneous electrical machinery, equipment and supplies	369	55
	59000	Motor vehicles and equipment	371	56
	60000	Aircraft and parts	372, 376 (ex. 3761)	pt. 57
	61990	Other transportation equipment	373, 374, 375, 379 (ex. 3795)	58
	61060	Mobile homes	2451	pt. 9
2	62000	Professional, scientific and controlling instruments and supplies	381, 382 (ex. 3825), 384, 387	pt. 59
2	63000	Optical, ophthalmic, and photographic equipment and supplies	383, 385, 386	60
	64000	Miscellaneous manufacturing	39 (ex. 39996)	61[a]
		TRANSPORTATION		
Sectors not included	65010	Railroads and related services	40, 474, pt. 4789	70
	65020	Local, suburban, and interurban highway passenger transportation	41	71
	65030	Motor freight transportation and warehousing	42, pt. 4789	72
	65040	Water transportation	44	—
	65050	Air transportation	45	73
	65060	Pipelines ex. natural gas	46	74
	65070	Transportation services	47 (ex 474 and pt. 4789)	75

APPENDIX B
RELATION OF THE LEARNING CURVE CHARACTERISTIC TO THE AUTONOMOUS TREND

Let annual production be P(t) and assume it has been growing at an average rate α (fraction/year) for many years. The cumulative production is then

$$CP = \int P(t')dt' = P(t)/\alpha \qquad \text{(B1)}$$

In one year cumulative production increases by the ratio

$$\frac{P/\alpha + P\,(1+\alpha)}{P/\alpha}$$

Total unit costs (excluding the cost of products from other sectors) are assumed to have the dependence

$$UC = k\,(CP)^{-\beta} \qquad \text{(B2)}$$

where, according to the 20% reduction-per-doubling-of-CP characteristic,

$$2^{-\beta} = 0.8, \; or \;\; \beta = 0.32$$

The annual change of unit costs is given then by the factor:

$$(1+\alpha)^{-\beta} \approx 1 - \alpha\beta$$

For $\alpha = 0.2$, the average growth rate for manufacturing in recent decades, the rate of decline of unit costs is:

$$-\alpha\beta = 0.6\% \;\; per\, year.$$

Since Eq. A2 overestimates cumulative production in a typical product cycle, where growth rates begin high and then decline, the typical rate of decline would be faster than 0.6% per year. Analyses of the rate of energy costs in total costs and the different roles of fuel and electricity consumption would be needed before this rough estimate can be converted into autonomous trends for the energy intensities.

APPENDIX C

DOCUMENTATION FOR LONG-TERM INDUSTRIAL ENERGY FORECASTING MODEL (LIEF)

(LBL 9/91)*

A spreadsheet model in Lotus 1-2-3, Release 3.0, has been created for long-term industrial energy demand forecasting. All industry or any subsector can be modeled in terms of four subgroups. The general approach is described elsewhere (Marc Ross and Roland Hwang, "A Model for Long-Term Industrial Energy Forecasting (LIEF)," LBL, 1991 Draft Final). The specific equations, definitions of inputs and sample inputs are presented here.

1. DEFINITIONS

Sector i: These four sectors will, in the usual application, be: (1) all sectors not included in the 2nd, 3rd, and 4th groups, (2) fast-growing sectors, (3) energy-intensive sectors with no appreciable recycling, and (4) energy-intensive sectors where recycling is, in principle, possible for most product lines (e.g., paper, plastics, glass, and metals).

Energy form j: Only two forms are incorporated in the present version: fossil fuel and electricity.

E_{ij}: Energy consumption by sector i of energy form j.

Q_i: Production by sector i. In the present input files, base year production is gross output in the $ of that year; and growth rates are for BLS real output.

T: Period between years for which forecasts are made (e.g., 5 years). There are 10 periods in the forecast.

t_o: base year.

$EI_{ij} = E_{ij}/Q_i$: energy intensity of sector i for fuel type j.

p_{ij}: price of fuel for given sector.

2. EQUATIONS

Most equations are for an iteration, e.g., from time $t\text{-}T$ to time t. Neglect, for the moment, price-induced fuel switching, and assume a constant growth rate describes the autonomous change. Then the general structure of the iteration is:

$$EI_{ij}(t) = (1 - PEN) * EI_{ij}(t\text{-}T) * exp(-B_{ij}) + PEN * IEI_{ij}(p_{ij},t)$$

where $IEI_{ij}(t)$ is the equilibrium energy intensity for the prices expected in the time interval ending at t.

More generally, the iteration is:

$$EI_{ij}(t) = (1 - PEN) * EI_{ij}(t\text{-}T) * F_1(p_{ij}/p_{ij'}) * f_1(t) + PEN * IEI_{ij}(t) * F_2(p_{ij}/p_{ij'})$$

* Address questions to Marc Ross, Physics Department, University of Michigan, Ann Arbor, MI 48809 (313) 764-4459.

where $IEI_{ij}(t)$ is conservation supply curve, a function of prices p_{ij} and time:

$$IEI_{ij}(p_{ij},t) = IEI_{ij}(t_o) * CSC(p_{ij}) * f_2(t)$$

Here the F_k's show the price-induced switching between fuel and electricity, and

$$F_2(t) = F_1 * F_2(t-T) \text{ with } F_2(t_o) = 1.$$

The f_k's show the autonomous technological trend (price independent) and $f_2(t) = f_1 * f_2(t-T)$ with $f_2(t_o) = 1$.

2.1 Production

Production for the four sectors is given by the following equation

$$Q_i(t) = K * exp[T ln(1+g_i(t))] * Q_i(t-T)$$

$$\text{where } K = \frac{\left[\sum_i Q_i(t-T)\right] * exp\,[T\, ln\,(1 + G\,(t))]}{\sum_i \left\{Q_i(t-T) * exp\,[T\, ln\,(1 + g_i\,(t))]\right\}} \qquad (4)$$

Here, the g_i's are relative growth rates for the four sectors. They are all adjusted by the factor K to achieve an overall growth rate $G(t)$.

2.2 Ideal Energy Intensity

The conservation supply curve in year t is the energy intensity $IEI(t)$. It is a function of the expected price of energy, EP (and the behavioral capital recovery factor CRF).

$EP_{ij}(t)$ is the expected price appropriate to the investment at the time of decision. In the model runs reported here, the expected price is taken to be

$$EP_{ij}(t) = m\,t + b$$

where m is the slope and b is the y-intercept of a line (using the least squares method) determined by the energy prices from t-2 to t-7 years. That is, when evaluating the project, the decision-maker linearly extrapolates the price history two years into the future when the project will have been in use a year or two.

Then

$$IEI_{ij}(p_{ij},t) = IEI\,(t_o) * exp\left\{-A_{ij} * \ ln\left(\frac{EP_{ij}(t)\,/\,CRF\,(t-T)}{p_{ij}\,(t_o)/\,CRF\,(t_o)}\right)\right\}$$

$$* \ exp\left(-\sum_{n=0}^{N}\,[B_{ij}(nT) * T] - B_{ij}\,(0) * \frac{T}{2}\right)$$

where $N = ((t-t_o)/T)-1$ is the number of the period less one, and

$$B_{ij}(t) = B_{ij}(0) * [1-(t-to)/(T * Bpr)]$$

is the rate of autonomous technical change (which declines to zero in Bpr periods), and

$$IEI_{ij}(t_o) = (1 - Gap0) * EI_{ij}(t_o)$$

for base year, where $EI_{ij}(t_o)$ is the actual energy intensity at time t_o and $Gap0$ is the base year fractional difference between actual and ideal energy intensity.

2.3 Iteration of Energy Intensity

2.3.1 Electricity-fuel share:

Previous period's energy intensity adjusted for fuel switching is given by

$$PEI_{ij}(t) = EI_{ij}(t-T) * [1 + \Delta S_{ij}(t)]$$

$$\text{where, } DS_{ij} = \left(\frac{C}{S_{ij}(t-T)}\right) * ln\left[\frac{p'_{ij}(t-T)\,/p_{ij}(t-T)}{p'_{ij}(t-2T)\,/p_{ij}(t-2T)}\right]$$

and the prime denotes the price of the energy form other than j.

$$\text{Here, } S_{i,e}(t) = \frac{HRATE * E_{i,e}(t)}{HRATE * E_{i,e}(t) + E_{i,f}(t)} \quad \text{and} \quad S_{i,f}(t) = 1 - S_{i,e}(t)$$

with subscripts, *e,f* for electricity and fuel respectively.

2.3.2 Conservation supply curve and autonomous technical change:

$$EI_{i,j}(t) = PEI_{i,j}(t) * exp\,(-B_{i,j}(t) * T) * (1 - PEN\,(t)) + PEN\,(t) * IEI_{i,j}(t) * SE_{ij}\,(t)$$

$$\text{where, } SE_{ij}(t) = \frac{PEI_{i,j}(t)}{EI_{i,j}(t-T)} * SE_{i,j}(t-T) \text{ for } t > t_o \text{ and } SE_{ij}\,(t_o) = 1.$$

$SE_{ij}(t)$ is the cumulative fuel-switching factor. In addition,

$$PEN(t) = 1 - \exp[T * \ln(1-PENYR(t))],$$

The equation for $EI(t)$ is critical in its time steps. The conservation supply curve is determined by past price trends. After adjusting the conservation supply curve point, $IEI(t)$, for the fuel switching which has occurred, it becomes the target energy intensity. The intensity of the previous period after adjusting for fuel switching, $PEI(t)$, is the starting point. The latter is first adjusted for autonomous technical change (taken to be as the same rate as for the CSC). Then the energy intensity moves toward the CSC point as dictated by a penetration factor. Penetration is likely to be in the PENYR = 5 to 15% per year range if energy has a high priority, and PENYR will be near zero if energy price has a low priority.

3. INPUT PARAMETERS

The following table lists the input parameters that the model requires. Some reminders are:

(i) In the present LOTUS implementation of LIEF (LIEF.Wk3), GAP0 and PENYR(t) are the same for all sectors.

(ii) The recycling parameters are an average for all of sector 4.

(iii) To omit a sector, e.g. to work with 3 sectors, one cannot set the base-year energy use of an omitted sector to zero; rather set it to small value.

TABLE 1
INPUT PARAMETERS

Symbol	Description	Unit	Size of Field
Historical			
$Q_i(t_o)$	base-year production rate	$ or user's choice	1 x 4
$R(t_o)$	base-year recycling fraction	fraction	see below
$E_{ij}(t_o)$	base-year energy consumption	trillion Btu/yr or user's choice[a]	2 x 4
$P_j(t)$	average price in base year and prior period (constant $ as for forecast)	$/million Btu or user's choice[a]	see below
DP_{ij}	price difference (sector$_i$ average)	as for RP	2 x 4
REI_j	recycle energy intensity in sector 4 as a fraction of that for primary process	fraction	1 x 2
$CRF(t_o)$	implicit capital recovery factor (typically 15 to 50%)	% per year	see below
GAPO	base year fractional difference between actual energy intensity and CSC based on implicit *CRF*	dimensionless	1
Forecast, not Policy Related			
$g_i(t)$	relative production growth	% per year	4 x 10
$B_{ij}(0)$	autonomous time trend[b]	fraction per year	2 x 4
BPR	saturation period for autonomous time trend. Perhaps *BPR* * *T* = 50 years.	time periods	1
T	time period (e.g., 5 years)	years	1
t_o	base year (e.g., 1985)	year	1
HRATE	factor for combining electricity and fuel into resource energy	dimensionless	1

TABLE 1 (*cont.*)
INPUT PARAMETERS

Symbol	Description	Unit	Size of Field
Forecast, Possibly Policy Related			
$P_j(t)$	average price (constant $)	$/million btu or user's choice	2 x 12
$G(t)$	overall production growth rate[b] (manufacturing real output has been growing slower than GNP by about 2% per year)	% per year	1 x 10
$R(t)$	recycling fraction in sector 4 (fraction of production using recycled material from sources external to sectors 3 &4	fraction	1 x 11[c]
A_{ij}	CSC "slope". $A = 0.5$ implies 1% price increase leads to 0.5% energy savings eventually.	dimensionless	2 x 4
C	fuel switch coefficient (both fuel prices $RP_j(t)$ must be in same units). $0 < C < 0.05$	dimensionless	1
Forecast, Possibly Policy Related (cont.)			
$CRF(t)$	implicit or effective capital factor.	% per year	1 x 11[c]
$PENYR(t)$	percent toward which energy intensity moves to "ideal" energy intensity per year. Refers to period before t.	% per year	1 x 10

Notes:

[a] Units must be consistent.

[b] If B has been estimated from historical data, then consistency in definition of production series, especially for growth rate G, between historical and future periods is important.

[c] Including historical year(s).

4. FAST GROWING SECTORS

In the present input files, sector 2 basically consists of the high tech sectors: SIC:25 excluding 251, 27, 283 and 284, 30, 357 and 359, 365 through 369, 3761 and 3795, and 38. These are respectively:

furniture and fixtures excluding household furniture
printing and publishing
drugs and toiletries
rubber and miscellaneous plastics products
computer and office equipment and miscellaneous industrial machinery
electronic equipment and components, communication equipment and miscellaneous electrical equipment
selected military equipment
instruments

These are the National Energy Accounts sectors which grew roughly 4% per year and above for the period 1971 to 1985.

5. RESULTS

Model results are printed out with the table or graph desired plus all four input screens on a single sheet. Since model results are presented in tables, fixed decimal form, if base-year energy inputs are large or small compared to one, it will be useful to renormalize the energy values (keeping fuel and electricity in the same units). Base-year production inputs are renormalized within the model so that total production, ΣQ_i, in the base year is equal to 1. All energy intensities are quoted relative to these renormalized production levels. An annotated printout is attached.

6. OPERATING INSTRUCTIONS

The model must be run on release 3.0 of Lotus 123 and runs best on a 386. It is assumed that new model users are already familiar with DOS.

Copy the contents of the floppy onto the hard drive. The floppy contains the model, LIEF.Wk3, and input file sub-directory, IN_DAT which contains two files BAU.Wk3 ("Business as Usual") and CONSV.Wk3 ("Conservation"). While in DOS, go to the root directory and create a new sub-directory. Copy the contents of the floppy into the new sub-directory. For example this procedure would be:

MD MODEL	makes directory
CD MODEL	changes to directory
COPY A: LIEF.Wk3	copies into directory
COPY A:IN_DATA*.*	copies subdirectory and contents into directory

Then start Lotus 123 v3.0, reset the directory to C:\MODEL and retrieve LIEF.Wk3. The model's custom menus should automatically appear as follows:

Help Edit Tables Graphs Print File Quit

The screen is split to allow you to view a screen of inputs on the left hand side and a screen of outputs on the right hand side. The custom menus allows you to select the screens you wish to view by choosing **Tables** or **Graphs**. In the current version of the model, the year tables and figures cannot be called by the model menu.

Input data may be edited by choosing the **Edit** menu. Four screens of data must be entered. The attached sample printout shows all four input screens and one output screen. Refer to Table 1 for explanations and section 3 for an explanation of the input parameters. If you are unsure of what parameter values to use, refer to the background document for guidance. The model currently has default values for parameters already entered. The default values may be retrieved by choosing **File** and then **Default.** Two example scenarios,"Business as Usual" (BAU.Wk3) and "Conservation" (CONSV.Wk3), can be run by choosing **File** and then **Retrieve.** See the main report (Marc Ross and Roland Hwang, "A Model for Long-Term Industrial Energy Forecasting (LIEF)," LBL, 1991 Draft Final) for an explanation of these parameters.

To save a scenario, save the input data entered into the four input screens by selecting **File** and then **Save.** Save file under the IN_DATA subdirectory. Name the input data set, for example:

C:\MODEL\IN_DATA\(name)

Give each input data set a new name. To run a previous scenario, choose **File** and then **Retrieve.**

If by accident, you switch to the normal Lotus menus, align the material in an acceptable form on the split screen and press Alt - H, and the Lotus will return you to the custom menus.

SAMPLE PRINTOUT
"Business As Usual" Scenario (BAU.Wk3)

Simplified Energy Forecasting Model of the Industrial Sector

Date of analysis: 26-Nov 11:45 AM

OUTPUT SCREEN

Total output is normalized in the base year

Energy price input

Summary (Electricity)

Year	EI	Q	E	P
1985	2.164	1.00	2.164	13.10
1990	2.169	1.09	2.371	11.00
1995	2.192	1.23	2.698	10.88
2000	2.215	1.38	3.055	11.31
2005	2.227	1.52	3.375	11.79
2010	2.205	1.66	3.652	12.28
2015	2.165	1.79	3.884	12.33
2020	2.108	1.93	4.073	12.38
2025	2.048	1.99	4.078	12.43
2030	1.978	2.05	4.058	12.47
2035	1.974	2.11	4.172	12.50

Capital Recovery Factor (%/yr)

Annual penetration, PENYR (%/yr)

Relative sectoral ouput growth rates (%/yr)

INPUT SCREENS

0.02 C

0.2 Gap0
0.5 REIelec
0.5 REIfuel
5 Period
1985 Base
10 Bpr(periods)

year	Ref Price Elec (*)	Fuel (*)	CRR %	R %	G %	P %
1980	10.70	3.06	33			
1985	13.10	3.41	33	25		
1990	11.00	2.40	33	25	1.80	2
1995	10.88	2.65	33	28	2.40	2
2000	11.31	3.47	33	30	2.30	2
2005	11.79	4.31	33	30	1.90	2
2010	12.28	5.15	33	32	1.80	2
2015	12.33	5.48	33	32	1.60	2
2020	12.38	5.82	33	35	1.50	2
2025	12.43	6.04	33	35	0.60	2
2030	12.47	6.25	33	35	0.60	2
2035	12.50	6.50	33	35	0.60	2

* $/million BTU

secto		E(0)	DP	A	B
S1	el	0.729	2.53	0.60	-0.018
	fu	1.815	0.26	0.50	0.004
S2	el	0.306	3.19	0.60	-0.005
	fu	0.436	0.37	0.50	0.004
S3	el	0.455	-1.6	0.50	-0.015
	fu	4.255	-0.0	0.40	0.006
S4	el	0.674	-1.8	0.50	-0.015
	fu	3.167	0.1	0.40	0.006
TotEl		2.164			
TotFu		9.673			

year	<--- Growth Rate ----> Sec1	Sec2	Sec3	Sec4
1990	1	5	0.5	0.5
1995	1	5	0.5	0.5
2000	1	4	0.5	0.5
2005	1	4	0.5	0.5
2010	1	4	0.5	0.5
2015	1	4	0.5	0.5
2020	1	3	0	0
2025	1	3	0	0
2030	1	3	0	0
2035	1	3	0	0

	<-- Production Rate --> Sec1	Sec2	Sec3	Sec4
1985	1181	551	331	178

Relative recycle intensity

Recycle fraction in Sector 4 (%)

B_{ij} is not in %

Time for B to decline to zero

Overall growth rate of mfg. output (%/yr)

Sectoral energy price difference; not a significant effect.

APPENDIX D
HISTORICAL DATA SERIES

Sources of Data

Output:

Office of Productivity and Technology, Bureau of Labor Statistics 1958-1985, U.S. Department of Labor.

Deflated using producer price index for total manufacturing production, BLS.

Energy Use:

National Energy Accounts (NEA) 1958-1985, U.S. Department of Commerce, Office of Business Analysis.

Energy Price:

Calculated from NEA database using following formula:

$$\frac{[\textit{producer energy value}]_{ij}}{[\text{energy use}]_{ij}}$$

Current value from NEA deflated by the authors using the producer price index for total manufacturing production, BLS.

Energy Intensity:

Calculated from BLS and NEA databases using following formula:

$$\frac{[\textit{energy use}]_{ij}}{[\textit{output value}]_{ij}}$$

SECTOR 1

YEAR	Output *mil 82$*	ELECTRICITY Price *82$/mil Btu*	 Use *tril Btu*	 EI *KBtu/82$*	FUEL Price *82$/mil Btu*	 Use *tril Btu*	 EI *KBtu/82$*
1958	605,815	12.89	248.37	0.4100	1.44	1,898.30	3.133
1959	665,905	12.61	279.43	0.4196	1.43	1,896.78	2.848
1960	672,723	12.24	287.52	0.4274	1.43	1,896.54	2.819
1961	664,571	13.12	291.00	0.4379	1.46	1,810.59	2.724
1962	719,406	12.36	315.06	0.4379	1.47	1,910.61	2.656
1963	755,815	11.99	333.71	0.4415	1.48	1,920.35	2.541
1964	798,732	11.36	367.64	0.4603	1.44	2,118.82	2.653
1965	863,582	11.02	389.89	0.4515	1.41	2,193.08	2.540
1966	919,385	10.32	420.03	0.4569	1.41	2,322.08	2.526
1967	935,957	10.76	458.63	0.4900	1.41	2,499.12	2.670
1968	983,729	10.03	518.22	0.5268	1.42	2,712.89	2.758
1969	1,002,941	9.76	553.63	0.5520	1.43	2,653.62	2.646
1970	936,377	9.69	584.54	0.6243	1.48	2,621.74	2.800
1971	962,554	9.70	598.69	0.6220	1.51	2,649.87	2.753
1972	1,043,620	10.21	640.45	0.6137	1.75	2,695.30	2.583
1973	1,120,003	10.22	675.26	0.6029	1.97	2,561.43	2.287
1974	1,093,118	10.13	656.99	0.6010	2.23	2,343.77	2.144
1975	998,695	11.20	652.65	0.6535	2.54	2,250.44	2.253
1976	1,089,763	11.62	678.60	0.6227	2.78	2,299.02	2.110
1977	1,164,382	12.32	695.60	0.5974	3.06	2,311.57	1.985
1978	1,214,603	13.11	705.71	0.5810	3.09	2,376.67	1.957
1979	1,217,062	12.86	699.47	0.5747	3.22	2,292.60	1.884
1980	1,139,347	12.93	681.31	0.5980	3.40	2,140.44	1.879
1981	1,129,450	13.40	686.34	0.6077	3.61	2,049.06	1.814
1982	1,057,199	14.51	685.75	0.6486	3.78	1,972.42	1.866
1983	1,091,621	15.23	689.60	0.6317	3.68	2,063.78	1.891
1984	1,172,926	15.43	744.43	0.6347	3.77	2,048.73	1.747
1985	1,180,517	15.49	728.90	0.6174	3.92	1,815.32	1.538

SECTOR 2

YEAR	Output *mil 82$*	ELECTRICITY Price *82$/mil Btu*	ELECTRICITY Use *tril Btu*	ELECTRICITY EI *KBtu/82$*	FUEL Price *82$/mil Btu*	FUEL Use *tril Btu*	FUEL EI *KBtu/82$*
1958	115,209	13.84	52.35	0.4544	1.41	300.86	2.611
1959	131,268	13.50	60.81	0.4633	1.39	296.39	2.258
1960	136,582	12.99	64.72	0.4739	1.39	305.27	2.235
1961	141,448	13.99	68.92	0.4873	1.41	297.92	2.106
1962	153,073	13.02	77.49	0.5062	1.43	324.65	2.121
1963	158,368	12.58	81.83	0.5167	1.45	321.94	2.033
1964	166,425	11.89	89.22	0.5361	1.42	333.85	2.006
1965	183,509	11.47	100.65	0.5485	1.40	376.47	2.052
1966	203,960	10.61	118.33	0.5802	1.43	387.59	1.900
1967	216,012	11.23	124.33	0.5756	1.44	432.40	2.002
1968	227,139	10.45	143.02	0.6297	1.46	432.61	1.905
1969	239,309	10.16	160.31	0.6699	1.46	493.95	2.064
1970	231,642	10.06	172.71	0.7456	1.54	483.84	2.089
1971	232,675	10.04	179.18	0.7701	1.57	514.13	2.210
1972	264,722	10.83	191.50	0.7234	1.79	547.55	2.068
1973	289,028	11.11	206.49	0.7144	2.03	510.72	1.767
1974	291,514	11.14	197.35	0.6770	2.33	479.23	1.644
1975	264,598	11.81	203.78	0.7701	2.66	452.63	1.711
1976	288,111	12.36	209.26	0.7263	2.85	452.75	1.571
1977	327,227	13.18	225.41	0.6888	3.09	488.26	1.492
1978	352,752	13.93	233.35	0.6615	3.16	483.80	1.371
1979	374,256	13.89	234.45	0.6264	3.30	479.45	1.281
1980	384,882	14.03	235.99	0.6132	3.48	458.06	1.190
1981	402,024	14.61	249.73	0.6212	3.76	442.21	1.100
1982	416,768	14.44	283.08	0.6792	3.92	447.92	1.075
1983	449,845	14.80	292.08	0.6493	3.80	475.23	1.056
1984	522,261	16.14	301.24	0.5768	3.93	485.73	0.930
1985	551,425	16.42	306.00	0.5549	4.11	436.89	0.792

SECTOR 3

YEAR	Output *mil 82$*	ELECTRICITY Price *82$/mil Btu*	Use* *tril Btu*	EI *KBtu/82$*	FUEL Price *82$/mil Btu*	Use *tril Btu*	EI *KBtu/82$*
1958	169,171	7.14	137.62	0.814	0.98	3,649.47	21.57
1959	184,248	7.17	153.71	0.834	0.99	3,972.02	21.56
1960	186,141	7.38	160.86	0.864	1.01	4,064.48	21.84
1961	187,858	7.02	178.16	0.948	1.04	4,039.43	21.50
1962	196,948	7.12	190.85	0.969	1.02	4,194.55	21.30
1963	208,761	7.16	209.85	1.005	1.05	4,354.59	20.86
1964	223,612	7.16	206.78	0.925	1.06	4,542.90	20.32
1965	231,124	6.87	255.68	1.106	1.03	4,749.34	20.55
1966	240,614	6.94	281.67	1.171	1.06	4,907.96	20.40
1967	247,741	6.49	299.53	1.209	1.07	4,970.55	20.06
1968	264,585	6.14	322.12	1.217	1.09	5,165.56	19.52
1969	277,152	6.10	348.72	1.258	1.06	5,289.05	19.08
1970	275,729	6.33	331.08	1.201	1.12	5,265.24	19.10
1971	282,582	6.57	362.83	1.284	1.19	5,339.87	18.90
1972	299,736	6.78	396.36	1.322	1.41	5,512.96	18.39
1973	302,825	6.76	407.14	1.344	1.61	5,676.87	18.75
1974	322,771	7.13	411.47	1.275	2.14	5,927.52	18.36
1975	306,638	8.11	401.16	1.308	2.49	5,445.13	17.76
1976	338,133	8.43	429.10	1.269	2.95	5,686.35	16.82
1977	367,208	9.26	443.26	1.207	2.80	5,742.02	15.64
1978	370,987	10.02	466.96	1.259	3.19	5,653.31	15.24
1979	391,209	10.00	457.10	1.168	3.41	5,594.01	14.30
1980	351,593	10.42	449.33	1.278	3.53	5,262.28	14.97
1981	336,592	11.05	451.58	1.342	3.46	4,707.26	13.99
1982	312,846	12.82	419.05	1.339	3.26	4,309.58	13.78
1983	324,523	12.31	441.93	1.362	3.20	4,422.40	13.63
1984	335,822	12.26	470.17	1.400	3.17	4,532.28	13.50
1985	330,994	12.32	454.74	1.374	3.22	4,255.42	12.86

** Electricity purchases for uranium enrichment (i.e. gaseous diffusion plants) have been subtracted from SIC 2819 (NEA 27010). Output value for this activity is not reflected in BLS output series. The following series was used for uranium enrichment electricity purchases:*

Year	GDP Use *tril Btu*	Year	GDP Use *tril Btu*	Year	GDP Use *tril Btu*	Year	GDP Use *tril Btu*
1958	179.73	1966	103.96	1974	97.78	1982	77.13
1959	179.73	1967	92.32	1975	109.56	1983	77.20
1960	179.15	1968	81.60	1976	139.73	1984	85.80
1961	173.35	1969	65.60	1977	147.44	1985	84.44
1962	160.75	1970	57.30	1978	116.21		
1963	158.74	1971	62.22	1979	119.80		
1964	142.53	1972	77.85	1980	87.24		
1965	118.77	1973	96.28	1981	77.00		

Source: Private communication with U.S. DOE, July 1984. Conversion factor - 1kWh = 3413 Btu

SECTOR 4 (excluding Steel Industry)

YEAR	Output	ELECTRICITY Price	ELECTRICITY Use	ELECTRICITY EI	FUEL Price	FUEL Use	FUEL EI
	mil 82$	*82$/mil Btu*	*tril Btu*	*KBtu/82$*	*82$/mil Btu*	*tril Btu*	*KBtu/82$*
1958	57,100	6.22	158.03	2.768	1.15	1,273.59	22.30
1959	65,565	5.87	191.39	2.919	1.14	1,325.81	20.22
1960	65,132	6.07	200.10	3.072	1.14	1,366.73	20.98
1961	67,089	5.66	198.14	2.953	1.15	1,349.37	20.11
1962	71,779	5.85	217.68	3.033	1.15	1,442.58	20.10
1963	76,053	5.89	230.75	3.034	1.15	1,491.90	19.62
1964	80,290	5.78	245.86	3.062	1.12	1,565.69	19.50
1965	87,450	5.80	273.02	3.122	1.09	1,675.66	19.16
1966	98,851	5.90	299.80	3.033	1.09	1,773.82	17.94
1967	94,100	5.29	318.25	3.382	1.09	1,778.86	18.90
1968	100,215	4.92	328.36	3.277	1.11	1,853.83	18.50
1969	106,437	4.87	366.45	3.443	1.12	1,939.35	18.22
1970	100,320	5.21	376.07	3.749	1.19	1,898.48	18.92
1971	101,155	5.57	362.24	3.581	1.26	2,001.12	19.78
1972	111,138	5.75	394.62	3.551	1.54	2,069.37	18.62
1973	122,951	5.45	448.78	3.650	1.80	2,011.46	16.36
1974	122,509	5.74	497.54	4.061	2.15	2,047.06	16.71
1975	99,358	6.60	436.62	4.394	2.35	1,789.18	18.01
1976	114,431	6.86	480.08	4.195	2.48	1,859.80	16.25
1977	120,737	7.33	505.75	4.189	2.72	1,881.56	15.58
1978	126,772	7.84	520.99	4.110	2.76	1,834.74	14.47
1979	128,102	7.70	545.02	4.255	2.91	1,867.77	14.58
1980	121,751	7.88	553.27	4.544	3.12	1,773.51	14.57
1981	122,719	8.32	559.22	4.557	3.39	1,649.72	13.44
1982	110,999	9.94	455.48	4.103	3.46	1,566.94	14.12
1983	120,675	10.43	456.05	3.779	3.29	1,683.07	13.95
1984	126,160	10.28	507.60	4.023	3.29	1,676.85	13.29
1985	119,780	10.42	477.90	3.990	3.30	1,522.22	12.71

STEEL INDUSTRY

YEAR	Physical Output *mil tons of SMP*	ELECTRICITY Price *82$/mil Btu*	ELECTRICITY Use *tril Btu*	ELECTRICITY EI *mil Btu/ton*	FUEL Price *82$/mil Btu*	FUEL Use *tril Btu*	FUEL EI *mil Btu/ton*
1958	59.9	9.02	85.55	1.428	1.97	2,347.26	39.19
1959	69.4	8.88	98.26	1.416	1.89	2,514.48	36.23
1960	71.1	9.65	104.44	1.469	1.89	2,710.86	38.13
1961	66.1	7.91	109.82	1.661	1.83	2,562.88	38.77
1962	70.5	8.91	113.59	1.611	1.84	2,635.88	37.39
1963	75.6	9.21	122.17	1.616	1.82	2,732.22	36.14
1964	84.9	9.13	141.38	1.665	1.84	3,085.45	36.34
1965	92.7	9.08	151.70	1.636	1.77	3,243.21	34.99
1966	90	9.57	164.98	1.833	1.77	3,281.99	36.47
1967	83.9	7.32	174.52	2.080	1.76	3,094.79	36.89
1968	91.9	7.07	185.16	2.015	1.77	3,166.95	34.46
1969	93.9	7.27	202.59	2.158	1.81	3,413.84	36.36
1970	92.2	7.63	197.51	2.142	2.15	3,281.21	35.59
1971	83.1	8.09	201.24	2.422	2.23	3,018.31	36.32
1972	93.9	8.45	210.72	2.244	2.40	3,175.62	33.82
1973	107	8.37	244.54	2.285	2.62	3,468.64	32.42
1974	105.7	8.45	251.15	2.376	3.76	3,355.74	31.75
1975	83.4	9.82	215.42	2.583	3.91	2,869.73	34.41
1976	92.4	9.98	229.65	2.485	3.95	2,983.72	32.29
1977	89.1	10.99	245.91	2.760	3.90	2,863.56	32.14
1978	99.9	11.75	262.27	2.625	4.33	3,069.64	30.73
1979	99.7	11.38	272.46	2.733	3.74	3,040.05	30.49
1980	81.3	11.64	238.25	2.931	3.53	2,430.62	29.90
1981	90.7	11.82	247.93	2.734	3.59	2,446.08	26.97
1982	56.3	14.19	178.75	3.175	3.70	1,590.91	28.26
1983	67	14.51	168.24	2.511	3.61	1,748.58	26.10
1984	73.9	13.37	204.39	2.766	3.66	1,781.31	24.10
1985	73.3	13.41	195.73	2.670	3.67	1,645.17	22.44

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