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Warren Downe Devine, Jr. for the degree of Doctor of Philosophy

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Title: DETERMINANTS OF ELECTRICAL ENERGY DEMAND FOR A STATE; METHODOLOGY AND SYSTEM SIMULATION

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(John C. Ringle)

The determinants of electrical energy demand for the State of Oregon are represented in a mathematical model. This model is structured to operate in parallel with a computer simulation model of the state and is utilized independently to investigate electrical energy consumption during various scenarios of economic activity and energy prices.

The introductory chapters discuss the importance of the inclusion into energy forecasts of the effects of significant changes in economic and demographic variables as well as consumer responses to increasing energy prices. Alternate methodologies used in forecasting are reviewed. It is argued that the determinants of electricity demand should be viewed as interrelated elements of a socio-economic system and must be addressed in concert with one another. The Oregon State Simulation Model (OSSIM) and the system simulation methodology employed in its development are described.

Chapter four presents the data base, structure, and dynamics of the electrical energy demand model. Intensiveness of electricity use and economic activity are exhibited separately, to demonstrate whether increases in consumption are due to changes in intensiveness, to economic growth, or to both and in what proportion. Increasing energy prices induce electricity conservation, interfuel substitution, and changes in appliance saturation trends. These phenomena are modeled explicitly, recognizing that each can affect intensiveness of use and can be characterized by different time constants and limits.

The following four chapters develop electrical energy intensiveness functions for thirty-seven consumer categories which are divided among four major sectors. The industrial sector consists of nineteen two-digit SIC groups and three irrigation regions; twelve household appliances and one residual group are included in the residential sector; the commercial sector covers all service activities with the exception of street/highway illumination, which composes the transportation sector. Underlying causes of changing electrical energy intensiveness are explored and price-independent projections of intensiveness are proposed. These projections are linear functions of time in the non-residential categories and sigmoidal functions in twelve residential categories.

Results of model operation with exogenous functions of economic activity are discussed in the concluding chapter, together with a description of sensitivity testing and validation criteria. Scenarios investigated demonstrate the significance of the detailed representation of consumer responses to energy price changes. Model utility appears to lie in the ability to illustrate causes of changes in electricity consumption growth rate, to assess alternate scenarios of energy prices, and--when utilized in concert with the OSSIM--to estimate electrical energy requirements based upon self-consistent scenarios of underlying economic activity.

Determinants of Electrical Energy Demand for a State; Methodology and System Simulation

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DETERMINANTS OF ELECTRICAL ENERGY DEMAND FOR A STATE; METHODOLOGY AND SYSTEM SIMULATION

1. INTRODUCTION

1.1 Problem Definition

Until recently there has been little incentive for academic consideration of energy utilization at the state level. Examples of personal inconvenience or attenuation of economic growth due to increasing prices or local shortages of electricity have been rare. Now, however, the environmental, economic, and social impacts of local electrical energy production and consumption are major concerns. To deal with these concerns, various policies, both exogenous and endogenous to the state, have been developed or are proposed; many of them carry serious implications for electricity costs and availability. In view of definite changes in energy prices, shortages of some energy forms, and imposition of new energy-related policies, the determination of future electrical energy demand for individual states has become a challenging problem.

Techniques which have been used in the past to attack this problem (Section 1.3) have been remarkably accurate. This does not necessarily mean, however, that comparable techniques employed today will yield equally good results. Until very recently energy demand projections have been performed within a context of surplus or at least adequate energy which was sold at low, and in some cases steadily declining, real prices. These conditions do not exist today and are not likely to pertain in the future. Higher energy prices and energy shortfalls can induce electricity conservation, changes in saturation of electrical appliances, substitution of machines which utilize cheaper energy forms for those which consume more expensive ones, and changes in the attractiveness of regions to industries highly intensive in electrical energy.

Just as changes in energy prices and availability require a broad approach to the problem of future demand, so do changes in other economic and demographic conditions within states. For example, impacts on future electrical energy demand can be expected from

- changes in magnitude and pattern of economic activity;
- changes in the population;
- increases in the importance of the services sector; and
- modifications in the electricity rate structure.

An investigation of the determinants of electrical energy demand for the State of Oregon is performed in this thesis. A mathematical model is proposed which includes conservation, saturation, interfuel substitution, and industrial location responses.

Finally, the methodology is integrated into a computer simulation model of the state, allowing a full range of questions to be addressed.

1.2 Pertinence to Nuclear Power

The economic development of Oregon has been based, in part, upon the hydroelectric resources of the Pacific Northwest and adequate imported fossil fuels. In fact, the abundance of low cost electrical energy has led to patterns of energy consumption in Oregon that differ significantly from average national patterns. However, the ultimate capacity of the region's hydroelectric system will soon be reached and the entire Pacific Northwest is in a state of transition to an electricity supply system based on thermal generating stations. Although current economics indicate that this system could well be dominated by nuclear power plants, this configuration is by no means assured. In the course of this fundamental change, citizens are presented with new and complex problems; one of these is how future requirements for electrical energy shall be met. Indeed, one school of thought even questions whether future requirements <u>should</u> be met and economic growth permitted.[1] Germane to this debate is the estimation of electrical

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[1] See, for example, Howard T. Odum, "Energy, Ecology, and Economics," <u>Ambio</u>, II, No. 6 (1973), 220-27.

energy demand in the context of rapidly changing socio-economic conditions.

Demand for electricity in the Pacific Northwest is expected to increase by about 5.3% per year through 1991 (10). This is considerably less than the average annual growth rate of 6.6% experienced in Oregon between 1963 and 1973. Some observers may view this decrease as a forerunner of still lower growth rates, and claim, therefore, that we need not proceed with the installation of proven electricity generating systems, but rather that we have time to develop new systems viewed as being more acceptable. Research and development concerning electricity generating systems and their environmental impact is thus related to predictions of future electrical energy demand. Relatively low growth rates could indeed decrease the urgency with which short- and intermediate-term supply options must be deployed, allowing additional time to determine whether longer-run alternatives are desirable and viable and, if so, to perfect them. On the other hand, a low growth rate over the short-run may be a transient phenomenon rather than a prognostic of longer-term trends. The complex energy demand system contains a variety of time delays; its response may well be governed by processes which tend to increase demand rather than by those which tend to reduce it. Thus a variety of energy demand scenarios must be explored. If relatively low growth rates are only temporary, the ultimate costs of <u>not</u> proceeding with the installation of current, proven generating systems could well be exorbitant.

It is emphasized in the following chapters that energy demands should be viewed as arising from components of a complex system. It is vital that this viewpoint be appreciated by state level decision-makers, whose actions can influence not only the electricity supply system but the general economic condition of the state. For example, in the latter half of 1974 the United States electric utility industry cancelled or deferred large numbers of generating stations, particularly nuclear power plants. Analysis by L. J. Perl (39) indicates that these cancellations largely reflect a capital shortage, and places the blame on state regulatory commissions for failure to grant prompt rate relief. Thus the regulatory commission, having the capability of directly influencing both electricity prices and supplies, is an important component of a state's energy system. And it is important that key inputs to any complex, dynamic system be manipulated with maximum understanding of possible outcomes, both direct and indirect, short-term and long-term.

Thus there is need for a methodology capable of analyzing electrical energy demand for the State of Oregon from the standpoint of basic determinants. These determinants are, in general, interrelated elements of a complex socio-economic system and can only be correctly addressed in concert with one another. The development of such a tool to complement current forecasting techniques is pertinent to the orderly evolution of electricity supply systems.

1.3 Forecasting Methodology

Methods of forecasting demands for commodities can be broadly classified as trend analysis, scenario analysis, and causal analysis.

1.3.1 Trend Analysis

These techniques share the hypothesis that historical activity can serve as a quantitative indicator of future activity.

Extrapolation. This method involves extension of persistent trends of the past (such as growth rates of energy consumption) through the present and into the future. It relies upon the attribution of historical constancy to major features of the system under consideration; these features are then assumed to remain unchanged in the future, and predictions are made on the basis of a continuation of the past. Sometimes extrapolations of energy demands are slightly modified with the aid of special information provided the forecaster, such as opinions of industrial plant managers, appliance market surveys, or exogenous predictions of business and demographic activity.

Obviously, predictions produced by extrapolation are realistic only to the extent that the future replicates the past; they are of limited value when dealing with major new developments such as large energy price swings, energy shortages, changes in industrial composition, and new technology.

According to information presented in References 33 and 35, virtually every electric utility in the Pacific Northwest relies upon extrapolation modified by special information for preparation of its energy demand forecasts; there is some limited use of correlation techniques by a few utilities. Regional forecasts result from aggregation of the independent utility estimates.

Correlation. Correlation techniques endeavor to discover empirical consistency in relations between observations, without necessarily inquiring into the theoretical bases for such correlations. Predictions are then made under the assumption that what has covaried in the past will continue to do so. An econometric forecasting model is an equation or set of equations involving correlations derived from historical data which are expected to apply in the future. Forecasts are produced by assuming future levels of the independent (exogenous) variables and solving for the dependent (endogenous) variables.

Econometric models provide somewhat more insight than extrapolation techniques because the methodology forces one to consider future energy demand in an ensemble of influences, rather than as a completely autonomous phenomenon. However a problem common to all correlation methods is the need to obtain concomitant forecasts of the independent or exogenous variables such as population, industrial output, etc. These are not always obtained with any greater confidence than would be associated with forecasting energy demand directly by means of extrapolation. Furthermore, one may be tempted to draw conclusions concerning causal relationships from correlations which have some degree of statistical significance but little logical connection. Finally, the forecasting ability of econometric models rests upon the past being representative of the future, and upon inclusion into the models of those factors which best explain the behavior of the endogenous variables.

Input/Output. Input/output tables consist of coefficients specifying the inputs--from every subsector of the economy--required to produce a unit of output in every other subsector. These coefficients represent sets of equations which designate dollar or energy flows within the economy. The equations, usually exhibited in matrix form, thus constitute an economic model which can be used to calculate the dollars or energy required by each subsector to produce some exogenously designated output. Although I/O shares with correlation the need for forecasts of output, the former is generally superior to extrapolation and correlation for analytical purposes because it takes detailed account of technological relationships between subsectors. However, there is no systematic way to modify the coefficients with time or account for changes in them due to variations in energy prices or availability; in fact, users often treat this problem with simple extrapolation techniques. Thus, as an intermediate or long range forecasting tool, the input/output methodology is of limited value.

1.3.2 Scenario Analysis

This methodology is based upon the antithesis of trend analysis: no value whatever is assigned to historical patterns of activity. Rather, scenarios for the future are formulated by somewhat less quantitative methods (the delphi technique, for example); little attention is given to the alternate paths which system state variables might traverse between the present and the future. Each future scenario contains implications for individual disciplines. For example, Weinberg and Hammond (73) have proposed a global scenario in which each person consumes energy at approximately double the rate of present United States per capita consumption. Although the analysis suggests ways in which this demand might ultimately be met, it does not provide a quantitative description of the world economic-environmental-energy system as it tries to achieve this level of consumption and production.

1.3.3 Causal Analysis

A third method of forecasting lies between trend and scenario analysis; unlike these, it does not rely entirely on the past to describe the future nor on a future to dictate the present. Rather, causal analysis employs explanatory theory to relate causes and effects, logically linking the past, present, and future.

Use of causal techniques implies the system can be modeled as an initial value problem. Analysis begins with a comprehensive description of the state of the system at initial time, utilizes mathematical expressions of presumed laws to relate system variables and constants, and produces a description of the system from the present into the future. Of course, the model is an accurate representation of the real world system only to the extent that the causal relationships can be justified; often such justification comes from other methodologies, particularly correlation.

The methodology which is the subject of this thesis is causal in structure; it relies to a limited extent upon correlation and extrapolation. The structure of this model is such that electricity use and economic activity are exhibited separately, demonstrating whether changes in consumption are due to increased use, to economic growth, or to both, and in what proportion. Electricity conservation, interfuel substitution, appliance saturation, and industrial expansion are considered explicitly, recognizing that each of these phenomena can be characterized by different time constants and are inherently limited. Wide variations in energy prices charged each ultimate consumer and major shifts in composition of the industrial sector can be simulated.

Despite some advantages over alternate approaches, the utility of this methodology should not be viewed as being proportional to the "accuracy" of its forecasts or how well they compare with those produced by other methods. First, many of the phenomena addressed here are not taken into account at all by extrapolation techniques. Second, some submodels are highly aggregated; in a few cases special information provided utility forecasters by individual customers may be more realistic. Finally, the energy demand model was designed to complement a much larger simulation model; this model was built to consider a variety of problems, of which energy is only one. The utility of the present methodology lies, rather, in its ability to:

a. illustrate causes of changes in the growth rate of electricity consumption;

b. assess alternate scenarios and certain energy-related government policies; and

c. provide a structure for analysis of the determinants of electricity demand in a self-consistent manner.

When coupled with the simulation model described in Chapter 3, a major strength of the present methodology is that self-consistent assumptions concerning the determinants of energy demand are ensured. That is, most variables that are exogenous to econometric models, and thus whose self-consistency cannot be demonstrated mathematically, are endogenous to this model. M. F. Searl, in a recent review of contemporary energy modeling efforts (47), lends support to the importance of this feature:

> "Historically, most energy models have not been coupled to comprehensive economic models. Instead, the economic input to the energy model was in terms of individual demographic and economic projections presumed to be consistent but rarely derived from a comprehensive economic model."

In summary, this effort should be viewed as being complementary to alternate methodologies, particularly econometric methods. The numerical results produced by a socio-economic simulation model must be assumed to have large error bands. But, in turn, the ensemble of state variables in which trend analysis models are embedded must be assumed to contain inconsistencies. Thus, before complete faith is placed in any one model, consideration should be given to the results of others; jointly they may provide a more powerful approach to the study of complex economic systems than any one taken alone.

2. ENERGY DEMAND: A SYSTEM COMPONENT

2.1 An Economic System

A closed system is illustrated in Figure 2.1. The component D represents all sectors of a regional economy which consume commodity x. Demands for this commodity are endogenous to, or arise within D. The component S represents the sector which responds to these demands and supplies commodity x. These supplies, Sx, are either sufficient or insufficient to meet the demands Dx. Under conditions of perfect competition, information about these supplies and demands leads to the determination of a price for the commodity in marketplace M. This price, Px, may affect both demand and supply, and may do so over a period of time, rather than instantaneously. Thus this simple diagram represents a closed loop feedback system, replete with time lags and error adjustment. The variables are not necessarily in static or even dynamic equilibrium.

If the region under consideration is taken to be a single state, and if commodity x is taken to be electrical energy (hereafter signified by the subscript "e"), the closed system of Figure 2.1 becomes the open system of Figure 2.2. The system is open because few states, if any, are self-sufficient in energy; demands for electricity within states are influenced by exogenous forces; and

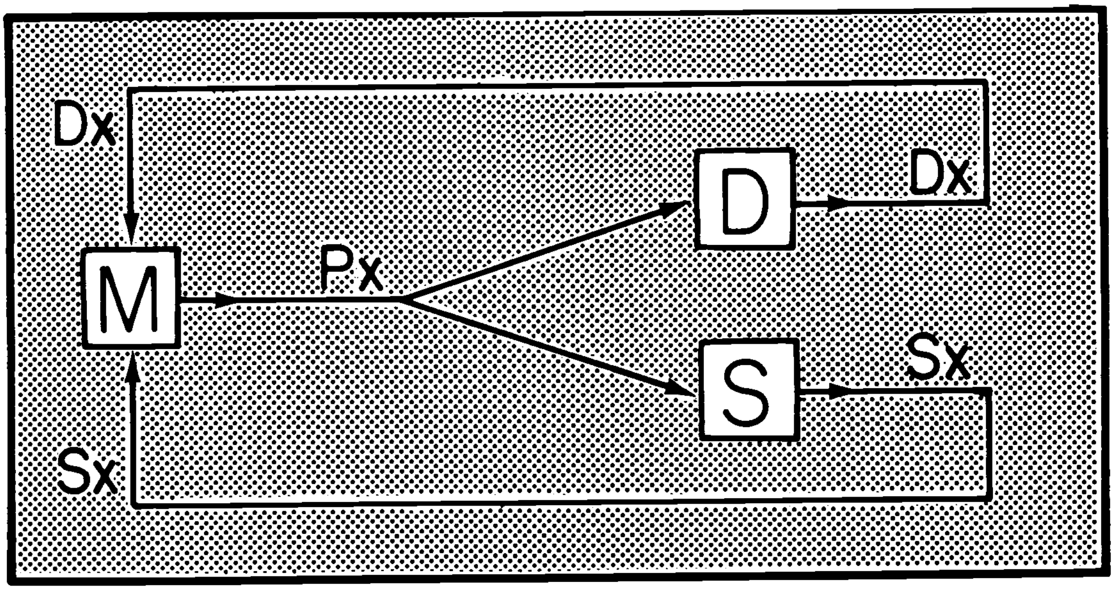

Figure 2.1. A closed economic system.

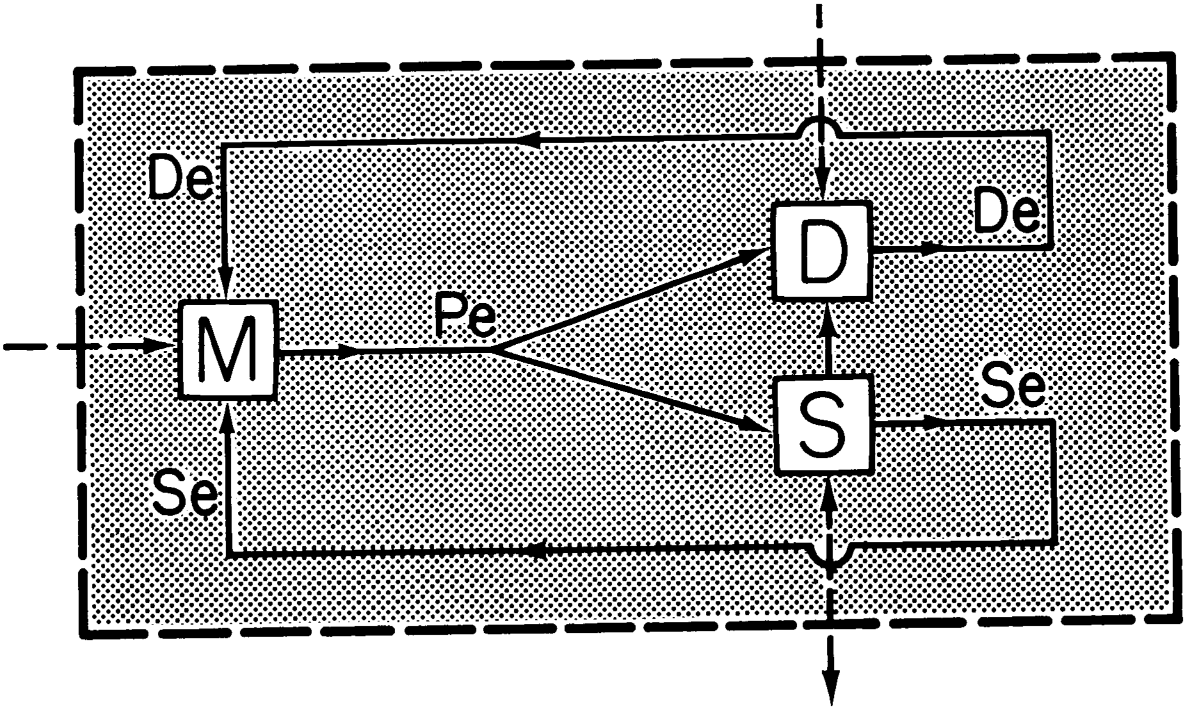

Figure 2.2. Electrical energy demand as a system component.

price resolution in the marketplace is constrained by regulatory policy.

Consideration of the Oregon electricity supply subsystem and the price determination process is not within the scope of this thesis. Attention is directed instead to electrical energy demand. This subsystem is isolated from the whole system in Figure 2.3. By redefining the system in this manner, electricity price becomes one of several exogenous inputs to a new energy demand system, the investigation of which is the subject of this thesis.

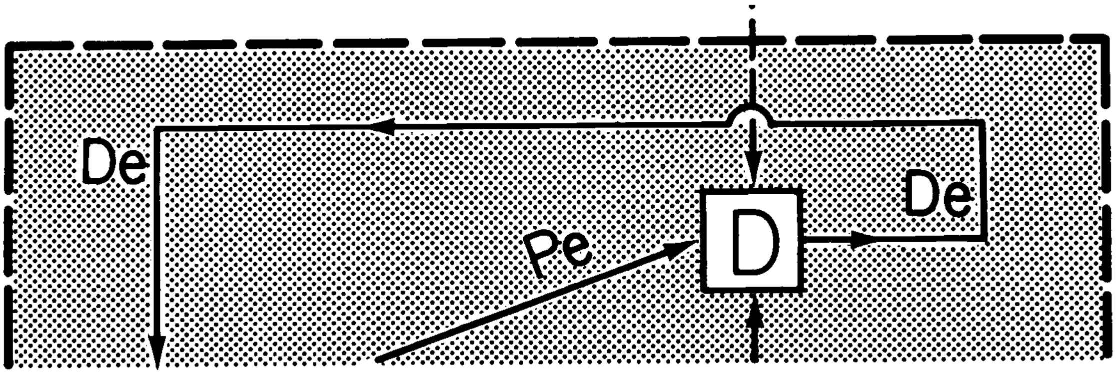

Figure 2.3. The electrical energy demand subsystem.

2.2 The Factors of Demand

The level of demand for a commodity is a fundamental state variable of economics. When applied to energy, the level of demand is a manifestation of the technical requirements of machines, the pattern of use of the various energy forms, and the level of activity of energy consumers. The use of a single variable--demand--does not enable one to distinguish between the inherent energy consumed by a unit of activity and the amount of activity taking place.

The basic assertion of this thesis is that understanding is enhanced if the level of demand for electrical energy is expressed as the product of two factors, here designated as U and Y:

$$\underline{D} = \underline{U} \cdot \underline{Y} \tag{2.1}$$

U represents the inherent energy use of various sectors of activity, and will be called "energy intensiveness." It is a manifestation of the pattern of use of alternate forms of energy which has developed over time in response to changes in technology and energy prices. In a highly disaggregated and detailed model, U would be very close to actual technical requirements of machines at a given time. For example, U might represent the electrical energy necessary to produce one ton of aluminum ingot. Its units, then, would be KWH per ton. In a more highly aggregated model like the one to be described in Chapters 3 and 4, energy intensiveness is a quantity characteristic of larger sectors, such as certain groups of manufacturing industries.

Y is a surrogate for the economic activity of the various sectors characterized by U. This activity may be expressed in terms of dollars of output or in terms of numbers of people or groups of people involved in certain activities.

Note that energy prices may affect each of the two factors of demand, as illustrated in Figure 2.4. However, although the response of U to a given change in price is not necessarily the same as that of Y, the observed demand De is identical in Figures 2.3 and 2.4.

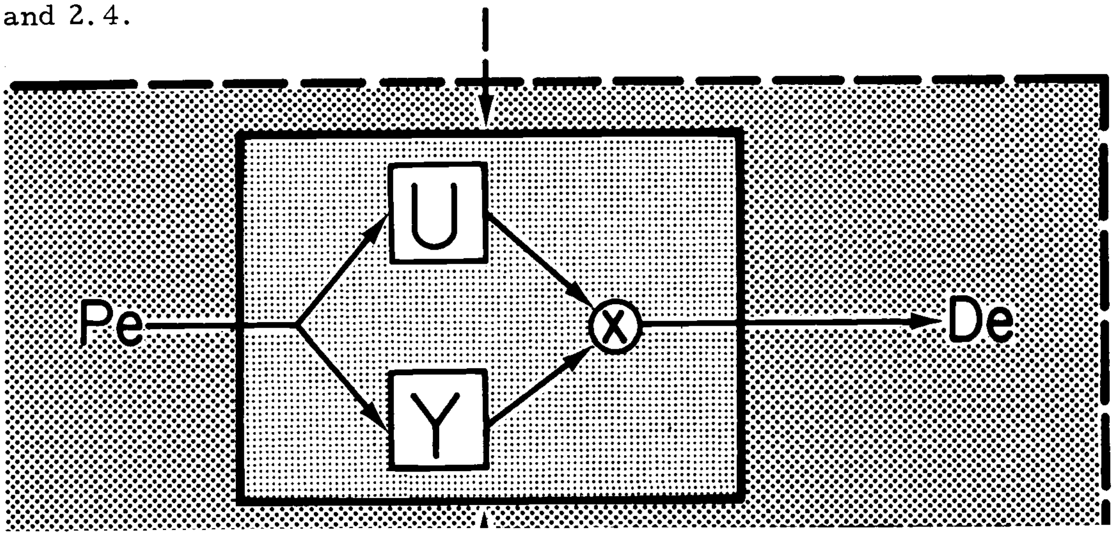

Figure 2.4. The factors of energy demand.

U and Y, then, comprise the determinants of electrical energy demand. Derivation of electrical energy intensiveness functions for various socio-economic sectors is the subject of Chapters 5 through 8. Having done this, it is then possible to use any one of a variety of projections of economic activity as co-factors. However, a requirement of such projections is that they be self-consistent. That is, not only must the same energy price scenario be input to both U and Y, but the effects of the various socio-economic sectors upon one another must be included. This is ensured when the computer simulation model, to be described in the next chapter, is used to provide the needed scenarios of economic activity. In fact, as will be shown in Chapters 3 and 4, this simulation model and the energy demand methodology have been designed to supplement one another.

3. COMPUTER SIMULATION APPLIED TO SOCIO-ECONOMIC SYSTEMS

3.1 Brief Review

Simulation has been broadly defined as the development and use of models to aid in the evaluation of ideas and the study of dynamic systems or situations (28). Computer simulation modeling of a system is, in general, a flexible, iterative, investigative process. This process, illustrated in Figure 3.1, includes formulation of the problem or problems, development of a mathematical simulation model, testing and refinement of the model, and finally employment of the model (and ideally the modelers) to produce potential problem "solutions." The iterative nature of simulation modeling becomes increasingly significant as the system under consideration becomes more complex and/or multidisciplinary.

The use of computer simulation models to study engineering systems is well established practice. Simulation techniques have more recently gained widespread use in the analysis of ecological, economic, and socio-economic systems.[2] However, the value

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[2] See, for example, the following works: B. C. Patten, ed., Systems Analysis and Simulation in Ecology (New York: Academic Press, 1971); T. H. Naylor, Computer Simulation Experiments with Models of Economic Systems (New York: John Wiley, 1971); and J. W. Forrester, Urban Dynamics (Cambridge: MIT Press, 1969).

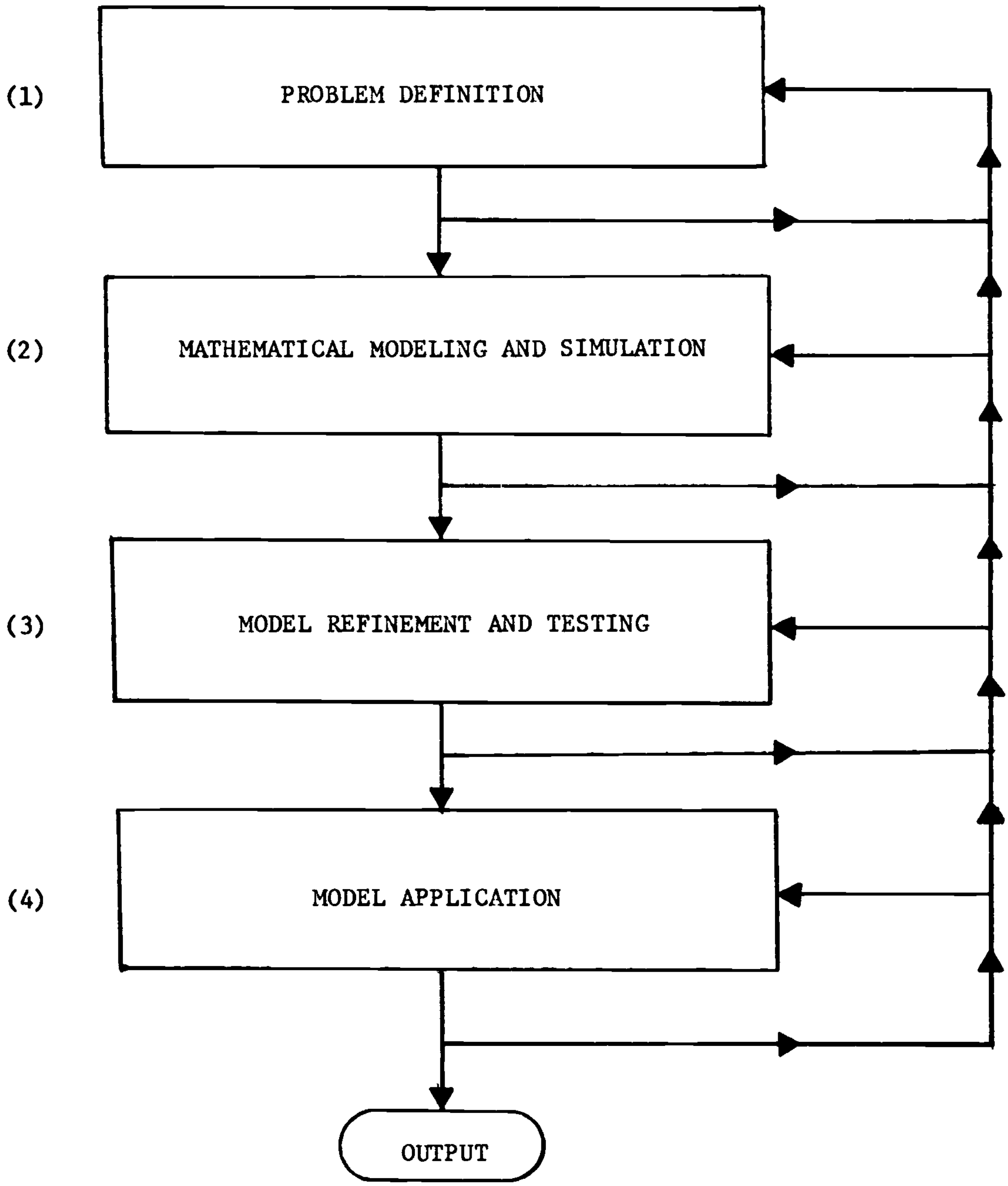

Figure 3.1. Computer simulation as an iterative problem investigation process.

derivable from simulation is not necessarily the same for all classes of subject systems; it depends to a large extent upon how the simulation model is to be used. Table 3.1 summarizes the author's experience with computer simulation models which have been used for the various purposes indicated.

Table 3.1. Relative value of computer simulation.

	Simuland	
Intended use for simulation model	Engineered system	Socio-economic system
A teaching device	excellent	good
An analytical tool	good	fair
A design technique	good	no experience to date

One reason for the differences in Table 3.1 is that the development of a computer model is a double translation process. The first is the translation of a conceptual view of the real-world system into a mathematical model, and the second is the translation of that model into a computer program. The degree to which the program replicates the behavior of the real-world system rests upon the validity and accuracy of both translations. These translations are liable to be more accurately performed in the case of engineered systems, since engineered systems are designed by synthesis from simply-modeled subsystems with all attendant linkages exhibited.

Social systems, on the other hand, are not easily broken down into a closed set of simply-modeled subsystems with explicit links. Finally, especially in the case of social systems, each of the two translations is only one of many which can, in principle, be devised.

3.2 Development of the Oregon State Simulation Model

Work on this thesis was carried out while the author was associated with an interdisciplinary research project entitled "Man's Activities as Related to Environmental Quality," sponsored in part by the Rockefeller Foundation. One of the objectives of the project was to produce results useful to state-level decision makers as they make choices related to environmental quality and economic growth in Oregon. A major effort involved the development of a computer simulation model of the state, presently designated the "Oregon State Simulation Model" (OSSIM).

Model development involved significant interaction with state government officials and professionals from commercial, industrial, and research institutions. Although this interaction was especially useful in the problem definition phase, contact continued throughout the various stages illustrated in Figure 3.1. In view of the iterative nature of simulation, model format was kept flexible, allowing incorporation of changes in structure as they appeared necessary.

Relevant theory from many disciplines, together with real-world insight, provided a plethora of problems, information, and data around which to structure the various models. But the task of developing models which are both realistic and grounded in theory was never a simple matter. In the development of the Energy Component, the author was frequently confronted with a situation well enunciated by Blalock:[3]

> "The dilemma of the scientist is to select models that are at the same time simple enough to permit him to think with the aid of the model but also sufficiently realistic that the simplifications required do not lead to predictions that are highly inaccurate."

The Oregon State Simulation Model is continuous, predominantly deterministic, and dynamic; the system modeled is open (Section 2.2) and the relationships between variables are casual (Section 1.3). Figure 3.2 illustrates the basic structure of OSSIM. The seven components are dynamically interconnected as shown; however many other feedback paths have not been provided in the illustration for reasons of space, clarity, and pertinence. In general, each of the components may be viewed as a "black box" which receives inputs from other components and generates outputs, as illustrated in Figure 3.3. Brief descriptions of the various components, with emphasis on those which provide dynamic inputs to

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[3] H. M. Blalock, Causal Inferences in Non-Experimental Research (Chapel Hill: University of North Carolina Press, 1961).

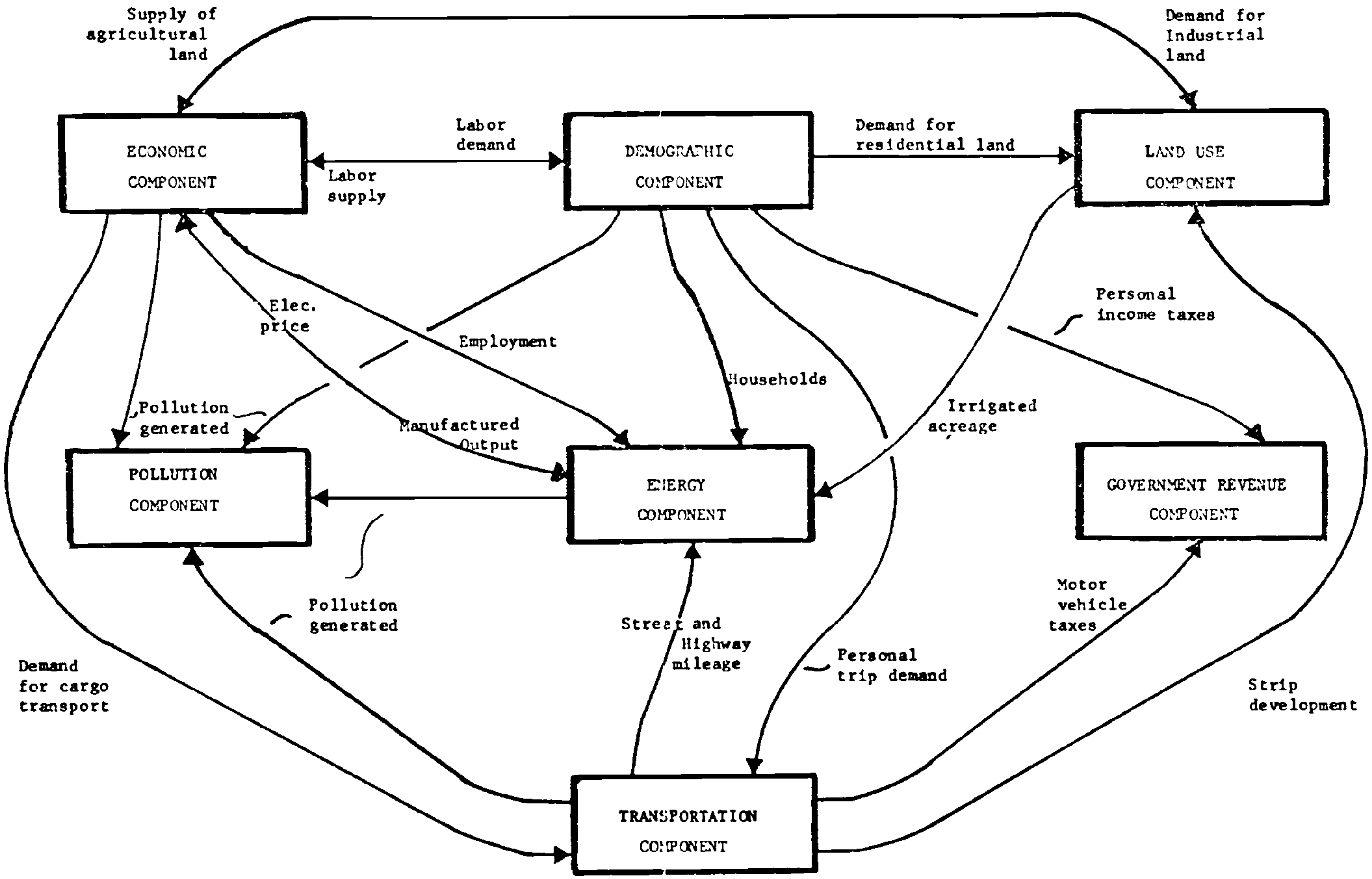

Figure 3.2. Oregon State Simulation Model (OSSIM).

the Energy Component, are offered in Appendix I.

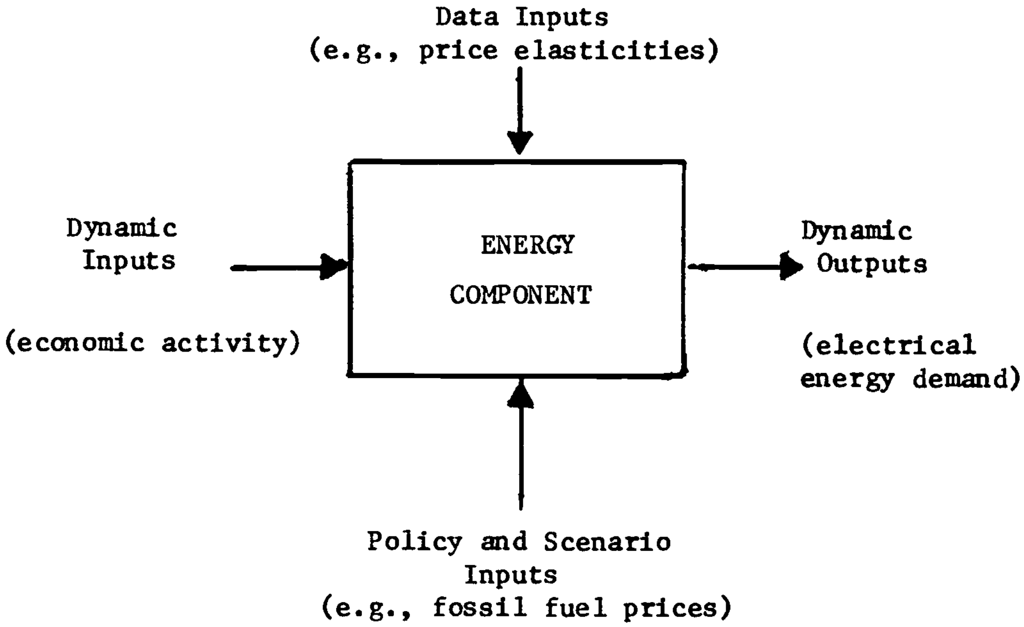

Figure 3.3. OSSIM Component viewed as a "black box".

OSSIM consists of parallel models, structurally identical but numerically different, which operate in three spatial nodes. The spatial resolution utilized, illustrated in Figure 3.4, was selected because of differences in physiography, population, and economic base between the three regions of the state. Data limitations, however, prevented meaningful determination of electrical energy consumption according to this regional breakdown. State-wide electricity demand is simulated, with a time range up to fifty years (1970-2020).

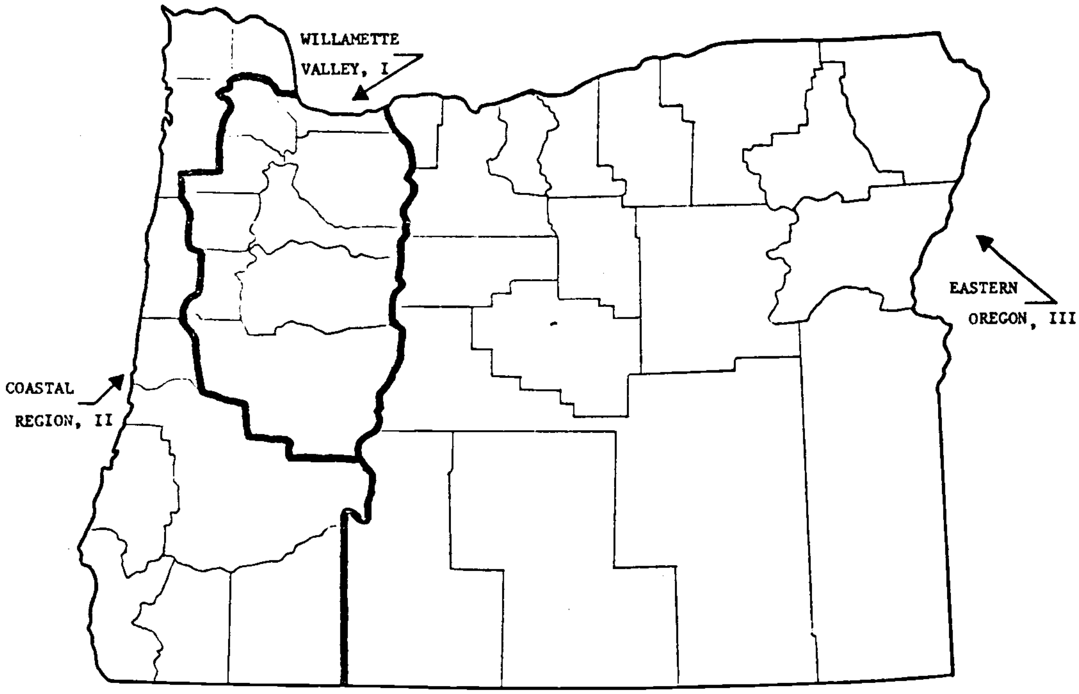

Figure 3.4. OSSIM spatial nodes.

4. METHODOLOGY AND ASSUMPTIONS

4.1 Sources of Data

Analysis of the determinants of energy demand requires historical consumption data broken down into as many classes of consumers as possible. This type of electrical energy consumption data originates from two major sources: Oregon's 35 electric utilities and the Bureau of the Census of the U.S. Department of Commerce.

4.1.1 Electric Utility Data

Consumption data provided by Oregon's electric utilities is compiled and reported by the four organizations listed in Table 4.1.

Table 4.1. Electric utility data - Oregon.

Reporting Organization	Coverage	Reference
Edison Electric Institute	all utilities aggregated	12
Oregon Public Utility Commission	all investor-owned utilities (4)	37
	all municipal utilities (11)	37
Federal Power Commission	all investor-owned utilities (4)	70
	5 of 11 municipal utilities	71
	2 of 4 PUD's	71
Rural Electrification Administration	13 of 16 cooperatives	53
	1 of 4 PUD's	53

The utilities are listed in Table 4.2, which indicates that there is some duplication of coverage and that detailed energy sales data for 5 of the 35 utilities is not reported separately in the literature. Note that, for consistency with OSSIM, consumption data for only the State of Oregon is desired. Thus the Oregon sales of utilities numbered 2, 3, 4, 17, and 20--all of which have sales outside Oregon--must be separated from their overall sales data. Fortunately this has already been done by the four reporting organizations of Table 4.1.

The Bonneville Power Administration reports energy sales to its customers as well (61). BPA's customers are electric utilities and several individual industrial and governmental consumers located throughout the Pacific Northwest. Consumption data for only those industrial consumers physically located in Oregon has been obtained directly from BPA (48).

4.1.2 Census Data

The Bureau of the Census reports data on energy consumption by manufacturing and mining industries according to the 2-digit standard industrial classification system (65). This information is reported by the industries themselves to the Bureau, compiled, and published for each state in the *Census* and *Annual Survey of Manufacturers* (57, 55) and in the *Census of Mineral Industries* (58).

Table 4.2. Oregon electric utilities.

No.	Name	Type	Service Area (OSSIM Region)	Reference
1	Portland General Electric Co.	inv.-owned	1	37, 70
2	Pacific Power and Light Co.	inv.-owned	1, 2, 3	37, 70
3	Idaho Power Co.	inv.-owned	3	37, 70
4	California Pacific Utility Co.	inv.-owned	3	37, 70
5	Blachly-Lane County Co-op. Elec. Assn.	co-op	1	53
6	Consumers Power, Inc.	co-op	1	53
7	Umatilla Electric Co-op. Assn.	co-op	3	53
8	Douglas Electric Co-op., Inc.	co-op	2	53
9	Lane Electric Co-op., Inc.	co-op	1	53
10	Coos-Curry Electric Co-op., Inc.	co-op	2	53
11	Central Electric Co-op., Inc.	co-op	3	53
12	Wasco Electric Co-op., Inc.	co-op	3	53
13	Columbia Basin Electric Co-op., Inc.	co-op	3	53
14	West Oregon Electric Co-op.	co-op	1, 2	53
15	Columbia Power Co-op. Assn.	co-op	3	53
16	Midstate Electric Co-op., Inc.	co-op	3	53
17	Harney Electric Co-op., Inc.	co-op	3	53
18	Hood River Electric Co-op.	co-op	3	-
19	Salem Electric	co-op	1	-
20	Surprise Valley Electrification Corp.	co-op	3	-
21	City of Ashland	municipal	2	37
22	City of Bandon	municipal	2	37
23	Canby Utility Board	municipal	1	37
24	Cascade Locks City Light	municipal	1	37
25	City of Drain Light and Power	municipal	2	37
26	Eugene Water and Electric Board	municipal	1	37, 71
27	City of Forest Grove Light and Power	municipal	1	37, 71
28	City of McMinnville Water and Light Dept.	municipal	1	37, 71
29	Milton-Freewater Light and Power	municipal	3	37, 71
30	City of Monmouth	municipal	1	37
31	Springfield Utility Board	municipal	1	37, 71
32	Tillamook PUD	PUD	2	71, 53
33	Central Lincoln PUD	PUD	1, 2	71
34	Clatskanie PUD	PUD	2	-
35	Northern Wasco County PUD	PUD	3	-

4.2 The Data Base and Sectors of Consumption

The classes of energy consumers, or socio-economic sectors, used in this analysis are the following:

Industrial
Residential
Commercial
Transportation

The first three of these sectors have been traditionally used by energy analysts, and another classification, "Other," is generally employed by utilities. It will be shown, however, that the consumers usually included in "Other" can be divided among the four sectors given above.

Electric utility customers are billed under a large variety of rate schedules which may not always correspond to the socio-economic category of the consumer. These detailed billing categories are then aggregated into broader classifications for reporting. The larger groupings used, however, are not necessarily common to all reporting organizations, as Table 4.3 illustrates.

The Edison Electric Institute reports aggregated consumption data from the entire electric utility industry according to the most common classification system on a state-by-state basis (12). Due to convenience, therefore, EEI data are used here in determining the historical consumption of the Commercial and Transportation

Table 4.3. Classifications of sales of electrical energy.

Energy sales classification	EEI	PUC (Investor-Owned)	PUC (Municipal)	FPC (Investor-Owned)	FPC (Municipal, PUD)	REA
Residential	X	From 1961		X	X	
Rural	Thru 1960					
Residential and Rural		Thru 1960	X			
Residential Service Farm and Non-Farm						X
Irrigation						From 1961
Small Light and Power (Loads $\leq$ 1000 KW)	X	X	X	X	X	
Large Light and Power (Loads > 1000 KW)	X	X	X	X	X	
Commercial and Industrial Small (Transformer Capacity $\leq$ 50 KVA)						X
Commercial and Industrial Large (Transformer Capacity >50 KVA)						X
Public Street and Highway Lighting	X	X	X	X		
Other Sales to Public Authorities	X	X	X	X		
Railroads and Street Railways	X	X	X	X		
Other Ultimate Consumers					X	
Other Electric Service						X
Interdepartmental	X	X	X	X		
Total Sales to Ultimate Consumers (Sum of all above)	X	X	X	X	X	
Sales for Resale		X	X	X	X	X
Total Sales (Includes Sales for Resale)						X

Sectors, and for obtaining the total consumption of the Residential Sector.

Before proceeding further, however, the composition of the various EEI consumption categories shall be reviewed. It will be asserted that the electric utility data base is acceptable for use in analysis of the Commercial and Transportation Sectors but is less than adequate for the Industrial and Residential Sectors.

4.2.1 Residential

The EEI Residential category does not necessarily consist of all the energy consumed in residences. First, it may not include all residences, as some master-metered apartment houses may be billed under a Small Light and Power (SL&P) rate schedule. Second, a variety of rate schedules may be applied to farms: the consumption of some farms may be ultimately classified as Residential, and that of other farms as SL&P. Thus the Residential category may include some non-household farm use and SL&P may include some non-farm household use. Although these inaccuracies are unavoidable when using the aggregated utility data base, it is not felt that they cause the data reported by EEI as Residential to be significantly different from the actual energy consumed by households. Nevertheless, the EEI Residential data is not extensively used in this work. As will be seen in Chapter 8, more insight into the determinants of energy demand can be obtained from a detailed consideration of household end uses of electricity.

4.2.2 Rural

EEI employed a "Rural" classification through 1960. This category included electricity consumed in agricultural production processes, including irrigation, and some non-farm rural consumption, such as that used in commercial buildings. Unfortunately there is no data base sufficient to allow isolation of the electrical energy consumption of agricultural production other than irrigation. Most of the electricity used in agriculture is, however, for the pumping of irrigation water (29). Thus, if the energy used for irrigation is subtracted from that reported as Rural, the remainder should be primarily commercial use. In other words, it is assumed that

$$\begin{bmatrix} \text{rural} \\ \text{consumption} \end{bmatrix} - \begin{bmatrix} \text{irrigation} \\ \text{consumption} \end{bmatrix} = \begin{bmatrix} \text{rural} \\ \text{commercial} \\ \text{consumption} \end{bmatrix} + \begin{bmatrix} \text{other consumption} \\ \text{in agricultural} \\ \text{production (small)} \end{bmatrix} \qquad (4.1)$$

After 1960, energy formerly classified as Rural was divided between SL&P and Large Light and Power (LL&P). Thus the subtraction of irrigation consumption from the sum of the SL&P and LL&P categories would leave the rural commercial use embedded in this sum, analogous to expression 4.1. These assumptions will be utilized in the derivation of Commercial Sector consumption in Chapter 6.

4.2.3 Small Light and Power

This category is sometimes taken to be synonymous with a "Commercial" classification. However it is not necessarily true that all of the energy reported under SL&P is consumed in commercial establishments. The Federal Power Commission has defined this category as consisting of consumers whose loads are less than or equal to 1000 KW (70). Thus some strictly residential energy consumed by apartment dwellers and the consumption of some small industries may appear under the SL&P classification. It is also probable that some strictly commercial consumers, such as large office buildings or shopping centers, have loads sufficient to be classified as Large Light and Power. Thus it is also not necessarily true that all commercial consumption is included under SL&P. Therefore the simple equating of SL&P to the Commercial Sector is not considered an accurate enough procedure for this analysis. Chapter 6 describes how the utility data base is manipulated to yield more representative consumption data for this sector.

4.2.4 Large Light and Power

The amount of energy reported in this category is often equated to industrial consumption. However, as noted in the preceding paragraph, some industrial consumption may appear under SL&P and some commercial consumption may be listed as LL&P. Thus the equating of the LL&P category to the Industrial Sector is not adequate. Fortunately it is unnecessary to do this, as the Industrial Sector can be treated in considerably more detail by use of the Bureau of the Census data base. This is described in Chapter 5.

The difference between the electric utility and Bureau of the Census data bases is largely one of classification. Table 4.4 compares electrical energy consumption figures for Oregon as reported by EEI as LL&P and as reported by the Census as "manufacturing."

Table 4.4. Comparison of data bases for industrial sector.

	Electrical Energy Sales 10^6 KWH		
Year	EEI (LL&P)	Census (Manufacturing)	Census ÷ EEI
1954	2,050	3,486	1.701
1955	2,265	4,796	2.117
1956	2,563	5,091	1.986
1957	2,687	5,053	1.881
1958	3,027	4,358	1.440
1959	3,837	5,569	1.451
1960	4,245	5,650	1.331
1961	3,816	5,820	1.525
1962	6,674	6,220	0.932
1963	6,703	5,550	0.828
1964	7,801	6,598	0.846
1965	8,633	7,590	0.879
1966	9,190	8,094	0.881

The fact that the EEI data are consistently less than the Census data through 1961 and thereafter consistently greater, suggests that rather significant changes in classification have occurred. This hypothesis is illustrated in Figure 4.1 and supported by a quotation from EEI's Statistical Yearbook of the Electric Utility Industry (12):

> "Owing to differences among respondents in the classification of SL&P and LL&P sales and the continuous reclassifications in these categories, year-to-year comparisons are more significant when total LL&P and SL&P sales are combined rather than when comparisons are made of each separate classification."

Thus it is asserted that the electric utility data base--as aggregated by EEI--is inappropriate for analysis of the Industrial Sector.

4.2.5 Other Categories

The electrical energy consumption reported in the EEI category "Other Sales to Public Authorities" is closely related to the services provided by government to the public. Consumption occurs in Federal, state and local government office buildings; in schools; in government service facilities such as sewage plants; and in recreational areas such as parks. These consumers are among those that will be defined to compose the Commercial Sector in Chapter 6. Thus it is reasonable to assume that little error is incurred if the category "Other Sales to Public Authorities" is considered to be part of that sector.

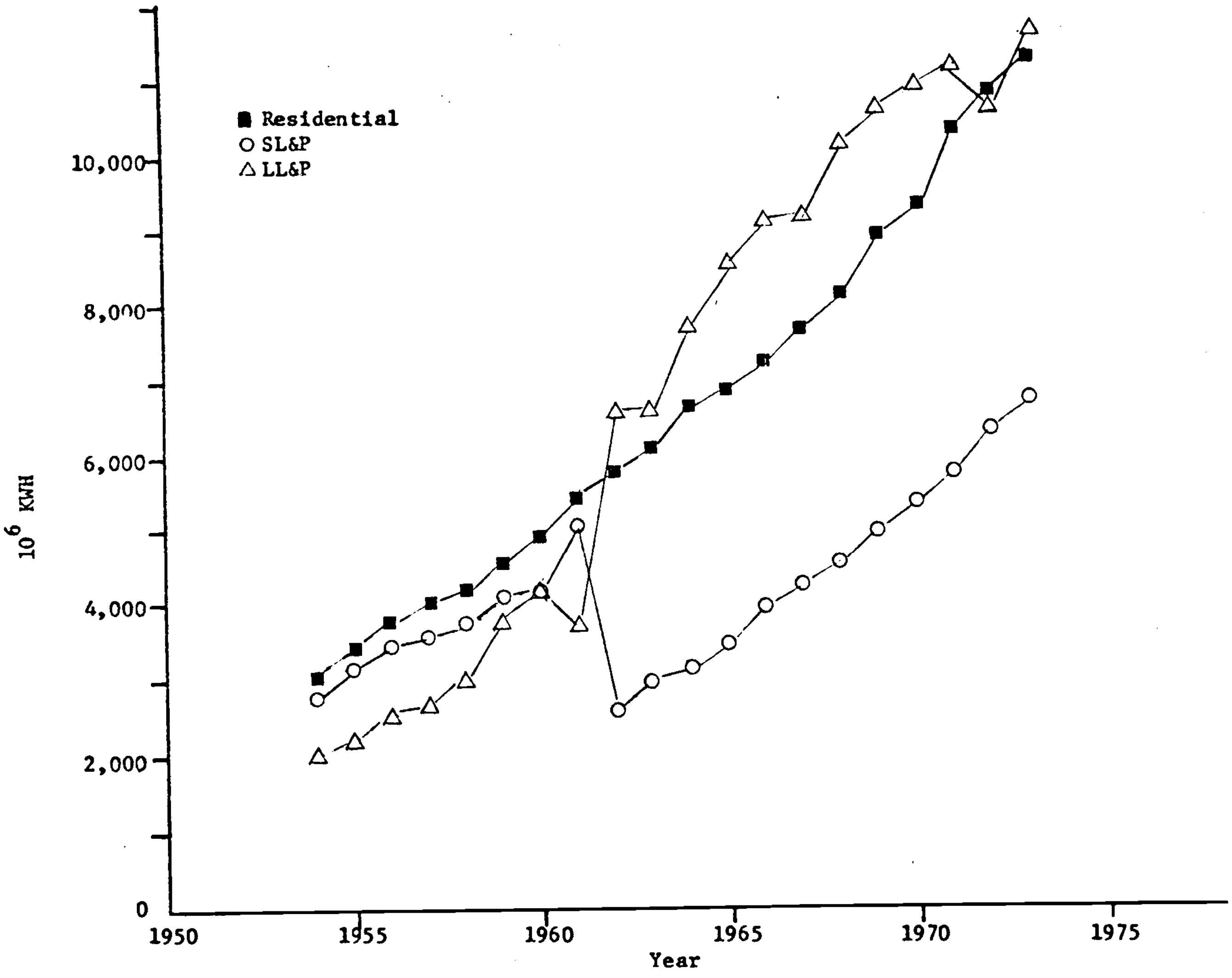

Figure 4.1. Oregon electricity consumption by EEI category.

The "Interdepartmental" category includes electricity consumption by electric utilities themselves for the purposes of (a) operating natural gas or water supply systems, if applicable, and (b) operating administrative buildings and other facilities and supplying customer service. Purpose (a) applies to only a few utilities and is small in comparison to (b), which is predominantly energy consumed in the provision of services to the public. Since these services are also among those activities which will be included in the definition of the Commercial Sector, the "Interdepartmental" category will also be considered a part of that Sector.

Finally, the energy reported under the EEI categories "Public Street and Highway Lighting" and "Railroads and Street Railways" is related to transportation. Electrical energy consumed by transportation is considered in Chapter 7.

4.3 Equations of Demand

The calculation of electrical energy demand is based on expression 2.1 and is summarized for the three major socio-economic sectors in Table 4.5. For complete generality, energy prices, p, have been shown affecting both intensiveness and economic activity, as shown in Figure 2.4.

It is now assumed that the energy intensiveness function U(p, t) can be expressed as the product of two factors, one of which

Table 4.5. Equations of demand.

Sector	Electrical Energy Demand	Electrical Energy Intensiveness	Economic Activity
Industrial	$De_{i_j} = Ue_j(p,t) \cdot Y_j(p,t)$ $j = 1 \ldots N$ $De_i = \sum_{j=1}^{N} De_{i_j}$ [KWH/yr]	$Ue_j(p,t)$ KWH per constant dollar of value added for the jth manufacturing category [KWH/$]	$Y_j(p,t)$ constant dollars of value added by manufacturing for the jth category [$/yr]
Residential	$De_r = Ue_r(p,t) \cdot Y_r(p,t)$ [KWH/yr]	$Ue_r(p,t)$ KWH per household per year [KWH/yr]	$Y_r(p,t)$ number of households in any year
Commercial	$De_c = Ue_c(p,t) \cdot Y_c(p,t)$ [KWH/yr]	$Ue_c(p,t)$ KWH per commercial employee per year [KWH/yr]	$Y_c(p,t)$ number of people employed in commercial activities in any year

is independent of energy price:

$$U(p, t) = U_o(t) \cdot F(p)$$

For electrical energy in particular:

$$Ue(p, t) = Ue_o(t) \cdot Fe(p) \qquad (4.2)$$

Thus all the effects of changing prices are contained in the function F, which modifies a price-independent function U_o, to produce the observed electrical energy intensiveness, U. The factors F and U_o are discussed in sections 4.4 and 4.5, respectively.

The three expressions for demand presented in Table 4.5 can then be written:

$$De_{i_j} = [Ue_{o_j}(t) \cdot Fe_j(p)] \cdot Y_j(p, t) \qquad (4.3)$$

$$De_r = [Ue_{o_r}(t) \cdot Fe_r(p)] \cdot Y_r(p, t) \qquad (4.4)$$

$$De_c = [Ue_{o_c}(t) \cdot Fe_c(p)] \cdot Y_c(p, t) \qquad (4.5)$$

As will be seen in section 4.4, it is reasonable to assume that the Fe functions have the same form for all three sectors. The subscripts on Fe can then be dropped and, recognizing that the prices charged for energy vary with the consuming sector, the demand expressions become:

$$De_{i_j} = [Ue_{o_j}(t) \cdot Fe(p_j)] \cdot Y_j(p_j, t) \quad (4.6)$$

$$De_r = [Ue_{o_r}(t) \cdot Fe(p_r)] \cdot Y_r(p_r, t) \quad (4.7)$$

$$De_c = [Ue_{o_c}(t) \cdot Fe(p_c)] \cdot Y_c(p_c, t) \quad (4.8)$$

Further simplifications will be left to the sections describing individual sectors of comsumption.

4.4 Price Effects

4.4.1 Price Elasticity of Demand

Economists have demonstrated that changes in energy prices can affect the level of demand for energy (14, 76). Two general effects have been observed:

1. A change in the price of energy relative to other prices tends, in some instances, to alter demand.
2. A more rapid change in the price of one form of energy relative to alternate forms tends to shift demand away from more costly forms toward cheaper alternatives.

The latter effect is generally referred to as "interfuel competition," while the former effect is a manifestation of at least three modes of consumer behavior:

1a. Consumption. A consumer may waste energy when it is cheap, and he may conserve energy when it becomes more expensive.

1b. Saturation. The fraction of all consumers in a given sector which possess a certain appliance is called the "saturation" of that appliance. Low cost energy may contribute to a rapid increase in saturation of a non-essential appliance,[4] while higher cost energy may slow the increase in saturation of that appliance.

1c. Location. Low energy prices may attract certain kinds of consumers to a given region, and high prices may cause them to move to or preferentially expand their operations in other locations.

The influence of a price change on demand is quantified by use of an "elasticity," which represents the total, long-term fractional change in demand per unit fractional change in price. A hypothetical relationship between electricity demand and electricity price is illustrated by the curve of Figure 4.2:

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[4] The term "appliance" is used in its broadest sense; it includes industrial machinery and commercial equipment, as well as household appliances. An "essential appliance" shall be taken to mean an appliance which performs a function integral to the sustenance of the consumer. Examples are electric arc furnaces in steel mills, ovens in restaurants, and heaters in homes. Changes in saturation of essential appliances are considered to be due to inter-fuel competition.

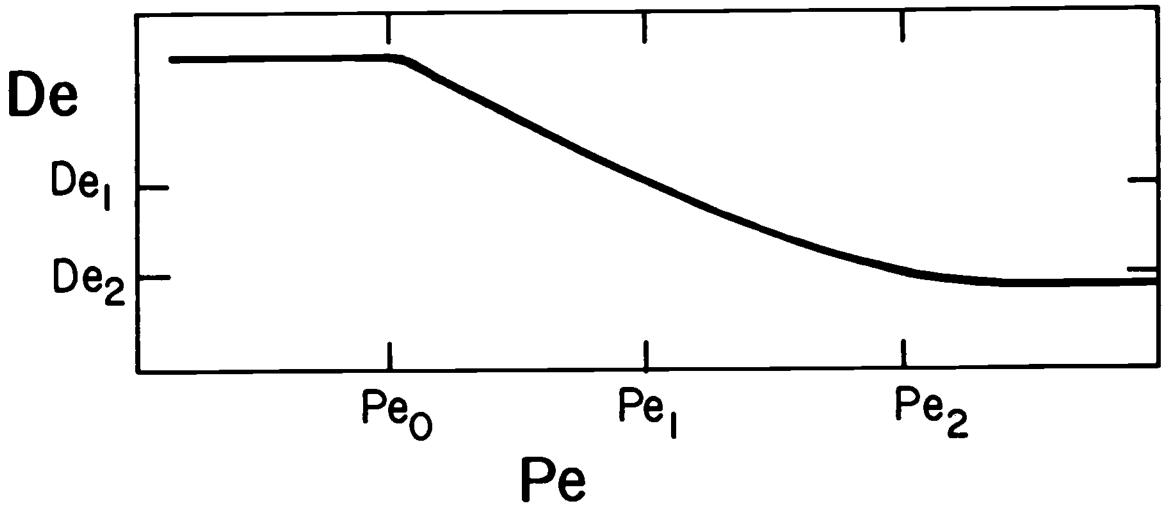


Figure 4.2. Hypothetical economic demand curve for electrical energy.

Price elasticity of demand for electricity, ϵ_{ee}, is defined at a particular point on the demand curve, such as (Pe_1, De_1) as follows:

$$\epsilon_{ee_1} = \left. \frac{\frac{\partial De}{De}}{\frac{\partial Pe}{Pe}} \right|_{Pe=Pe_1} = \left. \frac{\partial De}{\partial Pe} \frac{Pe}{De} \right|_{Pe=Pe_1} \tag{4.9}$$

Furthermore, elasticities are defined not only with respect to the price of the energy form in question (the "own elasticity of demand"), but also with respect to the price of competing energy forms. Thus

$$\epsilon_{eg} = \frac{\partial De}{\partial Pg} \frac{Pg}{De} \tag{4.10}$$

is the "cross elasticity of demand" for electricity with respect to the price of gas. It measures the extent of substitution of electricity for gas due to changes in the price of gas.

Some additional comments are pertinent to the interpretation of the foregoing definitions:

1. Price elasticity of demand is a dimensionless quantity. Demand is said to be elastic if the absolute value of its elasticity is greater than or equal to 1.0. Otherwise it is inelastic.
2. The "percent change" represented by an elasticity refers to the difference between the modified demand and the demand which otherwise would have been observed without the price change.
3. Price elasticity is a measure of a partial effect, i.e., the effect of changes in one price alone when all other prices and factors affecting demand are held constant.
4. A given elasticity applies only at a particular point on the demand curve, such as at (Pe_1, De_1). In other words, elasticities are not independent of price. For example, the elasticity at price Pe_2 is not the same as that at Pe_1. Furthermore, as long as price remains less than Pe_o, price increments will not affect demand. At prices above Pe_o, however, the change in demand depends

not only on the size of the price increment, but on the price prior to the increment.[5]

The effects of price changes on demand are functions of time. That is, a given change in price may have little immediate effect on demand, but can have significant impact after considerable time has elapsed. Economists frequently distinguish between these short- and long-term effects by defining corresponding "short-run" and "long-run" elasticities. In other words, quotation of an elasticity is almost meaningless unless some time-response information is also provided.

This delay or lag in the response of energy demand to changes in energy prices arises from the fact that energy is an intermediate good, used primarily to obtain the services of appliances. Thus responses of demand are inextricably tied to stocks of these appliances; decisions concerning changes in operating techniques and the replacement or expansion of these stocks cannot usually be implemented instantaneously. This is due, in part, to the inertia of established operating procedures and the considerable investment in plant and equipment of many sectors of consumers.

As an example, consider the response of a given sector to a large, step-wise increase in the price of electricity with no changes

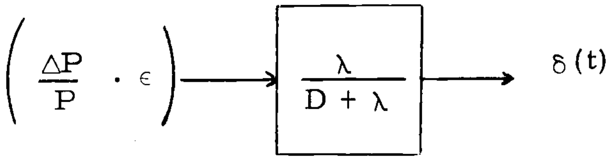
[5]This is not surprising because as the price of a particular energy form increases, consumers become more sensitive to further changes in it. Once they have responded to a certain point, however, further response becomes more and more difficult.

in prices of fossil fuels. Shortly after the price rise, demand might be slightly less than it otherwise would have been because some consumers are able to undertake conservation measures relatively rapidly. As time passes, other consumers find they can achieve savings by replacing aging electrical equipment with that which utilizes natural gas. A few industrial consumers may eventually decide to expand their facilities in another state where electrical energy is cheaper. Eventually, perhaps many years after the price increase, almost all of those consumers who are going to respond to the price change have done so; the demand for electricity is now some fraction of what it would have been without the price increase.

Examination of data summarized by Chapman, Tyrrell and Mount (11) indicates that the response of energy demand to a change in price can be approximated by the response of a first-order, linear system described by the equation

$$\tau\dot{\delta} + \delta = f(t) \qquad (4.11)$$

λ, the reciprocal of τ, is the time constant of the response. τ can be taken to be the average delay on the part of consumers prior to implementation of changes in their patterns of energy use. By τ years after a price change, for example, the modification in demand is 63% of the ultimate modification represented by the associated elasticity. Thus $\delta(t)$, the current fractional change in demand, can be modeled schematically as



where the price elasticity, ϵ, represents the total fractional change in demand per unit fractional change in price and D is the differential operator.

4.4.2 Price Elasticity of Intensiveness

It has been stated that responses of consumers to changing energy prices affect the demand for energy. This statement is too general, however, because energy conservation, appliance saturation, and interfuel substitution actually affect how energy is used, or, its pattern of use. In Chapter 2, energy intensiveness was defined as a quantity characteristic of patterns of energy use, and it was asserted that the product of intensiveness and economic activity represents demand. Thus changes in energy prices do not affect energy demand directly, as implied throughout section 4.4.1, but do so by way of the factors of demand. The preceding discussion of price elasticity of demand, however, is still applicable. We have only to define a new quantity, price elasticity of intensiveness, which is completely analogous to price elasticity of demand:

$$\xi_{ee} \equiv \frac{\partial Ue}{\partial Pe} \frac{Pe}{Ue} \qquad (4.12)$$

In addition, we can define analogous time constants, λ, which are associated with the time required for each sector to change its average pattern of energy use, or energy intensiveness, in response to price changes. The following paragraphs discuss these new parameters and their application to the three major socio-economic sectors.

Four kinds of consumer responses to energy price changes were listed earlier and have been repeated in Table 4.6. These responses differ from one another in that they develop over different lengths of time following a price change. Furthermore, the average reaction time associated with a given kind of consumer response varies with the socio-economic sector; however, the table indicates that not all responses are important in each sector.

Table 4.6. Effects of price changes by sector.

	Appliance Saturation	Appliance Consumption	Interfuel Substitution	Industrial Location
Time period of response:	very short	short	medium	long
Sector of importance:				
Industrial		X	X	X (effective)
Residential	X	X	X	
Commercial	X	X	X	

Industrial Sector. Energy conservation in industry reflects, in part, decisions to alter procedures currently used in the operation of machines. Sometimes this can be done quickly, but in many cases it requires basic changes in operating techniques, re-optimization of processes, or additional capital investment. The average delay may be on the order of about 2 years.

Industries may respond to changes in relative energy prices by replacing machines which utilize more expensive energy forms with those which consume cheaper alternate forms. The effective rate of turnover of machines is a measure of how fast such interfuel substitution occurs, and thus of how fast the average energy intensiveness can be changed. This number is close, but not necessarily equal to the average lifetime of the process equipment of a given group of industries. The effective rate of turnover might also depend on the length of any existing long-term fuel contracts. Finally, if industrial equipment is designed to consume alternate fuels interchangeably, the effective turnover time would be much shorter than the average equipment lifetime. Thus the average delay depends on the group of industries in question, and typically might be on the order of 3-10 years.

Only the most highly energy intensive industries would consider the price of energy a factor in their locational decisions. Because of the large investments involved and the long lead times required to expand or construct new facilities, this is potentially the longest-range response of any considered in Table 4.6. Furthermore, this response is not treated here as one which directly affects energy intensiveness, but as one which affects industrial output via capital investment. Thus the associated time constant is designated an "effective" one, and is taken up in the discussion of the various industrial models of the Economic Component of OSSIM in Appendix I.

Residential Sector. Saturation of non-essential appliances reflects a decision to either purchase or not to purchase. This decision can be implemented with very little delay.

Conservation entails alteration of habits or adaptation of procedures involving the use of appliances. Sometimes this can be done quickly, but it also may require considerable time: consumers must first become aware of conservation potentials, and then make modifications in lifestyles or in certain physical attributes of their homes. The average delay, therefore, might be on the order of one to two years.

Analogous to the Industrial Sector, it is the effective rate of turnover of household appliances that determines the speed of interfuel substitution in residences. This parameter can be approximated by the average lifetime of individual household appliances, which ranges from about 2 to 20 years.

Commercial Sector. As in the Residential Sector, modification of the rate of change of appliance saturation involves very little time delay.

Energy conservation by commercial enterprises reflects, in part, decisions to alter procedures used in the operation of commercial appliances; these decisions can be implemented in relatively little time. Conservation also includes, however, the design and construction of new office buildings and other facilities. Several years may elapse, therefore, before the effect of newer, more energy-efficient structures appears in the average energy intensiveness of the Commercial Sector.

Finally, the effective rate of turnover of commercial appliances is important to interfuel competition in the Sector. This number is close to the average depreciable lifetime of commercial equipment, which is on the order of 5-10 years.

Individual values of price elasticity of intensiveness will be discussed in chapters describing the various sectors of demand. Some comments follow, however, concerning the relative importance of these elasticities and the factors upon which they depend. These statements, taken in part from a National Academy of Engineering report (32), are based upon consumer responses to past price changes. It is possible that future price changes may be of such a magnitude that the following generalities are inappropriate.

1. The primary factor which determines the magnitude of price elasticity in the Residential and Commercial Sectors is the availability and cost of competing alternative energy forms. Elasticity is likely to be substantial only in cases where potential alternatives are clearly present.
2. In the Industrial Sector the most important consumer response is one of location. Energy intensiveness is price inelastic for most 2-digit industrial groups; it is elastic only for those industries which are exceptionally energy intensive and which are technically able to conserve or utilize alternate energy forms.
3. The magnitude of price elasticity is directly related to the portion of the consumer's total expenditures accounted for by the commodity in question.
4. A consumer's response to price changes depends on whether he is aware of the impact of his energy-use decisions on his energy expenditures. Since commercial and industrial consumers generally account for expenditures more closely than residential consumers, the energy intensiveness of the Residential Sector might be expected to be historically the least elastic of the three sectors.

The average delay associated with the responses of each sector and the relative importance of each component of the observed elasticity are summarized in Table 4. 7.

4.4.3 Elasticity Model

The function accounting for the effects of energy price changes on electrical energy intensiveness, implied in equations 4.6, 4.7, 4.8, is derived in the following paragraphs.

Define, for any given socio-economic sector, the following quantities:

Ue: electrical energy intensiveness, joules/eca[6]

Ug: gas energy intensiveness, joules/eca

Up: petroleum energy intensiveness, joules/eca

Ut: total energy intensiveness, joules/eca

In defining the above quantities, electrical energy consumed is assumed converted by its joule-heating equivalent, and only those petroleum products used as fuels by ultimate consumers are included. Thus, if direct consumption of coal and wood is neglected

$$Ut = Ue + Ug + Up \tag{4.13}$$

Ut represents the heat equivalent of all energy directly consumed by

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[6] The term "eca" represents units of economic activity. It may be dollars of value added by manufacture, number of services employees, etc.

Table 4.7. Relative average delays and elasticities of intensiveness by sector.

Sector		Response Mode			
		Saturation	Conservation	Interfuel Substitution	Location
Industrial	ξ		sometimes important	sometimes important	important
	τ		2 yrs	3-10 yrs	> 5 yrs
Residential	ξ	less important	less important	important	
	τ	< 1 yr	1-2 yrs	2-20 yrs	
Commercial	ξ	least important	less important	important	
	τ	< 1 yr	1-3 yrs	5-10 yrs	

a sector; changes in Ut with time are characteristic of the sector in question and do not reflect changes in electricity generation efficiency.

The electrical energy intensiveness function can be written

$$Ue = Ue(Pe, Pg, Pp, \theta) \tag{4.14}$$

where Pe, Pg, Pp represent prices of electricity, gas, petroleum products and θ represents all the non-price factors which cause changes in intensiveness. One such factor is technological change.

Taking the total differential

$$dUe = \frac{\partial Ue}{\partial Pe} dPe + \frac{\partial Ue}{\partial Pg} dPg + \frac{\partial Ue}{\partial Pp} dPp + \frac{\partial Ue}{\partial \theta} d\theta \tag{4.15}$$

and holding all non-price effects constant ($d\theta = 0$)

$$dUe = \frac{\partial Ue}{\partial Pe} dPe + \frac{\partial Ue}{\partial Pg} dPg + \frac{\partial Ue}{\partial Pp} dPp \quad . \tag{4.16}$$

Now multiply through by $1/U_e$; furthermore, multiply the first term on the right by Pe/Pe, the second term on the right by Pg/Pg, and the third term on the right by Pp/Pp. Thus

$$\frac{dUe}{Ue} = \frac{\partial Ue}{\partial Pe} \frac{Pe}{Ue} \frac{dPe}{Pe} + \frac{\partial Ue}{\partial Pg} \frac{Pg}{Ue} \frac{dPg}{Pg} + \frac{\partial Ue}{\partial Pp} \frac{Pp}{Ue} \frac{dPp}{Pp} \tag{4.17}$$

Now define:

$$\frac{\partial Ue}{\partial Pe}\ \frac{Pe}{Ue} \equiv \xi_e,$$ the own-elasticity of intensiveness of electricity;

$$\frac{\partial Ue}{\partial Pg}\ \frac{Pg}{Ue} \equiv \xi_g,$$ the elasticity of substitution of electricity for gas;

$$\frac{\partial Ue}{\partial Pp}\ \frac{Pp}{Ue} \equiv \xi_p,$$ the elasticity of substitution of electricity for petroleum.

Then 4.17 becomes

$$\frac{dUe}{Ue} = \xi_e \frac{dPe}{Pe} + \xi_g \frac{dPg}{Pg} + \xi_p \frac{dPp}{Pp} \ . \qquad (4.18)$$

Since, in general, consumers respond to a change in electricity price by conserving, substituting alternate fuels, and relocating,

$$\xi_e = \xi_{e_c} \text{ (conservation)} + \xi_{e_s} \text{ (substitution)} + \xi_{e_\ell} \text{ (location)} \qquad (4.19)$$

where each of the elasticities on the right has an associated time constant--λ_c, λ_s, λ_ℓ --respectively.

Note that

$\xi_e = \frac{\partial Ue}{\partial Pe}\ \frac{Pe}{Ue}$ is comparable to ϵ_{ee}, the own price elasticity common in economic literature (Reference 11 for example) and

$$\xi_e = \frac{\partial Ue}{\partial Pe}\ \frac{Pe}{Ue} = \left(\xi_{e_c} + \xi_{e_s} + \xi_{e_\ell} \right) \leq 0 \qquad (4.20)$$

The substitution term, ξ_{e_s}, reflects the substitution of gas- or petroleum-using appliances for those which use electricity.

Thus

$$\xi_{e_s} = \xi_{e_{e \longrightarrow g}} + \xi_{e_{e \longrightarrow p}} \tag{4.21}$$

and so

$$\xi_e = \xi_{e_c} + \xi_{e_{e \longrightarrow g}} + \xi_{e_{e \longrightarrow p}} + \xi_{e_\ell} \; . \tag{4.22}$$

$\xi_{e_{e \longrightarrow g}}$ and $\xi_{e_{e \longrightarrow p}}$ may be comparable, but it is likely that $\xi_{e_{e \longrightarrow p}} > \xi_{e_{e \longrightarrow g}}$ and $\tau_p < \tau_g$ due to the mobility of the respective fuels. Note also that $\xi_{e_{e \longrightarrow g}}$ and $\xi_{e_{e \longrightarrow p}}$ are negative, while ξ_g and ξ_p are positive numbers.

Figure 4.3 illustrates that although substitution of gas for electricity causes Ug to increase and substitution of petroleum for electricity causes Up to increase, nevertheless the combined effects of Ug and Up increasing and Ue decreasing do not necessarily leave Ut unchanged. This decrease in Ut represents conservation, providing we also hold industrial location and technological change and other non-price effects constant.

$$\xi_{e_c} = \left. \frac{\partial Ut}{\partial Pe} \frac{Pe}{Ut} \right|_{\substack{\text{location and} \\ \theta = \text{constant}}} , \quad \xi_{e_c} \leq 0 \tag{4.23}$$

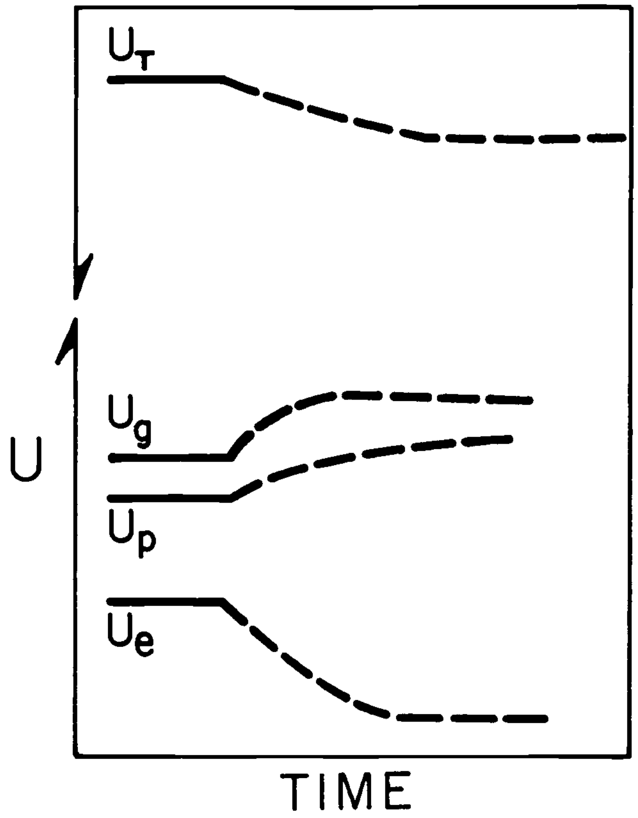

Figure 4.3. Hypothetical energy intensiveness functions.

In summary, using 4.18 and 4.22:

$$\frac{dUe}{Ue} = \xi_{e_c} \frac{dPe}{Pe} + \xi_{e_{e \longrightarrow g}} \frac{dPe}{Pe} + \xi_{e_{e \longrightarrow p}} \frac{dPe}{Pe} + \xi_g \frac{dPg}{Pg} + \xi_p \frac{dPp}{Pp} \qquad (4.24)$$

It has been assumed here, as noted earlier, that the locational effect does not affect intensiveness; rather it affects regional capital investment and is included in the individual industrial models of the Economic Component of OSSIM.

Equation 4.24 can be slightly modified by changing the differentials to differences:

$$\frac{\Delta Ue}{Ue} = \xi_{e_c} \frac{\Delta Pe}{Pe} + \xi_{e_{e \longrightarrow g}} \frac{\Delta Pe}{Pe} + \xi_{e_{e \longrightarrow p}} \frac{\Delta Pe}{Pe} + \xi_g \frac{\Delta Pg}{Pg} + \xi_p \frac{\Delta Pp}{Pp} \quad (4.25)$$

This expression represents the total fractional change in electrical energy intensiveness due to changes in prices of electricity, gas, and oil. But it does not reflect the fact that these changes occur slowly, with an average delay τ associated with each elasticity.

Time dependence is introduced by recognizing that each of the terms on the right side of (4.25) represents the limit--as time goes to infinity--of some $\delta(t)$ which is the solution to the equation

$$\tau\dot{\delta} + \delta = \xi \frac{\Delta P}{P} \quad (4.26)$$

Since δ represents a fractional change in Ue, it can be used to define the function Fe, which is the total, time-dependent modification factor for Ue due to all price changes:

$$Fe \equiv 1 + \frac{\Delta Ue}{Ue}$$

In the time domain,

$$Fe(t) = 1 + \delta_{e_c}(t) + \delta_{e_{e \longrightarrow g}}(t) + \delta_{e_{e \longrightarrow p}}(t) + \delta_g(t) + \delta_p(t) \quad (4.27)$$

where the $\delta(t)$ can be positive or negative. Furthermore, since energy prices are functions of time, the function Fe is more completely designated

$$Fe = Fe(Pe[t], Pg[t], Pp[t], t) \tag{4.28}$$

Finally, note that four of the five terms on the right side of expression (4.25) represent interfuel substitution. The form of this expression is such that price changes take effect through the relative prices of competing alternatives. However, the same percent increase in all energy prices would leave the mix of energy forms unchanged only if the cross elasticities of intensiveness were identical.[7] It is important to note that such a situation could still result in conservation (via ξ_{e_c}) and location (via capital investment) effects.

Appendix II contains further description of the function Fe and the remainder of the electrical energy demand model. The required input includes a set of price elasticities for each sub-sector. In principle these elasticities are smooth functions of price, as in Figure 4.2. Unfortunately inadequate data prevents exhibition of the various energy intensiveness versus price curves. Therefore the computer program utilizes price elasticities which are assumed

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[7] That is, if $\xi_{e_{e \longrightarrow g}} = \xi_g$ and $\xi_{e_{e \longrightarrow p}} = \xi_p$.

to be equal to a given value for prices greater than a specified minimum price, as in Figure 4.4.

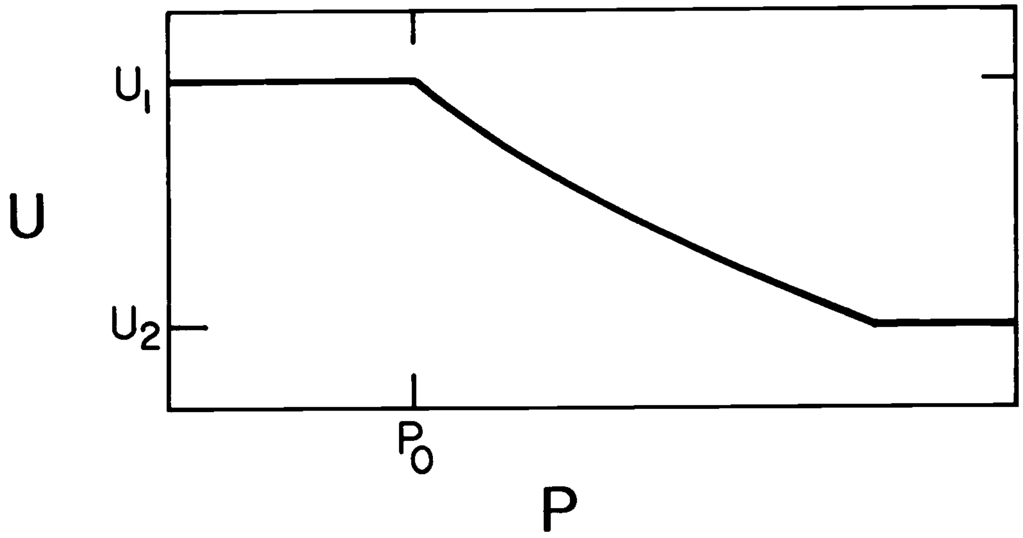

Figure 4.4. Input for elasticity model.

The elasticity ξ in expression 4.26, for example, is thus provided as:

$$\xi = 0 \qquad P < P_o$$

$$\xi = \frac{\partial U}{\partial P}\frac{P}{U} = -k \qquad P \geq P_o \text{ and } \qquad \Delta U < (U_1 - U_2)$$

$$\xi = 0 \qquad \text{otherwise}$$

To this point, energy intensiveness has been assumed responsive only to changes in energy prices. However energy conservation may be motivated by factors other than price increases, rendering somewhat moot the use of elasticities derived from historical data. Effectively applied government policies and real or anticipated electrical energy shortfalls, for example, could also lead to significant conservation efforts in all socio-economic sectors. However, two features of the conservation response modeled here are applicable regardless of motivating factor:

1. Energy-saving is subject to technical limits which can usually be identified by engineering analysis. This means that electrical energy intensiveness can at most be reduced to some fraction of what it would have been in absence of conservation, such as U_2 in Figure 4.4. In other words, a total conservation effort can yield--in the long-run--"one-time only" results.
2. The speed with which a sector can respond to conservation pressures is characterized by a time constant, λ_c; this parameter is assumed to be invariate, regardless of whether the sector is responding to incremental price increases or to forces calling for maximum response in minimum time.

In addition, interfuel substitution may result from shortages of electricity, gas, or oil just as it results from relative price changes. This analogy is plausible because: a) shortages often precede price increases and consumers sometimes respond in an anticipatory fashion; b) consumers are more likely to convert to a plentiful energy form than to one which has been in short supply;

and c) the unavailability of a commodity may be thought of as availability at an infinite price. Thus, the function Fe can, in principle, be used to simulate conservation and interfuel substitution arising from both energy price changes and energy shortfalls.

4.5 Base Energy Intensiveness

The demand for electrical energy by a given socio-economic sector is written, according to Table 4.5, as

$$De = Ue(p, t) \cdot Y(p, t) \qquad (4.29)$$

where

$$Ue(p, t) = Ue_o(t) \cdot Fe(p) \qquad (4.2)$$

Equation 4.2 asserts that: a) some change in energy intensiveness occurs irrespective of energy price, and b) it is the compound effect of these basic changes and changes in energy prices which is observed as Ue. The underlying price-independent component, Ue_o, will be referred to as "base energy intensiveness."

Base energy intensiveness is most easily examined by consideration of the Industrial Sector; its meaning in the Commercial and Residential Sectors is discussed in Chapters 6 and 8.

In industry, a history of low and declining electricity prices has been a factor in the substitution of capital for labor and in the substitution of electricity for the direct combustion of fossil fuels. However, even with the effects of changes in electricity price statistically removed from the data, Fisher and Kaysen found that there was still an increase over the years in the electrical energy intensiveness of most manufacturing industries (14). This increase was attributed, in part, to technological change, or technical progress. Although several analysts have attempted to resolve technological change into its component parts (18, 26), comparable unfolding of Ue_o (with the exception of the Residential Sector) is not consistent with the level of aggregation of the Oregon State Simulation Model. For now it suffices to say that changes in base energy intensiveness are due to forces exogenous to the system under consideration, and that an important such force is technological change. The observed electrical energy intensiveness, Ue, is thus the resultant of these exogenous forces and energy price changes; its magnitude may, depending on the price elasticities, be considerably different from that of Ue_o.

Conceptually, the parameters ξ and λ needed to isolate the function Fe(p) for the recent past can be obtained from observed energy intensiveness functions, Ut, Ue, Ug, Up and energy price histories; or, avoiding significant statistical problems, these parameters can be obtained from other sources (Reference 11 for example) and Fe(p) obtained directly. In either case, determination of Fe(p) would permit unfolding Ue(p, t) to obtain $Ue_o(t)$. Unfortunately, the data required to execute this procedure are incomplete; acquisition and the statistical techniques involved in isolating Ue_o are beyond the scope of this work. However it will be shown that, under certain assumptions, isolation of Ue_o is unnecessary.

A number of electrical energy intensiveness curves, Ue, covering the recent past are exhibited in Chapters 5 through 8. They are, in general, strong functions of time. Caution must be exercised, however, in considering future values of energy intensiveness. These functions will continue to behave in the future as they have in the past only if their individual factors, $Ue_o(t)$ and Fe(p) behave as they have in the past. The utility of factoring Ue(p, t) lies in the isolation of two components which will, in all probability, behave quite differently from one another in the future. That is, $Ue_o(t)$ can reasonably be expected to follow past trends, while Fe(p) will most likely deviate considerably from its historical pattern.

Ideally, then, we would like to obtain $Ue_o(t)$ for the recent past and identify the basic forces, such as technical progress, which have caused it to change with time. Then, assuming that these forces will continue to be important, $Ue_o(t)$ can be extrapolated into the future with reasonable assurance. Finally, application of the price-effects function Fe(p) to $Ue_o(t)$ over the recent past would yield the observed energy intensiveness Ue(p, t). But the goal, of course, is continued application of Fe(p) into the future, only now using various future energy price scenarios. The resulting Ue(p, t), when used with concomitant scenarios of economic activity, provides estimates of future energy demand.

As has been pointed out, the response of energy intensiveness to changes in energy prices is not instantaneous, but occurs over a period of time. Figure 4.5 shows Ue_o increasing linearly and a hypothetical price decrease between time 5 and 25. Ue begins to respond at 5, and is still responding at 30; in fact, it does not complete its reaction to the price decrease, or achieve equilibrium, until approximately 35. Once equilibrium has been attained, however, and in the absence of further price changes, the function Fe(p) is a constant and intensiveness can be written

$$Ue(p,t) = Ue_o(t) \cdot Fe(p) = Ue_o(t) \cdot K \equiv Ue_{eq}(t) \qquad (4.30)$$

Thus the pattern of change of energy intensiveness (e.g., linear, exponential, etc.) then becomes the same as that of the base intensiveness $Ue_o(t)$ and is subject to extrapolation on the same basis. Future energy intensiveness is then determined by future price changes according to

$$Ue(p,t)\Big|_{future} = Ue_{eq}(t) \cdot Fe(p) \qquad (4.31)$$

Here Fe is equal to unity prior to any further price changes; its value of K at t>35 has been incorporated into $Ue_{eq}(t)$.

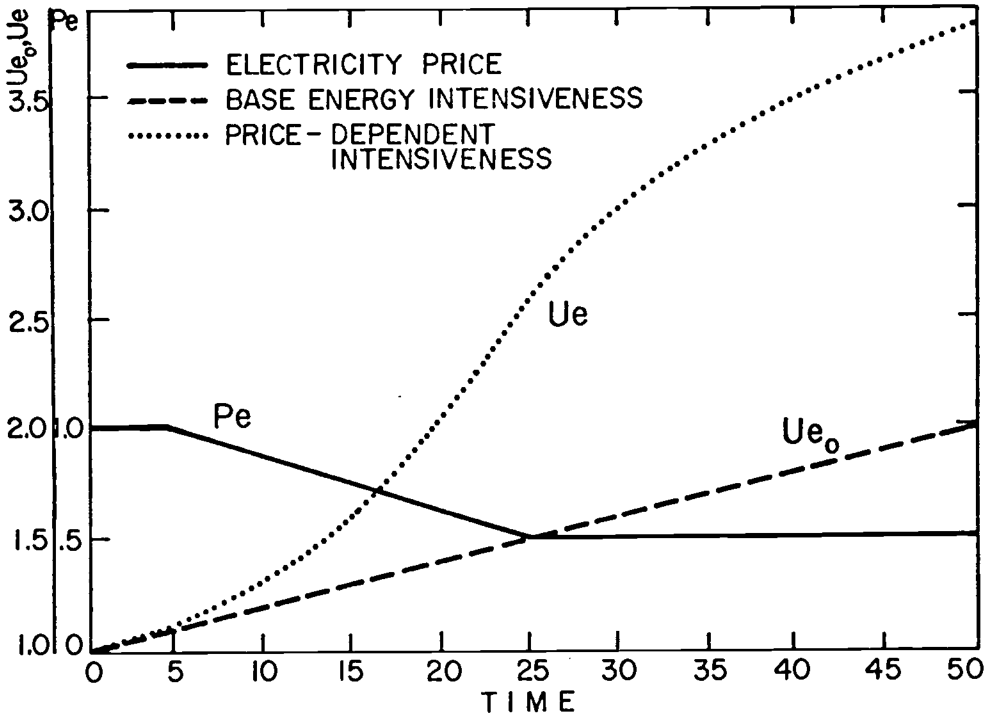

Figure 4.5. Electrical energy intensiveness and equilibrium.

In general, the base intensiveness functions $Ue_o(t)$ have not been isolated in this work for the reasons mentioned earlier. However, in order to consider future behavior of the observed Ue(p, t) it is not necessary to know $Ue_o(t)$ if equilibrium has been approached. This may not be a bad assumption if:

1. energy prices have been relatively constant for a period of time at least as long as the longest average delay characteristic of the consuming sector; or

2. price elasticities have been so small in the past that $Ue(p,t)$ has not significantly deviated from $Ue_o(t)$. In this case

$$Ue(p,t) = Ue_o(t) \cdot Fe(p) = Ue_o(t) \tag{4.32}$$

$$Ue(p,t)\Big|_{future} = Ue_o(t) \cdot Fe(p) \tag{4.33}$$

Examination of recent price histories and all available elasticity data in later chapters reveals that in many cases the use of expressions 4.30 and 4.31 (assumption I) or expressions 4.32 and 4.33 (assumption II) is acceptable. Unfortunately lack of quantitative work regarding the disequilibrium with respect to price of current energy demands makes the adoption of one of these assumptions mandatory in this thesis.

In summary, assuming equilibrium, $Ue(p,t)$ will have the same functional form as $Ue_o(t)$ but may differ in magnitude and rate of change depending on the past price history. The procedure that will be followed is to extrapolate the recent trends of $Ue(p,t)$, hoping that it is close to Ue_{eq}, and then to apply $Fe(p)$ to obtain the future behavior $Ue(p,t)$. The error is dependent upon the extent to which electrical energy intensiveness has responded to past price changes at the time the extrapolation is made.

5. THE INDUSTRIAL SECTOR

5.1 Historical Energy Consumption

5.1.1 Definition of Industrial Sector

The Industrial Sector normally consists of all industries classified as manufacturing or mining by the Standard Industrial Classification Manual (65). This system classifies industries by major two-digit groupings and thence in much greater detail by appending up to two additional digits. For example, SIC 33 covers all primary metals industries, SIC 333 is restricted to industries engaged in primary smelting and refining of nonferrous metals, while SIC 3334 includes only those concerns performing the smelting and refining of aluminum. The level of aggregation considered in this work is the two-digit breakdown, due primarily to data availability. Table 5.1 presents the industry groups at this level, subject to two exceptions:

1. Mining in Oregon contributes only about 0.4% of the Gross State Product (34) and thus has not been represented by a dynamic model in OSSIM. Therefore it is not included in the present coverage of the Industrial Sector.
2. SIC 21, Tobacco Manufacturers, is not applicable to Oregon. In its place is SIC 01, Agricultural Production -

Table 5.1. Industry groups included in Industrial Sector.

SIC	Group Name
20	Food and Kindred Products
22	Textile Mill Products
23	Apparel and Related Products
24	Lumber and Wood Products
25	Furniture and Fixtures
26	Paper and Allied Products
27	Printing and Publishing
28	Chemicals and Allied Products
29	Petroleum Refining and Related Industries
30	Rubber and Misc. Plastic Products
31	Leather and Leather Goods
32	Stone, Clay, and Glass Products
33	Primary Metals Industries
34	Fabricated Metal Products
35	Machinery Except Electrical
36	Electrical and Electronic Machinery
37	Transportation Equipment
38	Instruments and Related Products
39	Miscellaneous Manufacturers
01	Agricultural Production - Crops

Crops, which here includes only the electrical energy used for irrigation.

5.1.2 Determination of Consumption

Nineteen Manufacturing Industry Groups. The only source providing information on energy consumption at a level below the industrial sector as a whole is the Census and Annual Survey of Manufacturers (57, 55). Unfortunately even these data are less than adequate, especially at the level of individual states. Thus it was often necessary to infer Oregon energy consumption patterns from national characteristics, and so both Oregon and national data were collected. Table 5.2 indicates the extent of the data made available by the Census Bureau to the present time. It is particularly unfortunate that state-by-state data, which were collected for the 1967 Census and subsequent years, have not been made available by the Bureau. However, the 1971 Survey files are currently being reviewed to determine whether additional electrical energy data can be published (8).

Separate figures were collected by the Bureau for electrical energy, coal, coke, fuel oil, gas, and "other fuels." Quantities of fossil fuels reported exclude those used by manufacturing establishments as raw materials; i.e., quantities reported are used for heat and power only. Table 5.3 indicates which fuels are included in the

Table 5.2. Bureau of the Census energy data base.

			Number of 2-digit SIC's Reported			
			Electrical Energy		Fossil Fuels	
Year	Census	Survey	Oregon	USA	Oregon	USA
1954	X		T	20	T	20
1955		X	1	20		
1956		X	1	20		
1957		X	1	20		
1958	X		9	20	9	20
1959		X	T	20		
1960		X	T	20		
1961		X	T	20		
1962		X	9	20	10	20
1963	X(1)		9	20		
1964		X	T	20		
1965		X	T	20		
1966		X	T	20		
1967	X			20		20
1968		X				
1969		X		20		
1970		X		20		
1971		X		20	8	20
1972	X(2)					
1973						

(1) Contains data for 1962
(2) Contains data for 1971
T: state-wide total only reported; this total is also reported for those years in which individual SIC's are reported.

Table 5.3. Energy data aggregation and conversion.

Energy Category	Bureau of Census Categories	Conversion Factor[1]
electricity	purchased electricity; electricity internally generated and consumed by the industry	3.6×10^{6} joules/KWH
gas	gas: natural, manufactured, still, blast-furnace, and coke-oven (natural gas only in 1971)	1.092×10^{6} joules/cu. ft.
oil	fuel oil: distillate and residual	6.388×10^{9} joules/barrel
	other fuels: gasoline, LPG, wood (includes gases other than natural in 1971)	8.604×10^{8} joules/dollar[2] (6.120×10^{8} joules/dollar in 1971)
coal	coal: anthracite, bituminous, lignite	2.764×10^{10} joules/ton
	coke and breeze	2.742×10^{10} joules/ton

(1) From recommendations made by Bureau of the Census
(2) Purchases of "other fuels" originally given in terms of cost

various Census categories, how the Census categories were aggregated for purposes of this work, and the conversion factors used to reduce the raw data to a common energy unit--the joule. Complete consumption data is provided in Oregon State Simulation Model (OSSIM); Final Report (Reference 74).

Tables 5.4 and 5.5 summarize some of the pertinent consumption information. In 1958 and 1962, the last years for which state electricity data by SIC were provided, five manufacturing groups accounted for 95% of the electrical energy consumed in manufacturing. One group, Primary Metals Industries, consumed roughly half the total. However SIC 33 is not a major consumer of gas and oil, consumption of which is dominated by Paper and Allied Products and Lumber and Wood Products.

Data on coal consumption by Oregon manufacturers are extremely scanty and unreliable. Combustion of coal provided only about one percent of the energy derived directly from fossil fuels in 1971, and less than one percent of the total energy consumed. Thus, due to lack of data which would allow the development of energy intensiveness information, as well as its very minor present role, coal will be neglected in subsequent portions of this study.

Agricultural Production - Crops (Irrigation). The only published source of data concerning electrical energy used for irrigation is provided by the Rural Electrification Administration (53).

Table 5.4. Distribution of consumption of electrical energy among Oregon manufacturers, 1958 and 1962.

1958				1962			
SIC	Consumption, 10^6 KWH	% of Total Mfg. Consumption	Cumulative %	SIC	Consumption, 10^6 KWH	% of Total Mfg. Consumption	Cumulative %
all Mfg.	4787	100	--	all Mfg.	6657	100	--
33	2292	47.8	47.8	33	3441	51.8	51.8
24	1054	22.0	69.8	24	1342	20.2	72.0
26	770	16.1	85.9	26	1066	16.0	88.0
28	246	5.1	91.0	28	289	4.3	92.3
20	171	3.6	94.6	20	198	3.0	95.3
32	76	1.6	96.2	32	102	1.5	96.8
34	31	0.6	96.8	34	45	0.7	97.5
35	24	0.5	97.3	25	12	0.2	97.7
27	20	0.4	97.7	29	7	0.1	97.8

Table 5.5. Distribution of consumption of energy from gas and oil among Oregon manufacturers, 1971.

Gas				Oil			
SIC	Consumption, 10^{15} Joules	% of Total Mfg. Consumption	Cumulative %	SIC	Consumption, 10^{15} Joules	% of Total Mfg. Consumption	Cumulative %
all Mfg.	47.3	100	--	all Mfg.	25.559	100	--
26	19.9	42.1	42.1	26	10.204	39.9	39.9
24	11.2	23.4	65.5	24	8.925	34.8	74.7
20	6.0	12.7	78.2	28	1.992	7.8	82.5
28	1.2	2.5	80.7	20	1.047	4.1	86.6
29	0.7	1.5	82.2	29	0.315	1.2	87.8
36	0.5	1.1	83.3	36	0.201	0.8	88.6
35	0.3	0.6	83.9	35	0.180	0.7	89.3
37	0.2	0.4	84.3	37	0.038	0.15	89.45

Unfortunately this data base has two shortcomings: it covers only 14 of Oregon's 35 electric utilities, and it reports irrigation sales separately only after 1960. To make up for these deficiencies, letters were written to each of the utilities requesting data on irrigation sales since 1950 and on corresponding number of acres irrigated. Although many of the companies went to considerable trouble to respond as completely as possible, no word was received from 12 utilities. To achieve total state coverage, therefore, data provided by the Bonneville Power Administration (48) were used and are summarized in Reference 74. According to BPA, these data were taken from reports by individual utilities to the Federal Power Commission; in many cases they differ from that provided by the utilities directly to the author.

5.2 Methodology

5.2.1 Economic Activity

Economic activity in the Industrial Sector is simulated in the Manufacturing, Wood Products, Paper Products, and Farm Products Models of the Economic Component and in the Land Use Component of OSSIM. The economic activity of the various manufacturing groups is represented by constant dollars of value added by manufacture ($VA), and that of Agricultural Production--Crops is represented by the number of acres under irrigation.

Value Added. Value added by manufacture is defined as the total value of manufactured output minus the cost of purchased materials (including fuels and electricity); it thus incorporates costs of labor, capital, and taxes. Historical \$VA for Oregon and the Nation, taken from the Census and Annual Survey of Manufacturers, are provided in Reference 74. Data for SIC 33 for Oregon after 1963 were not provided by the Bureau due to the disclosure law, and were estimated by deduction. Table 5.6 lists Oregon's two-digit manufacturing groups according to their respective shares of the total, statewide dollars of value added by manufacturing in 1970. It is noteworthy that the resource-based industries composing SIC's 24, 20, and 26 contributed nearly 60% of the value added in that year.

Raw \$VA reflect inflation as well as changes in real output through time. These numbers must be converted to "constant dollars" in order to be directly comparable from one year to another and in order to be consistent with the OSSIM. The effects of inflation have therefore been removed by the following "deflation" process, attributable to K. P. Anderson of the Rand Corporation.

The "Implicit Price Deflator" is given as

Table 5.6. Relative economic importance of Oregon manufacturing groups, 1970.

Rank	SIC	Group name	Percent of total $VA
1	24	Lumber and Wood Products	34.8
2	20	Food and Kindred Products	14.4
3	26	Paper and Allied Products	9.5
4	35	Machinery Except Electrical	7.0
5	33	Primary Metals Industries	6.4
6	36	Electrical and Electronic Machinery	5.0
7	37	Transportation Equipment	4.0
8	34	Fabricated Metal Products	3.8
9	27	Printing and Publishing	3.8
10	28	Chemical and Allied Products	2.1
11	32	Stone, Clay, and Glass Products	1.9
12	38	Instruments and Related Products	1.6
13	22	Textile Mill Products	1.4
14	23	Apparel and Related Products	1.3
15	25	Furniture and Fixtures	1.1
16	39	Miscellaneous Manufacturers	1.1
17	29	Petroleum Refining and Related Industries	0.5
18	30	Rubber and Misc. Plastic Products	0.4
19	31	Leather and Leather Goods	0.1

$$D_{GNP}(t) \equiv \frac{GNP(t)\Big|_{\text{current prices}}}{GNP(t)\Big|_{\substack{\text{constant prices} \\ \text{(relative to 1958 = 100.0)}}}} \tag{5.1}$$

Let j refer to any of the two-digit SIC manufacturing groups and define a "National Group Deflator" as

$$D_N(j, t) \equiv D_{GNP}(t) \cdot \frac{WPI(j, t)}{WPI_A(t)} \tag{5.2}$$

WPI(j, t) is the wholesale price index for manufacturing group j and $WPI_A(t)$ is the wholesale price index for all commodities; $D_N(j, t)$ reflects the fact that inflation does not necessarily affect every manufacturing group equally. The "Oregon Group Deflator" is next defined as

$$D_O(j, t) \equiv D_N(j, t) \cdot \frac{CPI_O(t)}{CPI_N(t)} \tag{5.3}$$

where $CIP_O(t)$ is the Consumer Price Index for Oregon and $CPI_N(t)$ is the National Consumer Price Index. $D_O(j, t)$ reflects differences between the inflation rate in Oregon and the national average. The data used in calculating the deflators and the deflators for Oregon and the Nation are available in Reference 74.

When the deflators are applied to the raw value added data, a time series of real output (in constant 1958 dollars) of Oregon's manufacturing groups and those of the Nation as a whole is obtained. These results are given in Reference 74 as well.

Irrigated Acreage. Data on number of acres irrigated which correspond to electricity consumption for irrigation are extremely difficult to acquire. The U.S. Department of Agriculture recorded the number of irrigated acres by county in 1949, 1954, 1959, 1964, and 1969 (54). In addition, the Oregon State Water Resources Board has obtained estimates of irrigated acreage in selected areas in various years. However discussion with a Board engineer (5) revealed that their data does not necessarily correspond to that of the Department of Agriculture.[8] Finally, a few of the electric utilities contacted by letter were able to provide the requested acreage and energy data for several selected parts of the state. The data acquired will be more fully discussed in the next section where estimates of the electrical energy intensiveness of irrigation are made.

5.2.2 Energy Intensiveness

Energy intensiveness is a quantity characteristic of patterns and trends in energy use per unit of economic activity. When applied

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[8] Aerial photography by the Water Resources Board resulted in an estimate of 17,400 irrigated acres in Douglas County in 1969; the Census of Agriculture reported 11,700 acres under irrigation for that year.

to manufacturing, energy intensiveness is defined as the energy consumed per constant dollar of value added; when applied to irrigation, intensiveness shall be defined as the electrical energy consumed per acre of irrigated land.

Manufacturing. The energy intensiveness of each two-digit manufacturing group has been calculated for both Oregon and the Nation as a whole utilizing the following definition:

$$\underset{[\text{KWH or joules/\$}]}{\text{Energy Intensiveness}_j} = \underset{[\text{KWH/yr or joules/yr}]}{\text{Energy Consumption}_j} \div \underset{[\text{\$/yr}]}{\text{Value Added by Manufacture}_j} \qquad (5.4)$$

In order to provide a complete picture of historical patterns, the calculations cover as many years as possible between 1954 and 1971 for electricity, gas, and oil in Oregon and for electricity, gas, oil, and coal in the Nation. The numerator of expression 5.4 is the historical energy consumption of the jth manufacturing group while the denominator is taken from the deflated value added time series. The use of this constant-dollar measure of economic activity renders the resulting energy intensiveness as close as possible to a true technical characteristic.

Tables 1 and 2 of Appendix III present electrical energy intensiveness in KWH/$VA. Note that total electrical energy consumed was used in these calculations rather than only that purchased from utilities. Energy intensiveness of manufacturing for the fossil fuels and total energy intensiveness is provided in Reference 74.

The relative energy intensiveness of two-digit manufacturing groups in 1971 is summarized in Tables 5.7, 5.8, and 5.9. In Oregon, three industry groups--Primary Metals, Chamicals, and Paper Products are by far the most electrical energy intensive. However, Stone, Clay, and Glass Products is also high in total energy intensiveness by virtue of its being highly gas and oil intensive. It is noteworthy that of the five industry groups ranked highest in total energy intensiveness, only Primary Metals and Chemicals are more intensive in electricity than in gas and oil; in fact, the majority of Oregon's manufacturing groups depended more on direct combustion of fossil fuels than on electricity in 1971. Furthermore, the electrical energy intensiveness of most of Oregon's manufacturing groups is somewhat higher than the national average for those same groups. But the tables also reveal that Oregon industry is, in general, more intensive in all forms of energy than the national average.[9] Further discussion of this point is left to Section 5.4.

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[9] A significant exception is SIC 29. The composition of this group is quite different in Oregon, however, due to the absence of petroleum refineries. Note also that the pattern of energy use in SIC's 33 and 28 differs between Oregon and the Nation. For example, SIC 33 in Oregon is extremely high in electrical energy intensiveness, and much less so in gas and oil, respectively; for the Nation as a whole, however, this group is highest in gas intensiveness, followed by coal, electricity, and oil.

Table 5.7. Manufacturing groups according to 1971 electrical energy intensiveness.

	Oregon		National	
Rank	SIC	KWH/$VA	SIC	KWH/$VA
1	33	50.0	33	10.77
2	28	12.0	26	6.94
3	26	10.10	29	6.23
4	32	3.60	28	4.86
5	22	3.36	32	3.61
6	24	2.88	22	3.36
7	30	2.23	24	2.49
8	34	1.44	30	2.23
9	20	1.30	20	1.64
10	36	1.29	34	1.44
11	29	1.20	36	1.29
12	35	1.12	35	1.12
13	37	1.08	37	1.08
14	31	1.03	31	1.03
15	25	1.00	25	1.00
16	39	1.00	39	1.00
17	27	0.77	27	0.77
18	38	0.72	38	0.72
19	23	0.59	23	0.59
20			21	0.51

Table 5.8. Oregon manufacturing groups according to 1971 energy intensiveness.

	Total Energy		Electrical Energy		Energy from combustion of			
					Gas		Oil	
Rank	SIC	10^6J/$VA	SIC	10^6J/$VA	SIC	10^6J/$VA	SIC	10^6J/$VA
1	33	223.5	33	180.0	32	149.0	26	52.1
2	32	211.2	28	43.2	26	101.6	32	49.2
3	26	190.1	26	36.4	29	49.7	28	40.7
4	28	108.4	32	13.0	33	29.0	29	22.4
5	29	76.4	22	12.1	28	24.5	33	14.5
6	24	39.5	24	10.4	20	22.6	24	12.9
7	20	31.2	30	8.0	24	16.2	20	3.9
8	34	20.0	34	5.2	34	11.2	34	3.6
9	36	13.2	20	4.7	36	6.1	36	2.5
10	35	8.6	36	4.6	35	2.8	35	1.7
11	37	6.7	29	4.3	37	2.4	37	0.5
12			35	4.0				
13			37	3.9				
14			31	3.7				
15			25	3.6				
16			39	3.6				
17			27	2.8				
18			38	2.6				
19			23	2.1				

Table 5.9. National manufacturing groups according to 1971 energy intensiveness.

					Energy from Combustion of					
	Total Energy		Electrical Energy		Gas		Oil		Coal	
Rank	SIC	10^6J/$VA	SIC	10^6J/$VA	SIC	10^6J/$VA	SIC	10^6J/$VA	SIC	10^6J/$VA
1	29	356.4	33	38.8	29	308.5	26	49.2	33	43.7
2	33	190.7	26	25.0	32	107.8	29	23.3	32	38.8
3	32	179.7	29	22.4	33	88.1	32	20.1	26	30.0
4	26	164.0	28	17.5	28	63.6	33	20.1	28	20.8
5	28	112.8	32	13.0	26	59.9	24	15.4	22	5.6
6	24	44.1	22	12.1	20	22.4	28	10.8	20	5.5
7	22	42.4	24	9.0	24	18.6	22	10.2	30	4.5
8	20	40.2	30	8.0	22	14.5	20	6.4	38	3.3
9	30	25.4	20	5.9	34	12.1	31	5.1	37	2.9
10	34	21.3	34	5.2	30	8.3	30	4.6	21	2.4
11	35	16.0	36	4.7	35	8.1	39	3.1	29	2.1
12	31	16.0	35	4.0	36	6.4	34	2.7	31	1.9
13	37	15.0	37	3.9	39	6.2	21	2.3	35	1.7
14	36	14.2	31	3.7	37	6.1	35	2.3	34	1.3
15	38	13.8	39	3.6	31	5.3	37	2.2	24	1.2
16	39	13.4	25	3.6	25	5.1	38	2.2	25	1.2
17	25	11.7	27	2.8	27	3.3	36	2.1	36	1.0
18	21	8.7	38	2.2	38	3.0	25	1.8	39	0.5
19	27	7.0	23	2.1	21	2.2	23	1.0	23	0.4
20	23	5.2	21	1.8	23	1.6	27	0.9	27	0.04

Electrical energy demand of the jth manufacturing group is given by the product of electrical energy intensiveness and economic activity:

$$\underset{[KWH/yr]}{\text{Electrical Energy Demand}_j} = \underset{[KWH/\$]}{\text{Electrical Energy Intensiveness}_j} \times \underset{[\$/yr]}{\text{Value Added by Manufacture}_j} \qquad (5.5)$$

or, as given in Table 4.5:

$$De_{i_j} = Ue_j(p_j, t) \cdot Y_j(p_j, t) \qquad (5.6)$$

Under the assumptions of Section 4.3, demand can be rewritten as

$$De_{i_j} = [Ue_{o_j}(t) \cdot Fe(p_j)] \cdot Y_j(p_j, t) \qquad (5.7)$$

which is the same as expression 4.6. Finally, the total manufacturing demand is given by

$$De_{i_M} = \sum_{\substack{j=20 \\ j \neq 21}}^{39} De_{i_j} \qquad (5.8)$$

Note that examination of the relative changes in the factors of expression 5.6 enables one to determine whether changes in energy demand are due primarily to increases in manufacturing output or to alterations in the pattern of energy use by industries of group j.

<u>Irrigation.</u> The electrical energy intensiveness of irrigation has been estimated by means of the expression

$$\underset{[\text{KWH/acre}]}{\text{Electrical Energy Intensiveness}_k} = \underset{[\text{KWH/yr}]}{\text{Electricity Consumption}_k} \div \underset{[\text{acres/yr}]}{\text{Number of Irrigated Acres}_k} \qquad (5.9)$$

The numerator is the electrical energy consumed by irrigation and drainage pumps in a specific region k of the state, and the denominator is the corresponding number of acres of land under irrigation. Estimates of this intensiveness can be expected to vary widely due to climatic differences around Oregon and from one year to the next depending on weather conditions. However, since the number of irrigated acres in each of the regions of the state is simulated in the Land Use Component of OSSIM, average values of intensiveness for these same three regions are desired. Table 5.10 presents the raw data and resulting values of intensiveness for specific areas of the state.

The electrical energy demand of irrigation in OSSIM region k is given by the product of average electrical energy intensiveness and number of irrigated acres in that region:

$$\underset{[\text{KWH/yr}]}{\text{Electrical Energy Demand}_k} = \underset{[\text{KWH/acre}]}{\text{Electrical Energy Intensiveness}_k} \times \underset{[\text{acres/yr}]}{\text{Irrigated Acreage}_k} \qquad (5.10)$$

Table 5.10. Electrical energy intensiveness, irrigation.

OSSIM Region	Specific Area	Year	Consumption, KWH/yr	Corresponding Irrigated acreage	Intensiveness, KWH/irr.acre
I Willamette Valley	Willamette Basin	1965	54,000,000 source: Pacific Northwest River Basins Commission [38]	244,000 source: same	221
	service area of Portland General Electric	1973	51,315,122 source: Portland General Electric Co. [40]	227,098 source: same	226
	Willamette Valley	1974-			400 (surface water) 460-570 (wells) source: Pacific Power and Light Co. [45]
II Coastal and Southern Oregon	Tillamook County[1]	1969	391,404 source: Rural Electrification Administration [53]	3,673 source: U.S.Department of Agriculture [54]	107
III Eastern Oregon	Vale Substation	1968	7,601,910 Source: Idaho Power Co. [19]	33,626 source: U.S.Bureau of Reclamation [23]	226
	Union County[2]	1969	3,723,094 source: California-Pacific Utilities Co. [41]	41,040 source: Reference 54	91
	service area of Central Electric	1970	23,309,824 source: Reference 53	122,500 source: Central Electric Co-op. Inc. [42]	190
	service area of Umatilla Electric	1951-73			3000 source: Umatilla Electric Co-op. Ass. [24]
	Central Oregon and Klamath Basin	1974-			700 (surface water) 1150-1600 (wells) source: Reference 45
	land adjacent to Columbia River	1974-			2500-4500 (Columbia River water with pivot irrigation) source: Reference 45

(1) The service area of Tillamook PUD corresponds to Tillamook County, allowing use of Census of Agriculture acreage data

(2) California-Pacific serves all of Union County except for the Blue Mountains, where there is no irrigation. According to EPA, these are the only Oregon counties serviced exclusively by a single utility.

or, analogous to expression 5.6 for each region k,

$$De_{i_k} = Ue_k(p_k, t) \cdot Y_k(p_k, t) \quad (5.11)$$

It will be assumed that the prices of electricity and fossil fuels do not directly affect the number of acres under irrigation. Thus Y_k is not a function of price, and

$$Y_k(p_k, t) = Y_k(t) \quad (5.12)$$

Expression 5.11 is therefore written

$$De_{i_k} = Ue_k(p_k, t) \cdot Y_k(t) \quad (5.13)$$

or

$$De_{i_k} = [Ue_{o_k}(t) \cdot Fe(p_k)] \cdot Y_k(t) \quad (5.14)$$

The total electrical energy demand of the Industrial Sector is then given from expressions 5.8 and 5.14:

$$De_i = \sum_{\substack{j=20 \\ j\neq 21}}^{39} De_{i_j} + \sum_{k=1}^{3} De_{i_k} \quad (5.15)$$

5.2.3 Implications

The use of the expression

$$De_{i_j} = Ue_j(p_j, t) \cdot Y_j(p_j, t) \quad (5.6)$$

implies that at any time t the electricity requirements of industries in group j are linearly related to output. This is perhaps not a good assumption for individual manufacturing concerns. For example, at near zero output a plant can still consume electricity for lighting and heating; see Figure 5.1. However for aggregates of industries as large as the two-digit groupings, these more microscopic considerations become statistically insignificant, other things being equal.[10] Furthermore, this consideration is appropriate only in the short-run. Since Ue_j is a function of time, expression 5.6 is implicitly non-linear and, in the long-run, electricity demand is not directly proportional to output.

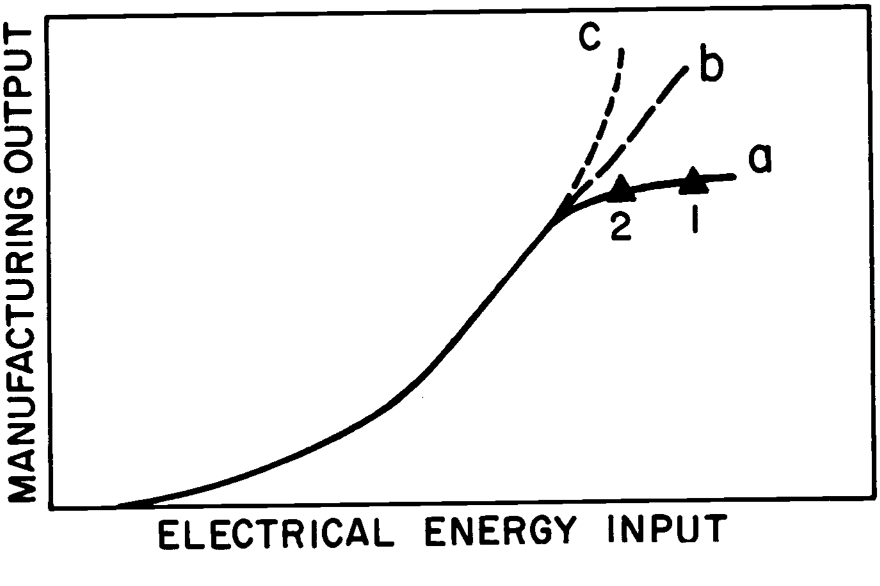

Figure 5.1. Hypothetical production function.

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[10] This is discussed by Anderson in Reference 2.

A more important problem is the estimation of an appropriate production function at this level of aggregation. Curve (a) of Figure 5.1 illustrates the classic production function (see, for example, Reference 20) while extensions (b) and (c) represent other possibilities. Curve (a) might characterize the production process in a given year; the electrical energy intensiveness for that year reflects this production function and the point on it (on the average) where the industries have been operating. Variation of Ue_j with time reflects change in the production function, the operating point, or both, with time. For example, a uniform shift to the right of curve (a) would represent the manufacturing group becoming more intensive in its use of electricity. On the other hand, a shift of the average operating point along curve (a) from point (1) to point (2) would be reflected by a decrease in electrical energy intensiveness.

5.3 Manufacturing Composition

The electrical energy intensiveness data of four major manufacturing groups, derived in section 5.2.2, is plotted versus time in Figures 5.2 and 5.3; plots for the remaining SIC's are provided in Appendix III. Two features of the data are apparent;

1. In most of the groups for which state data are available, the electrical energy intensiveness of Oregon industry is greater than the national average;

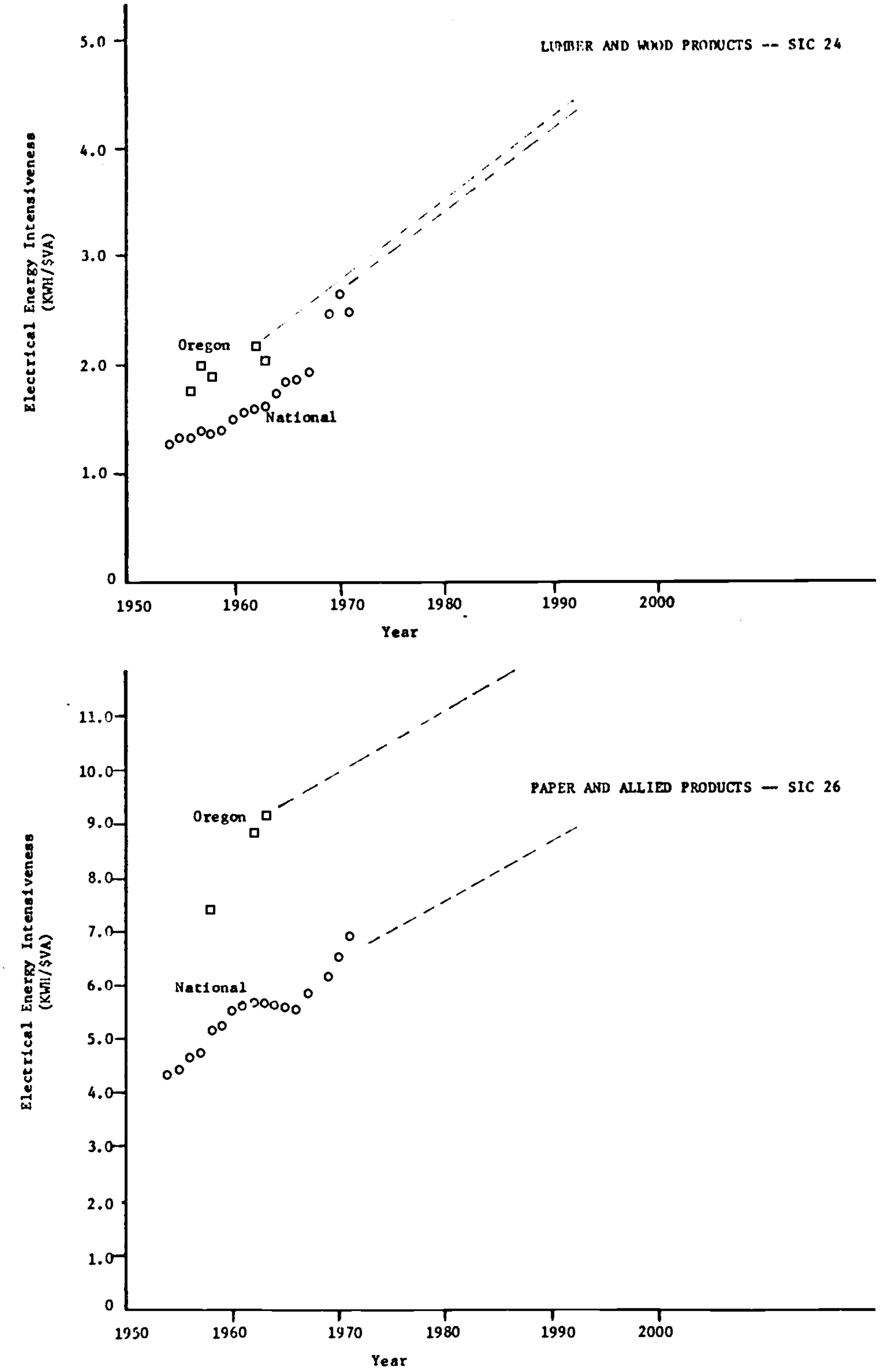

Figure 5.2. Electrical energy intensiveness, SIC's 24 and 26.

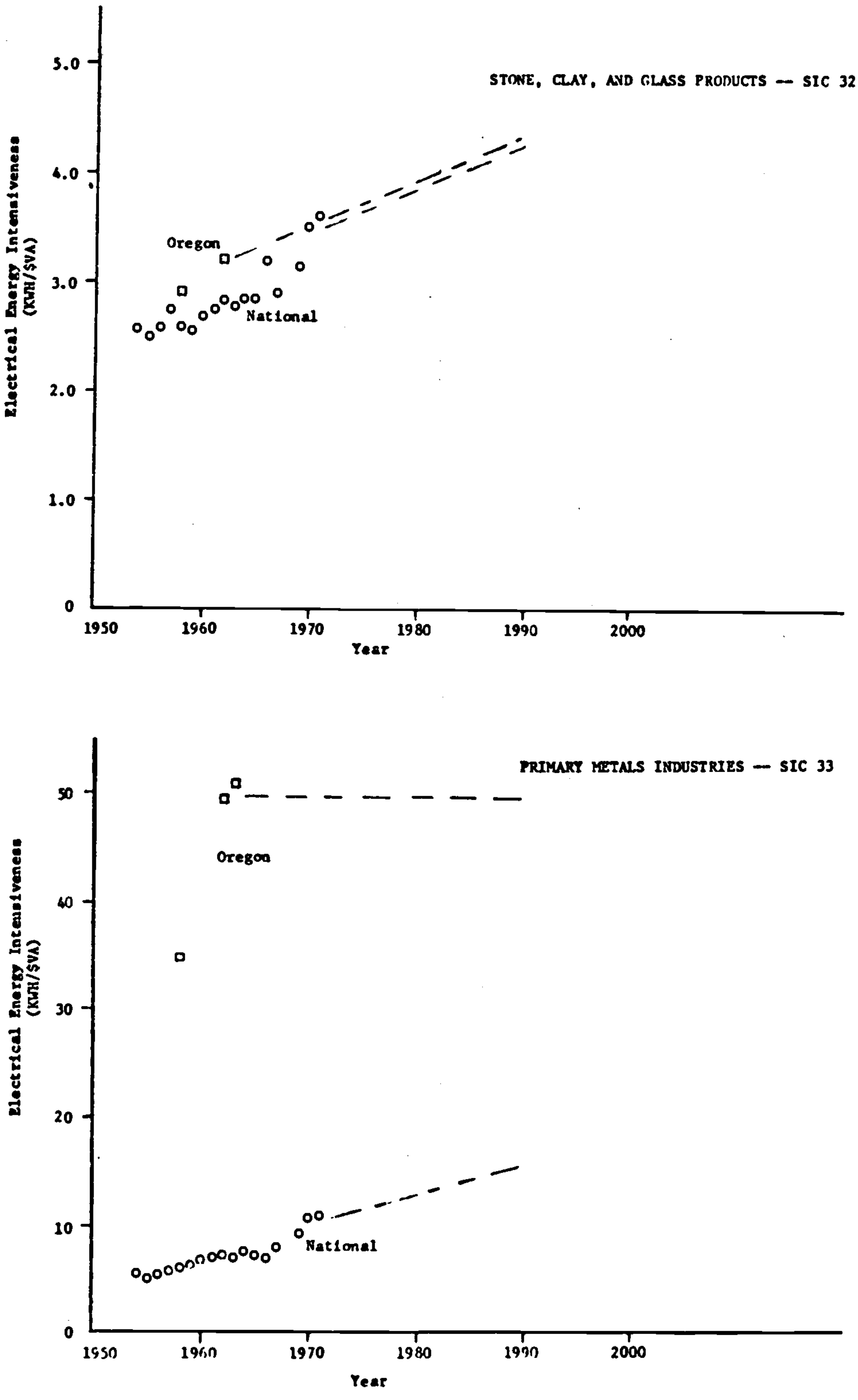

Figure 5.3. Electrical energy intensiveness, SIC's 32 and 33.

2. Electrical energy intensiveness has been increasing with time in almost all of the manufacturing groups.

An important determinant of these patterns is the composition of each individual two-digit group, i.e., the mixture of industries at the three- and four-digit level of classification. A number of factors have caused certain kinds of industries to flourish in Oregon to an extent greater than the national average. If these industries are highly intensive in the use of electricity, their predominance in a particular two-digit manufacturing group largely determines the intensiveness characteristic of that group. Furthermore, changes in time of this mixture of three- and four-digit industries can be expected to contribute to the time-varying characteristics depicted in the figures.

Limited value added data for three-digit manufacturing industry groupings is provided by the Census of Manufacturers for 1958, 1963, and 1967. The contribution, in percent, of each three-digit group to the total output of its respective two-digit group is presented in Reference 74. These data provide an indication of two-digit group composition at three points in time and changes in this composition over a 10-year period.

Unfortunately, lack of corresponding energy data at the three-digit level permits only a qualitative assessment of the role of composition in determining the changes of electrical energy intensiveness with time. Some examples of the kinds of conclusions that can most readily be drawn from this data follow.

Wood and Paper Products. SIC 243--Millwork, Veneer, and Plywood--is somewhat more intensive in electrical energy than other industries in SIC 24. Since its contribution to the total output of SIC 24 is greater in Oregon than the national average and is increasing, it is reasonable to expect that this greater role has contributed to Oregon's higher electrical energy intensiveness. In like manner the predominance of SIC's 262 and 263--Paper and Paperboard Mills--contribute to the higher electrical energy intensiveness of SIC 26 in Oregon than in the Nation as a whole.

Stone, Clay, and Glass Products. Well over half the output of SIC 32 in Oregon is contributed by SIC 327--Concrete, Gypsum, Plaster Products--in which electrically driven machines for crushing, grinding, and mixing play a major role. This subgroup is of much less importance in the Nation as a whole, and these proportions are reflected in the relative magnitudes of electrical energy intensiveness.

Primary Metals Industries. The national average electrical energy intensiveness of the primary metals industries has increased steadily. One reason is that the fractional share of the output of SIC 33 attributable to the ferrous metals industries (SIC's 331 and 332) has decreased, while the nonferrous metals industries have increased in importance. Electricity consumption in the latter group is dominated by the primary production of aluminum, one of the most energy intensive of all metallurgical products. Figure 5.3 indicates that Oregon's primary metals industries are far more intensive in electrical energy than the national average. Although three-digit value added data is not published for SIC 33 for Oregon, the composition of this group is known to be dominated by the primary smelting and refining of nonferrous metals. Even in the ferrous metals industries, however, Oregon exceeds the national average in electrical energy intensiveness. For example, all production of steel ingot is done in electric furnaces which require an average of 725 KWH per ton; the national average, weighted by blast furnaces utilizing coke, was 343 KWH per ton in 1969.

Chemicals and Allied Products. One reason why SIC 28 in Oregon is considerably more intensive in electrical energy than the national average is Oregon's greater representation in SIC 281--Industrial Inorganic Chemicals, and SIC 287--Agricultural Chemicals. Products of these industries include chlorine, caustic soda, and fertilizers, all of which are quite high in electrical energy intensiveness. The national electrical energy intensiveness for SIC 28 shows a fairly regular decrease between 1958 and 1969, contrary to other manufacturing groups. Since SIC 281 dominates SIC 28 nationally, trends in this industry play a major role in the determination of average national energy intensiveness. Three-digit value added data show that the fractional contribution of SIC 281 decreased slightly between 1958 and 1967, which could be one cause for the decrease in overall electrical energy intensiveness.

Petroleum Refining and Related Industries. Oregon has, at present, no petroleum refineries and its representation in SIC 29 consists of paving and roofing materials and other miscellaneous petroleum products. The significant difference in electrical energy intensiveness between Oregon and the national average is therefore not surprising.

In conclusion, although analysis of industry-group composition helps to understand differences in electrical energy intensiveness between Oregon and the Nation, changes in composition alone are not sufficient to explain the increases in national average electrical energy intensiveness. Most of the industries in the two-digit groups have simply become more intensive in their use of electricity. Thus the electrical energy intensiveness curves are taken to represent compositionally invariant groupings or "pure" industries. This means that price elasticity data used to describe the responses of these constant-composition groups should have been obtained in a manner such that they represent conservation and interfuel substitution rather than compositional differences between regions, which reflect the locational decisions of industries. Fortunately the results of some recent econometric analysis meet this requirement and are presented in Section 5. 5. 1.

5.4 Determinants of Intensiveness

It has been argued that industry-group compositional change is not the sole cause of the significant increase in electrical energy intensiveness observed in almost all of the two-digit SIC groups. Consideration of other determinants of intensiveness is therefore necessary before conclusions can be drawn as to future trends in this factor.

5.4.1 Patterns of Energy Consumption by Manufacturing

A comprehensive study of energy end-uses by manufacturing industries was performed by Stanford Research Institute for the United States as a whole for the year 1968. Pertinent data is summarized in Table 5.11. However, it must be recognized that a comparable study for the State of Oregon would likely show somewhat different numbers, in view of the generally higher electrical energy intensiveness of Oregon industry.

The first category of end uses includes those for which electricity is uniquely suited and interfuel substitution is highly unlikely: "mechanical drive" refers to the direct drive of machinery and equipment by electric motors (rather than by water wheels,

Table 5.11. Patterns of energy use in the industrial sector in the United States, 1968. Source: Reference 50.

Major Industrial Sector End Uses	Energy Form utilized to satisfy each end use, percent				Per cent of Total Energy Consumed, Industrial Sector	Per cent of Total Electrical Energy Consumed in Industrial Sector	Main Phenomena Governing Changes in Electrical Energy Intensiveness
	Electricity	Gas	Petrol	Coal			
Electrified:							
Mechanical Drive	100				9.2	80	saturation
Process Energy: Electrolytic	100				1.3	12	consumption
Lighting, Air Conditioning	∿100				0.4	3	consumption, saturation
Partially Electrified:							
Direct Heat	2	41	12	45	31.4	5	interfuel substitution
Process Energy: Steam	∿ 0	57	20	23	47.4	∿ 0	interfuel substitution
Unelectrified:							
Feedstock	0	20	73	7	10.3	0	

steam engines, or diesel engines); electrolytic processes, such as the conversion of alumina to aluminum, owe their existence to electricity; and finally, industrial lighting and air conditioning, which are extremely minor consumers in this sector. End uses in the second category involve the generation of heat, and electricity contributed only a minor share of the required energy in 1968. "Direct heat" includes fuel burned directly in processes such as the manufacture of steel or cement and, as a minor share, that used for space heating;[11] process steam is the largest industrial application of energy and includes some minor use of steam for industrial space heating and the internal generation of electricity. The table indicates that by far the major use of electricity by manufacturing in 1968 was in applications in which there was little competition from other energy forms.

Table 4.6 indicated that the major phenomena governing changes in electrical energy intensiveness in the Industrial Sector are changes in consumption by individual appliances and interfuel substitution. These processes are listed in Table 5.11 following the end use to which they particularly apply.

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[11] Presumably if substitution by an electrolytic process occurs, the electrical energy is then counted in the "electrified" category.

Consumption. The average annual electrical energy consumption of all industrial appliances may change in the long run. However this response mode predominates in the totally-electrified end use category.

Interfuel Substitution. Interfuel substitution is of particular importance in the partially-electrified end use category because of the very large potential for electrification.

Saturation. Appliance saturation is indicated to be of importance to two end uses in the totally-electrified category. This response mode is not dealt with explicitly in the Industrial Sector for two reasons:

1. The data base does not allow individual appliances to be considered;
2. The application of mechanical drive equipment is primarily a process of replacing human labor by machines. This is considered to be a fundamental cause of increasing electrical energy intensiveness and is discussed in the next section.

Location. Industrial location is a major determinant of energy consumption of states, but is not treated as one which affects energy intensiveness at the two-digit level of aggregation. Rather, the influence is modeled by way of changes in capital investment and thence manufacturing output.

Additional insight into energy use trends in groups of manufacturing industries can be gained by examination of the total energy intensiveness data available in Reference 74. When the data are plotted, many curves are of a sawtooth nature and definite trends are indiscernible. However the total energy intensiveness of half of the manufacturing groups--at the national level--does exhibit definite decreasing trends, and that of four groups appears to be increasing. Although the data are more fragmented and inconclusive for Oregon, two groups appear to be increasing in total energy intensiveness, and two appear to be decreasing. Trends in total energy intensiveness are particularly similar between Oregon and the national average in SIC's 26 and 32 (Figure 5.4) and are of interest when considering possible limits to increasing electrical energy intensiveness.

5.4.2 Underlying Causes of Changing Energy Intensiveness

Manufacturing. The prime factor underlying increases in electrical energy intensiveness of manufacturing industries is considered to be technological change. A second and presently unquantified factor is pollution abatement.

Technical progress in the generation and distribution of electricity has resulted in steady decreases in the national average real price of electricity to the various manufacturing groups (see Section 5.5.1). This has contributed to the replacement of human labor by electrical energy-intensive capital. In a study published in 1962 and covering the United States as a whole, Fisher and Kaysen (14) found

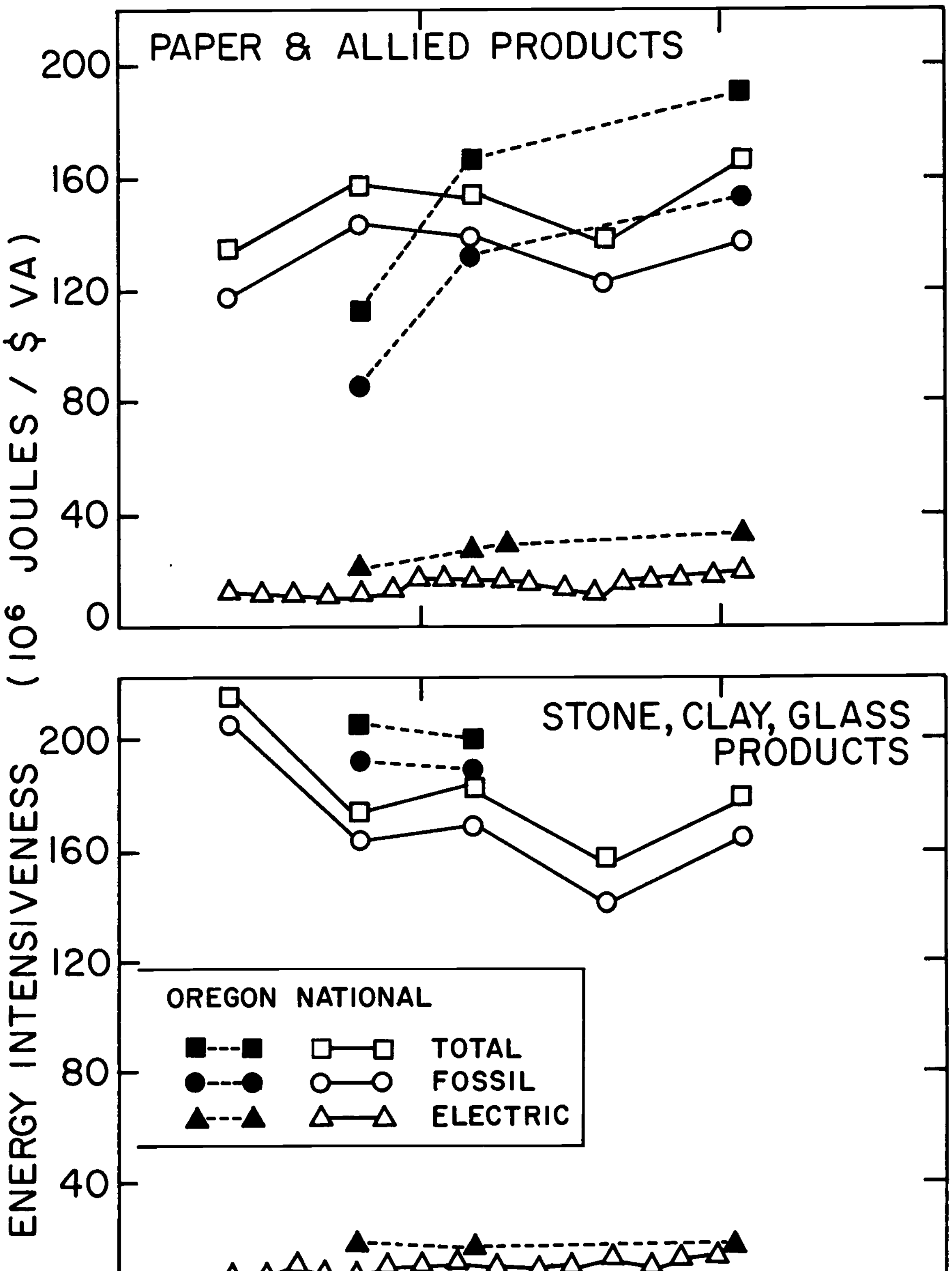

Figure 5.4. Total, fossil, and electrical energy intensiveness, SIC's 26 and 32.

that when the effects of falling electricity prices were statistically removed from electrical energy intensiveness data, intensiveness still increased in most two-digit manufacturing groups. Although this study did not consider the relative prices of competing fuels, later work by Baxter and Rees (6) implies that even when relative price changes are taken into account, the chief determinants of changes in industrial electricity demand are growth in output and technological change within each industry.

Strout (52) defines technological change as "any change, from whatever cause, in quantities of goods and services used to produce one unit of a particular industry's output." Thus technological change encompasses

- changes in the kinds of products produced,
- substitution in the factors of production,
- economies of scale, and
- shifts in the production function (Figure 5.1).

Note that there is no requirement that technological change be accompanied by favorable energy price movements; it is possible for significant increases in production efficiency to outweigh neutral or even adverse relative price changes.

Technological change, then, is exogenous to the system under consideration by OSSIM. It is observable, however, in that changes in energy intensiveness in the various manufacturing groups all reflect--to some degree--technical progress in the individual industries. The relationships are summarized in Figure 5.5.

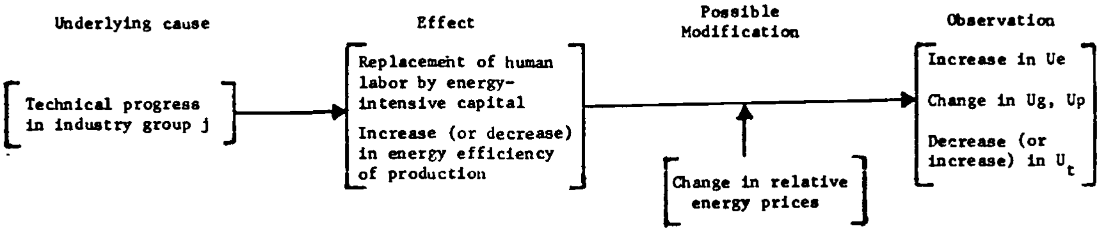

Figure 5.5. Determinants of energy intensiveness of manufacturing industries.

A body of literature considers technical progress to proceed in an exponential fashion.[12] A casual review of the exponential-like increase in electrical energy intensiveness of many manufacturing groups even suggests that this factor might serve as a surrogate for technical progress. However it must be repeated that observed electrical energy intensiveness reflects past changes in relative energy prices. Only a rigorous unfolding of $Ue_j(p_j, t)$ to obtain $Ue_{o_j}(t)$ would yield a function which could serve as a measure of technical progress in industry group j. It is also possible to view

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[12] See for example, R. G. D. Allen (1), Chauncey Starr (51), and A. R. Fusfeld (18).

decreasing trends in total energy intensiveness as a reflection of technical progress in each industry group. An input/output analysis by Reardon (43) resolves primary fuel use changes between 1947 and 1963 into changes due to final demand and changes due to technology. In many cases, changes due to technology were negative, indicating increased industrial efficiency.

The incorporation of pollution abatement equipment by industries in each manufacturing group may have contributed to recent increases in electrical energy intensiveness. Incorporation of such equipment may, in some industries, cause consumption of additional electricity to produce the same output because the process is rendered less efficient, the abatement equipment itself requires large amounts of additional energy, or both. Unfortunately there are no comprehensive data concerning electrical energy consumption by two-digit manufacturing groups for pollution abatement activities at the national or state level. The only inquiry, on a closely related subject, was performed by the U. S. Office of Emergency Preparedness. Their report, The Potential for Energy Conservation (66), includes a list of total capital expenditures for pollution control as a percent of 1970 capital outlays--at the national level and by two-digit SIC. Attempts to correlate this data with increases in electrical energy intensiveness were unsuccessful, and the subject is left for future investigation.

Irrigation. The electrical energy intensiveness of irrigation is subject to significant variation--in the long run--in each major region of the state. Reasons include changes in irrigation technology, in the length of the irrigation season, and in major types of crops grown.

Changes in irrigation methods and technology have included pumping water through greater heights, increasing use of sprinkler systems, and the introduction of rotating sprinkler or "pivot" devices. As more land becomes treated by these more electricity-intensive systems, the regional averages of Table 5.10 will increase. These averages, furthermore, reflect an irrigation season of a given length, for example, the summer months only. Extension of the season in certain parts of the state to, say, ten months would have a nearly proportional effect on electrical energy intensiveness. Finally, agricultural policy decisions involving alternate crops with different water requirements could also result in significant changes in intensiveness.

5.5 Future Electrical Energy Intensiveness

5.5.1 Price Effects and Base Energy Intensiveness

Manufacturing. Electrical energy consumption of the jth manufacturing group was given as

$$De_{i_j} = Ue_j(p_j, t) \cdot Y_j(p_j, t) \qquad (5.6)$$

where

$$Ue_j(p_j, t) = Ue_{o_j}(t) \cdot Fe(p_j) \qquad (4.2)$$

$Ue_j(p_j, t)$ is the observed electrical energy intensiveness, given over the recent past in Figures 5.2 and 5.3, for example; $Ue_{o_j}(t)$ is the base electrical energy intensiveness; and $Fe(p_j)$ simulates the effects of energy price changes.

Before statements can be made about future electrical energy intensiveness, it is necessary to investigate the validity of approximations I or II of Section 4.5:

$$Ue(p, t) = Ue_o(t) \cdot Fe(p) \doteq Ue_o(t) \cdot K = Ue_{eq}(t) \qquad (4.30)$$

or

$$Ue(p, t) = Ue_o(t) \cdot Fe(p) \doteq Ue_o(t) \qquad (4.32)$$

Reference 74 contains the development of real price histories of electricity and fossil fuels to two-digit groups of industries for Oregon and for the Nation as a whole. The results are illustrated for the average of all manufacturing and for two representative SIC's in Figure 5.6.

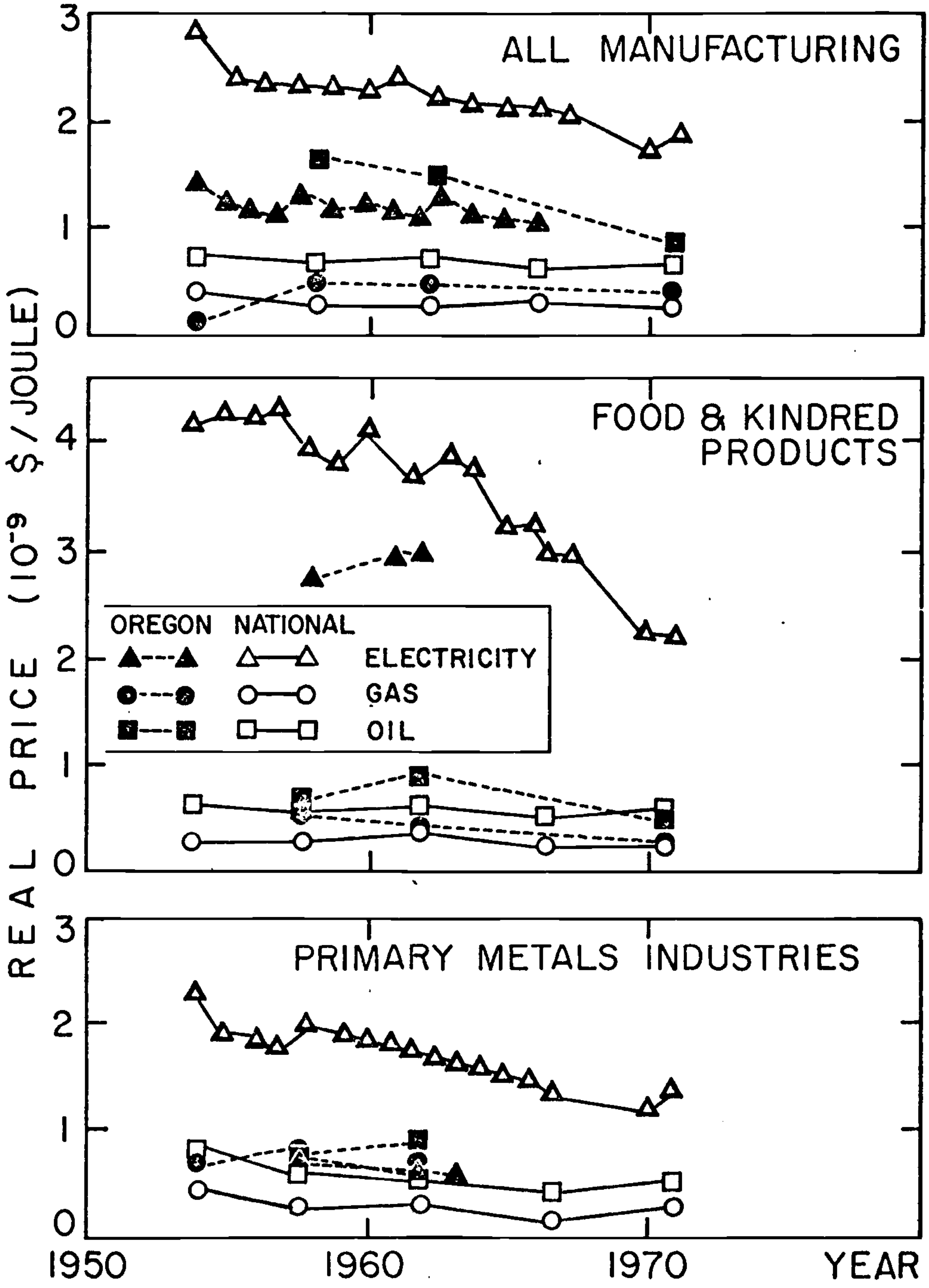

Figure 5.6. Real energy prices to manufacturers.

The data indicate that electrical energy is considerably more expensive per joule consumed than energy derived from direct combustion of the fossil fuels, and that prices of electricity to all manufacturers have been lower in Oregon than the national average. On the other hand, Oregon manufacturers have paid prices greater than the national average for fossil fuels. In almost every case the national average electricity price ceased its dramatic decrease and began to increase after 1970. Electricity prices in Oregon, already quite low in the 1950's, have not experienced drastic changes. In addition, the figure illustrates the considerable difference in electricity price paid by two industry groups which are very low and very high in electrical energy intensiveness, respectively.

In summary, the national average electricity price to manufacturers generally decreased prior to 1970, while the national average electrical energy intensiveness of most industry groups increased. These opposing trends do not necessarily imply a large absolute value of price elasticity of intensiveness, however.

Only five researchers have addressed price elasticity of demand for the Industrial Sector at the two-digit SIC level. The common econometric technique, known as "cross-sectional analysis," addresses differences in electricity demand in the various states at a particular point in time. Elasticities derived using this technique reflect the fact that some industries tend to locate in those parts of the country where electricity is inexpensive.[13] Thus these elasticities include both the elasticity of intensiveness, which reflects how electricity is actually used, and industrial locational decisions. There is some agreement that the locational component of this observed elasticity is dominant, and that when it is purged from the data, industrial electrical energy intensiveness is price inelastic. Unfortunately only two econometricians have actually performed this exercise, and the coverage of SIC groups is sparse; the results are summarized in Table 5.12. Note that when the locational effect is removed, demand is--in many cases--considerably less elastic. Due to data limitations, however, it has not been possible to remove all the effects of industrial location from the demand elasticity. Thus the estimates of intensiveness elasticity are lower bounds; the true values could range considerably closer to zero. Note also that, as expected, those manufacturing groups highest in electrical energy intensiveness have demonstrated the greatest sensitivity to price changes. Unfortunately, it has not been possible--on the basis of existing data--to divide the own elasticities of intensiveness into a portion attributable to interfuel substitution and another portion attributable to conservation. The only hint of a plausible division comes from NERA (33) which has

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[13] This, to some extent, accounts for the considerable differences in composition of two-digit industry groups discussed in Section 5.3.

Table 5.12. Own price elasticity for manufacturing groups.

	Price Elasticity of Demand			Price Elasticity of Intensiveness	
SIC	Fisher and Kaysen (14)	Wilson (76)	Wilson (75)	NERA (33)	Anderson (2)
20		-1.33	-1.09		
21					
22	-1.62	-1.22	-1.22	-1.31	-0.57
23					
24		-1.64	-1.64		
25		-0.97	-0.97		
26	-0.97	-1.64	-1.48	-1.53	-0.56
27		-0.73			
28	-2.60	-1.60	-2.23	-2.23	-0.91
29		-0.69		-1.97	-0.91
30					
31			-0.76		
32		-1.30	-1.08		
33	-1.28	-1.13	-1.51	-1.43, -1.75	-0.98, -1.26
34					
35	-1.33	-1.16	-1.16		
36	-1.82	-1.49	-1.76		
37		-1.01	-1.01		
38					
39					

indicated that for the Residential Sector, conservation represents about one-third of the total elasticity, while the remaining two-thirds is attributable to interfuel substitution.

Estimates of cross elasticities of intensiveness vary widely. Chapman et al. (11) believe the elasticity of substitution of electricity for gas to be about 10 percent of the own-elasticity, while Wilson (76) estimates it as approximately one-third of the own elasticity. Only NERA has developed cross elasticities of intensiveness for two-digit manufacturing groups. Their results are given below.

Table 5.13. Cross price elasticity for manufacturing groups. Source: Reference 33

SIC	ξ_g	ξ_p
22	+ 0.22	
26		+ 0.41
28		+ 0.27
29	+ 0.20	
33		+ 1.11

The cost of electrical energy has historically been a minor fraction of the value of manufactured output in the United States. Table 5.14 ranks the manufacturing groups according to this measure. By comparison to Table 5.12, it is seen again that those

Table 5.14. Relative economic importance of purchased electricity to manufacturers. Source: Reference 32.

Rank	SIC	Group Name	1967 National Average Cost of Electricity, Per Cent of Value of Shipments
1	33	Primary Metals Industries	1.5
2	28	Chemical and Allied Products	1.4
3	32	Stone, Clay, and Glass Products	1.4
4	26	Paper and Allied Products	1.0
5	30	Rubber and Misc. Plastic Products	0.9
6	22	Textile Mill Products	0.9
7	24	Lumber and Wood Products	0.8
8	29	Petroleum Refining and Related Industries	0.6
9	34	Fabricated Metal Products	0.6
10	35	Machinery Except Electrical	0.5
11	36	Electrical and Electronic Machinery	0.5
12	25	Furniture and Fixtures	0.5
13	39	Miscellaneous Manufacturers	0.5
14	20	Food and Kindred Products	0.4
15	37	Transportation Equipment	0.4
16	38	Instruments and Related Products	0.4
17	31	Leather and Leather Goods	0.4
18	27	Printing and Publishing	0.4
19	23	Apparel and Related Products	0.3
20	21	Tobacco Manufacturers	0.01
Average for all manufacturing			0.8

industries to which electricity is most important have displayed the greatest response to price changes. However, since the price of electricity to Oregon manufacturers has been considerably less than the national average, it is likely that its cost represents a lesser fraction of the value of manufactured output. Thus, at current electricity price levels, it is probable that the electrical energy intensiveness of Oregon industries is even less elastic than indicated by the data of Table 5.12. On the other hand, Oregon industry may be more sensitive to prices of competing energy forms.

Elasticities derived from cross-sectional studies and purged of locational effects can be used as first approximations to elasticities of intensiveness for Oregon industries with two cautionary notes.

1. The results for manufacturing groups whose composition is known to be drastically different in Oregon (such as SIC 29) are probably not applicable.
2. The magnitude of price elasticity is not necessarily the same in periods of rising real energy prices as in periods of declining real energy prices. It is unlikely that manufacturers respond to increasing prices in a fashion completely opposite to their response to decreasing prices. For example, when electricity prices were decreasing, capital was being substituted for labor; it does not follow that labor will be substituted for capital in response to

price increases. Conservation would be a more probable first step to be taken by manufacturers.

Electrical energy intensiveness data for Oregon manufacturing groups is incomplete, as seen in Figures 5.2 and 5.3. Thus more distinct trends in national average Ue_j are used to aid in determining appropriate base energy intensiveness characteristics for Oregon industry. The aforementioned elasticities are then applied to these characteristics in the manner indicated in Section 4.5.

In general, the national average price of electricity to manufacturers ceased its dramatic decrease about 1970. It is thus assumed that national average electrical energy intensiveness is not appreciably far from equilibrium and that assumption I of Section 4.5 holds:

$$Ue_j(p_j, t) = Ue_{o_j}(t) \cdot Fe(p_j) = Ue_{o_j}(t) \cdot K = Ue_{j_{eq}}(t) \qquad (5.16)$$

Future price-dependent electrical energy intensiveness is given by application of $Fe(p_j)$ to future equilibrium intensiveness, as in expression 4.31:

$$Ue_j(p_j, t) = Ue_{j_{eq}}(t) \cdot Fe(p_j) \qquad (5.17)$$

As argued in Chapter 4, trends in $Ue_{j_{eq}}$ largely reflect technological change, characterized by Ue_{o_j}; and because of expression

5.16, historical values of Ue_j may be used to obtain a first approximation to future values of $Ue_{j_{eq}}$. Two alternatives are possible in considering these future values:

1. Continuation of past trends in technological change. It is assumed that technical progress in industry group j will proceed, resulting in a continuation of past trends in the replacement of human labor by machines and in the change in energy efficiency of production. However there must exist an upper limit to the electrical energy intensiveness of an industry, one first approximation to which is the point of total electrification. Using SIC 26 as an example (Figures 5.2 and 5.4) it is seen that electrical energy intensiveness can increase by about a factor of six before this limit is reached. Even if industries in SIC 26 become steadily more efficient in their use of energy--such that total energy intensiveness experiences a steady decline--electrical intensiveness must still increase considerably before "saturating." Of course, whether Ue_j follows historical trends or whether it deviates considerably from $Ue_{j_{eq}}$ and saturates at an entirely different level depends on energy prices and availability, simulated in the function $Fe(p_j)$.
2. Variable composition scenarios. Electrical energy intensiveness has been assumed representative of groups of

industries whose composition at the three-and four-digit level is relatively constant (Section 5. 3). If this restriction is relaxed, $Ue_{j_{eq}}$ no longer represents a continuation of trends in technological change. Rather, it can be selected to reflect a variety of scenarios in which sub-groups of industries of varying intensiveness rise or fall from economic prominance.

Alternative (1) is used for all analysis in this thesis. Trends in national average electrical energy intensiveness have been extrapolated from 1970 and are indicated in Figures 5.2, 5.3, and Appendix III.

Increases in electrical energy intensiveness at the two-digit level of Oregon industry reflect not only technological change, but also locational preferences on the part of three- and four-digit industry groups. In fact, this compositional change below the two-digit level may be the predominant reason for the striking increase in Ue_{33}, for example. Unfortunately the data base does not permit further quantification, and equilibrium intensiveness for Oregon industries is obtained as follows:

1. It is assumed that the composition of each two-digit industry group will remain equal to that of 1970. That is, further changes in equilibrium electrical energy intensiveness due to three- and four-digit industries

becoming more or less prominent in Oregon must be an explicit input, as in (2) above.

2. The remaining increases in $Ue_{j_{eq}}$ are due primarily to technological change in each industry, and the curves for Oregon are assumed to follow national trends.[14]

3. For those SIC's lacking sufficient state data, $Ue_{j_{eq}}$ for Oregon is taken equal to the national average. Exceptions are SIC's 28 and 29, where $Ue_{j_{eq}}$ is taken equal to the most recent known value of Ue_j due to significant compositional differences between Oregon and the Nation as a whole. $Ue_{33_{eq}}$ is taken equal to the average of the two most recent known values of Ue_{33} due to the high degree of electrification of the primary metals industries in Oregon as opposed to the Nation as a whole.

In summary, Oregon industry is shown as being more intensive in electrical energy than the national average in five SIC's, less intensive in two SIC's (attributable to compositional differences), and equal to the national average in the remaining thirteen. It is felt, however, that Oregon is probably more electrical energy intensive in many of the latter.

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[14] The assumption that these purely technological curves are in equilibrium with price changes (expression 5.16) may be somewhat better for Oregon since electricity prices to Oregon manufacturers have been relatively constant over the past twenty years.

Irrigation. The electrical energy consumption of irrigation in region k was given as

$$De_{i_k} = Ue_k(p_k, t) \cdot Y_k(t) \qquad (5.13)$$

where

$$Ue_k(p_k, t) = Ue_{o_k}(t) \cdot Fe(p_k) \qquad (4.2)$$

is the observed electrical energy intensiveness estimated in Table 5.10.

Lack of data hinders development of histories of electrical energy intensiveness of irrigation for each region. However, intensiveness has not necessarily changed significantly over the recent past. For example, Umatilla Electric (24) reports that approximately the same number of kilowatt hours per irrigated acre have been utilized since 1951. Changes in technology have evidently led to the withdrawal from sources of less water per acre of application but greater pumping requirements per gallon withdrawn.

Histories of prices paid for electricity by irrigators are also unavailable. However, some electricity for irrigation has been sold under various Commercial accounts, and real Commercial Sector electricity prices are low and have been decreasing (see Chapter 6). Although it is possible these low prices have played a role in changing electrical energy intensiveness of irrigation, such changes cannot be identified from available data.

No studies have been reported concerning possible electricity price elasticity of demand for irrigation. However it is not likely that this parameter would be very great. Once irrigation systems are in place, possibilities for conservation and interfuel substitution are minimal. Variations in electrical energy intensiveness due to location of water source, technology, and policy will most likely considerably overshadow variations due to energy prices. Thus expression 5.13 is rewritten as follows for the simulation of future electricity requirements of irrigation:

$$De_{i_k} = Ue_{o_k}(t) \cdot Y_k(t) \tag{5.18}$$

Values of Ue_{o_k} for 1970 are summarized in the next section, while future values are left as scenario variables.

5.5.2 Model Summary

Should prices of electricity, gas, and petroleum products charged manufacturing group j increase to the point of response, two direct effects and one indirect effect are simulated:

1. a short-term effect corresponding to conservation in the use of industrial appliances, especially those in the electrolytic process, lighting, and air conditioning end use categories;

2. a medium-term effect corresponding to interfuel substitution in the direct heat and process steam end use categories; and

3. a long-term effect, representing the expansion of industries in states other than Oregon due to any electricity price advantage.

The first two responses are simulated directly with the function $Fe(p_j)$ while the third appears indirectly in manufacturing output, $Y_j(p_j, t)$. The method of modifying capital investment by manufacturing industries to reflect relative electricity prices is discussed in Appendix I.

Table 5.15 presents 1970 electrical energy consumption as given by the model for the Industrial Sector. In order to compare the result to that provided by the Edison Electric Institute, the following modifications are made:

Total Consumption (Table 5.15)	$11,052 \times 10^6$ KWH
Industrial Internal Generation[15]	(-) 239
Purchased by Industrial Sector	10,813
Purchased for Irrigation	(-) 393
Purchased for Manufacturing	10,420

Thus 10,420 million KWH is to be compared to EEI's 10,995

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[15] Estimated from historical data in Reference 74.

Table 5.15. 1970 Oregon electrical energy consumption: Industrial Sector.

SIC	Ue_j (1) Electrical Energy Intensiveness (KWH/$VA)	Y_j (2) Value Added (10^6 1958 $)	De_{i_j} Electrical Energy Consumption (10^6 KWH)
20	1.27	260.1	330.33
22	3.32	27.0	89.64
23	0.62	25.3	15.69
24	2.81	623.0	1,750.63
25	0.96	23.3	22.37
26	10.00	185.9	1,859.00
27	0.73	69.8	50.95
28	12.00	45.9	550.80
29	1.20	11.3	13.56
30	2.09	7.7	16.09
31	1.00	1.1	1.10
32	3.55	35.7	126.74
33	50.00	107.4	5,370.00
34	1.49	65.4	97.45
35	1.01	123.4	124.63
36	1.24	89.1	110.48
37	1.12	78.9	88.37
38	0.71	28.9	20.52
39	1.01	19.9	20.10
01			393.40(2)
Total			11,051.85

(1) From Table III-1.
(2) From Reference 74

million KWH[16] consumed by Large Light and Power customers, there being no other source of manufacturing consumption data for 1970. Comparison is made through computation of the fraction

$$\frac{\text{manufacturing consumption}}{\text{LL\&P consumption}} = \frac{10,420}{10,995} = 0.948$$

This result is consistent with comparable data presented in Table 4.4. Therefore the 1970 values of electrical energy intensiveness of manufacturing provided in Table 5.15 are used as initial values in the simulation. The initial values of intensiveness of irrigation are chosen such that when each is multiplied by the number of irrigated acres in region k and summed, the result is 393.4×10^6 KWH. The values chosen for regions I and II were 226.0 and 106.6, respectively, which are resultants reported in Table 5.10. The value for region III, 276.1, is a consequence of the normalization; it appears to be reasonable when compared to other numbers estimated for that region.

The Economic Component of OSSIM does not presently contain dynamic models of all 19 manufacturing groups included in the Industrial Sector. Value added by manufacture, $Y_j(p_j, t)$ is provided for SIC's 20, 24, and 26 individually and for all other

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[16] Comprehensive EEI data is given in Table 6.1.

manufacturing groups combined. Thus, for the 16-group aggregate, the electrical energy intensiveness of each group is weighted by the relative economic importance of that group prior to multiplication by Y. In general, however, the relative economic importance of each two-digit group will change with time. Thus, A_n--the weighting factor or relative importance of manufacturing group n--is given by

$$A_n(t) = \frac{\$VA_n(t)}{\sum_{\substack{n=22 \\ n \neq 24, 26}}^{39} \$VA_n(t)} \qquad (5.19)$$

These importance functions, one for each of the 16 non-resource-based manufacturing groups, are inputs to the energy model, thus allowing variations in the "industrial mix" to be considered as alternate scenarios. Two sets of possible importance functions are cited as examples:

1. The relative economic importance of Oregon's manufacturing industries in 1970 was provided in Table 5.6. Values of A_n calculated from this table can be used directly, which implies a constant industrial mix throughout time.

2. The Bureau of Economic Analysis (60) has projected earnings of two-digit manufacturing groups on a state-by-

state basis through year 2000. When $A_n(t)$ is derived from this data, it is seen that BEA expects Oregon's Primary Metals Industries to decline in relative economic importance, and secondary metals and machinery industries to increase in importance. This is of significance because the latter are considerably less intensive in electrical energy than the former. Table 5.16 presents data for this scenario.

The calculations proceed as previously described at each time step:

$$Ue_j(p_j, t) = Ue_{j_{eq}}(t) \cdot Fe(p_j) \qquad j = 20, 22 \ldots 39 \qquad (5.17)$$

$$De_{i_j} = Ue_j(p_j, t) \cdot Y_j(p_j, t) \qquad j = 20, 24, 26 \qquad (5.6)$$

$$De_{i_\alpha} = \left[\sum_{\substack{j=22 \\ j \neq 24, 26}}^{39} Ue_j(p_j, t) \cdot A_j(t) \right] \cdot Y_\alpha(p_\alpha, t) \qquad (5.20)$$

where α refers to OSSIM's non-resource-based manufacturing model. Thus

$$De_{i_M} = De_{i_{20}} + De_{i_{24}} + De_{i_{26}} + De_{i_\alpha} \qquad (5.21)$$

Finally, the economic output Y_j simulated in OSSIM is in units of constant 1970 dollars, while Ue_j is in units of KWH per constant 1958 dollar. For compatibility, therefore, Y_j is reduced to 1958

Table 5.16. Oregon manufacturing industries: Percent of total dollar value added, by decade. Source: Reference 60.

SIC	1970	1980	1990	2000
20	14.4	12.1	11.4	10.6
21	-	-	-	-
22	1.4	0.8	0.8	0.7
23	1.3	1.0	1.0	1.0
24	34.8	36.1	32.3	29.1
25	1.1	1.0	1.0	1.0
26	9.5	8.0	8.0	8.0
27	3.8	3.3	3.6	3.8
28	2.1	2.2	2.4	2.6
29	0.5	0.5	0.5	0.5
30	0.4	0.4	0.5	0.6
31	0.1	0.2	0.3	0.4
32	1.9	2.0	2.0	2.0
33	6.4	6.2	5.8	5.4
34	3.8	4.9	5.5	6.1
35	7.0	6.2	7.4	8.5
36	5.0	6.5	8.1	9.6
37	4.0	6.6	7.2	7.7
38	1.6	1.1	1.2	1.3
39	1.1	0.9	1.0	1.1

dollars by multiplication by the ratio of deflators:

$$Y_j \Big|_{1958\ \$} = \frac{D_O(j, 1958)}{D_O(j, 1970)} \cdot Y_j \Big|_{1970\ \$} \tag{5.22}$$

where $D_O(j, 1958) = 100.00$.

For the 16-group aggregate, the denominator is the sum of Oregon group deflators weighted by the 1970 importance factors:

$$D_O(\alpha, 1970) = \sum_{\substack{n=22 \\ n \neq 24, 26}}^{39} D_O(n, 1970) \cdot A_n(1970) \tag{5.23}$$

6. THE COMMERCIAL SECTOR

6.1 Historical Electrical Energy Consumption

6.1.1 Definition of Commercial Sector

The Commercial Sector is a large and amorphous category of electricity use. It consists of all electrical energy consumption which is not explicitly considered in the other categories of industrial, residential, and transportation. Thus it includes electricity use by such diverse consumers as

wholesale and retail trade establishments
finance, insurance, real estate, law offices
hotels and restaurants
entertainment and recreational facilities
construction and repair services
communication facilities
electric, gas, petroleum service facilities
government buildings
sanitary and other government service facilities
education, fine arts, and religious institutions
transportation service facilities (i.e., non-motive)
miscellaneous

The activities related to energy consumption in this sector can be categorized as household, business, and government services; these activities are taken into account in the services model of the Economic Component of OSSIM.

Energy consumption in the Commercial Sector cannot be analyzed at the end use level because of data limitations. For example, there are no appliance saturation histories available and there are only very limited data on commercial appliance electricity consumption. Even if such data were available, the Commercial Sector is such a diverse one that the number of sub-sectors and appliances for consideration would be enormous. Thus the model to be described is highly aggregated in that it does not explicitly consider electricity end uses.

6.1.2 Determination of Consumption

Other chapters demonstrate that it is possible to analyze the consumption of the Industrial and Residential Sectors in a detailed manner by the use of data bases other than those provided by electric utilities. However, there are no data sources for the Commercial Sector other than those originating with the utilities; and examination of EEI's classification system (Section 4.2) reveals that there is no single category which unambiguously corresponds to what has here been defined as commercial consumption.

The historical energy consumption of the Commercial Sector is obtained in a manner similar in principle to that employed by Mooz and Mow (29) and consists of subtracting the consumption listed in all precisely defined categories from the total consumption by ultimate consumers as given by EEI. This method is consistent with the definition of the Services Sector of OSSIM. In other words:

$$\begin{bmatrix} \text{Commercial} \\ \text{Consumption} \end{bmatrix} = \begin{bmatrix} \text{Total} \\ \text{Consumption} \\ \text{by Ultimate} \\ \text{Consumers} \end{bmatrix} - \begin{bmatrix} \text{Residential} \\ \text{Consumption} \end{bmatrix} - \begin{bmatrix} \text{Industrial} \\ \text{Consumption} \end{bmatrix} - \begin{bmatrix} \text{Transportation} \\ \text{Consumption} \end{bmatrix} \quad (6.1)$$

Table 6.1 presents the historical consumption data of EEI and that of the Bureau of the Census, and expression 6.1 is rewritten in terms of the column numbers of that table:

$$(11) = (1) - (2) - (8 + 9 + 10) - (4 + 6) \qquad (6.2)$$

Note that industrial consumption is the sum of consumption in mining, agriculture, and manufacturing, which is the same definition of industry as used in OSSIM. Mining, however, is not represented by a dynamic model, and agricultural consumption is assumed to be entirely due to irrigation. Note also that transportation consumption consists of the EEI categories "Street and Highway Lighting" and "Railroads." Another way of viewing expression 6.2 is that the resulting consumption of the Commercial Sector turns out to be approximately the sum of the non-industrial portion of SL&P plus LL&P, the non-irrigation portion of "Rural"; "Other Public Authority"; and "Interdepartmental." That this must indeed be the case which was brought out in the discussion of the individual categories of EEI in section 4.2.

Table 6.1. Determination of commercial consumption. (Units are 10^6 KWH except as indicated) Source: Reference 12 unless otherwise noted.

Year	(1) Total Sales	SL&P	(2) Residential	LL&P	(3) Rural	(4) Street & Highway Lighting	(5) Public Authorities	(6) Railroads	Number of Railroad Customers	(7) Interdepartmental
1950	5904	1100	1998	2565	71	36	102	28	1	2
1951	6603	2125	2232	2047	81	38	54	23	1	2
1952	6988	2259	2513	1993	96	41	64	20	1	2
1953	7561	2479	2774	2084	98	44	63	17	1	2
1954	8145	2768	3062	2050	112	48	69	14	1	2
1955	9170	3178	3441	2265	143	52	76	10	1	5
1956	10211	3526	3815	2563	158	60	78	7	1	4
1957	10747	3648	4077	2687	171	71	80	7	1	6
1958	11334	3763	4200	3027	172	76	86	4	1	6
1959	13002	4149	4639	3837	196	79	96	1	1	5
1960	13728	4233	4965	4245	82	85	113	0	0	5
1961	14598	5083	5456	3816	NA	95	136	0	0	12
1962	15414	2675	5819	6674	NA	97	136	0	0	13
1963	16075	2955	6152	6703	NA	105	135	0	0	15
1964	17930	3205	6667	7801	NA	107	133	0	0	17
1965	19332	3519	6917	8633	NA	111	135	0	0	17
1966	20818	4038	7311	9190	NA	117	142	0	0	20
1967	21602	4334	7743	9242	NA	116	149	0	0	18
1968	23251	4568	8215	10176	NA	121	154	0	0	17
1969	25067	5002	9042	10698	NA	129	176	0	0	20
1970	26125	5406	9389	10995	NA	135	177	0	0	23
1971	27699	5807	10353	11218	NA	141	156	0	0	24
1972	28368	6384	10913	10728	NA	149	168	0	0	26
1973	30244	6805	11343	11767	NA	167	132	0	0	30

Table 6.1. Continued

Year	(8) Mining[b]	(9) Agriculture[c]	(10) Manufacturing[c]	(11) Commercial	(12) Commercial, % of total	(13) Number of Employees[e]	(14) Ue_c (10^3KWH/ Employee)
1950	28a	20.0	3,277	517	8.8	371,046	1.393
1951	27a	27.0	NA	--	--	377,718a	--
1952	26a	32.5	NA	--	--	384,390a	--
1953	25a	33.8	NA	--	--	391,062a	--
1954	24	64.3	3,486	1447	17.8	397,734a	3.638
1955	23a	77.4	4,796	771	8.4	404,406a	1.907
1956	22a	92.4	5,091	1124	11.0	411,078a	2.734
1957	21a	93.9	5,053	1424	13.3	417,750a	3.409
1958	20	92.7	4,358	2583	22.8	424,422a	6.086
1959	20.4a	99.8	5,569	2594	20.0	431,094a	6.017
1960	20.8a	106.5	5,650	2901	21.1	437,769	6.627
1961	21.2a	122.7	5,820	3083	21.1	450,779a	6.839
1962	21.6a	151.7	6,220	3105	20.1	463,789a	6.670
1963	22	155.0	5,550	4091	25.5	476,799a	8.580
1964	20.9a	189.0	6,598	4348	24.3	489,809a	8.877
1965	19.9a	203.9	7,590	4490	23.2	502,819a	8.930
1966	18.8a	255.0	8,094	5022	24.1	515,829a	9.736
1967	17.7	290.5	NA	--	--	528,839a	--
1968	16.6a	321.7	NA	--	--	541,849a	--
1969	15.6a	324.7	NA	--	--	554,859a	--
1970	14.5a	393.4	10,419d	5774	22.1	567,866	10.168
1971		379.9	NA	--	--	--	--
1972		459.7	NA	--	--	--	--
1973			NA	--	--	--	--

NA: not applicable or not available
a: by linear interpolation or extrapolation
b: source: Reference 58
c: data from Chapter 5
d: from Table 5.15
e: source: Reference 59

The historical consumption of the Commercial Sector is given in column 11 and in column 12 as a percent of the total consumption reported by EEI. Note that the figures of column 11 are considerably different than those reported under SL&P, which are usually equated to commercial consumption.

6.2 Methodology

6.2.1 Economic Activity : Service Employees

Economic activity in the Commercial Sector is simulated in the services model of the Economic Component. Among its outputs are indicators of dollar value added by services, gross output in dollars, and the number of people employed in household, business, and government services.

Unfortunately there is little historical data on value added or gross output of what has here been defined as services. However the number of employees in services is a reasonable surrogate for economic activity, and is available from the Bureau of the Census (59) for the years 1950, 1960, and 1970. Data for intercensal years is kept by the Oregon Employment Division, but frequent changes in the categories of employees included render the figures inconsistent with those of the Census; the trends, however, are comparable. The numbers obtained, displayed as column 13 of Table 6.1, were determined by subtracting the people employed in non-service activities from the total number of employed persons. That is, the historical employment in the Commercial Sector was calculated as follows:

$$\begin{bmatrix}\text{Services}\\ \text{Employment}\end{bmatrix} = \begin{bmatrix}\text{Total}\\ \text{Employment}\end{bmatrix} - \begin{bmatrix}\text{Manufacturing}\\ \text{Employment}\end{bmatrix} - \begin{bmatrix}\text{Number of}\\ \text{Employees in}\\ \text{Agriculture,}\\ \text{Forestry,}\\ \text{Fishing}\end{bmatrix} - \begin{bmatrix}\text{Mining}\\ \text{Employment}\end{bmatrix} \quad (6.3)$$

Future employment in services, manufacturing, and agriculture (including forestry and fisheries) is determined in the Economic Component; mining is not included in OSSIM.

6.2.2 Electrical Energy Intensiveness

Energy intensiveness has been described in earlier chapters as a quantity characteristic of trends in energy consumption per unit of economic activity in various socio-economic sectors. The electrical energy intensiveness of the Commercial Sector is therefore defined as the energy consumed per person employed in commercial activities. Historical intensiveness, given in column 14 of Table 6.1 and in Figure 6.1, was calculated by means of the following expression for each year:

$$\underset{\frac{\text{KWH}}{\text{employee}}/\text{yr}}{\begin{matrix}\text{Electrical Energy}\\ \text{Intensiveness}\end{matrix}} = \underset{\frac{\text{KWH}}{\text{yr}}}{\begin{matrix}\text{Electrical Energy}\\ \text{Consumed}\end{matrix}} \div \begin{matrix}\text{Number of}\\ \text{Services Employees}\end{matrix} \quad (6.4)$$

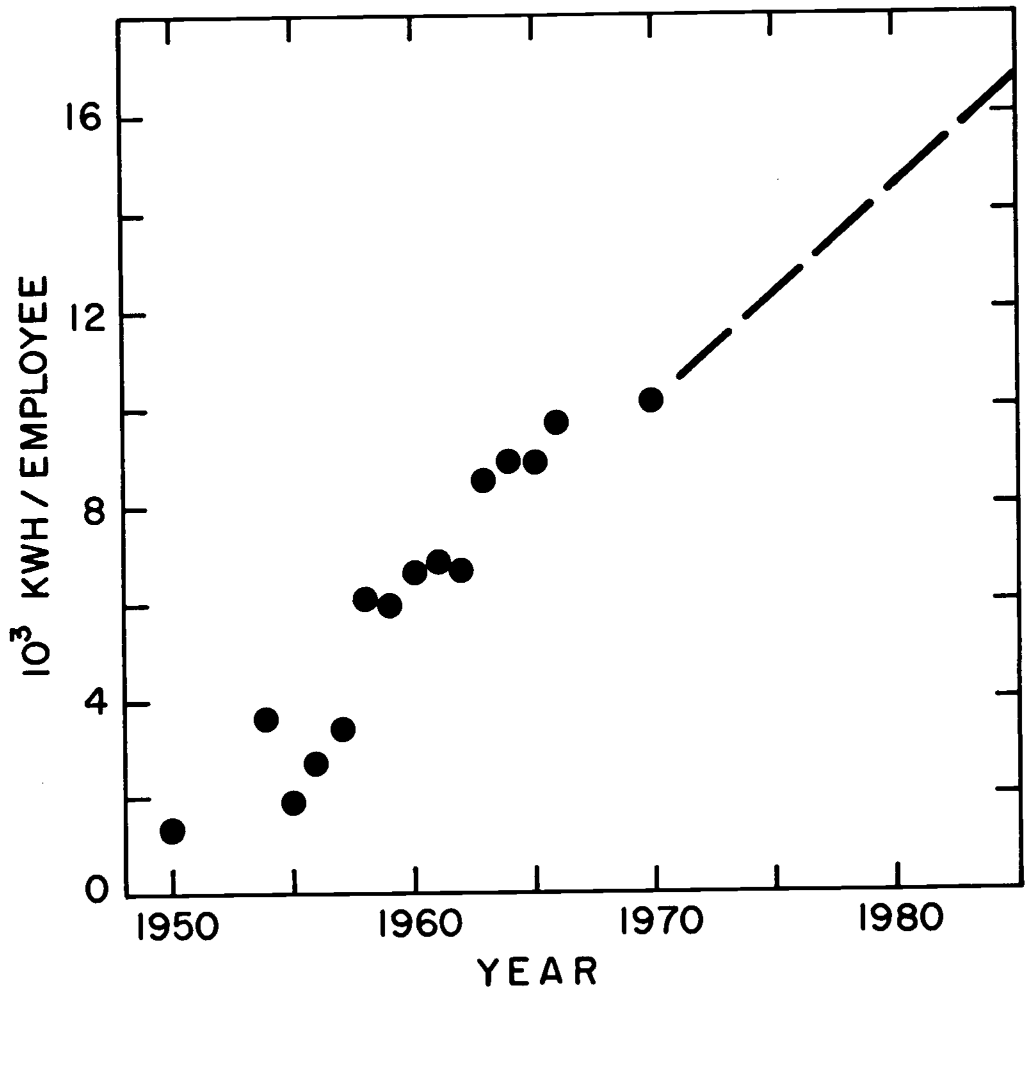

Figure 6.1. Electrical energy intensiveness, Commercial Sector.

The numerator is the historical energy consumption of the Commercial Sector, column 11 of Table 6.1., while the denominator is given in column 13.

Energy demand is given as the product of intensiveness and economic activity:

$$\text{Electrical Energy Demand [KWH/yr]} = \text{Electrical Energy Intensiveness [KWH/employee/yr]} \times \text{Number of Employees} \quad (6.5)$$

or, as given in Table 4.5:

$$De_c = Ue_c(p_c, t) \cdot Y_c(p_c, t) \quad (6.6)$$

It is assumed that the prices of electricity and fossil fuels do not <u>directly</u> affect the number of persons employed in the service industries. Thus Y_c is not a function of price and

$$Y_c(p_c, t) = Y_c(t) \quad (6.7)$$

Expression 6.6 is therefore written

$$De_c = Ue_c(p_c, t) \cdot Y_c(t) \quad (6.8)$$

and, recalling the assumptions of Section 4.3,

$$De_c = [Ue_{o_c}(t) \cdot Fe(p_c)] \cdot Y_c(t) \quad (6.9)$$

which is nearly identical to expression 4.8.

Examination of the relative changes in the factors of expression 6.8 enables one to determine whether changes in energy demand are due primarily to changing activity in the Commercial Sector or to changing use of electricity within the sector. It can be noted from Table 6.1 that electrical energy intensiveness has historically experienced a considerably more rapid average annual rate of increase than economic activity.

6.2.3 Alternate Methods

Energy consumption in the Commercial Sector has been treated somewhat differently by other analysts. A brief review of their methods provides additional insight into the reasons for the use of the present methodology.

Schurr (46) assumes that the "Small Light and Power" category of EEI is equivalent to commercial consumption. Two historical correlations are then derived and used to determine future commercial consumption from information about the Residential Sector:

$$\text{a)}\quad \frac{\text{number of commercial consumers}}{\text{number of households}} = \text{constant}$$

$$\text{b)}\quad \frac{\text{average consumption per commercial consumer}}{\text{average consumption per household}} = \text{constant}$$

In general, the use of constant historical correlations such as these is avoided in this thesis. One reason is that the factors involved may vary widely depending on the particular scenario under consideration, rendering assumptions about constant relationships invalid. For example, there is no reason to expect relationship (a) to hold indefinitely in view of the fact that the Commercial Sector is a particularly rapidly growing sector of the economy. Furthermore, examination of national data since 1960 reveals that relationship (b) has not held; electricity consumption per commercial consumer rose faster than consumption per household during this period. Even prior to 1960, assertion (b) was considerably weaker than assertion (a). Another reason for the avoidance of historical correlations is that wherever possible effort has been made to directly simulate the factors involved. For example, the denominator of (b) is a primary output of the Residential Sector of the Energy Component, and the numerator is comparable to commercial energy intensiveness.

Many analysts (38, 46, 62, 63) use the average consumption per commercial electric utility customer as a parameter subject to projection. It would have been tempting to use this quantity in place of energy consumption per employee if the number of commercial customers were available in OSSIM. However, on an intuitive basis, the average consumption per commercial utility customer is a number with a relatively large standard deviation. This is so because of the very great diversity of the Commercial Sector--it includes everything from small neighborhood shops to the largest office buildings. It would seem that the standard deviation of the average consumption per commercial employee would be somewhat smaller, although the author has not tested this hypothesis.

Mooz and Mow (29) define electrical energy intensiveness of the Commercial Sector as energy consumed per dollar of gross state product, the latter quantity being used as a surrogate for the gross product attributable to commercial enterprise. As the authors point out, this substitution is satisfactory only if the ratio between the commercial sector gross product and the total gross state product is constant. To avoid having to make this assumption, use of the Oregon GSP has been avoided.

Finally, Fisher (15) holds that the energy requirements of commerce grow at a rate equal to the growth rate of employment in commerce provided the energy content per unit output of goods and services, or per person employed, remains relatively unchanged. To account for changes in this energy content, he used a constant "per-working-capita" growth in energy content of 0.9% per year. Fisher's technique corresponds more closely to that used in the present work, except for the fact that the electrical energy intensiveness of commercial activity in Oregon has experienced a significantly more rapid average annual growth rate, as indicated in Figure 6.1.

6.3 Determinants of Intensiveness

The combination of rapidly increasing electrical energy intensiveness and expanding economic activity has resulted in the Commercial Sector becoming a much more important consumer of electricity in Oregon since 1950. Table 6.1 indicates that commercial consumption has increased from less than 9% of the total in 1950 to over 24% in 1966. That the Commercial Sector has been the most rapidly growing sector with respect to electricity consumption is further emphasized in Figure 6.2 and Table 6.2.

Table 6.2. Average annual growth rates of Oregon electrical energy consumption (percent). Source: Table 6.1.

	Industrial	Commercial	Residential	Total
1950-1960	5.7	18.8	9.5	8.8
1960-1966	6.4	9.6	6.7	7.2

Table 6.1 also indicates that between 1960 and 1966 Commercial Sector economic activity increased at an average rate of 2.8 percent per year while electrical energy intensiveness increased with an average annual growth rate of 6.6 percent. Thus whether these observations indicate that this sector is destined to become the most important electricity consumer in Oregon depends considerably upon future electrical energy intensiveness of the sector. Consideration

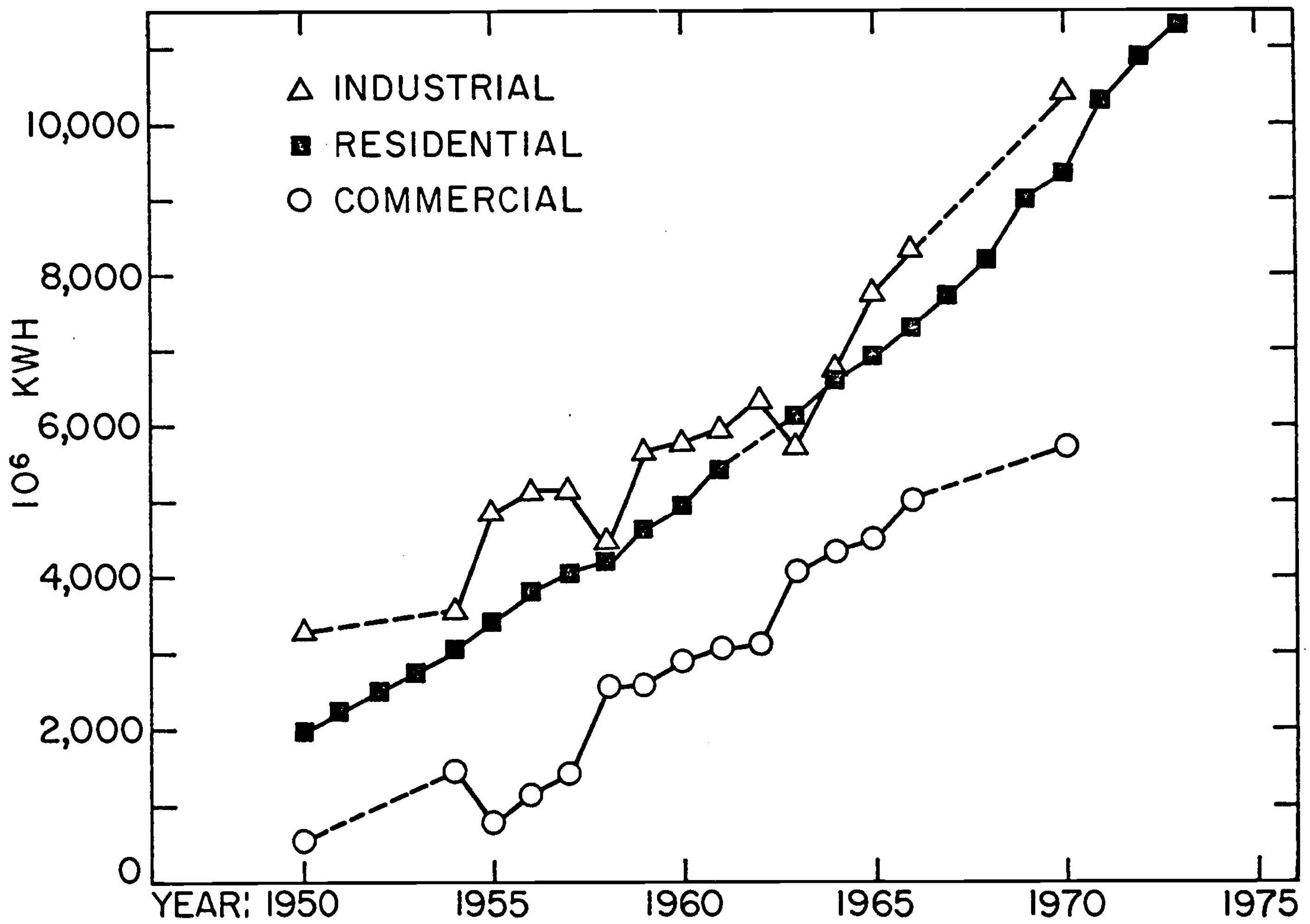

Figure 6.2. Oregon electricity consumption by major sectors.

of the various determinants of intensiveness in the service industries is therefore necessary.

6.3.1 Patterns of Energy Consumption

The use of a single characteristic--electrical energy intensiveness--to represent consumption trends in an entire socio-economic sector is admittedly not as intuitively satisfying as the greater detail undertaken for the Industrial and Residential Sectors. Unfortunately the heterogeneity of the Commercial Sector renders any kind of sub-sector or use-by-use analysis a long and laborious task; furthermore, adequate data are not available.

The only study of electricity end-use in the Commercial Sector was performed by Stanford Research Institute for the United States as a whole for the year 1968. Pertinent data are summarized in Table 6.3. It must be recognized that the numbers for the State of Oregon are likely to be somewhat different, in keeping with the pattern of higher electrification in the Pacific Northwest vs. the nation as a whole.

The first category of end uses includes those that would not otherwise be possible in the absence of electricity. Except for lighting, these end uses involve the utilization of electric motors to perform various tasks. The generation of heat is common to the end uses in the second category, where the application of electricity is relatively small. By far the major consumers of electricity in the Commercial Sector are currently end uses in which there is essentially no competition from other forms of energy. The phenomena governing changes in electrical energy intensiveness have been considered to be appliance saturation, average annual energy consumption of individual appliances, and the substitution of appliances using one energy form for those that utilize another. These are also listed in Table 6.3 following the end use to which they are particularly applicable.

Saturation. Appliance saturation in the Commercial Sector refers only to appliances that most establishments could have but which are not integral parts of their product or service. Of the end uses given in the table, this definition of saturation applies primarily to air conditioning and certain classes of mechanical drive equipment.

Consumption. The average annual consumption of essentially all appliances may change in the long run.

Interfuel Substitution. This process is of particular importance in the latter three end uses due to the relatively low penetration of electricity.

6.3.2 Underlying Causes of Changing Energy Intensiveness

Needs for household, business, and government services are determined by the magnitude and activity of the Industrial and Residential Sectors. Thus the underlying factors determining energy use

Table 6.3. Patterns of energy use in the Commercial Sector in the United States, 1968. Source: References 15, 50.

Major Commercial Sector End Uses	Energy Form Utilized to Satisfy Each End Use, Percent				Percent of Total Energy Consumed in Commercial Sector	Percent of Total Electrical Energy Consumed in Commercial Sector	Prime Phenomena Governing Changes in Energy Intensiveness
	Electricity	Gas	Petrol.	Coal			
Electrified:							
Lighting, Mechanical Drives	100				5	35	consumption and saturation
Refrigeration	100				4	23	consumption
Air Conditioning	80	20			7	34	consumption and saturation
Partially Electrified:							
Water Heating	17	83			7	8	interfuel substitution
Cooking	6	94			2	<1	interfuel substitution
Space Heating	<1	29	57	13	61	<1	interfuel substitution
Unelectrified:							
Feedstock	0	0	100	0	14		

in the Commercial Sector are the same as those which are important in the "driving" sectors, namely population, income, economic activity, technological change, and pollution control. However, there are two additional factors operable in the service industries which tend to raise energy intensiveness, and a third which may or may not raise intensiveness:

1. Since most electricity uses have the common characteristic of contributing to personal comfort and convenience, competition forces service industries to continually use more attractive lighting, space conditioning, and modern, automated office, production, and storage facilities.
2. The complexity of many services, communication, and government expands disproportionately as the number of individuals being served grows (21). Increased complexity often means decreased energy efficiency and thus increased energy consumption.
3. Commercial businesses have replaced some functions formerly done in the hone; on the other hand, some functions formerly performed by commercial establishments have shifted back to the home (32).

Lack of data hinders quantification of these effects. These general statements, however, and the patterns of energy use presented in Table 6.3 support the assertion that the electrical energy intensiveness of the Commercial Sector will continue to increase.

6.4 Future Electrical Energy Intensiveness

The demand for electrical energy in the Commercial Sector was given earlier as

$$De_c = Ue_c(p_c, t) \cdot Y_c(t) \tag{6.8}$$

where

$$Ue_c(p_c, t) = Ue_{o_c}(t) \cdot Fe(p_c) \tag{4.2}$$

$Ue_c(p_c, t)$ is the observed electrical energy intensiveness, given over the recent past in Figure 6.1; $Ue_{o_c}(t)$ is the base electrical energy intensiveness; and $Fe(p_c)$ simulates the effects of energy price changes.

Before future electrical energy intensiveness can be estimated, it is necessary, as before, to investigate the validity of the approximations

$$Ue(p, t) = Ue_o(t) \cdot Fe(p) \doteq Ue_o(t) \cdot K = Ue_{eq}(t) \tag{4.30}$$

or

$$Ue(p, t) = Ue_o(t) \cdot Fe(p) \doteq Ue_o(t) \tag{4.32}$$

Figure 6.3 illustrates the time series of average Commercial Sector energy prices over the recent past, calculated in Reference 74. Note that between 1960 and 1970 the oil price decreased 10%, the gas price decreased over 70%, and the electricity price decreased probably close to 50% relative to other prices. Meanwhile, Figure 6.1 shows that a significant increase in electrical energy intensiveness occurred over the same period. Unfortunately no study of price elasticities of intensiveness, which may reflect the extent to which these trends are related, has been performed for Oregon. However, literature figures for price elasticity of demand can be examined in their place. This can be done because energy price changes have probably had no direct effect on the number of employees in the Commercial Sector. Rather, price changes--if they have had any influence at all--affected the intensiveness of the sector, and the effects appear as a change in observed demand. Thus it can be assumed that, for the Commercial Sector, price elasticity of demand is the same as price elasticity of intensiveness.

Various analysts disagree on the magnitude of the price elasticity of demand for the Commercial Sector, as indicated in Table 6.4. If there is any consensus at all, it is that if energy prices rise appreciably there will likely be some response. This statement seems applicable to Oregon since the price of electricity to commercial consumers is at present significantly less than the national average (74).

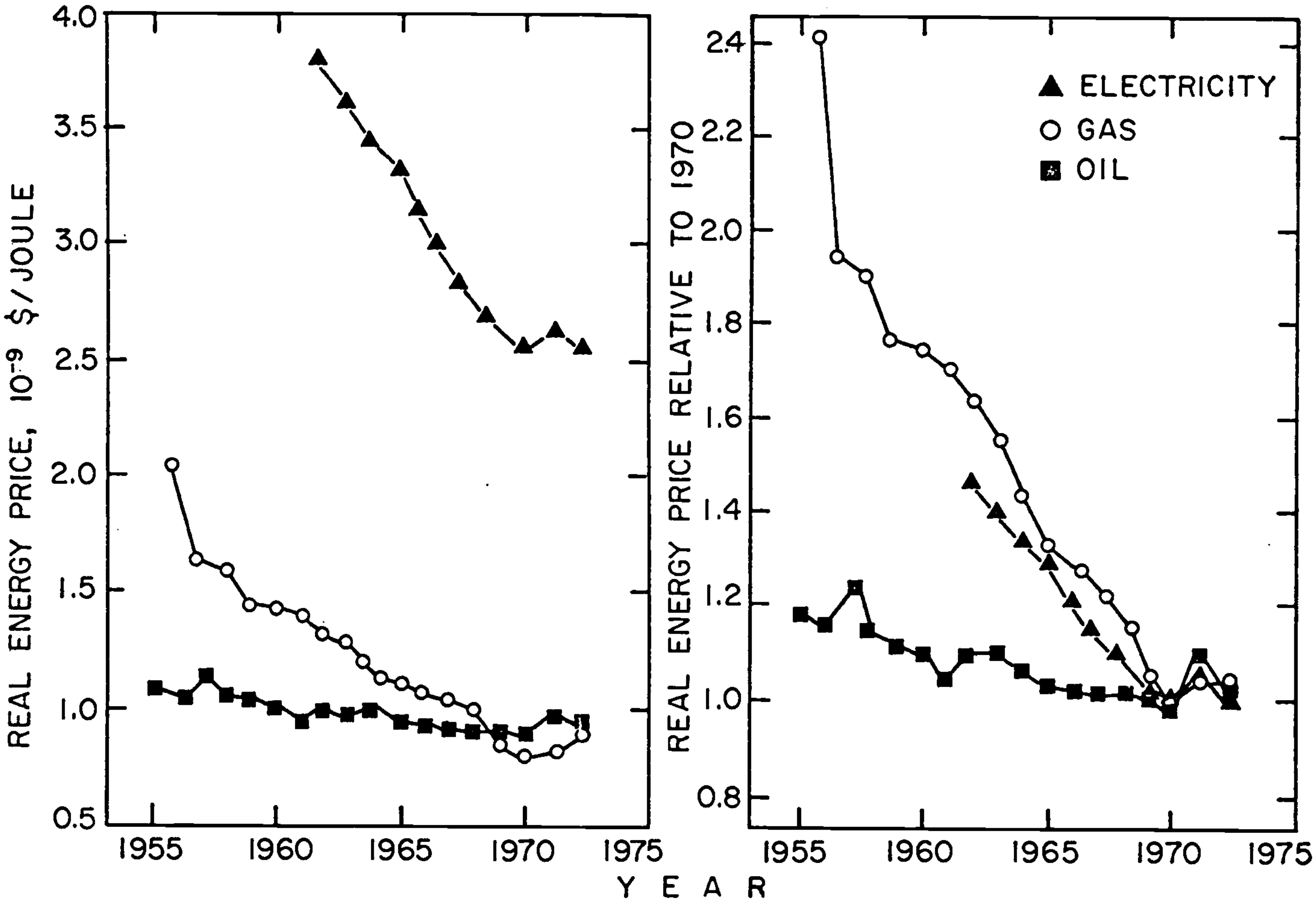

Figure 6.3. Energy prices to Commercial Sector, Oregon.

Table 6.4. Price elasticity of intensiveness - Commercial Sector.

Source	Elasticity	Time Response	Geographic Area of Applicability
1. Federal Power Commission (68)	"...inelastic except for space heating."	--	U.S.
2. National Academy of Engineering (32)	"...extremely low."	--	U.S.
3. Chapman, Tyrell, Mount (11)	$\xi_e = -1.5$ $\xi_g = +0.15$	first year: 11%; 7 years for 50% of total response	U.S.
4. Stanford Research Institute (49)	"...completely inelastic at current prices."	--	California
5. Rand (29)	$\xi_e = -1.11$ $\xi_g = +0.27$	all appliances assumed to have a 10 year life	California

The historical increase in electrical energy intensiveness displayed in Figure 6.1 has, then, been due to technological change, commercial competition, and--to some unquantified extent--favorable energy price changes. However, Figure 6.3 indicates that 1970 marked the end of historical trends in energy prices. It is assumed, therefore, that after 1970 electrical energy intensiveness tended towards equilibrium with energy price changes. That is,

$$Ue_c(p_c, t) = Ue_{o_c}(t) \cdot Fe(p_c) \doteq Ue_{o_c}(t) \cdot K = Ue_{c_{eq}}(t) \qquad (6.10)$$

The underlying price-independent forces behind the steady increase in electrical energy intensiveness were posed in Section 6.3.2, and it is assumed that these forces will continue to be important in the future. Thus, in view of expression 6.10, a first approximation to future equilibrium energy intensiveness, $Ue_{c_{eq}}$, is given by an extrapolation of recent historical trends in Ue_c, as in Figure 6.1. The extrapolation can be extended well into the future because of the relatively low degree of electrification of the Commercial Sector. There is, of course, no reason to expect future electrical energy intensiveness to match the extrapolation. Howsoever Ue_c deviates from $Ue_{c_{eq}}$ or even tends to some saturation depends on future energy prices and availability. This is simulated by application of $Fe(p_c)$ to the extended curve of Figure 6.1, as in Section 4.5:

$$Ue_c(p_c, t) = Ue_{c_{eq}}(t) \cdot Fe(p_c) \tag{6.11}$$

Thus, should energy prices increase to a level such that applicable price elasticities are non-zero, two somewhat different effects are modeled:

a) a relatively short-run effect, corresponding to conservation in the use of appliances serving all six end uses and modification of the rate of increase of saturation of air conditioners and electric drive equipment; and

b) a longer-run effect, corresponding to interfuel substitution in the partially-electrified end uses.

In other words, the first two response modes given in Table 4.7, saturation and conservation, are treated as one because the response times are comparable and because of limited data. The third response mode, interfuel substitution, is treated separately. Finally, the long run effect on economic activity in the Commercial Sector is considered to be indirect and is handled through the various feedback paths of OSSIM rather than explicitly in the Energy Component. For example, if high energy prices or shortfalls cause a reduction in growth of industrial activity, lower employment in that sector follows, resulting in fewer households, lower demand for commercial services, and thus lesser employment in services.

7. THE TRANSPORTATION SECTOR

The historical consumption of electrical energy by transportation-related activities includes only that given under the "Street and Highway Lighting" and "Railroads and Railways" categories of EEI. The former category covers traffic control systems and all illuminated roads and highways, both municipal and rural; consumption by the latter category has been zero since 1960. These data were presented in Table 6.1.

Future electricity consumption of the Transportation Sector, however, includes whatever means of electrified transport may be developed. Various technological scenarios may be envisioned, such as electrified mass transit and electric automobiles rechargeable in individual residences. These possibilities are not treated in the present work, but are left as future scenarios to be analyzed in conjunction with the Transportation Component of OSSIM.

Electricity consumed by street and highway lighting has averaged merely about one-half of one percent of total Oregon consumption over the last 20 years. Figure 7.1 indicates, however, that consumption has increased faster than total street and highway mileage. The electrical energy intensiveness of the Transportation Sector (assumed, for the present, to consist only of street and highway lighting) is therefore defined as the energy consumed per mile of municipal and

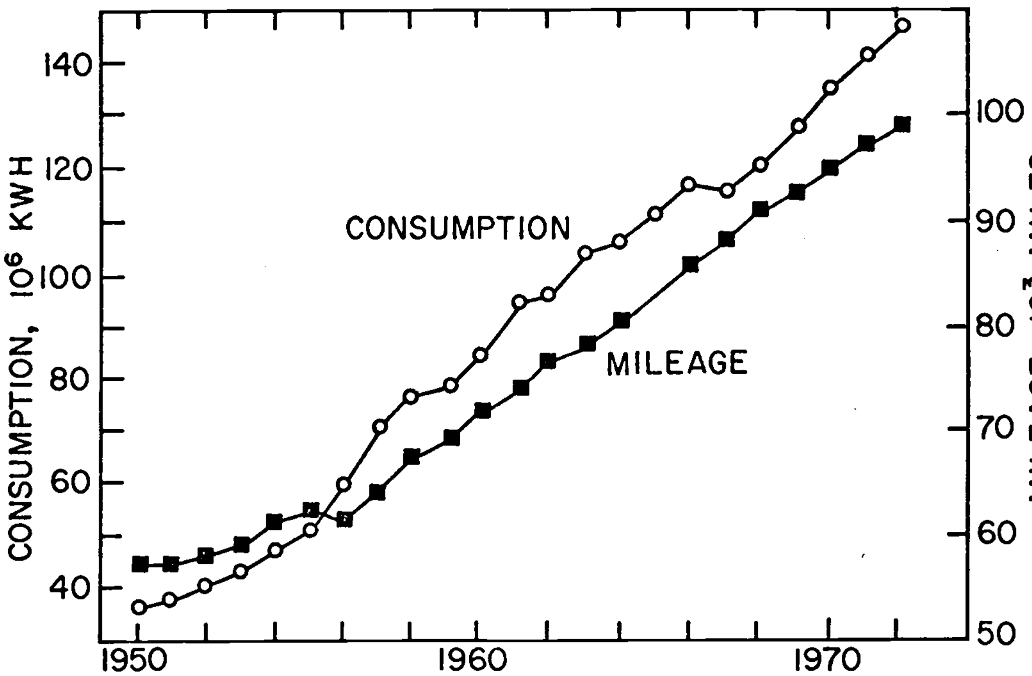

Figure 7.1. Electricity consumption for street and highway lighting; total mileage.

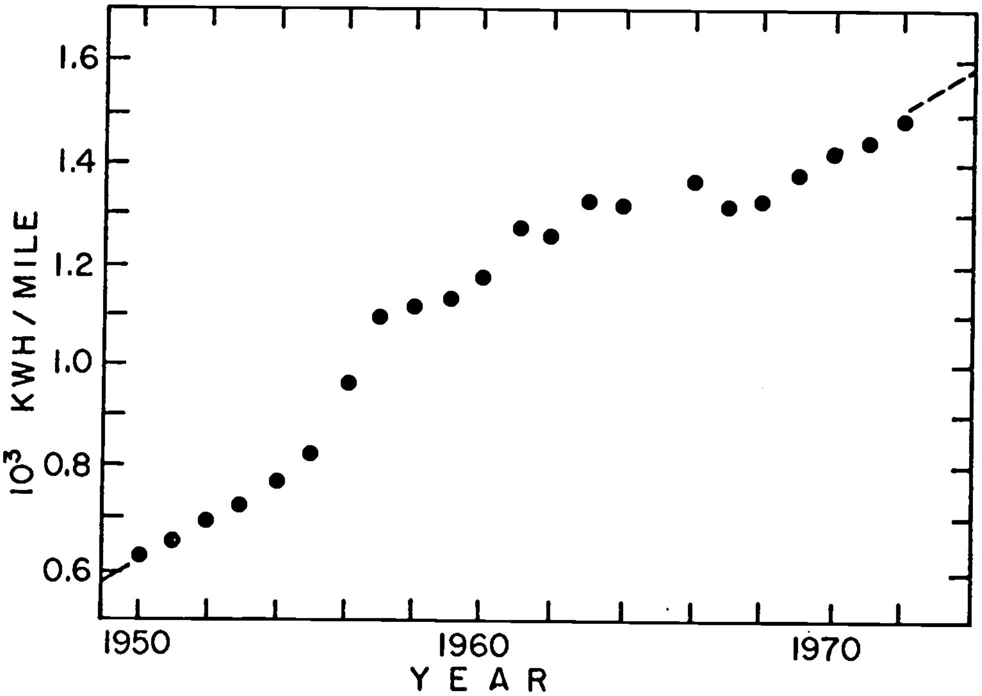

Figure 7.2. Electrical energy intensiveness, Transportation Sector.

rural road. It has been calculated in Table 7.1 for each year by means of the expression

$$\underset{\left[\frac{KWH}{mile}/yr\right]}{\text{Electrical Energy Intensiveness}} = \underset{\left[\frac{KWH}{yr}\right]}{\text{Electrical Energy Consumed}} \div \text{Total Street and Highway Mileage} \qquad (7.1)$$

Energy demand is given in the usual manner as the product of intensiveness and total mileage, where the latter factor has been taken as a surrogate for economic activity. That is,

$$\underset{[KWH/yr]}{\text{Electrical Energy Demand}} = \underset{[KWH/mile/yr]}{\text{Electrical Energy Intensiveness}} \times \text{Total Number of Miles} \qquad (7.2)$$

or, analogous to the expressions of Table 4.5,

$$De_{tr} = Ue_{tr}(p_{tr}, t) \cdot Y_{tr}(p_{tr}, t) \qquad (7.3)$$

Since electricity prices do not affect the number of miles of streets and highways

$$De_{tr} = Ue_{tr}(p_{tr}, t) \cdot Y_{tr}(t) \qquad (7.4)$$

Ue_{tr} has steadily increased, as illustrated in Figure 7.2. The percent of total street and highway mileage which is municipal would seem to play a role in such an increase, but this is a slowly varying number which has averaged about 7% over the past 20 years. Policies which probably account for the increase include enhancement of traffic

Table 7.1. Transportation Sector electrical energy consumption. Source: References 12 and 64.

Year	Consumption by Street and Highway Lighting, 10^6 KWH	Municipal Street Mileage	Total Street and Highway Mileage (Municipal Plus Rural)	Electrical Energy Intensiveness, 10^3 KWH/mile/yr	Municipal Mileage as a % of Total Street and Highway Mileage
1950	36	4,034	57,545	0.626	7.01
1951	38	4,996	57,474	0.661	8.69
1952	41	4,868	58,301	0.703	8.35
1953	44	4,726	59,268	0.742	7.97
1954	48	4,815	61,205	0.784	7.87
1955	52	4,937	62,513	0.832	7.90
1956	60	5,044	62,082	0.966	8.12
1957	71	5,143	64,435	1.102	7.98
1958	76	5,218	67,687	1.123	7.71
1959	79	5,362	69,627	1.135	7.70
1960	85	5,529	72,053	1.180	7.67
1961	95	5,638	74,617	1.273	7.56
1962	97	5,759	76,943	1.261	7.48
1963	105	5,764	78,678	1.335	7.33
1964	107	5,440	80,810	1.324	6.73
1965	111	NA	NA	--	--
1966	117	5,709	85,590	1.367	6.67
1967	116	5,843	88,329	1.313	6.62
1968	121	6,034	90,810	1.332	6.64
1969	129	6,150	93,139	1.385	6.60
1970	135	6,249	95,063	1.420	6.57
1971	141	6,348	97,453	1.447	6.51
1972	149	6,567	99,531	1.497	6.60

NA: Not available.

safety, lighting as a deterrent to crime, and increasing illumination of major non-municipal routes.

As described in Section 4.3, expression 7.4 can be written

$$De_{tr} = [Ue_{o_{tr}}(t) \cdot Fe(p_{tr})] \cdot Y_{tr}(t) \tag{7.5}$$

No investigations of effects of past electricity price changes on street and highway lighting have been made. However it is unlikely that the response has been appreciable. Furthermore, consumption by street and highway lighting is not readily subject to interfuel substitution. It is assumed, therefore, that $Fe(p_{tr})$ has been equal to unity over the recent past and that expression 4.32 holds:

$$Ue_{tr}(p_{tr}, t) = Ue_{o_{tr}}(t) \cdot Fe(p_{tr}) = Ue_{o_{tr}}(t) \tag{7.6}$$

Furthermore, if the factors underlying the steady increase in intensiveness are assumed to continue to be applicable in the future, a first approximation to future base energy intensiveness, $Ue_{o_{tr}}$, is an extrapolation of recent trends in Ue_{tr}, shown in Figure 7.2. Future price-dependent intensiveness, responding primarily by means of conservation, is then given as

$$Ue_{tr}(p_{tr}, t) = Ue_{o_{tr}}(t) \cdot Fe(p_{tr}) \tag{7.7}$$

8. THE RESIDENTIAL SECTOR

8.1 Historical Electrical Energy Consumption

Energy consumed by the Residential Sector is taken to consist solely of electricity utilized for domestic purposes, and was reported in the column numbered 2 of Table 6.1. It is seen that residential consumption in Oregon has averaged slightly greater than one-third of total electricity consumption in the state; about one-quarter of the electrical energy utilized in the United States as a whole is consumed in residences (68).

The average number of residential electric utility customers in each year since 1955 is reported by the Edison Electric Institute (12) and has been used with the consumption data of Table 6.1 to determine the average energy consumed per domestic customer per year. The results, displayed in Figure 8.1, indicate a steady increase in per-customer electricity use until 1972. Average residential consumption in Oregon was about double that of the nation as a whole in 1970, but the difference has been even greater in the past. In 1950, for example, the average residential consumer in Oregon used 2.8 times as much electricity as the national average consumer.

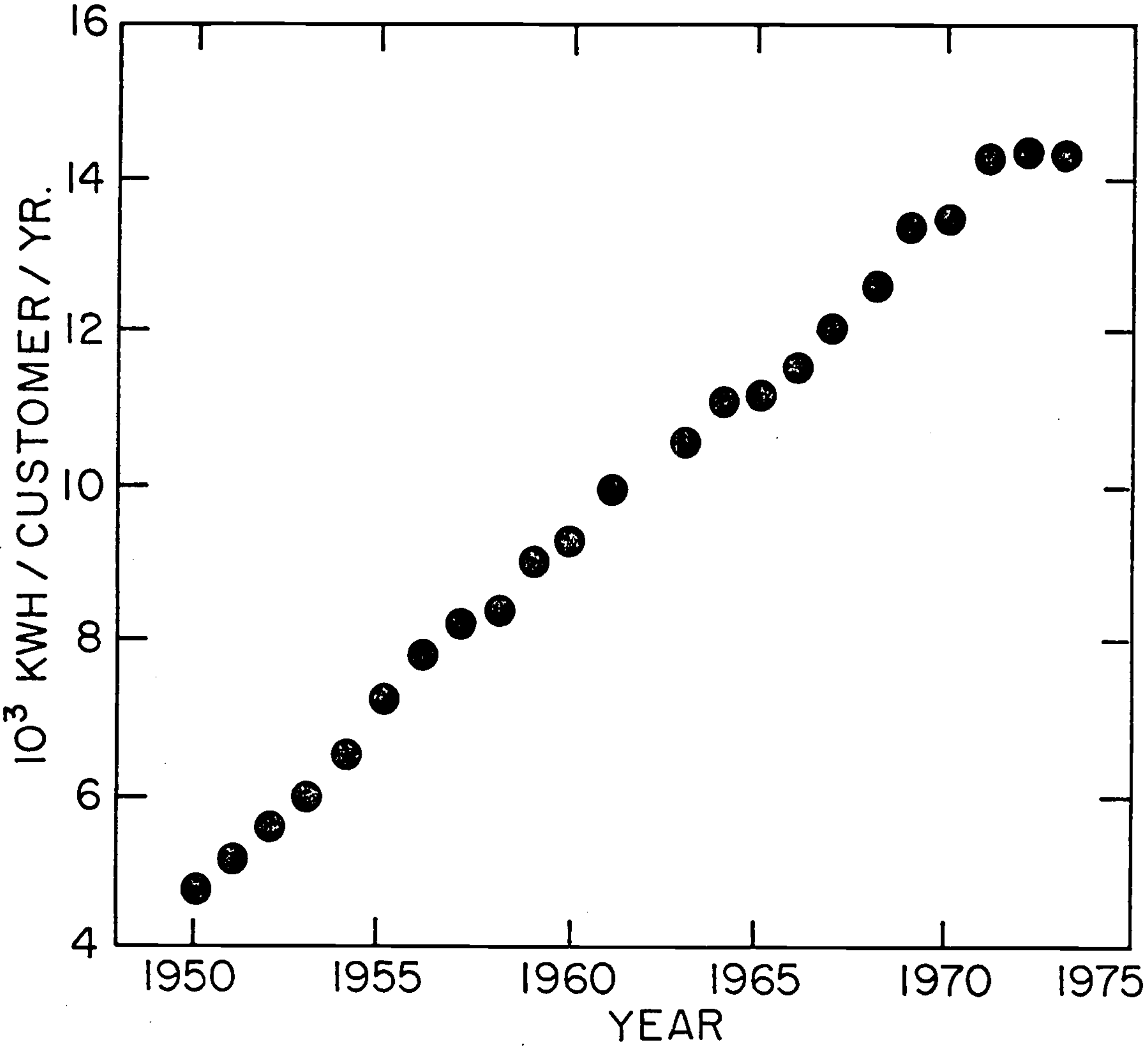

Figure 8.1. Electrical energy intensiveness, Residential Sector.

8.2 Methodology

8.2.1 Economic Activity

The number of residential electric utility customers shall be taken as a surrogate for economic activity in the Residential Sector. The bases for this variable are provided by the Demographic Component of OSSIM, which contains a detailed simulation of population characteristics, including the number of housing units as a function of income and family size. The required number of residential customers is obtained as follows:

$$\begin{bmatrix}\text{Residential}\\ \text{Sector}\\ \text{customers}\end{bmatrix}_t = \begin{bmatrix}\text{Demographic}\\ \text{Component}\\ \text{housing}\\ \text{units}\end{bmatrix}_t \times \begin{bmatrix}\text{Number of occupied}\\ \text{housing units per}\\ \text{Demographic}\\ \text{Component}\\ \text{housing unit}\end{bmatrix}_{1970} \times \begin{bmatrix}\text{Number of}\\ \text{residential}\\ \text{utility customers}\\ \text{per occupied}\\ \text{housing unit}\end{bmatrix}_{1970} \quad (8.1)$$

Using data from References 12 and 56, the latter two factors were determined to be 0.9406 and 1.002, respectively.

8.2.2 Electrical Energy Intensiveness

The electrical energy intensiveness of the Residential Sector is defined as the energy consumed per year per domestic electric utility customer (or "household") and was presented in Figure 8.1 for the recent past. It can be expressed as the sum of consumption by individual household appliances in a manner comparable to the "use-by-use" approach (69):

$$Ue_r(t) = \sum_{k=1}^{13} C_k(t) \cdot S_k(t) \tag{8.2}$$

C_k is the average annual electricity consumption per household by the kth appliance in KWH/yr; S_k is the fraction of all Oregon households possessing appliance k or, alternatively, the number of appliance k's owned per household; and Ue_r is the average annual electricity consumption per household of all electric appliances in KWH/yr. The product of the consumption and saturation functions for appliance k is the base electrical energy intensiveness for that appliance:

$$Ue_{o_k}(t) = C_k(t) \cdot S_k(t) \tag{8.3}$$

It will be shown in Section 8.4 that the saturation and consumption of various appliances is price dependent and differs among appliances. Thus the function Fe is appliance-dependent, and the "observed" energy intensiveness is more correctly written

$$Ue_r(p_r, t) = \sum_{k=1}^{13} Ue_{o_k}(t) \cdot Fe_k(p_r) \tag{8.4}$$

The electrical energy demand of the Residential Sector, in KWH/yr, is given by the product of intensiveness and the number of households, as in Table 4.5:

$$De_r = Ue_r(p_r, t) \cdot Y_r(p_r, t) \tag{8.5}$$

However, since energy prices have little effect on household formation, $Y_r(p_r, t) = Y_r(t)$ and

$$De_r = Ue_r(p_r, t) \cdot Y_r(t) \tag{8.6}$$

Table 8.1 presents the pattern of use of household electricity in Oregon in 1970. It is noteworthy that the four uses subject to interfuel competition (water heating, space heating, cooking, and clothes drying) accounted for 61% of the total average domestic consumption. The national average household, meanwhile, expended only 43% of its electricity to power the same "competitive" appliances (3). The miscellaneous category consists of all smaller appliances whose individual average annual consumption is less than 100 KWH/yr and for which no saturation data is available. Consumption for this group was estimated by deduction.

8.3 Determinants of Intensiveness

The primary determinants of residential electrical energy intensiveness are appliance saturation and appliance consumption, as posed in expression 8.3. This section deals with the determination of these functions for thirteen household electric appliances, while the effects of energy price changes on saturation and consumption are considered in Section 8.4.

Table 8.1. 1970 residential electricity consumption, Oregon. Sources: bracketed.

Appliance	Average Annual Consumption KWH/yr	Appliance Saturation, % (56)	Contribution to Average Household Consumption, KWH/yr	Share of Average Household Consumption, %
1. Space Heating	10,367 (67)	29.8	3,089	22.8
2. Water Heating	4,280 (31)	83.2	3,561	26.3
3. Space Cooling - Central	3,600 (68)	3.2	115	0.8
4. Space Cooling - Room	1,389 (68)	7.8	108	0.8
5. Food Freezer	1,220 (31)	46.4	566	4.2
6. Range	1,175 (68)	86.9	1,021	7.5
7. Refrigerator	1,150 (31)	100.0	1,150	8.5
8. Clothes Dryer	1,000 (31)	61.6	616	4.5
9. Illumination	675 (44, 56)	100.0	675	5.0
10. TV - Color	500 (31)	35.7	179	1.3
11. Dishwasher	400 (31)	32.5	130	1.0
12. TV - Monochromatic	362 (68)	93.7	339	2.5
13. Miscellaneous	2,000	--	2,000	14.8
			13,549	100.0

8.3.1 Appliance Saturation

Only two sources regularly report appliance saturation data: the Census of Housing (56) at ten year intervals, and Merchandising Week (27) in its annual statistical and marketing issue. State-wide average saturations were obtained from the Census for all major appliances and saturations of seven appliances for the service area of the Portland General Electric Company were obtained from Merchandising Week. The statistics of the latter publication are based on data provided by individual electric utilities which generally come from reports of local appliance retailers. Thus this data was filtered to remove obvious inconsistencies and normalized to the state-wide average. The results are displayed in Figures 8.2 and 8.3. Saturations of refrigeration and illumination are 100% and only the consumption of the miscellaneous small appliances is considered.

The spreading acceptance of various electric appliances with time is considered to be a subset of the process of diffusion of new technology throughout society. Thus, in the absence of other influences, the increase in saturation is modeled by assuming that the fractional change in saturation in each year is proportional to the fraction of all households which do not yet possess a given appliance but which could ultimately possess it. In other words,

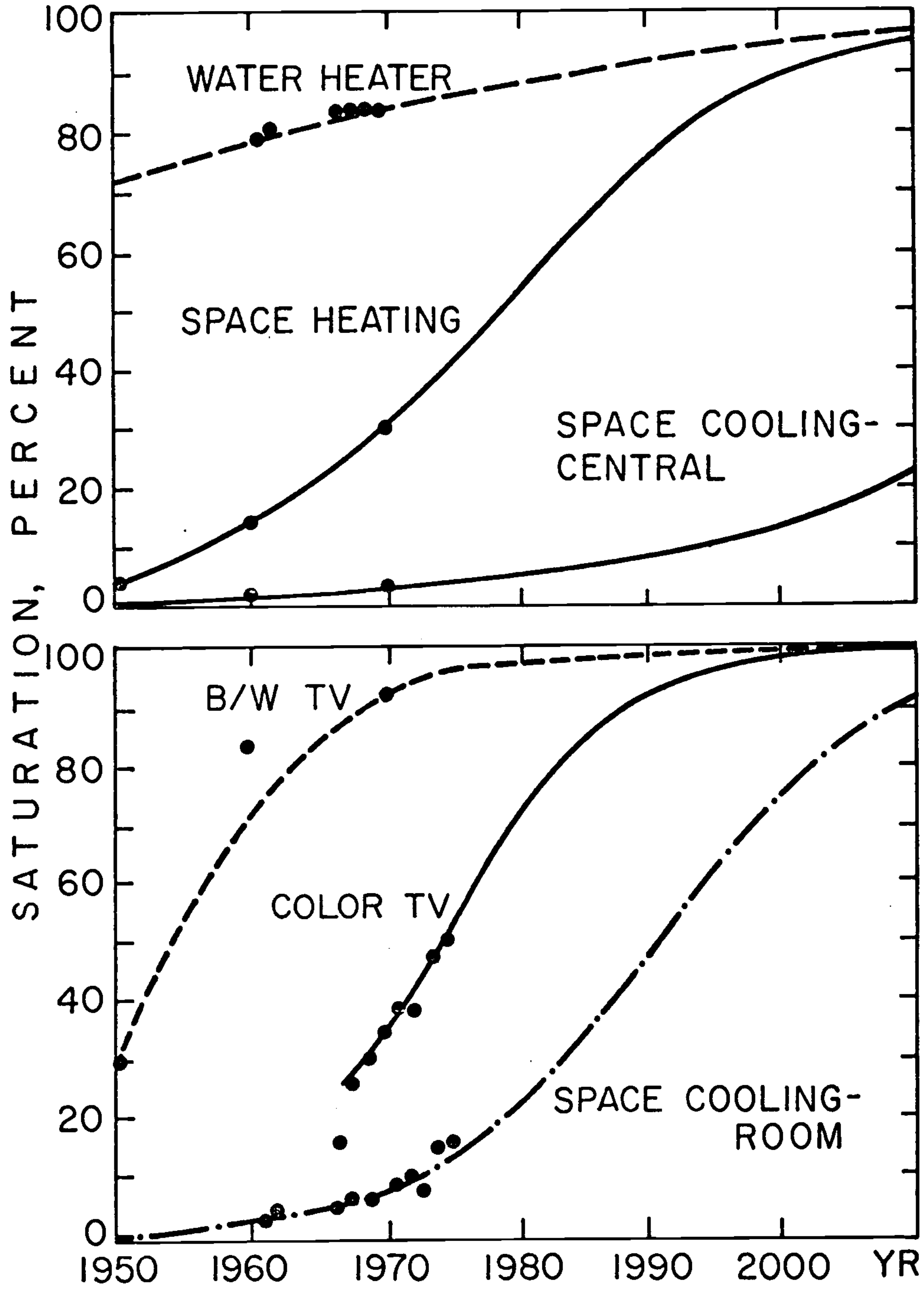

Figure 8.2. Electrical appliance saturations, Oregon.

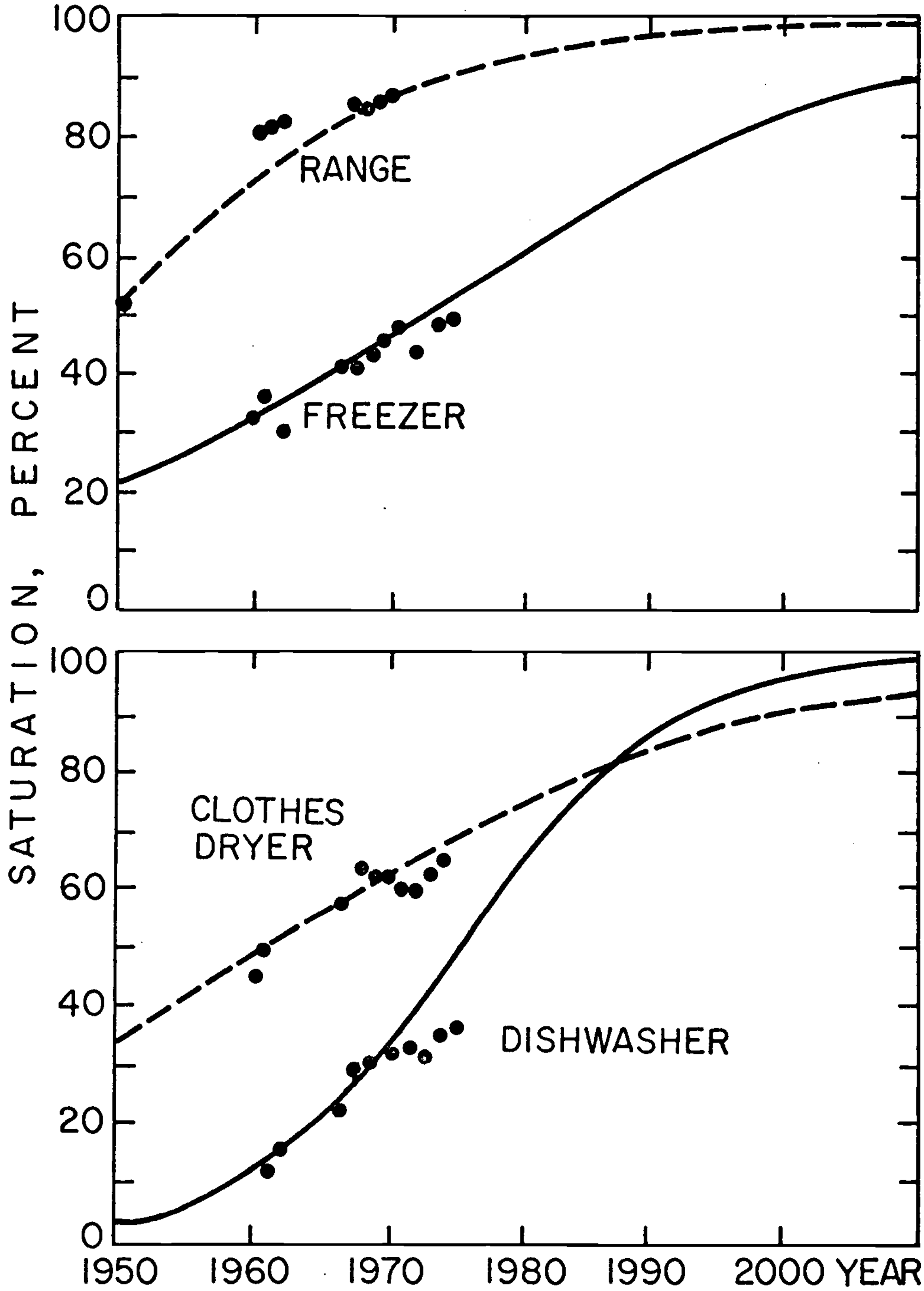

Figure 8.3. Electrical appliance saturations, Oregon.

$$\frac{1}{S}\frac{dS}{dt} \quad \alpha\,(S' - S) \qquad \text{or}$$

$$\frac{1}{S}\frac{dS}{dt} = \lambda\,(S' - S) \tag{8.7}$$

A solution to expression 8.7 is the logistic growth equation

$$S(t) = \frac{S'}{1 + Ke^{-\lambda S' t}} \tag{8.8}$$

which exhibits a sigmoidal shape on a linear plot of saturation versus time. Blackman (9) has found that this form represents the dynamics of the acceptance of many household electrical appliances at the national level with high correlation.

The data exhibited in Figures 8.2 and 8.3 has been used to determine the parameters of expression 8.8 and to calculate future saturations. These curves, which assume appliance saturation is uninfluenced by other factors such as energy price, are also provided in the aforementioned figures; the parameters are listed in Table 8.2 below. Inherent in the procedure to this point is the assumption that the ultimate saturation of each appliance is 100%. This ultimate level is a reasonable scenario if the only factors influencing saturation are technological change and diffusion. Of course, the actual saturation may deviate considerably from the paths shown, and may even cease to change at quite a different level than 100%. Such behavior depends on energy prices and availability and is simulated in the function $Fe_k(p_r)$ as shown in expression 8.4.

Table 8.2. Parameters for appliance saturation logistic equation.

Appliance	$\lambda S'$	K
Space Heating	0.0933	15.2
Space Cooling - Room	0.1198	130.
Space Cooling - Central	0.0535	88.0
Water Heater	0.0340	0.398
Range	0.0907	0.927
Clothes Dryer	0.0566	1.93
Freezer	0.0587	3.73
Dishwasher	0.1314	28.8
TV - Monochromatic	0.1773	2.33
TV - Color	0.1574	42.0

Appliance saturation is subject to influence by household disposable income. Although various researchers have calculated income elasticities of total residential electricity demand ranging between +0.3 and +1.13 (4, 11, 13), few estimates of the effect of changes in income on the saturation of individual appliances have been reported. Thus the approach considered here is to incorporate the "income effect" via changes in income distribution.

Two studies (7, 17) have concluded that the saturation of various household appliances varies significantly among income groups. As would be expected, higher income groups displayed higher saturation for all appliances with the exception of monochromatic television. Thus the assumption is made here that the diffusion of technology through society occurs at different rates in different income groups. That is, equation 8.7 applies in a slightly modified form:

$$\frac{1}{S}\frac{dS}{dt} = \lambda(I)\cdot(S' - S) \qquad (8.9)$$

Unfortunately it has not been possible to estimate $\lambda(I)$ within the time frame of this work. Furthermore, the data reported by the Ford Foundation and Berman et al. are not directly usable for the following reasons. First, the data reflect average national and metropolitan Los Angeles patterns, respectively; comparable data for Oregon is likely to be significantly different. Second, the studies consider one point in time only. And finally, the appliances subject to interfuel competition are not completely separated according to energy form utilized. Thus the effect of changes in income on residential electricity demand is not presently incorporated into the model, pending acquisition of appropriate data.

8.3.2 Appliance Consumption

Three kinds of factors affect average annual electricity consumption by individual household electric appliances: technological, geographic, and socio-economic.

Technological factors are embedded in the design of the appliance, and include any special features it may possess, its efficiency, and its size. Changes in any of these can affect an appliance's basic electricity consumption. They may be of such a nature that the effects cancel, rendering the average annual consumption relatively constant over a long period of time, or they may be cumulative, resulting in a fairly steady increase in average annual consumption. Technology also results in the introduction and spread of new appliances.

Geographic or climatic factors determine a base intensity of use of space conditioning appliances. Although weather conditions may vary from year-to-year, the average annual appliance use--determined over many years--may be taken as constant in a given region.

Socio-economic factors may produce deviation from the base use determined by technology and climate. These factors include electricity price, increases in which may induce reductions in usage; dwelling type; and number of persons per household. Price changes are considered in Section 8.4, while all other factors are discussed, as appropriate, below.

Space Heating. A ten-year average of 10,367 KWH/yr has been calculated for the service area of the Portland General Electric Company based on data published by the Federal Power Commission (67). In the absence of other data, this figure is taken as the state-wide average.

The electrical energy consumed per customer for space heating is, in general, a strong function of climate and size of house. This implies that a reasonable projection for future average household consumption would be a constant, since neither climate nor average size of house will change substantially. Average space heating consumption is not the same, however, for all types of dwellings. For a given housing unit size, location, and quantity of insulation, heat losses from a single family detached dwelling are larger than from a multi-family dwelling. A study reported by Levinson (25) determined that electricity used for space heating in apartments was 77% of that used for the same purpose in single family dwellings in Portland in 1969, and that mobile homes used nearly as much electricity as single family permanent structures, largely due to poor insulation. These facts are significant because the fraction of Oregon occupied housing units which are single family detached dwellings has decreased appreciably since 1960, as shown in Table 8.3. Thus shifts in the pattern of dwelling type could result in a decrease in the average annual consumption of electricity for space heating per household. Factors to simulate this phenomenon are not presently included in OSSIM, however, and the average value of 10,367 KWH/yr is assumed applicable throughout time.

Table 8.3. Oregon occupied housing units by type. Source: References 25, 56.

Number of Housing Units in Structure	Percent of Occupied Housing Units 1960	1970	Electric Space Heat Saturation, % 1969
1	84.9	76.9	24.0
≥ 2	12.6	18.0	57.0
Mobile Homes	2.5	5.1	12. - 15.

Other Major Appliances. A comprehensive review of consumption data for most household appliances between 1948 and 1969 has been performed by C. C. Mow et al. Their documentation (31) reveals that appliances can be divided into two groups. The first includes those whose average annual consumption has not changed significantly in the past and for which the balance of technological and geographic factors is such that future average annual consumption can be expected to remain relatively constant. The second group includes those for which the opposite is true, and the authors have extrapolated historical trends in consumption with ramp functions. The constant consumption chosen for appliances in the former category was provided in Table 8.1, and the functions representing consumption by individual appliances in the latter group are provided in Table 8.4.

Table 8.4. Average annual consumption of selected household appliances. Source: Reference 31.

Appliance	Consumption, KWH/HH/yr
Water Heater	4,280 + 20 t
Freezer	1,220 + 20 t
Refrigerator	1,150 + 25 t
Clothes Dryer	1,000 + 8 t

Note: t = 0 in 1970

The relatively large slopes associated with the first three of these appliances reflects the assumption that in 30 years time the average consumption of all appliances in use will approach the consumption of the most "modern" appliance of that type in use in 1970. These are the quick recovery water heater, 15 cu.ft. frost-free freezer, and 14 cu.ft. frost-free refrigerator, respectively.

Illumination. A national survey of residential lighting patterns (44) revealed an average annual energy consumption for illumination of 872 KWH per household, based upon an average household size of 3.88 persons. Using the Census of Housing (56) figure for Oregon of about 3.0 persons per occupied housing unit, an average consumption of 675 KWH/household/yr is obtained. It is assumed that this average value will not change significantly in the future.

Miscellaneous Small Appliances. An average annual consumption of 2,000 KWH/household by miscellaneous small appliances was obtained by subtracting the consumption of all major appliances from the state-wide average household total consumption. Although consumption data is reported for many small appliances (see, for example, Reference 68) saturation data is not available. The 2,000 KWH/household figure, however, is comparable to similar data reported in Reference 31 for California. Future consumption by this group of appliances must include the introduction and spread of new and perhaps yet undeveloped devices. To account for these, a linear increase in consumption by this group of 100 KWH/HH/yr is assumed. That is,

$$C_{13}(t) = 2,000 + 100 \cdot t \text{ KWH/HH/yr} \qquad (8.10)$$

This scenario input is highly subjective and important since it means that by 1985 small appliances consume 3,500 KWH/HH/yr. However this result is comparable to a Bonneville Power Administration estimate of 3,334 KWH/HH/yr (63).

8.4 Future Electrical Energy Intensiveness

Several studies (3, 76) have demonstrated that appliance saturation and appliance electricity consumption are sensitive to variations in energy prices. However the magnitudes of the responses of each of these factors and the time periods over which they occur are different, and in fact vary with the appliance in question. For the purposes of this model, the thirteen appliances under consideration may be divided into four categories.

Essential and Competitive. Space heaters, water heaters, and ranges are essential in that nearly every household has one of each, and competitive because heating and cooking can be performed utilizing alternate energy forms. The use of each is amenable to conservation, and the saturation of each is subject to interfuel competition.

Essential and Non-competitive. Every household possesses a refrigerator and electric lights, for which substitutes are not available or generally deemed unacceptable. Thus these appliances are also considered essential, but are not subject to interfuel competition. Conservation in their use, however, is possible.

Non-essential and Non-competitive. These appliances largely depend upon electricity for their existence, and substitution of fossil-fueled alternatives is impossible. They are not essential to the sustenance of the owner and the saturation of each is less than 100%. Saturation response to energy price changes is likely to be more rapid than for the essential appliances, since changes in saturation are driven more by the acquisition of new, smaller appliances than by the retirement of aging, large ones. Conservation possibilities vary with the appliance. Included in this category are air conditioners, the freezer, dishwasher, television, and all miscellaneous small appliances.

Non-essential and Competitive. The only appliance in this category is the clothes dryer, the use of which is subject to limited conservation. Saturation of electric- and gas-fired dryers combined is less than 100%. The saturation of electric dryers is thus subject to change due to interfuel competition during both first-time acquisition and replacement; its response in time is likely to be somewhat different than that for essential, competitive appliances.

The above characteristics are summarized in Table 8.5 and estimates of applicable elasticities from the literature are provided in Table 8.6. As was pointed out in Chapter 4, ξ_{e_c} applies to conservation and modifies $C_k(t)$; $\xi_{e_{e \rightarrow g}}$, $\xi_{e_{e \rightarrow p}}$, ξ_g, and ξ_p apply to interfuel substitution and modify $S_k(t)$. ξ_{e_a} refers to the effect of electricity price changes on the saturation of non-essential appliances and also modifies $S_k(t)$. All the elasticities of saturation reported were obtained by national cross-sectional analysis and will be assumed to apply in the future to Oregon. The elasticities of consumption were approximated from the latter by use of the general result of Anderson (3) which states that conservation represents approximately one-third of the total elasticity of demand for the residential sector.

The product of price-independent consumption and saturation functions for appliance k yields base electrical energy intensiveness:

Table 8.5. Characteristics of Categories of Household Appliances.

Factor Influenced:	Consumption, $C_k(t)$		Saturation, $S_k(t)$	
Possible Response to Energy Price Changes:	Conservation		Interfuel Substitution; Change in Acquisition Rate	
Appliance Category	Importance of Response	Time Period of Response	Substitution Possible	Time Period of Response
Essential, Competitive	high	~ 1 year	yes	~ appliance lifetime
Essential, Non-Competitive	low	~ 1 year	no	--
Non-Essential, Non-Competitive	medium	~ 1 year	no	< appliance lifetime
Non-Essential, Competitive	low	~ 1 year	yes	< appliance lifetime

Table 8.6. Price elasticities for individual household appliances. Sources: References 3, 33.

Appliance	ξ_{e_c}	$\xi_{e_{e \rightarrow g}}$	$\xi_{e_{e \rightarrow p}}$	ξ_g	ξ_p	ξ_{e_a}
Essential, Competitive						
Space Heater	-1.21	-2.43		+2.45		NA
Water Heater	-0.49	-0.97	NA	+3.79	NA	NA
Range	-0.37	-0.74	NA	+0.65	NA	NA
Essential, Non-Competitive						
Refrigerator	-0.31[1]	NA	NA	NA	NA	NA
Illumination		NA	NA	NA	NA	NA
Non-Essential, Competitive						
Clothes Dryer	-0.10	-0.20	NA	+0.48	NA	
Non-Essential, Non-Competitive						
Air Conditioner - Central	-0.54	NA	NA	NA	NA	-1.09
Air Conditioner - Room	-0.07	NA	NA	NA	NA	-0.14
Freezer	-0.31	NA	NA	NA	NA	-0.62
Dishwasher	-0.45	NA	NA	NA	NA	-0.91
TV - Color		NA	NA	NA	NA	0.
TV - Monochromatic		NA	NA	NA	NA	0.
Miscellaneous		NA	NA	NA	NA	

NA: not applicable

[1] Taken equal to that of freezer.

$$Ue_{o_k}(t) = C_k(t) \cdot S_k(t) \tag{8.3}$$

However the observed intensiveness of appliance k, as reflected in the consumption and saturation data provided earlier, has resulted from the influences of past energy price changes. Thus, as for previous sectors, the question of equilibrium must be addressed.

Figure 8.4 illustrates the time series of average energy prices paid by Oregon residential consumers as calculated in Reference 74. Prices for all three forms decreased steadily and significantly until 1970. It has been pointed out, furthermore, that appliance saturation is sensitive to energy prices; thus the observed price changes have likely contributed to the historical increase in electrical energy intensiveness of the Residential Sector. Appliance saturation, in particular, may not be in equilibrium with prices, leading to erroneous projections of future base intensiveness. Thus application of Fe_k to Ue_{o_k} is done with realization that absence of equilibrium of Ue_{o_k} may lead to future error in Ue_k for certain appliances. However this error is not felt to be large, especially in view of the significant change in historical price movements after 1970. Future price-dependent electrical energy intensiveness for appliance k is thus given by

$$Ue_k(p_r, t) = Ue_{o_k}(t) \cdot Fe_k(p_r) \tag{8.11}$$

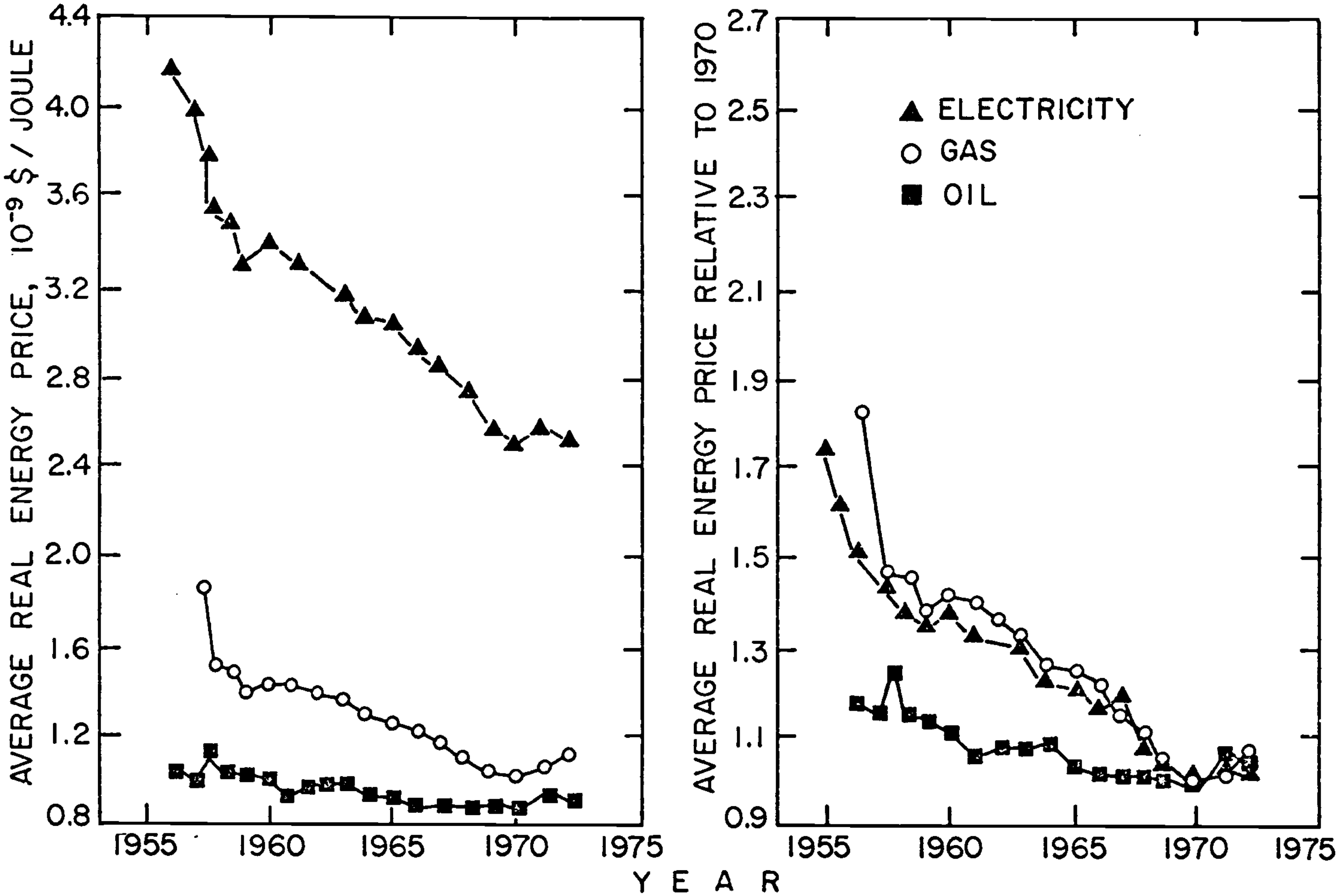

Figure 8.4. Energy prices to Residential Sector, Oregon.

9. MODEL OPERATION AND CONCLUSIONS

The model described in Chapters 4 through 8 has been programmed in two forms:

a. The electrical energy demand model alone, operable with user-supplied scenarios of economic activity; and

b. The demand model set in concert with OSSIM, utilizing simulated economic activity.

Results from runs of the energy demand model alone are discussed in the following sections; results utilizing OSSIM are contained in Reference 74.

9.1 Exogenous Economic Activity

Table 9.1 lists those variables representing economic activity in the various socio-economic sectors which are required input to the model; also provided are historical average annual growth rates and two alternate scenarios of future growth from government sources. It is interesting to note that although both estimates claim to be internally consistent, they differ somewhat from one another and from historical data. Furthermore, the BPA estimate for non-resource-based manufacturing assumes a constant industrial mix (Table 5.6) while the OBERS estimate assumes the mix will vary (Table 5.16). The BPA scenario was used as input to the model for

Table 9.1. Historical and predicted economic activity in Oregon.

Sector	Measure of Economic Activity	Symbol	Historical Average Annual Growth Rate			Predicted Average Annual Growth Rate			
						BPA[63]		OBERS[60]	
			%/yr	Period	Reference	%/yr	Period	%/yr	Period
Industrial	$VA, SIC 20	Y(3)	2.18	1960-71	74	PT		2.95	1970-2020
	$VA, SIC 24	Y(4)	0.50	1960-71	74	PT		3.24	1970-2020
	$VA, SIC 26	Y(5)	3.76	1960-71	74	PT		3.30	1970-2020
	$VA, Non-Resource-Based Manufacturing	Y(6)	4.56	1960-71	74	PT		4.57	1970-2020
	Irrigated Acreage, I	Y(7)	2.60	1959-69	54	3.35[1]	1965-85	NS	
	Irrigated Acreage, II	Y(8)	0.31	1949-69	54	3.35	1965-85	NS	
	Irrigated Acreage, III	Y(9)	0.86	1959-69	54	3.35	1965-85	NS	
Commercial	Service Employees	Y(1)	2.63	1960-70	Table 6.1	2.42	1970-80	2.73	1970-80
Transportation	Street, Highway Mileage	Y(2)	2.54	1963-72	Table 7.1	NS		NS	
Residential	Electric Utility Customers	Y(10)	3.15	1964-73	12	2.16	1970-85	1.35	1970-2020

PT: past trends specified

NS: not specified; historical growth rate assumed

[1] BPA assumes this growth rate applies throughout Pacific Northwest

all analyses to be described in this and the following section so that model results could be compared to several estimates of future electrical energy demand.

The distribution of 1970 electrical energy consumption is an initial condition common to all of the following computer runs. It is therefore provided for convenience as Table 9.2.

Table 9.2. 1970 Oregon electrical energy consumption by model subsector.

Sector	Subsector	Consumption, 10^6 KWH	Percent of Total
Industrial		11,052	42.0
	Food and Kindred Products	330	1.3
	Lumber and Wood Products	1,751	6.6
	Paper and Allied Products	1,859	7.1
	Non-Resource-Based Mfg.	6,719	25.5
	Irrigation, Region I	47	0.2
	Irrigation, Region II	10	0.0
	Irrigation, Region III	337	1.3
Commercial		5,774	21.9
Transportation		135	0.5
Residential		9,388	35.6
	Total	26,350	100.0

Historical Trends. The base case represents a continuation of historical trends prior to the early 1970's. Energy prices are assumed to remain low, and consumers do not undertake appreciable conservation, interfuel substitution, or alteration of trends in appliance saturation; base energy intensiveness increases in accordance with the discussions of Chapters 5 through 8; and economic activity is assumed to increase at rates specified by BPA (Table 9.1). A summary of model results for this case is given in Table 9.3.[17]

Table 9.3. Case I. Historical Trends: Constant Energy Prices.

Year	Total Electrical Energy Demand, 10^6 KWH	Average Annual Growth Rate, %
1970	26,350	
1975	34,525	5.5
1980	44,593	5.3
1985	56,818	5.0

The average annual growth rate for 1970-75 indicated in the table is identical to that recorded between 1969 and 1973 (Table 6.1) and--in one sense--serves to validate the model. However, despite the assumed exponential increase in economic activity, a slight decrease in growth rate occurs over the entire fifteen year period. This is due to aforementioned linear or zero increases in base energy intensiveness and increasing saturation of household electric appliances. Detailed output for Case I shows that the Commercial Sector remains

[17] Detailed model output for Case I is provided as a sample in Appendix IV.

the fastest growing electricity consumer, increasing its share of the total to 24% by 1985. The electrical energy intensiveness of the Residential Sector increases about 50% to over 21,000 KWH per household, while that of non-resource-based manufacturing increases only slightly due to the assumption of constant industrial composition.

Case I results are compared to projections of government agencies in Table 9.4. The BPA data are based upon a 5.4% average annual growth rate of energy consumption, which was derived by the author from data presented in Reference 63. The NTEC estimates reflect a 6.7% per year growth rate, which was derived from data in Reference 36.

Table 9.4. Comparison of electrical energy consumption calculations (10^6 KWH).

Year	Case I	BPA	NTEC
1970	26,350	26,350	26,350
1975	34,525	34,275	36,442
1980	44,593	44,585	50,399
1985	56,818	57,995	69,702

Case I and BPA estimates are based upon an identical scenario of economic activity. However, reconciliation of the differences between Case I and NTEC is not possible since the estimates of Reference 36 are not expressed in terms of explicit relationships to exogenous variables. Rather, the 6.7% per year growth rate was derived from an aggregation of individual utility estimates with no attempt to normalize the underlying parameters.

The second series of cases assumes that energy prices to ultimate consumers increase. It is not within the scope of this work to predict specific, real energy price increases, since these are complex functions of regulatory policy, inflation, and international relations. The intent, rather, is to demonstrate the capability of the energy demand model by driving it with various scenarios of energy prices which may be representative of future price trends.

Electricity Prices Increase. Case II assumes that electricity prices increase but that prices of fossil fuels remain constant. This scenario is unrealistic, of course; it is included to illustrate model performance and to demonstrate that estimates of future electricity consumption should not be made apart from a detailed consideration of interfuel substitution. Figure 9.1 illustrates the electrical energy prices used for this case. Prices to the Residential and Commercial Sectors increase at a rate of 2-1/2% of the 1970 price per year, while prices to all industrial groups except Primary Metals increase at the slightly faster rate of 3-1/3% of the 1970 price per year. The price to SIC 33, largely under control of long-term contracts with the Federal government, is assumed to increase by only 1% of the 1970 price per year. The price scenario of Figure 9.1, although more detailed, is comparable to those used in the econometric models of References 11. 33. and 39.

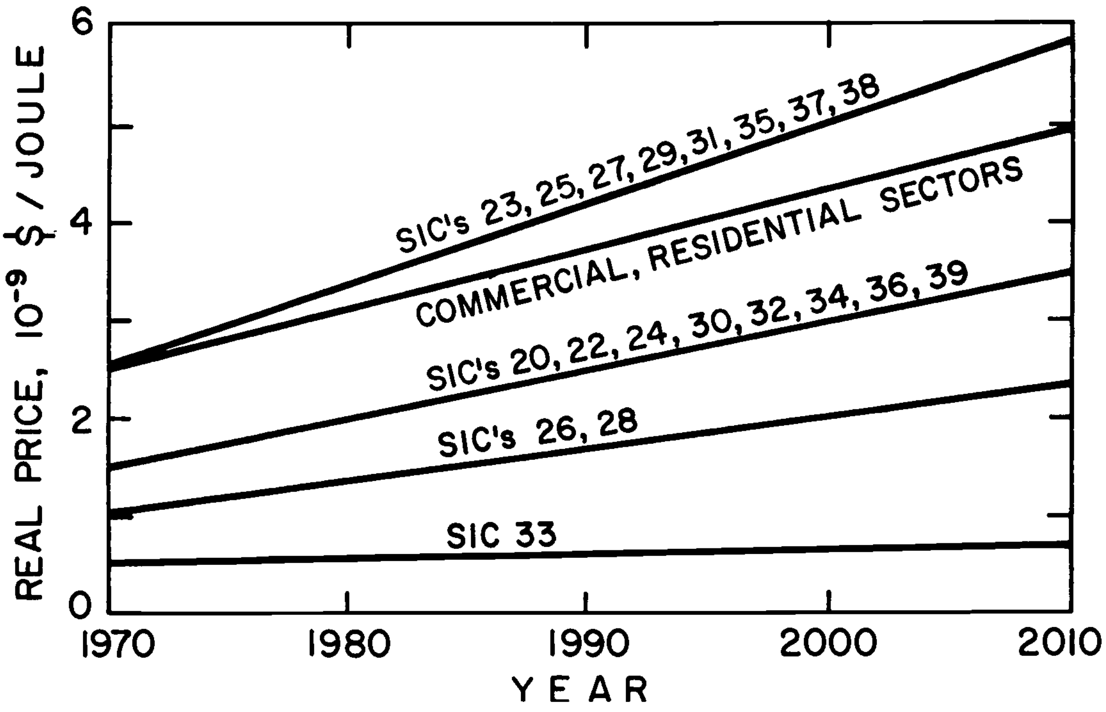

Figure 9.1. Electricity price scenario.

A summary of Case II results and comparison with Case I is provided in Table 9.5 and in Figures 9.2 and 9.3.

Although electricity price increases begin in 1970, it was assumed that not until 1973 do prices reach a level sufficient to invoke consumer response. Thus the 5.2% average annual growth rate between 1970 and 1975 reflects higher electricity prices only in 1974 and 1975. Thereafter, the growth rate declines significantly due to conservation and substitution of fossil-fuel-intensive equipment for

Table 9.5. Case II. Electricity prices increase.

Year	Total Electrical Energy Demand (10^6 KWH)		Case II ÷ Case I	Average Annual Growth Rate (percent)	
	Case II	Case I		Case II	Case I
1970	26,350	26,350	1.00		
1975	33,973	34,525	0.98	5.2	5.5
1980	41,013	44,593	0.92	3.8	5.3
1985	48,507	56,818	0.85	3.4	5.0
1990	57,071	71,500	0.80	3.3	4.7
1995	66,989	89,026	0.75	3.3	4.5
2000	78,524	109,912	0.71	3.2	4.3

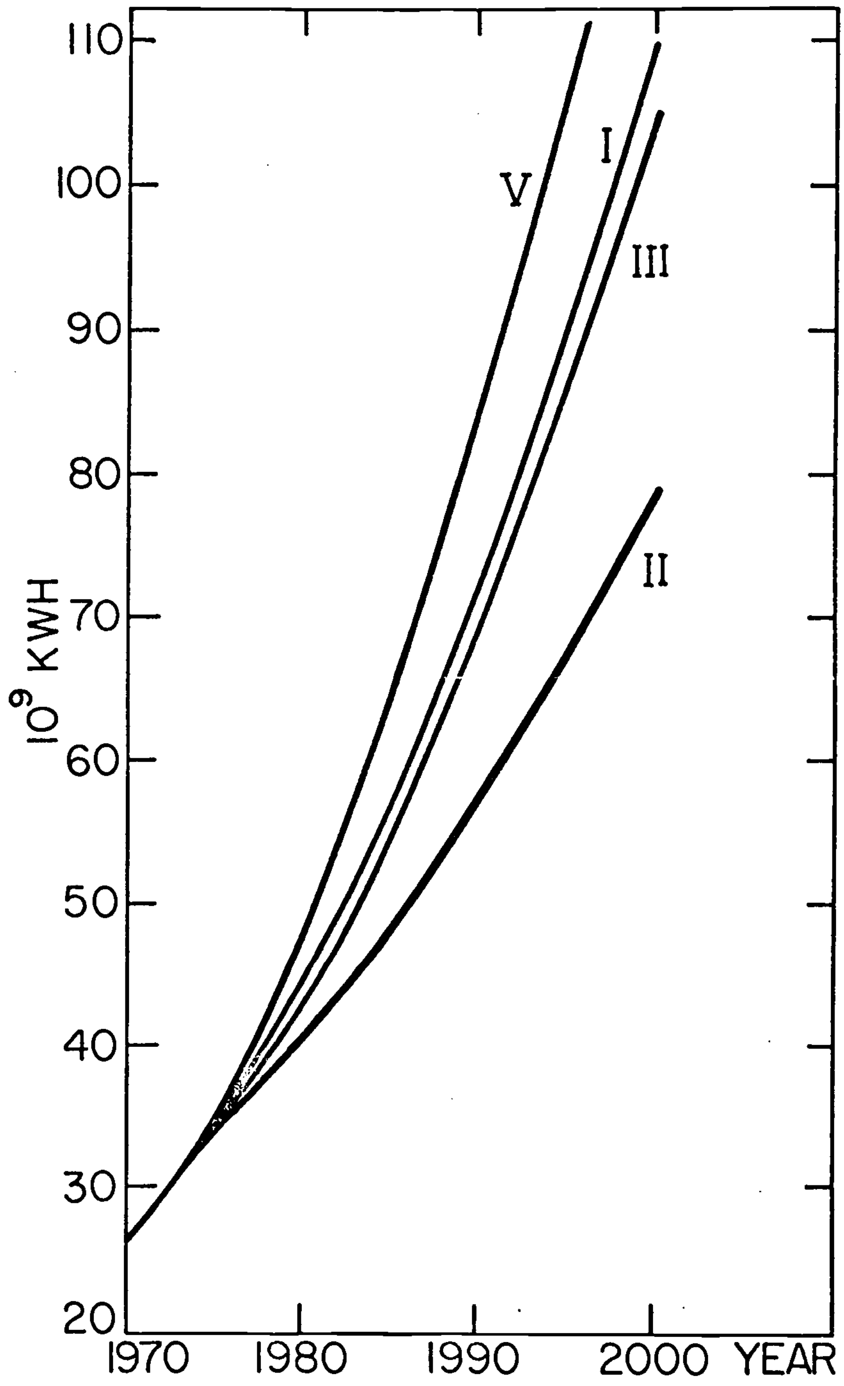

Figure 9.2. Model results with exogenous economic activity (linear).

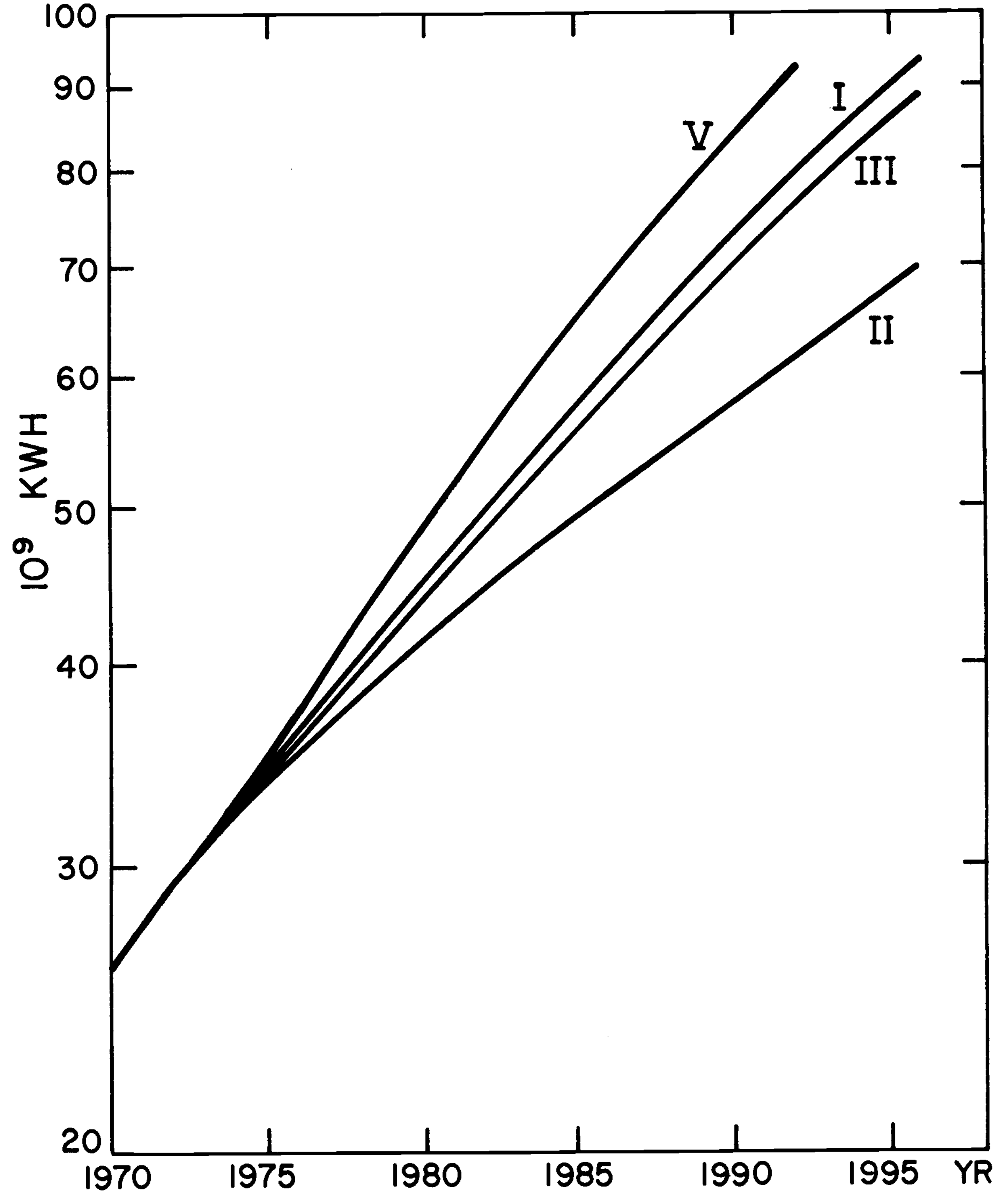

Figure 9.3. Model results with exogenous economic activity (logarithmic).

that which utilizes electricity. Due to somewhat shorter average delays, early declines in growth rate largely reflect conservation; about 10 years after initial response, however, the effects of interfuel substitution become manifest and the growth rate declines still further. These two regimes are evident in Figure 9.3.

Detailed output for Case II indicates that the Residential Sector experiences the largest decrease in electricity consumption growth rate. By 1985, for example, electrical energy intensiveness is less than 17,000 KWH per household versus 21,000 for Case I. Non-resource-based manufacturing, on the other hand, displays the smallest decrease in growth rate. The reason is that electrical energy intensiveness of this subsector is dominated by Primary Metals Industries and the electricity price to these manufacturers was assumed to increase at a slower rate than to other subsectors.

Thus conservation and interfuel substitution--in response to increasing electricity prices alone--yield moderate electrical energy savings in the short run (about 8% in 1980) and significant savings in the long run (over 20% in 1990, for example). However, this is not a viable scenario; fossil fuel prices have increased since 1970 and will, in all likelihood, continue to do so.

<u>All Energy Prices Increase.</u> In Case III all energy prices increase, while other model input is identical to that of Cases I and II. It is assumed and illustrated in Figure 9.4 that real prices of

petroleum products and gas to ultimate consumers increase faster than electricity prices. Oil prices have been taken to increase at 3-1/3% of the 1970 price per year, while gas prices increase by 5% of the 1970 price per year. Note that the energy price scenarios of Figures 9.1 and 9.4 approximately preserve existing price relationships between the various consuming entities.

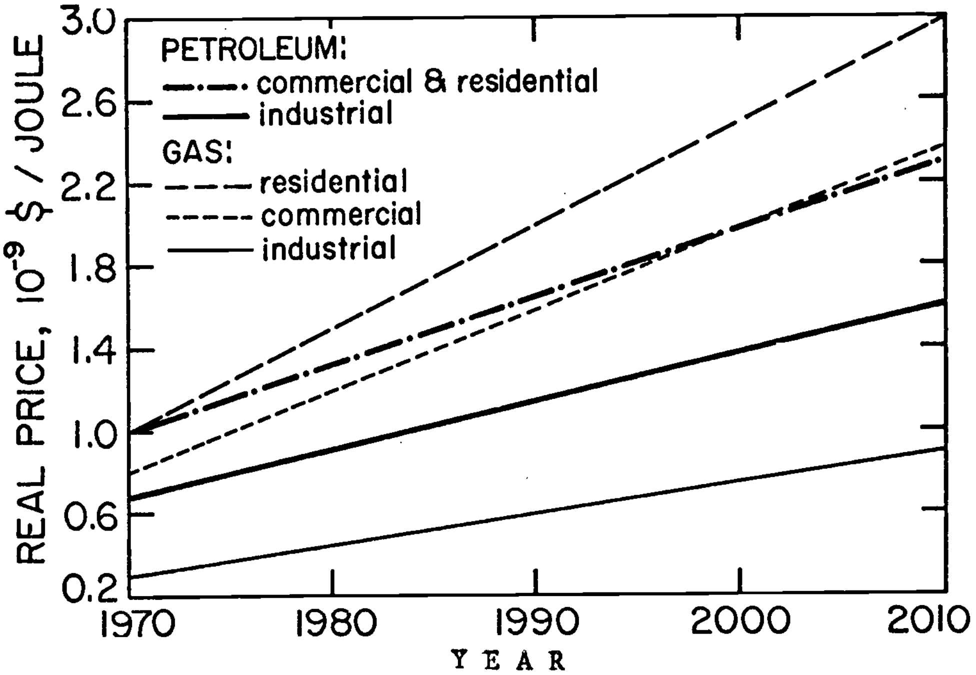

Figure 9.4. Fossil fuel price scenario.

The results of Case III are compared with Cases I and II in Table 9.6 and in Figures 9.2 and 9.3. The reduction in growth rate through 1980 of Case III is not nearly as great as that of Case II, where fossil fuel prices were assumed constant. Case III displays a reduction in electricity consumption of only several percent compared

Table 9.6. Case III. All energy prices increase.

Year	Total Electrical Energy Demand (10^6 KWH)			Case III ÷ Case II	Case III ÷ Case I	Average Annual Growth Rate (percent)		
	Case III	Case II	Case I			Case III	Case II	Case I
1970	26,350	26,350	26,350	1.00	1.00			
1975	34,252	33,973	34,525	1.01	0.99	5.4	5.2	5.5
1980	43,417	41,013	44,593	1.06	0.97	4.9	3.8	5.3
1985	55,328	48,507	56,818	1.14	0.97	5.0	3.4	5.0
1990	69,694	57,071	71,500	1.22	0.97	4.7	3.3	4.7
1995	85,425	66,989	89,026	1.28	0.96	4.2	3.3	4.5
2000	104,916	78,524	109,912	1.34	0.96	4.2	3.2	4.3

to Case I; the saving due to conservation is evidently negated by the substitution of electrical equipment for that which consumes fossil fuels. In fact, over the intermediate time period from 1980 to 1990, the growth rate of electricity consumption of Case III is nearly identical to that of the base case. However, the increased prices of fossil fuels cause earlier saturation of several household appliances, and after 1990 the growth rates again differ. Note that at no time does the case in which all energy prices increase differ by more than 4% from the case in which no energy prices increase. In the former instance, the substitution of electrical-energy-intensive equipment for gas- and oil-burning equipment negates the effects of the replacement of electrical by fossil-powered equipment and in addition considerably reduces the overall contribution of electricity conservation.

Detailed results of Case III show that all subsectors except paper products (SIC 26) and non-resource-based manufacturing experience moderate initial decreases in growth rate. The pulp and paper industries are especially sensitive to gas and oil prices due to extensive use of process steam boilers; and the model shows that SIC 26 experiences an almost immediate increase in electricity consumption growth rate. Furthermore, the electrical energy intensiveness of the Residential Sector is shown to be about 20,000 KWH per household in 1985--still less than the base case, but considerably greater than Case II.

Table 9.6 shows the significant difference between electrical energy demand when only electricity prices are assumed to increase (Case II) and when all energy prices are assumed to increase (Case III). On the other hand, the scenario in which all prices increase yields demands only slightly different from the base case, which assumed a continuation of historic trends. This result differs from those reported by other researchers (11, 16, 30), who find electrical energy demand in their geographic regions of concern to be more significantly attenuated from historic trends.

Further illustration of model capability is provided by three additional cases which to not necessarily represent realistic scenarios.

Absence of Conservation. Energy prices were assumed to behave in the same manner in Case IV as in Case III. By way of contrast, however, no electricity conservation was allowed in Case IV; that is, all elasticities of intensiveness pertaining to conservation (ξ_{e_c}) were set equal to zero. The effect of electricity conservation is then illustrated by comparison of these two cases in Table 9.7.

Note that no early decrease in growth rate occurs in the absence of conservation. Rather, the net result of the only response to price changes in Case IV--interfuel substitution--is an increased growth rate. This further illustrates the major impact on electrical energy demand of increases in the prices of fossil fuels. Of equal significance is that only about 9% more electrical energy is consumed in

Table 9.7. Case IV. No electricity conservation.

Year	Total Electrical Energy Demand (10^6 KWH)		Case IV ÷ Case III	Average Annual Growth Rate (percent)	
	Case IV	Case III		Case IV	Case III
1970	26,350	26,350	1.00		
1975	34,658	34,252	1.01	5.6	5.4
1980	45,839	43,417	1.06	5.7	4.9
1985	60,242	55,328	1.09	5.6	5.0
1990	78,094	69,694	1.12	5.3	4.7
1995	97,638	85,425	1.14	4.6	4.2
2000	121,229	104,916	1.16	4.4	4.2

1985 without conservation responses to increased electricity prices than with conservation. Of the 5×10^9 KWH conserved in that year, nearly half can be attributed to the Residential Sector and another 30% to the Commercial Sector. These results depend, of course, on the particular electricity price scenarios used.

Constant Electricity Prices. Case V indicates the effect on electrical energy demand of fossil fuel prices increasing as in Cases III and IV but with electricity prices remaining at their 1970 level. The substitution of electrical equipment for that which utilizes fossil fuels is the only consumer response in this instance. Table 9.8 and Figures 9.2 and 9.3 show the steady, significant increase in growth rate, which continues until 1985 when many appliances have approached 100% saturation. In that year about 15% more electrical energy is consumed than in the base case with no price increases. Nearly half of this increase occurs in the Residential Sector, with another 30% attributable to non-resource-based manufacturing and paper products.

Constant Economic Activity. Finally, it is of interest to know how much of the increase in electrical energy demand is due strictly to increasing economic activity and how much is due to changes in use of electricity. Case VI assumes constant economic activity in each subsector; all other inputs--including energy prices--are identical to Case III. Table 9.9 presents the resulting growth rates, which indicate that about 60% of the growth rate of Case III is due to

Table 9.8. Case V. Constant electricity prices.

Year	Total Electrical Energy Demand (10^6 KWH)		Case V ÷ Case I	Average Annual Growth Rate (percent)	
	Case V	Case I		Case V	Case I
1970	26,350	26,350	1.00		
1975	34,814	34,525	1.01	5.7	5.5
1980	47,579	44,593	1.07	6.4	5.3
1985	65,415	56,818	1.15	6.6	5.0
1990	83,555	71,500	1.17	5.0	4.7
1995	105,888	89,026	1.19	4.9	4.5
2000	133,615	109,912	1.22	4.8	4.3

increasing economic activity and the remainder to increasing electrical energy intensiveness.

Table 9.9. Case VI. Constant economic activity.

Year	Average Annual Growth Rate of Consumption (percent): Constant Economic Activity, Case VI	Historical Economic Activity, Case III	Case VI ÷ Case III
1970			
1975	2.4	5.4	0.44
1980	1.9	4.9	0.39
1985	2.0	5.0	0.40

Cases I, II, III, V indicate that changes in energy consumption in the short-run (1975, for example) due to changes in electrical energy intensiveness are small, regardless of the price scenario used. Since changes in economic activity represent more than half of the change in electricity consumption, large changes in consumption in short periods of time are likely to be due principally to comparable large changes in economic activity.

It must be emphasized that Cases I through VI do not represent predictions of future electrical energy demand. Different data inputs and price scenarios can, of course, produce different results. The cases do represent, however, the capability of the model to analyze the determinants of electricity consumption and illustrate the importance of considering the various phenomena described.

9.2 Sensitivity and Validation

Sensitivity testing involves varying key data and scenario inputs about a base value and observing the performance of the model. Those parameters whose variations cause the greatest overall deviation of model output from some specified base case are assumed to be those to which the model is most sensitive.

Since data inputs are usually empirically determined and can be subject to considerable variation in reliability, information leading to the identification of those data to which the model is most sensitive can be useful. Especially important is knowledge concerning model sensitivity to data which are very imprecisely known, or which were determined by conjecture. Then, if necessary, effort can be directed to the refinement of only these key parameters, rather than those which play little role in overall results.

To this end, model sensitivity to three important time constants was investigated by parametric analysis. The results, provided in Table 9.10, are relative to Case III in which prices of both electricity and fossil fuels were assumed to vary. The general lack of significant variation in total electricity consumption indicates that the model is probably not particularly sensitive to these parameters.

Table 9.10. Model sensitivity to selected data inputs.

Parameter	Subsector	Nominal Value (Case III)	Parameter Variation	Variation in Electrical Energy Demand, 1985: Total	Variation in Electrical Energy Demand, 1985: Subsector
Average delay, interfuel substitution	Residential Space Heat	10 years	-50% +50%	+0.8% -0.4%	+2.2% -1.2%
	Paper and Allied Products	3 years	-67% +100%	+0.2% -0.3%	+2.7% -3.4%
Average delay, conservation	Primary Metals	3 years	-67%	-0.1%	-0.5%

Scenario inputs are usually specified by the model user. Since the range of values that these inputs can assume is usually known, scenario inputs can be treated in a manner analogous to data inputs. However, conclusions drawn from studies of model sensitivity to scenario inputs pertain to the significance of the scenario or the utility of the policy being tested.

Model sensitivity to two scenarios which are also variations on Case III was investigated and the results summarized in Table 9.11. It is apparent that greater variation in overall results occurs in response to manipulation of these particular inputs than to those of the previous table. Thus the model is probably sensitive to these scenarios, and they become candidates for further investigation.

At least three ways of checking simulation model validity are recognized: direct comparison to the real-world system, comparison to results from an alternate model of the same system, and "piece-by-piece validation." The validity of the electrical energy demand model may be considered from these three standpoints.

1. Direct comparison. A simulation model is compared to its simuland by comparing responses emanating from the model with available information regarding the corresponding behavior of the simuland. This may be done in an historical and prospective sense.

In the former sense it is asked whether the model will duplicate--within reasonable limits--historical behavior of the real-world system.

Table 9.11. Model sensitivity to selected scenario inputs.

Scenario	Subsector	Nominal Scenario (Case III)	Alternate Scenario (Sensitivity Study)	Variation in Electrical Energy Demand, 1995	
				Total	Subsector
Electricity Price	Primary Metals Industries	Increase at 1% per year	Increase at 2% per year	-2.0%	-7.6%
Industrial Mix	Non-Resource-Based Manufacturing	Constant (Table 5.6)	Variable (Table 5.16)	-4.4%	-16.5%

In fact, before a simulation model can be said to be a useful tool for studying behavior under future conditions, its consistency must be checked with the simuland as it existed under past conditions. The success of this validation establishes a basis for confidence in the results that the model generates under new conditions. If a model cannot approximate system behavior without change, it cannot be expected to produce representative behavior with change. The results of Case I--historical trends--were presented in Table 9.3 and serve as an indication of model validity in this first sense.

Validation in the prospective sense consists of checking for consistency between anticipated real system responses and the simulation model that supposedly represents the system. Few socio-economic models are ever totally validated in this sense. Rather, varying degrees of confidence are established via a series of test runs and sensitivity studies. Cases II through VI and the sensitivity tests described earlier in this section have provided the author reasonable assurance that the model is valid. Ultimate judgment of validity, however, rests upon those who must accept the consequences that result from application of the model.

2. Cross comparison. Simulation model results can be compared to results generated by different models of the same simuland. If the alternate models are deemed valid, correspondence of output can be an indication of validity of the simulation model to the extent

that the problems being solved are identical. With these caveats, the comparison between Case I and BPA estimates in Table 9.4 may serve as a further indication of model validity.

3. Piece-by-piece validation. A simulation model can be said to be valid if it is possible to establish the validity of all assumptions and data upon which the model is based. Although the author feels both assumptions and data are valid, the emphasis in this work has been on the representation of phenomena rather than on the calculation of parameters. Thus the precise value of selected parameters may be disputed. And, since a given user can often make a simulation model perform as he wishes by parameter manipulation, piece-by-piece validity is a function of the knowledge, experience, and integrity of the investigators.

Finally, model validity is not an absolute concept. Whether a model is valid or not depends--to a large extent--on the purpose for which it was constructed. The purpose of the electrical energy demand model is to help investigators understand the determinants of electricity consumption within a context of changing socio-economic conditions and to illustrate factors which can cause changes in the historical rate of growth of consumption. Model development and results obtained thus far have, in the author's opinion, served this end.

9.3 Discussion

9.3.1 Implications for Nuclear Power

Significant reduction in anticipated electrical energy demand could justify installation of fewer nuclear and fossil fueled electric power plants than presently envisioned, and allow additional time for research and development on alternative power sources. In fact, future electricity demand has been called the strongest influence over the development of nuclear power (22). However the scenarios considered in this thesis do not substantiate expectations of large reductions in electricity consumption growth rate and concomitant lack of need for planned power plants.

Future growth rates of electrical energy consumption--under the assumption that historical trends will continue--were presented in Table 9.3. It was later pointed out that when prices of all energy forms increase--as is likely to be the case--the growth rates may not be significantly different. Furthermore, model results indicate that

a) the growth rate of electricity consumption strongly reflects economic activity; and

b) under conditions of constant economic growth, only in the long run can the growth rate of consumption be expected to decrease appreciably.

Thus rapid, large changes in growth rate are likely to be transient phenomena--primarily driven by rapid fluctuations in economic activity--and not indicative of long term trends.

Initial model results, then, confirm the need for the timely expansion of electrical energy supplies to the State of Oregon. This statement is based on scenarios which show little likelihood that demand for electrical energy will be significantly attenuated providing economic activity is comparable to that of the recent past. Alternate scenarios of economic development in Oregon may, of course, yield different electricity requirements.

9.3.2 Model Criticism and Advantages

The electrical energy demand model is amenable to improvement in at least the following four areas:

1. Although the industrial mix of the non-resource-based manufacturing subsector can be varied with time according to expression 5.19, none of the industry groups included therein are expressed as separate models in the OSSIM. Thus the extent to which the sixteen two-digit industrial groupings differ from one another in the dynamics of capital investment, output, and employment is not presently represented.
2. The effect of changes in household disposable income on residential electricity demand--via appliance saturation--was

not incorporated due to the absence of appropriate data. During periods of rising average income, the model will thus underestimate residential electrical energy consumption.

3. The effect of shifts in the pattern of dwelling type on electrical energy demand for space heating is not, at present, taken into account. If the trends of Table 8.3 continue, the model slightly overestimates electricity consumption for this purpose.

4. The methodology requires assumptions concerning future base electrical energy intensiveness. These parameters--in the Industrial, Commercial, and Transportation Sectors--have been assumed to increase linearly or to remain constant for reasons discussed in Chapters 4 through 7. This implies that even if economic activity is taken to increase exponentially, the overall growth rate of consumption of these sectors will eventually decrease slightly.

Despite these shortcomings, the model developed in this thesis contains several features not explicitly incorporated into other energy demand models:

1. Conservation, interfuel substitution, and appliance saturation are recognized to be separate phenomena and are addressed explicitly.

2. There are limits to the above phenomena; these limits are required input data.

3. The time-dependent nature of conservation, interfuel substitution, and appliance saturation is quantified. These processes are assumed to respond to forces--such as energy price--which can also be time-dependent.
4. The energy demand model is designed to operate in concert with a comprehensive socio-economic model of the state. It can also be used apart from this model.

The utility of these features lies in the ability of the model to illustrate causes of changes in the growth rate of electricity consumption, to assess alternate scenarios of energy prices, and--when coupled with the OSSIM--to estimate electrical energy requirements based upon self-consistent scenarios of underlying economic activity.

9.3.3 Further Research and Model Development

Development of the energy demand model has illuminated several areas of insufficient data, questions requiring additional research, and concepts whose incorporation would enhance the realism and usefulness of the Oregon State Simulation Model.

1. Data. Energy consumption and value added data is incomplete for several manufacturing industry groups, especially Primary Metals Industries. The disclosure law prevents the Bureau of the Census from publishing this information, and its acquisition from private sources is necessary.

A more detailed consideration of the Commercial Sector awaits the development of extensive appliance saturation and consumption data. Knowledge of appliance saturations for the Residential Sector should be improved.

Estimates of the various price elasticities of intensiveness applicable to Oregon should be refined, especially those pertaining to the substitution of electric appliances for those powered by fossil fuels.

2. Research. The effect of electrical energy supply shortfalls on manufactured output, employment, and the related synergistic effects can only be realistically included in the simulation following estimation of appropriate production functions. These functions were discussed in Section 5.2.3.

The accuracy of the projections of future base intensiveness depended upon the extent to which electrical energy intensiveness was in equilibrium with energy prices (Section 4.5). Additional quantitative work in this area could lead to improved estimates of this parameter.

3. Model Development. Incorporation into OSSIM of models of electrical energy supply and price determination would complete the feedback loop described in Section 2.1. This is especially important because the price of electricity to ultimate consumers obviously depends upon the kinds of power plants producing it. For example, 1978 Eastern Oregon costs of energy from coal and light water nuclear reactor power plants are about 19.6 and 12.6 mills per KWH,

respectively, at 80 percent plant factor (72); the cost of energy from federally financed hydroelectric stations--which currently provide the bulk of Oregon's electricity--is about 3.0 mills per KWH. Thus electricity price in Oregon will rise not only in accordance with the thermal power plant mix, but also due to the inevitable transition from hydro- to thermal-electric power. Furthermore, the scenarios of Section 9.1 treat the prices of electricity and fossil fuels as if they were independent. Should fossil fueled power plants generate a significant fraction of Oregon's electrical energy, this independence will not exist. Thus the important problem of the determination of a consistent set of energy prices to be used as input to the electrical energy demand model is left for future OSSIM development.

Finally, model application or implementation is a final phase of model development. OSSIM may serve as another tool available to state decision-makers, allowing them to gain additional insight into effects of alternate policies. As a minimum, OSSIM has acted and may continue to act as a common frame of reference for individuals of various disciplines, enhancing their ability to communicate. This alone, could be a meaningful accomplishment; for according to Kenneth Boulding,[18]

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[18] Kenneth E. Boulding, "The Economics of Energy," _The Annals of the American Academy of Political and Social Science_, 410 (November, 1973), p. 126.

". . . the general level of sophistication with which a society views the nature of its problems may be more important than any particular form of organization."

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APPENDICES

APPENDIX I. The Oregon State Simulation Model: Component Descriptions

A. Economic Component

The economic component contains four sectors: agriculture and food products, logging and wood products, manufacturing, and services. A component "bookkeeping" routine performs the tasks of summing up total labor demands by occupational category, comparing this demand with the labor force supplied from the demographic component, and computing unemployment rates and resulting wage rates. The economic component avoids reliance on exogenous variables by incorporating assumptions concerning fundamental natural and human resource bases that both support and limit regional production. The four sectors are discussed below.

Agriculture and food products sector. The agriculture and food products sector is viewed as depending on a natural resource base. Agricultural land and the capital stock associated with that land are assumed to be the key factors of agricultural production. Operating expenses, labor costs, taxes, and interest are deducted from the calculated value of gross production to determine net returns. A deferred annual capital gain, based on the increase in speculative value of agricultural land, is added to net returns and the sum forms the basis for capital formation in agriculture. The sector also accounts for all value added by primary processing of farm products and for the fisheries industry. Capital/output and labor/output ratios are used to determine requirements for food processing capital and labor in three occupational categories.

Logging and wood products sector. The level of logging activity is assumed to depend, over the long run, entirely on the resource base of mature and growing timber and its management. Very detailed projections of the annual sawtimber yields over the next one hundred years have been made by the U.S. Forest Service, and have been built into the model as exogenous information. Several different projections are supplied for each subregion, depending on the policy choices concerning rotation period and management intensity. While the actual annual cuts will vary from the projected yeild because of the short-run cyclical nature of the sector, these variances are assumed to have little long-run effect. This assumption can be checked by introducing pseudo-random variations on the projection. The annual sawtimber yield is then distributed among three wood products industry activities: production of lumber, plywood, and pulp and paper. The raw material inputs to each of these are calculated from the annual sawtimber projection by applying factors which apportion the board feet of sawtimber to lumber and veneer, and which give the volume of residues and small roundwood available for pulp and paper. The levels of capital stock in logging and in each wood product industry are updated by applying capital/output ratios to the input volumes and comparing the resulting needed levels with depreciated levels from the previous year. Labor/output ratios are used to determine the labor demand in each of the three occupational categories and value added by each wood product industry is estimated.

Manufacturing Sector. The manufacturing sector currently represents the 16 non-resource-based two-digit SIC manufacturing industry groups. Demands for manufactured goods from other sectors of the economic component are added to the export demand and the sum compared to current output. Any excess demand drives capital formation in the sector via a capital/output ratio which is a function of the rate of technical progress. Desired investment in new capital is determined by the smoothed excess demand for capital and a subsequent delay called the "excess demand closure time." Labor availability, state average industrial electricity price versus average external electricity price, and environmental standards influence the length of this closure time. A capital installation delay then accounts for the time between ordering and utilizing manufacturing plant and equipment. Total output and value added by the manufacturing sector is a function of the level of installed capital, and labor requirements in three skill categories are determined with the use of appropriate labor/output ratios.

Service Sector. The service sector accounts for all business and household services, including wholesale and retail trade, transportation, utilities, construction and financial, health care, educational and government services. The regional inter-industry demand is computed from the output of the other three sectors using technical input/output coefficients. Final demand is calculated as a function of household income, tourism, investment in the basic sectors, and government revenue. Inter-industry and final demands are then summed to provide the total regional demand for services. A "regional shift matrix" is employed to determine the regional breakdown of the supply of services, with some being imported from outside Oregon. As with the other sectors, value added, employment, and capital requirements are determined by applying appropriate ratios to the output.

B. Demographic Component

The demographic component provides a detailed accounting of the population of each region of Oregon, resolved into nine household size classes, two fertility classes, and two socio-economic strata. Numbers of households, rather than of individuals, are the principal variables since the household is the more significant unit for economic and energy considerations. This choice is a major departure from previous simulation models, which typically have used a standard age-cohort type of demographic analysis and projection.

The component traces the "life cycle" of households from formation to extinction. The major driving forces are the class-specific birth rates, which implicitly determine the age distribution within households and hence the fecundity and rates of maturation. These birth rates are modeled dependent upon economic expectations through the regional unemployment rate, and upon socio-economic stratum (a determinant of effectiveness of family planning). The dynamics of socio-economic stratification are modeled as processes of upward and downward diffusion between "marginal" and "mainstream" household classes.

A second driving force affecting Oregon's demographic characteristics is migration, which is modeled with two different types of relationships for three different age groups (age of head of household). Net migration in the age groups 15-29 and 30-44 is assumed to be sensitive to employment opportunity in the region, as measured by the unemployment rate, and to the social size of the region, as measured by its population. Only the parameters are different for these two age groups. The age group 45+ is assumed to continue a net inmigration to Oregon at a rate which depends on the number of such households already in Oregon. In addition, a joint distribution of households by income and family size is generated using wage income information supplied by the economic component. Other major outputs from the demographic component are: (1) the regional labor force in three different occupational categories; and (2) the regional demand for housing, and services, both of which are computed as functions of the household size and income distribution.

C. Land Use Component

The land use component maintains a current inventory of the land (by region) in each of eight use categories, and simulates the dynamic processes which result in transitions between categories. The demand for residential land in three density classes is driven by the demographic component. The housing demand is a function of household size and income, the price of land and housing, the cost of providing services to the land, and the residential density. Changes in the housing stock required to meet the changing demand are calculated, with appropriate adjustments for replacement and vacancies.

Agricultural land is the principal source of land entering the residential use category. Transfers of land to or from the forest land, "open space," or unused categories is permitted as a user-supplied scenario. The number of acres of land available for agricultural production is supplied to the agricultural sector of the economic component, where it is a factor of production.

The forest land use category accounts for all land upon which commercially harvestable timber is growing. Land transfer to or from the forest use category may involve agricultural land, "wilderness" land or unused land. The number of acres of forest land is supplied to the forestry and wood products sector of the economic component, where it influences the annual sawtimber yield. The industrial/commercial land use category responds to demands generated by the level of activity in the industrial and service sectors of the economic component, with agricultural and high density residential land acting as the sources. The open space/wilderness use category enables the model user to set aside agricultural/forest land in a preservation status. Unused land is that area of each region which does not qualify for one of the other seven use categories (a residual). The process of speculation in the land market is also modeled, and the deferred annual capital gain resulting from rising values of agricultural land (if any) influences capital formation in the agricultural sector of the economic component.

D. Pollution Component

The pollution component translates levels of polluting activities (e.g., transportation, manufacturing, space heating) furnished by other components of the model into rates of discharge of air pollutants (presently fine particulate and SO_x). The essence of the pollution component is contained in the following simplified equation:

$$\begin{bmatrix}\text{Rate of}\\ \text{emission}\\ \text{of pollutants}\\ \text{(g/sec)}\end{bmatrix} = \begin{bmatrix}\text{Level of}\\ \text{polluting activity}\\ \text{(e.g. vehicle miles}\\ \text{driven per year)}\end{bmatrix} \times \begin{bmatrix}\text{Emission Intensity}\\ \text{(g/sec of}\\ \text{pollutant per}\\ \text{vehicle mile)}\end{bmatrix} \times \begin{bmatrix}\text{Emission Intensity}\\ \text{Ratio (ratio of}\\ \text{emission intensity}\\ \text{in current year to}\\ \text{that in base year)}\end{bmatrix}$$

Thus, the level and emission intensity of various polluting activities in conjunction with the control strategy for that category of sources (as reflected in the emission intensity ratio) determine rate of pollutant emissions in that source category. When the emissions by each source category are added together, the impact of a particular emission control strategy on the aggregate emissions can be assessed.

The air quality management model consists of an atmospheric dispersion model, a pollution source location and specification game, and a method for focusing OSSIM down on a smaller study area (such as the Portland metropolitan area). This model will be used to assess the impact of alternative courses of action (economic development strategies, emission control strategies, etc.) on air quality in the study area.

E. Government Revenue Component

The function of the government revenue component is to translate certain output variables of the demographic, economic, and transportation components into the common language of tax dollars, with reference to three important taxes collected at the state level. The joint distribution of households by size and family income, generated in the demographic component, provides the basis for the state personal income tax revenue calculation. Corporate income tax revenue is projected on the basis of output values originating in each sector of the economic component. The assumption is that this tax can be approximated as a fraction of value added for each sector, utilizing empirically determined multipliers. Finally, the level of transportation activity, determined in the transportation component, is utilized to project motor vehicle tax revenue. Fuel taxes, registration fees, and the ton mile tax on commercial haulage are summed to form an indication of overall revenue in this class.

F. Transportation Component

The transportation component analyzes transport demand, provides measures of effectiveness of Oregon's transport service and determines the consequences of providing that service. Transportation demand between and within fifteen urban areas, the five largest in each region, is analyzed.

The transportation component allocates to each of the urban areas increments of regional population growth provided by the demographic component. Models of urban travel, intercity passenger travel, and intercity cargo transport estimate the total passenger vehicle miles and cargo ton miles of transport by significant modes. Travel demand and mode selection are influenced by travel time, availability of fuel, and transport costs. Estimates of total transport costs and energy consumption are provided. Vehicle miles of travel and estimates of registered vehicles are passed to the pollution and government revenues components to estimate pollutant emissions and user taxes. Other measures of effectiveness are passed to other components, such as fuel consumption and street and highway mileage to the energy component.

Various policies and actions can be evaluated by changing policy variables or modifying the transportation network. Some major policy variables are fuel availability, fuel costs, user tax rates, maximum speed limits and value of travel time. The concomitant economic and environmental consequences of any policy or action can be investigated.

APPENDIX II. The Electrical Energy Demand Model: Computer Program

The FORTRAN listing of the computer program for the electrical energy demand model of OSSIM follows this brief description. It is important to note that program EDMD may be used apart from OSSIM by providing exogeneous scenarios of economic activity, Y(t), in subroutine DEMAND. Note that the four major socio-economic sectors are numbered one through four and that each consists of a number of subsectors. Here, subsectors correspond to those parts of the major sectors for which a separate electrical energy intensiveness is calculated; they are referred to by the index K.

Electrical energy demand is calculated on a yearly basis. However, subroutine DELAY is capable of dividing each year into smaller intervals so that delayed price effects are accurately represented even if the average delay is assumed to be as small as one year. Although delays of any order may be simulated, it is felt that a first order delay best represents available data.

For each subsector K the following input information must be provided:

I. Data Inputs

A. Economic parameters

1. Five price elasticities of intensiveness; one representing

conservation and four representing interfuel substitution.

2. Five energy prices corresponding to the lowest price at which each of the above elasticities is applicable.

B. Technical characteristics

1. The maximum fractional change in electrical energy intensiveness deemed possible due to electricity conservation and substitution of gas for electricity, petroleum for electricity, electricity for gas, and electricity for petroleum.

2. The average delays, in years, characteristic of conservation and interfuel substitution.

II. Policy and Scenario Inputs

A. Electricity, gas, and petroleum prices by year.

B. The non-resource-based manufacturing industrial mix as a function of time.

C. An imposed limit on electrical energy intensiveness. If no limit is imposed, this parameter should be set to infinity.

In keeping with the convention used in presenting other models of OSSIM, a modified Industrial Dynamics diagram for part of the energy model is provided in Figure II-1. The diagram shows the elasticity model, or the price effects function, Fe(p), for each subsector K with base energy intensiveness represented as an auxiliary and economic activity as an exogenous input variable. Not shown in the figure is the link between energy price and capital investment in the Industrial Sector and the appliance saturation and consumption expressions in the Residential Sector.

```
      DEFINE MEMORY
      COMMON T,A(16),KA,NYRS
      COMMON PE(25,50),TE(25,50),PG(25,50),TG(25,50),
     1PP(25,50),TP(25,50)
      COMMON XEC(37),PLXEC(37),DULMEC(37),XEG(37),PLXEG(3
     17),DULMEG(37),XEP(37),PLXEP(37),DULMEP(37),XG(37),
     2PLXG(37),DULMG(37),XP(37),PLXP(37),DULMP(37)
      COMMON DELC(37),ORDERC(37),SUBDTC(37),DELS(37),
     1ORDERS(37),SUBDTS(37)
      COMMON TULIM(25),UELIM(25)
      COMMON DE(10),UE(10),Y(10),UE0(37),FE(37),PET(25),
     1UPE(25),PGT(25),DPG(25),PPT(25),DPP(25)
      COMMON SDLFEC(37),SDLFEG(37),SDLFEP(37),
     1SDLFG(37),SDLFP(37)
      COMMON DLTFEC(37),DLTFEG(37),DLTFEP(37),DLTFG(37),
     1DLTFP(37)
      COMMON DET,DDET,DEC,DDEC,DETR,DDETR,DEI,DDEI,DER
      COMMON DDER,DEC(10),CDE(10)
      COMMON UEJ(16),UEK(13)
      COMMON DEOUT(51,10),CCEOUT(51,10),PCTOUT(51,10),
     1UEOUT(51,10),YOUT(51,10),DETOUT(51),CCTOUT(51)
      COMMON C(13),CLIM(13)
      END

      PROGRAM FOMD
C   CALLS FOLLOWING SUBROUTINES FOR EACH SECTOR ONCE PER YR
C   SECTOR 1 = COMMERCIAL
C   SECTOR 2 = TRANSPORTATION
C   SECTOR 3 = INDUSTRIAL
C   SECTOR 4 = RESIDENTIAL
      INCLUDE MEMORY
      DIMENSION NPE(25),NPG(25),NPP(25)
      NSKTRS=4
C   INPUT CONTROL PARAMETERS
      READ(30,101) NKS,NYRS,IOUT,KTEST,IPVER,KOUT,KA
C   INPUT DATA BY SUBSECTOR
      DO 50 K=1, NKS
      READ(30,102)
C   PRICES
      IF(K.GT.25) GO TO 44
      READ(30,101) NPE(K),NPG(K),NPP(K)
      NPX = NPE(K)
      DO 41 L=1,NPX
41    READ(30,103)TE(K,L),PE(K,L)
      NPX = NPG(K)
      DO 42 L=1,NPX
42    READ(30,103)TG(K,L),PG(K,L)
      NPX  = NPP(K)
      DO 43 L=1,NPX
43    READ(30,103)TP(K,L),PP(K,L)
C   ELASTICITIES
 44   READ(30,104) XEC(K),PLXEC(K),DULMEC(K)
      READ(30,104) XEG(K), PLXEG(K), DULMEG(K)
      READ(30,104) XEP(K), PLXEP(K), DULMEP(K)
      READ(30,104) XG(K), PLXG(K), DULMG(K)
      READ(30,104) XP(K), PLXP(K), DULMP(K)
```

```
C  DELAY PARAMETERS
      READ(30,105) DELC(K),ORDERC(K),SUBDTC(K),DELS(K),
     1ORDERS(K), SUBDTS(K)
C INTENSIVENESS LIMIT POLICY VARIABLES
      IF(K.GT.25)GO TO 50
      READ(30,106) TULIM(K),UELIM(K)
   50 CONTINUE
C  VERIFY INPUT
      WRITE(61,200)
      WRITE(61,201) NKS
      WRITE(61,202) NYRS
      IF(IPVER.EQ.0)GO TO 61
      DO 60 K=1,NKS
      WRITE(61,203) K
      IF(K.GT.25)GO TO 54
      WRITE(61,204)
      NPX = NPE(K)
      DO 51 L=1,NPX
51    WRITE(61,205)TE(K,L),PE(K,L)
      WRITE(61,206)
      NPX = NPG(K)
      DO 52 L=1,NPX
52    WRITE(61,205)TG(K,L),PG(K,L)
      WRITE(61,207)
      NPX=NPP(K)
      DO 53 L=1,NPX
53    WRITE(61,205)TP(K,L),PP(K,L)
   54 WRITE(61,208)
      WRITE(61,209) XEC(K), PLXEC(K), DULMEC(K)
      WRITE(61,210) XEG(K), PLXEG(K), DULMEG(K)
      WRITE(61,211) XEP(K), PLXEP(K), DULMEP(K)
      WRITE(61,212) XG(K),PLXG(K), DULMG(K)
      WRITE(61,213) XP(K), PLXP(K), DULMP(K)
      WRITE(61,214)
      WRITE(61,215) DELC(K), ORDERC(K), SUBDTC(K)
      WRITE(61,216) DELS(K),ORDERS(K),SUBDTS(K)
      IF(K.GT.25)GO TO 60
      WRITE(61,217) TULIM(K),UELIM(K)
   60 CONTINUE
   61 T=0.0
      J=0
      NYRS = NYRS + 1
      DO 999 IYEAR=1,NYRS
      DO 500 ISKTR =1,NSKTRS
 500  CALL DEMAND(ISKTR)
      IF(T.EQ.0.0) GO TO 77
      DET0=DET
      DET=DEC+DETR+DEI+DER
      DDET=((DET-DET0)/DET0)*100.0
      GO TO 78
   77 DET=DEC+DETR+DEI+DER
      DDET=0.0
   78 CALL OUTPUT(IOUT,KTEST)
      J=J+1
      DO 80 K=1,10
      UEOUT(J,K)=UE(K)
```

```
      YOUT(J,K)=Y(K)
      DEOUT(J,K)=DE(K)
      DDEOUT(J,K)=DDE(K)
   80 PCTOUT(J,K)=(DE(K)/DET)*100.0
      DETOUT(J)=DET
      DDTOUT(J)=DDET
      T = T+1.0
  999 CONTINUE
      IF(KOUT.NE.0) CALL OUTSUM
  101 FORMAT(7I4)
 102  FORMAT(1H0)
 103  FORMAT(2F9.4)
 104  FORMAT(3F9.4)
 105  FORMAT(F7.2,2F5.1,F7.2,2F5.1)
 106  FORMAT(F9.4,E11.4)
 200  FORMAT(≠0INPUT DATA≠)
 201  FORMAT(≠0NUMBER OF SUBSECTORS:≠,I4)
 202  FORMAT(≠ SIMULATION TIME, YEARS:≠,I4)
 203  FORMAT(≠1SUBSECTOR NO.≠,I4)
 204  FORMAT(≠      TIME,YR.      ELEC. PRICE≠)
 205  FORMAT(6X,F4.1,8X,F9.4)
 206  FORMAT(≠      TIME,YR.      GAS PRICE≠)
 207  FORMAT(≠      TIME,YR.      PETROL PRICE≠)
 208  FORMAT(≠ PARAMETERS:          ELASTICITY   LOWEST PRICE
     1≠MAX INT. CHANGE≠)
 209  FORMAT(≠ CONSERVE ELEC      ≠,F9.4,6X,F9.4,6X,F9.4)
 210  FORMAT(≠ ELEC TO GAS        ≠,F9.4,6X,F9.4,6X,F9.4)
 211  FORMAT(≠ ELEC TO PETROL     ≠,F9.4,6X,F9.4,6X,F9.4)
 212  FORMAT(≠ GAS TO ELEC        ≠,F9.4,6X,F9.4,6X,F9.4)
 213  FORMAT(≠ PETROL TO ELEC     ≠,F9.4,6X,F9.4,6X,F9.4)
 214  FORMAT(≠                    AVG.DELAY,YR.      ORDER
     1≠NO.SUBINTERVALS≠)
 215  FORMAT(≠ CONSERVATION         ≠,F7.2,9X,F5.1,9X,F5.1)
 216  FORMAT(≠ SUBSTITUTION         ≠,F7.2,9X,F5.1,9X,F5.1)
 217  FORMAT(≠ TIME SWITCH FOR UE LIMIT:≠,F9.4,3X,
     1≠UE LIMIT:≠,E11.4)
      END

      SUBROUTINE DEMAND(ISKTR)
C CALCULATES DEMAND FROM UE AND Y FOR SECTOR ISKTR
      INCLUDE MEMORY
C     COMMON ECSLBR(3,3),TCHWYMI(3),DCHDT(3)
C     COMMON ECAFDVAL(3),ECFVLOGP(3),ECFVLUP(3),ECFVVEF(3)
C     COMMON ECFVPPP(3),ECMVAL(3),UCIRIG(3)
      GO TO (100,200,300,400),ISKTR
  100 CONTINUE
C  COMMERCIAL SECTOR
      K=1
      CALL INTENS(ISKTR,K)
C  WHEN NOT HOOKED TO OSSIM
      Y(K)=567866.0*EXP(0.0242*T)
C  WHEN HOOKED TO OSSIM
C     Y(K)=0.0
C     DO 10 J=1,3
C     DO 10 L=1,3
C 10  Y(K)=Y(K)+ECSLBR(J,L)*0.999965
```

```
      IF(T.EQ.0.0) GO TO 37
      DEO(K)=DE(K)
      DE(K)=UE(K)*Y(K)
      DEC=DE(K)
      DDE(K)=((DE(K)-DEO(K))/DEO(K))*100.0
      DDEC=DDE(K)
      RETURN
   37 DE(K)=UE(K)*Y(K)
      DEC=DE(K)
      DDE(K)=0.0
      DDEC=DDE(K)
      RETURN
  200 CONTINUE
C  TRANSPORTATION SECTOR
      K=2
      CALL INTENS(ISKTR,K)
C  WHEN NOT HOOKED TO OSSIM
      Y(K)=95063.0*EXP(0.0254*T)
C  WHEN HOOKED TO OSSIM
C     Y(K)=0.0
C     DO 20 J=1,3
C  20 Y(K)=Y(K)+TCHWYMI(J)
      IF(T.EQ.0.0) GO TO 38
      DEO(K)=DE(K)
      DE(K)=UE(K)*Y(K)
      DETR=DE(K)
      DDE(K)=((DE(K)-DEO(K))/DEO(K))*100.0
      DDETR=DDE(K)
      RETURN
   38 DE(K)=UE(K)*Y(K)
      DETR=DE(K)
      DDE(K)=0.0
      DDETR=DDE(K)
      RETURN
  300 CONTINUE
C  INDUSTRIAL SECTOR
      DO 310 K=3,5
  310 CALL INTENS(ISKTR,K)
C  RESOURCE-BASED MANUFACTURING
C    WHEN NOT HOOKED TO OSSIM
      Y(3)=260.1E 06*EXP(0.0218*T)
      Y(4)=623.0E 06*EXP(0.005*T)
      Y(5)=185.9E 06*EXP(0.0376*T)
C    WHEN HOOKED TO OSSIM
C     Y(3)=0.0 $ Y(4)=0.0 $ Y(5)=0.0
C     DO 311 J=1,3
C     Y(3)=Y(3)+ECAFDVAL(J)*0.7158*1.086695
C     Y(4)=Y(4)+(ECFVLOGP(J)+ECFVLUP(J)+ECFVVEP(J))*
C    1 .7097*1.371978
C 311 Y(5)=Y(5)+ECFVPPP(J)*0.7782*1.975209
C  NON-RESOURCE-BASED MANUFACTURING
      K=6
      CALL INTENS(ISKTR,K)
C    WHEN NOT HOOKED TO OSSIM
      Y(6)=760.1E 06*EXP(0.0456*T)
C    WHEN HOOKED TO OSSIM
```

```
C       Y(6)=0.0
C       DO 313 J=1,3
C 313 Y(6)=Y(6)+ECMVAL(J)*0.72988*1.0105
C   IRRIGATION
        DO 320 K=7,9
  320   CALL INTENS(ISKTR,K)
C     WHEN NOT HOOKED TO OSSIM
        Y(7)=207447.0*EXP(0.0335*T)
        Y(8)=92400.0*EXP(0.0335*T)
        Y(9)=1219574.0*EXP(0.0335*T)
C     WHEN HOOKED TO OSSIM
C       Y(7)=UCIRIG(1)*0.938771
C       Y(8)=UCIRIG(2)*0.992693
C       Y(9)=UCIRIG(3)*1.010187
        IF(T.EQ.0.0) GO TO 39
        DEI0=DEI
        DEI=0.0
        DO 41 K=3,9
        DE0(K)=DE(K)
        DE(K)=UE(K)*Y(K)
        DDE(K)=((DE(K)-DE0(K))/DE0(K))*100.0
   41   DEI=DEI+DE(K)
        DDEI=((DEI-DEI0)/DEI0)*100.0
        RETURN
   39   DEI=0.0
        DO 40 K=3,9
        DE(K)=UE(K)*Y(K)
        DDE(K)=0.0
   40   DEI=DEI+DE(K)
        DDEI=0.0
        RETURN
  400   CONTINUE
C   RESIDENTIAL SECTOR
        K=10
        CALL INTENS(ISKTR,K)
C   WHEN NOT HOOKED TO OSSIM
        Y(K)=692978.0*EXP(0.0216*T)
C   WHEN HOOKED TO OSSIM
C       Y(K)=0.0
C       DO 50 J=1,3
C  50   Y(K)=Y(K)+DCHDT(J)*0.9405966*1.0019476
        IF(T.EQ.0.0) GO TO 57
        DE0(K)=DE(K)
        DE(K)=UE(K)*Y(K)
        DER=DE(K)
        DDE(K)=((DE(K)-DE0(K))/DE0(K))*100.0
        DDER=DDE(K)
        RETURN
   57   DE(K)=UE(K)*Y(K)
        DER=DE(K)
        DDE(K)=0.0
        DDER=DDE(K)
        RETURN
        END

        SUBROUTINE INTENS(ISKTR,K)
```

```
C  CALCULATES UE FROM UE0 AND FE FOR ≠SUBSECTOR≠ KD
      INCLUDE MEMORY
      KD=K
      IF(K.EQ.6) GO TO 60
      IF(K.EQ.10) GO TO 100
      IF(K.GE.7) GO TO 70
      CALL BASE(ISKTR,K)
      CALL PEFE(K)
      UE(KD)=UE0(K)*FE(K)
      IF(T.GE.TULIM(K).AND.UE(KD).GT.UELIM(K)) UE(KD)=
     1UELIM(K)
      RETURN
   70 CONTINUE
C  IRRIGATION
      KK=K+15
      CALL BASE(ISKTR,KK)
      CALL PEFE(KK)
      UE(KD)=UE0(KK)*FE(KK)
      IF(T.GE.TULIM(KK).AND.UE(KD).GT.UELIM(KK)) UE(KD)=
     1UELIM(KK)
      RETURN
   60 CONTINUE
C  NON-RESOURCE-BASED MANUFACTURING
      A(1)=.03552 $ A(2)=.03329 $ A(3)=.03065 $ A(4)=.09183
      A(5)=.06039 $ A(6)=.01487 $ A(7)=.01013 $ A(8)=.00145
      A(9)=.04697 $ A(10)=.14130 $ A(11)=.08604
      A(12)=.16235 $ A(13)=.11722 $ A(14)=.10380
      A(15)=.03802 $ A(16)=.02618
      UE(6)=0.0
      DO 62 KK=6,21
      CALL BASE(ISKTR,KK)
      CALL PEFE(KK)
      J=KK-5
      UEJ(J)=UE0(KK)*FE(KK)
      IF(T.GE.TULIM(KK).AND.UEJ(J).GT.UELIM(KK)) UEJ(J)=
     1UELIM(KK)
      IF(KK.EQ.6) GO TO 62
      CALL TABLEA(J,T,AT)
      A(J)=AT
   62 UE(6)=UE(6)+UEJ(J)*A(J)
      RETURN
  100 CONTINUE
C  RESIDENTIAL SECTOR
      UE(10)=0.0
      DO 120 KK=25,37
      CALL BASE(ISKTR,KK)
      CALL PEFE(KK)
      J=KK-24
      UEK(J)=UE0(KK)*FE(KK)
      CLIM(J)=C(J)*(1.0+DLTFEC(KK))
      IF(UEK(J).GT.CLIM(J)) UEK(J)=CLIM(J)
  120 UE(10)=UE(10)+UEK(J)
      IF(T.GE.TULIM(25).AND.UE(10).GT.UELIM(25)) UE(10)=
     1UELIM(25)
      RETURN
      END
```

```
      SUBROUTINE BASE(ISKTR,K)
C  PROVIDES BASE ENERGY INTENSIVENESS FUNCTIONS
      INCLUDE MEMORY
      DIMENSION C1(10),C2(10),C3(13),C4(13),S(13)
      GO TO (100,200,300,400),ISKTR
 100  CONTINUE
C  COMMERCIAL SECTOR
      UEQ(K)=10168.+438.75*T
      RETURN
 200  CONTINUE
C  TRANSPORTATION SECTOR
      UEQ(K)=39.2*T+1420.0
      RETURN
 300  CONTINUE
C  INDUSTRIAL SECTOR
      IF(K.GT.21) GO TO 250
      IK=K-2
      GO TO (20,24,26,22,23,25,27,28,29,30,31,32,33,34,35,
     136,37,38,39),IK
  20  UEQ(3)=1.27+0.0435*T     $ RETURN
  24  UEQ(4)=2.81+0.0745*T     $ RETURN
  26  UEQ(5)=10.00+0.11*T      $ RETURN
  22  UEQ(6)=3.32+0.034*T      $ RETURN
  23  UEQ(7)=0.52+0.022*T      $ RETURN
  25  UEQ(8)=0.96+0.017*T      $ RETURN
  27  UEQ(9)=0.73+0.0265*T     $ RETURN
  28  UEQ(10)=12.00            $ RETURN
  29  UEQ(11)=1.20             $ RETURN
  30  UEQ(12)=2.09+0.063*T     $ RETURN
  31  UEQ(13)=1.0+0.0675*T     $ RETURN
  32  UEQ(14)=3.55+0.0415*T    $ RETURN
  33  UEQ(15)=50.0             $ RETURN
  34  UEQ(16)=1.49+0.0335*T    $ RETURN
  35  UEQ(17)=1.01+0.033*T     $ RETURN
  36  UEQ(18)=1.24+0.038*T     $ RETURN
  37  UEQ(19)=1.12+0.022*T     $ RETURN
  38  UEQ(20)=0.71+0.0145*T    $ RETURN
  39  UEQ(21)=1.01+0.02825*T   $ RETURN
 250  IIK=K-21
      GO TO (11,12,13), IIK
  11  UEQ(22)=226.0                        $ RETURN
  12  UEQ(23)=106.6                        $ RETURN
  13  UEQ(24)=276.0522+27.60522*T          $ RETURN
 400  CONTINUE
C  RESIDENTIAL SECTOR
C    1=SP.HT., 2=RM.AC, 3=CN.AC, 4=WAT.HT., 5=RANGE
C    6=DRYER, 7=FREEZER, 8=DISHW., 9=TV-BW, 10=TV-CLR.
C    11=REFRIG., 12=LIGHTING, 13=MISC.
      C1(1)=15.2  $  C1(2)=130.0  $  C1(3)=88.0
      C1(4)=0.398 $  C1(5)=0.927  $  C1(6)=1.93
      C1(7)=3.73  $  C1(8)=28.8   $  C1(9)=2.33
      C1(10)=42.0
      C2(1)=0.0932  $  C2(2)=0.1198  $  C2(3)=0.0534
      C2(4)=0.0339  $  C2(5)=0.0907  $  C2(6)=0.0565
      C2(7)=0.0586  $  C2(8)=0.1315  $  C2(9)=0.1773
```

```
      C2(10)=0.1575
      C3(1)=10367.   $   C3(2)=1389.   $   C3(3)=3600.
      C3(4)=4290.    $   C3(5)=1175.   $   C3(6)=1000.
      C3(7)=1220.    $   C3(8)=400.    $   C3(9)=362.
      C3(10)=500.    $   C3(11)=1150.  $   C3(12)=675.
      C3(13)=200.
      C4(1)=0.      $   C4(2)=0.      $   C4(3)=0.
      C4(4)=20.     $   C4(5)=0.      $   C4(6)=8.
      C4(7)=20.     $   C4(8)=2.      $   C4(9)=0.
      C4(10)=5.     $   C4(11)=25.    $   C4(12)=0.
      C4(13)=100.
      IK=K-24
      IF(IK.LE.10) GO TO 10
      S(IK)=1.0
      GO TO 201
   10 S(IK)=1.0/(1.0+C1(IK)*EXP(-1.0*C2(IK)*(T+20.)))
  201 C(IK)=C3(IK)+C4(IK)*T
      UEG(K)=C(IK)*S(IK)
      RETURN
      END

      SUBROUTINE PEFE(K)
C PROVIDES CURRENT VALUE OF PRICE EFFECTS MULTIPLIER FOR K
      INCLUDE MEMORY
      DIMENSION DLTFECI(37,5),DLTFEGI(37,5),DLTFEPI(37,5),
     1DLTFGI(37,5),DLTFPI(37,5),FT(37),FT0(37)
      IF(T.NE.0.0) GO TO 100
C INITIAL CONDITIONS
      SDLFEC(K)=0.0 $ SDLFEG(K)=0.0 $ SDLFEP(K)=0.0
      SDLFG(K)=0.0 $ SDLFF(K)=0.0 $ FT(K)=1.0
      FT0(K)=FT(K)
C OBTAIN CURRENT PERCENT DP/P * ELASTICITY
  100 CONTINUE
      CALL PRICES(K,GTEC,GTEG,GTEP,GTG,GTP)
C INPUT,ELECTRICITY CONSERVATION
      DFEC=GTEC
      DLFEC=FT(K)*DFEC
      TEMP1=SDLFEC(K)
      SDLFEC(K)=SDLFEC(K)+DLFEC
      IF(SDLFEC(K).GE.DULMEC(K)) GO TO 31
      DLFEC=DULMEC(K)-TEMP1
      DFEC=DLFEC/FT(K)
      SDLFEC(K)=DULMEC(K)
C  INPUT, OUT-SUBST ELEC TO GAS
   31 DFEG=GTEG
      DLFEG=FT(K)*DFEG
      TEMP1=SDLFEG(K)
      SDLFEG(K)=SDLFEG(K)+DLFEG
      IF(SDLFEG(K).GE.DULMEG(K)) GO TO 32
      DLFEG=DULMEG(K)-TEMP1
      DFEG=DLFEG/FT(K)
      SDLFEG(K)=DULMEG(K)
C  INPUT, OUT-SUBST ELEC TO PETROL
   32 DFEP=GTEP
      DLFEP=FT(K)*DFEP
      TEMP1=SDLFEP(K)
```

```
      SDLFEP(K)=SDLFEP(K)+DLFEP
      IF(SDLFEP(K).GE.DULMEP(K)) GO TO 33
      DLFEP=DULMEP(K)-TEMP1
      DFEP=DLFEP/FT(K)
      SDLFEP(K)=DULMEP(K)
C  INPUT, IN-SUBST GAS TO ELEC
   33 DFG=GTG
      DLFG=FT(K)*DFG
      TEMP1=SDLFG(K)
      SDLFG(K)=SDLFG(K)+DLFG
      IF(SDLFG(K).LE.DULMG(K)) GO TO 34
      DLFG=DULMG(K)-TEMP1
      DFG=DLFG/FT(K)
      SDLFG(K)=DULMG(K)
C  INPUT, IN-SUBST PETROL TC ELEC
   34 DFP=GTP
      DLFP=FT(K)*DFP
      TEMP1=SDLFP(K)
      SDLFP(K)=SDLFP(K)+DLFP
      IF(SDLFP(K).LE.DULMP(K)) GO TO 35
      DLFP=DULMP(K)-TEMP1
      DFP=DLFP/FT(K)
      SDLFP(K)=DULMP(K)
   35 CONTINUE
      IF(T.NE.0.0) GO TO 200
C EQUILIBRIUM INITIAL CONDITION
      DLTFEC(K)=SDLFEC(K) $ DLTFEG(K)=SDLFEG(K)
      DLTFEP(K)=SDLFEP(K) $ DLTFG(K)=SDLFG(K)
      DLTFP(K)=SDLFP(K)
C INITIAL CONDITIONS FOR DELAYS OF ORDER .GT. 1
      IOC=ORDERC(K) $ IOS=ORDERS(K)
      DO 11 L=1,IOC
   11 DLTFECI(K,L)=DLTFEC(K)/SUBDTC(K)
      DO 12 L=1,IOS
      DLTFEGI(K,L)=DLTFEG(K)/SUBDTS(K)
      DLTFEPI(K,L)=DLTFEP(K)/SUBDTS(K)
      DLTFGI(K,L)=DLTFG(K)/SUBDTS(K)
   12 DLTFPI(K,L)=DLTFP(K)/SUBDTS(K)
  200 CONTINUE
C TIME DEPENDENT PRICE EFFECTS
      CALL DELAY(SDLFEC(K),DLTFEC(K),DLTFECI(K),DELC(K),
     1ORDERC(K),SUBDTC(K))
      CALL DELAY(SDLFEG(K),DLTFEG(K),DLTFEGI(K),DELS(K),
     1ORDERS(K),SUBDTS(K))
      CALL DELAY(SDLFEP(K),DLTFEP(K),DLTFEPI(K),DELS(K),
     1ORDERS(K),SUBDTS(K))
      CALL DELAY(SDLFG(K),DLTFG(K),DLTFGI(K),DELS(K),
     1ORDERS(K),SUBDTS(K))
      CALL DELAY(SDLFP(K),DLTFP(K),DLTFPI(K),DELS(K),
     1ORDERS(K),SUBDTS(K))
C SUM OF PRICE EFFECTS
      DFT=DFEC+DFEG+DFEP+DFG+DFP
      DLFT=FT(K)*DFT
      FT(K)=FT(K)+DLFT
      FE(K) =FTG(K)+DLTFEC(K)+DLTFEG(K)+DLTFEP(K)+DLTFG(K)
     1+DLTFP(K)
```

```
      RETURN
      END
      SUBROUTINE PRICES(K,GTEC,GTEG,GTEP,GTG,GTP)
C PROVIDES CURRENT PRICE, FRACTIONAL CHANGE IN PRICE, AND
C (FRACTIONAL  CHANGE)*ELASTICITY FOR EACH SUBSECTOR
      INCLUDE MEMORY
      DIMENSION NPE(25),NPG(25),NPP(25)
      J=K
      IF(K.GT.25) J=25
C ELECTRICITY PRICE
      IF(K.GT.25) GO TO 135
      IF(T.NE.0.0) GO TO 110
      PET(J)=PE(J,1)
      NPE(J)=2
      GO TO 130
 110  L=NPE(J)
      LO=L-1
      IF(T.GE.TE(J,L)) GO TO 120
      PET(J)=PE(J,LO)
      GO TO 130
 120  PET(J)=PE(J,L)
      DPE(J)=(PE(J,L)-PE(J,LO))/PE(J,LO)
      NPE(J)=NPE(J)+1
      GO TO 135
 130  DPE(J)=0.0
 135  IF(DPE(J).LT.0.0) GO TO 140
      IF(PET(J).LT.PLXEC(K).OR.SOLFEC(K).LE.DULMEC(K))GO
     1TO 140 $ GTEC=XEC(K)*DPE(J)
      GO TO 150
 140  GTEC=0.0
 150  IF(PET(J).LT.PLXEG(K).OR.SOLFEG(K).LE.DULMEG(K))GO
     1TO 160 $ GTEG=XEG(K)*DPE(J)
      GO TO 170
 160  GTEG=0.0
 170  IF(PET(J).LT.PLXEP(K).OR.SOLFEP(K).LE.DULMEP(K))GO
     1TO 180 $ GTEP=XEP(K)*DPE(J)
      GO TO 200
 180  GTEP=0.0
 200  CONTINUE
C GAS PRICE
      IF(K.GT.25) GO TO 235
      IF(T.NE.0.0) GO TO 210
      PGT(J)=PG(J,1)
      NPG(J)=2
      GO  TO 230
 210  L=NPG(J)
      LO=L-1
      IF(T.GE.TG(J,L)) GO TO 220
      PGT(J)=PG(J,LO)
      GO TO 230
 220  PGT(J)=PG(J,L)
      DPG(J)=(PG(J,L)-PG(J,LO))/PG(J,LO)
      NPG(J)=NPG(J)+1
      GO TO 235
 230  DPG(J)=0.0
```

```
 235   IF(PGT(J).LT.PLXG(K).OR.SDLFG(K).GE.DULMG(K))GO
      1TO 240 $ GTG=XG(K)*DPG(J)
       GO TO 300
 240   GTG=0.0
 300   CONTINUE
C PETROL PRICE
       IF(K.GT.25) GO TO 335
       IF(T.NE.0.0) GO TO 310
       PPT(J)=PP(J,1)
       NPP(J)=2
       GO TO 330
 310   L=NPP(J)
       LO=L-1
       IF(T.GE.TP(J,L)) GO TC 320
       PPT(J)=PP(J,LO)
       GO TO 330
 320   PPT(J)=PP(J,L)
       DPP(J)=(PP(J,L)-PP(J,LO))/PP(J,LO)
       NPP(J)=NPP(J)+1
       GO TO 335
 330   DPP(J)=0.0
 335   IF(PPT(J).LT.PLXP(K).OR.SDLFP(K).GE.DULMP(K))GO
      1TO 340 $ GTP=XP(K)*DPP(J)
       GO TO 400
 340   GTP=0.0
 400   CONTINUE
       RETURN
       END

       SUBROUTINE DELAY(YIN,YOUT,YOUTI,DEL,ORDER,SUBDT)
       DIMENSION YOUTI(5)
       FACTOR=ORDER/(DEL*SUBDT)
       YOUT=0.0
       IORDER=ORDER
       JORDER=SUBDT
       DO 10 J=1,JORDER
       XIN=YIN/SUBDT
       DO 20 L=1,IORDER
       XOUT=YOUTI(L)
       YOUTI(L)=XOUT+(XIN-XOUT)*FACTOR
  20   XIN=XOUT
  10   YOUT=YOUT+YOUTI(IORDER)
       RETURN
       END

       SUBROUTINE OUTPUT(ICLT,KTEST)
C  SELECTED OUTPUT
       INCLUDE MEMORY
       GO TO (100,200,300,400,500,600), IOUT
 100   CONTINUE
C  OUTPUT FOR TEST OF FE FOR SUBSECTOR KTEST
       K=KTEST
       J=K
       IF(K.GT.25) J=25
       IF(T.NE.0.0) GO TO 50
       WRITE(61,9) K
```

```
      WRITE(61,11)
   50 WRITE(61,21) T,DPE(J),DPG(J),DPP(J),DLTFEC(K),DLT
     1FEG(K),DLTFEP(K),DLTFG(K),DLTFP(K),FE(K)
      RETURN
  200 CONTINUE
C  COMMERCIAL SECTOR
      K=1
      IF(T.NE.0.0) GO TO 51
      WRITE(61,9) K
      WRITE(61,10)
   51 WRITE(61,20) T,FE(K),UE0(K),UE(K),Y(K),DEC,DDEC
      RETURN
  300 CONTINUE
C  TRANSPORTATION SECTOR
      K=2
      IF(T.NE.0.0) GO TO 52
      WRITE(61,9) K
      WRITE(61,10)
   52 WRITE(61,20) T,FE(K),UE0(K),UE(K),Y(K),DETR,DDETR
      RETURN
  400 CONTINUE
C  INDUSTRIAL SECTOR
      K=KTEST
      IF(K.GE.6 .AND. K.LE.21) GO TO 63
      IF(T.NE.0.0)GO TO 53
      WRITE(61,9) K
      WRITE(61,10)
   53 WRITE(61,20) T,FE(K),UE0(K),UE(K),Y(K),DE(K),DDE(K)
      RETURN
   63 IF(T.NE.0.0)GO TO 64
      WRITE(61,9)K
      WRITE(61,13)
   64 J=K-5
      AA=A(J)*100.0
      WRITE(61,22)T,FE(K),UE0(K),UEJ(J),AA,UE(6),Y(6)
      RETURN
  500 CONTINUE
C  RESIDENTIAL SECTOR
      K=KTEST
      IF(T.NE.0.0)GO TO 54
      WRITE(61,9)K
      WRITE(61,14)
   54 J=K-24
      WRITE(61,24)T,FE(K),UE0(K),UEK(J),UE(10),Y(10),
     1DE(10) $ RETURN
  600 CONTINUE
C  DEMAND SUMMARY
      IF(T.NE.0.0) GO TO 55
      WRITE(61,15)
   55 WRITE(61,25)T,DEC,DDEC,DETR,DDETR,DEI,DDEI,DER,DDER,
     1DET,DDET
    9 FORMAT(≠1SUBSECTOR NO.≠,I4)
   10 FORMAT(≠0 YR      FE          UE0            UE           ≠,
     1≠Y                DE        PC CH     ≠,/)
   11 FORMAT(≠0 YR    DPE     DPG      DPP     DFEC     ≠,
     1≠DFEG    DFEP    DFG     DFP      FE≠,/)
```

```
13   FORMAT(≠1 YR      FE       UEJ            UEJ            A  ≠,
    1≠     UE(6)              Y(6)≠,/)
14   FORMAT(≠1 YR      FE        UEC            UEK            UER   ≠,
    1≠            YR             CER≠,/)
15   FORMAT(≠1 YR    DEC       PC       DETR    PC     DEI       ≠,
    1≠PC    DER         PC      CET      PC≠,/)
20   FORMAT(1H ,F4.1,1X,F6.4,1X,E10.4,1X,E10.4,1X,E11
    1.5,1X,E12.6,1X,F5.2)
21   FORMAT(1H ,F4.1,9F7.4)
22   FORMAT(1H ,F4.1,1X,F6.4,1X,E10.4 ,1X,E10.4,1X,F5.1,
    11X,E10.4,1X,F10.4)
24   FORMAT(1H ,F4.1,1X,F6.4,1X,3(E10.4,1X),E11.5,1X,E12
    1.6)
25   FORMAT(1H ,F2.0,1X,2(E8.2,1X,F3.1,1X),2(E9.3,1X,F3.1
    1,1X),E9.3,1X,F3.1)
     RETURN
     END

     SUBROUTINE OUTSUM
C  OUTPUT SUMMARY
     INCLUDE MEMORY
     DO 100 L=1,5
     GO TO (1,2,3,4,5),L
 1   WRITE(61,31)  $  WRITE(61,37)
     KD=1  $  GO TO 90
 2   WRITE(61,32)  $  WRITE(61,37)
     KD=3  $  GO TO 90
 3   WRITE(61,33)  $  WRITE(61,37)
     KD=5  $  GO TO 90
 4   WRITE(61,34)  $  WRITE(61,37)
     KD=7  $  GO TO 90
 5   WRITE(61,35)  $  WRITE(61,37)
     KD=9
90   KD1=KD+1
     DO 99 J=1,NYRS
     JYR=J-1
99   WRITE(61,41) JYR,UEOUT(J,KD),YOUT(J,KD),DEOUT(J,KD),
    1DDEOUT(J,KD),PCTOUT(J,KD),UEOUT(J,KD1),YOUT(J,KD1),
    2DEOUT(J,KD1),DDEOUT(J,KD1),PCTOUT(J,KD1)
100  CONTINUE
     WRITE(61,38)
     DO 101 J=1,NYRS
     JYR=J-1
101  WRITE(61,39)JYR,DETOUT(J),DOTOUT(J)
31   FORMAT(1H1,15X,≠COMMERCIAL SECTOR                    ≠,
    125X,≠TRANSPORTATION SECTOR≠)
32   FORMAT(1H1,15X,≠FOOD PRODUCTS,SIC 20              ≠,
    125X,≠LUMBER+WOOD PRODUCTS,SIC 24≠)
33   FORMAT(1H1,15X,≠PAPER+ALLIED PRODUCTS, SIC 26≠,
    125X,≠NON-RESOURCE-BASED MANUFACTURING≠)
34   FORMAT(1H1,15X,≠IRRIGATION, REGION 1                 ≠,
    125X,≠IRRIGATION, REGION 2≠)
35   FORMAT(1H1,15X,≠IRRIGATION, REGION 3                 ≠,
    125X,≠RESIDENTIAL SECTOR≠)
37   FORMAT(≠0YR    INT,KWH/ECA   EC.ACTIVITY   DEMAND,KWH≠,
    1≠   PC CH    PC         INT,KWH/ECA   EC.ACTIVITY   DEMAND,
```

```
     2≠,≠KWH    PC CH    PC ≠,/)
41    FORMAT(1H ,I2,3X,2(E11.5,2X,E11.5,2X,E11.5,2X,F5.1,
     12X,F4.1,4X))
38    FORMAT(≠1YR   TOT.DEMAND,KWH   PC CHANGE≠,/)
39    FORMAT(1H ,I2,3X,E12.6,5X,F6.2)
      RETURN
      END

      SUBROUTINE TABLEA(J,T,AT)
      DIMENSION A(16,6)
      A(1,1)= .03552 $ A(1,2)= .01827 $ A(1,3)= .01642
      A(1,4)= .01345 $ A(1,5)= .01280 $ A(1,6)= .01027
      A(2,1)= .03329 $ A(2,2)= .02238 $ A(2,3)= .02090
      A(2,4)= .01922 $ A(2,5)= .01813 $ A(2,6)= .01716
      A(3,1)= .03065 $ A(3,2)= .02283 $ A(3,3)= .02090
      A(3,4)= .01922 $ A(3,5)= .01813 $ A(3,6)= .01716
      A(4,1)= .09183 $ A(4,2)= .07534 $ A(4,3)= .07463
      A(4,4)= .07271 $ A(4,5)= .07253 $ A(4,6)= .07231
      A(5,1)= .06039 $ A(5,2)= .05023 $ A(5,3)= .04975
      A(5,4)= .04965 $ A(5,5)= .04906 $ A(5,6)= .04826
      A(6,1)= .01487 $ A(6,2)= .01142 $ A(6,3)= .01045
      A(6,4)= .00961 $ A(6,5)= .00917 $ A(6,6)= .00858
      A(7,1)= .01013 $ A(7,2)= .00913 $ A(7,3)= .01045
      A(7,4)= .01153 $ A(7,5)= .01088 $ A(7,6)= .01027
      A(8,1)= .00145 $ A(8,2)= .00457 $ A(8,3)= .00597
      A(8,4)= .00769 $ A(8,5)= .00917 $ A(8,6)= .00858
      A(9,1)= .04697 $ A(9,2)= .04566 $ A(9,3)= .04129
      A(9,4)= .03812 $ A(9,5)= .03626 $ A(9,6)= .03447
      A(10,1)=.14130 $ A(10,2)=.14155 $ A(10,3)=.11990
      A(10,4)=.10314 $ A(10,5)=.09066 $ A(10,6)=.07921
      A(11,1)=.08604 $ A(11,2)=.11187 $ A(11,3)=.11393
      A(11,4)=.11659 $ A(11,5)=.11796 $ A(11,6)=.11874
      A(12,1)=.16235 $ A(12,2)=.14155 $ A(12,3)=.15323
      A(12,4)=.16240 $ A(12,5)=.16702 $ A(12,6)=.17389
      A(13,1)=.11722 $ A(13,2)=.14840 $ A(13,3)=.16766
      A(13,4)=.18354 $ A(13,5)=.19411 $ A(13,6)=.20653
      A(14,1)=.10380 $ A(14,2)=.15069 $ A(14,3)=.14876
      A(14,4)=.14702 $ A(14,5)=.14697 $ A(14,6)=.14631
      A(15,1)=.03802 $ A(15,2)=.02511 $ A(15,3)=.02488
      A(15,4)=.02498 $ A(15,5)=.02538 $ A(15,6)=.02589
      A(16,1)=.02618 $ A(16,2)=.02055 $ A(16,3)=.02090
      A(16,4)=.02114 $ A(16,5)=.02176 $ A(16,6)=.02237
      IF(T.GE.50.0) GO TO 10
      I=1.0+T/10.
      T1=I-1
      AT=(A(J,I+1)-A(J,I))*(T-T1*10.)/10.+A(J,I)
      RETURN
10    AT=A(J,6)
      RETURN
      END
```

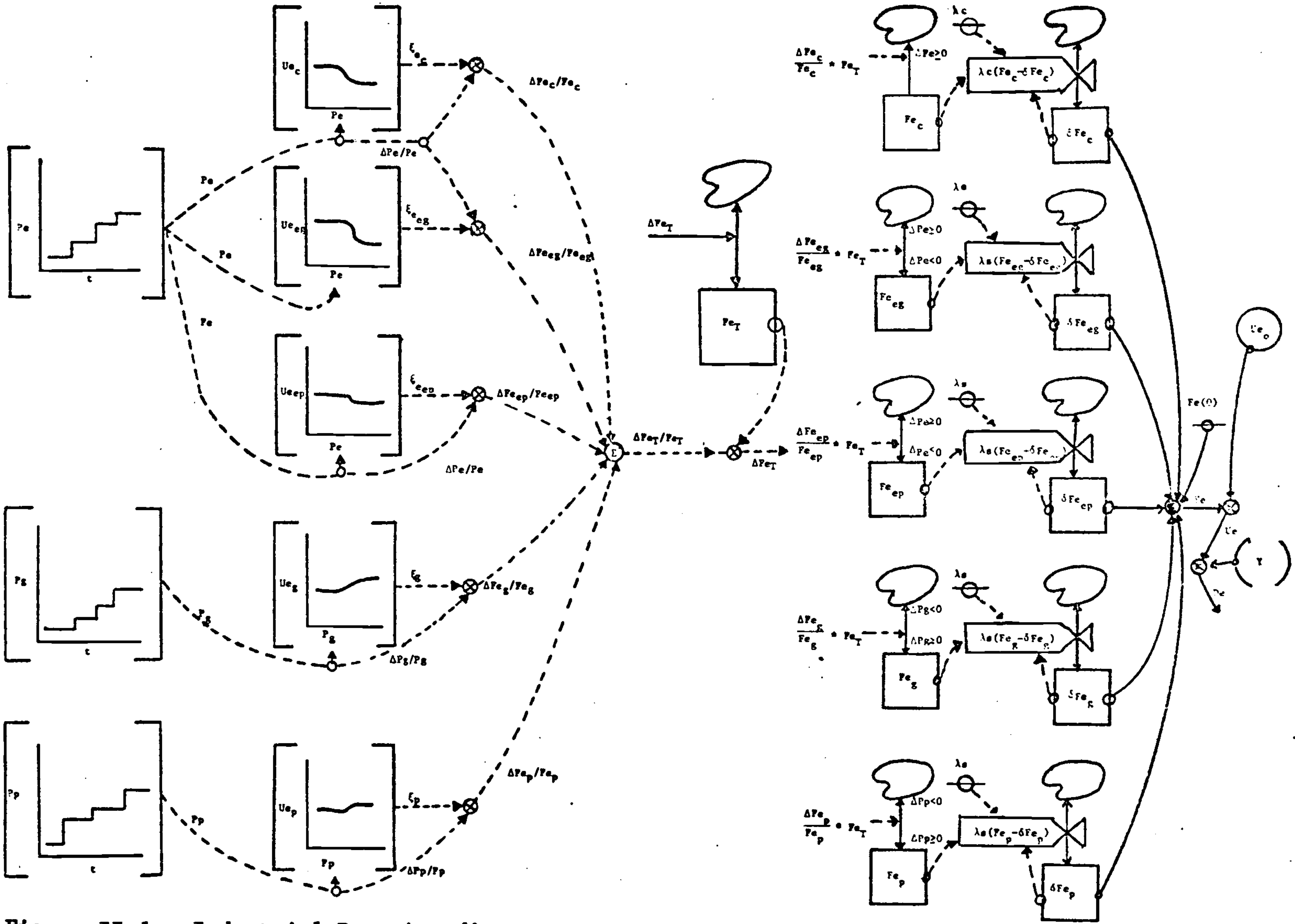


Figure II-1. Industrial Dynamics diagram.

APPENDIX III. Supplementary Tables and Figures

Table III-1. Oregon electrical energy intensiveness, manufacturing (KWH/$VA).

SIC	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
20					0.858				0.968	0.960								
22																		
23																		
24			1.761	1.990	1.892				2.201	2.056								
25									0.749	0.557								
26					7.432				8.841	9.219								
27					0.443													
28					12.487				12.032									
29									1.210	≥0.773								
30																		
31																		
32					2.890				3.219	1.980								
33					34.833				49.357	≥50.599								
34					0.664				0.971	0.612								
35					0.625													
36																		
37																		
38																		
39																		

Table III-2. National electrical energy intensiveness, manufacturing (KWH/$VA).

SIC	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
20	0.952	0.924	0.917	0.890	1.020	1.021	1.028	1.080	1.091	1.097	1.200	1.188	1.251	1.220		1.319	1.588	1.635
21	0.321	0.317	0.295	0.306	0.324	0.306	0.317	0.338	0.241	0.301	0.314	0.358	0.398	0.448		0.456	0.470	0.505
22	2.578	2.518	2.502	2.583	2.641	2.530	2.625	2.669	2.631	2.747	2.791	2.655	2.657	2.926		3.020	3.316	3.355
23	0.175	0.202	0.223	0.220	0.293	0.287	0.292	0.289	0.335	0.348	0.415	0.403	0.387	0.412		0.537	0.616	0.586
24	1.279	1.332	1.339	1.439	1.374	1.392	1.511	1.563	1.596	1.636	1.763	1.795	1.817	1.930		2.472	2.671	2.486
25	0.553	0.534	0.548	0.570	0.620	0.605	0.621	0.647	0.622	0.633	0.691	0.647	0.623	0.679		0.773	0.957	1.002
26	4.369	4.454	4.686	4.835	5.172	5.271	5.558	5.646	5.723	5.690	5.660	5.593	5.552	5.804		6.207	6.564	6.942
27	0.239	0.251	0.248	0.252	0.379	0.383	0.389	0.419	0.432	0.431	0.466	0.455	0.438	0.490		0.590	0.731	0.768
28	5.974	7.617	8.257	8.247	8.154	7.348	7.535	7.509	6.909	6.408	6.159	5.660	5.252	5.407		4.521	4.595	4.864
29	4.040	3.623	3.435	4.033	5.288	4.967	4.735	4.946	5.194	5.196	5.288	5.041	4.435	4.477		5.156	5.786	6.226
30	1.626	1.747	1.703	1.652	1.666	1.600	1.707	1.684	1.523	1.650	1.685	1.669	1.858	1.706		1.888	2.093	2.228
31	0.396	0.399	0.409	0.415	0.409	0.433	0.441	0.475	0.537	0.571	0.544	0.596	0.696	0.682		0.779	0.998	1.025
32	2.577	2.512	2.588	2.770	2.594	2.568	2.701	2.767	2.824	2.789	2.845	2.836	3.196	2.900		3.149	3.501	3.611
33	5.631	5.213	5.503	5.808	6.263	6.395	6.916	7.192	7.266	7.121	7.523	7.244	6.960	8.131		9.202	10.370	10.769
34	0.634	0.675	0.721	0.744	0.774	0.786	0.844	0.871	0.849	0.865	0.972	0.916	0.923	1.008		1.247	1.486	1.440
35	0.526	0.545	0.549	0.601	0.654	0.665	0.714	0.750	0.738	0.750	0.734	0.698	0.675	0.771		0.866	1.011	1.124
36	0.611	0.626	0.678	0.689	0.771	0.776	0.815	0.807	0.831	0.850	0.885	0.898	0.857	0.976		1.102	1.240	1.294
37	0.727	0.723	0.797	0.798	0.893	0.875	0.899	0.938	0.900	0.888	0.928	0.888	0.865	0.948		0.983	1.120	1.077
38	0.425	0.430	0.418	0.436	0.494	0.480	0.498	0.559	0.544	0.586	0.616	0.573	0.551	0.581		0.674	0.710	0.724
39	0.694	0.730	0.711	0.701	0.541	0.576	0.587	0.642	0.667	0.679	0.695	0.685	0.699	0.781		0.878	1.012	1.001

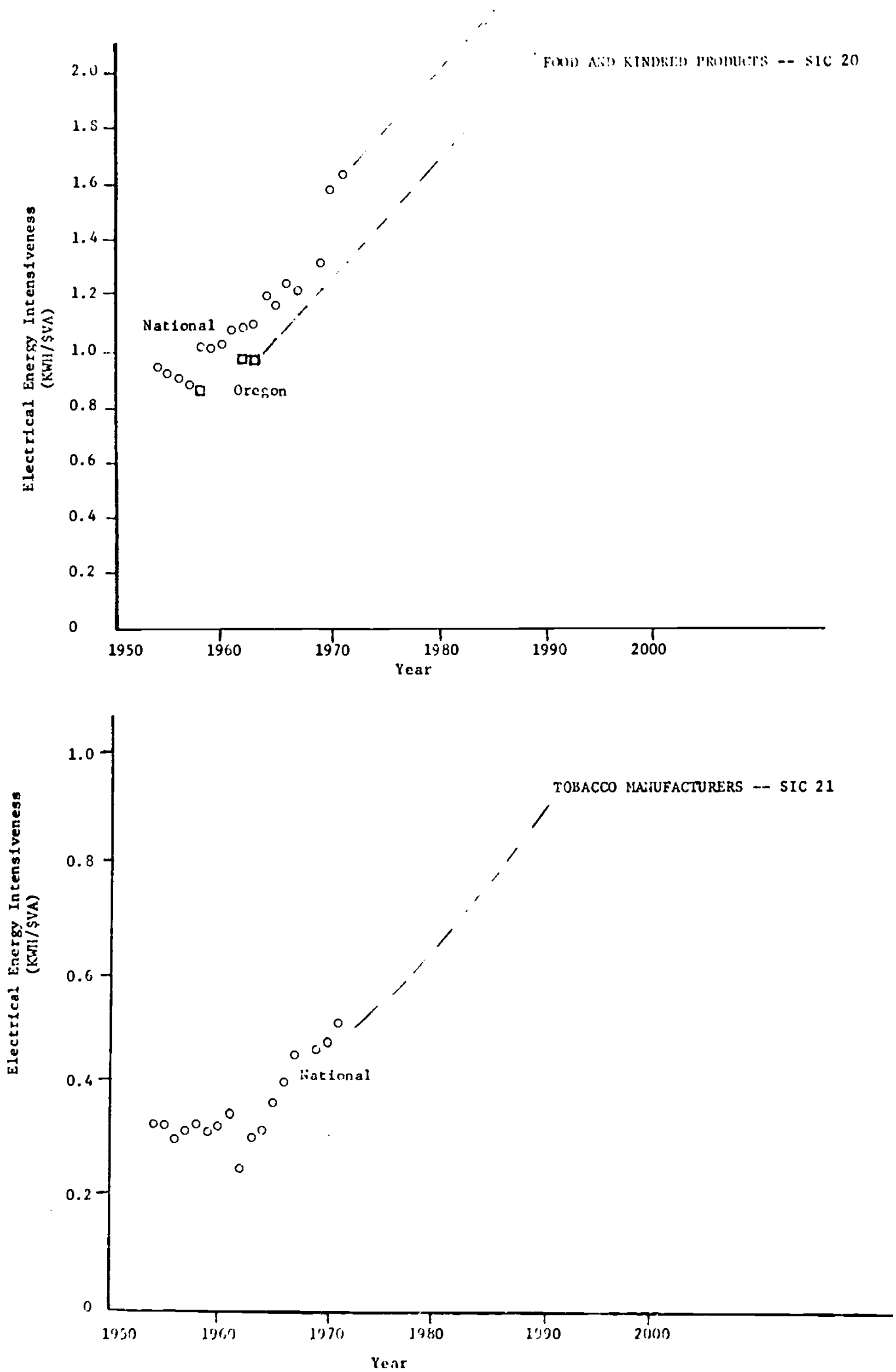
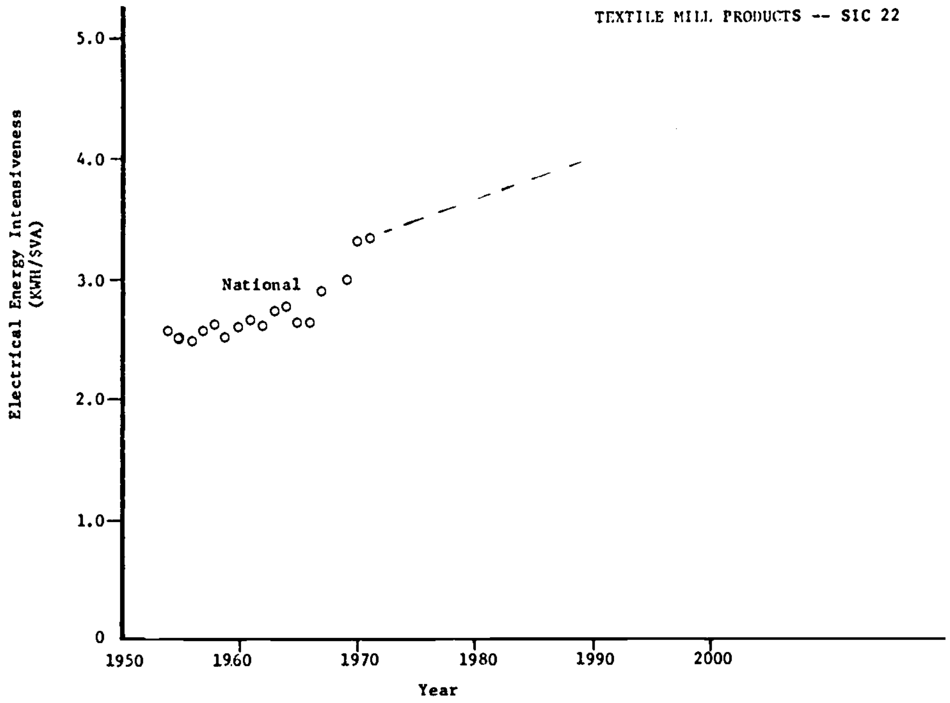


Figure III-1. Electrical energy intensiveness, SIC's 20 and 21.



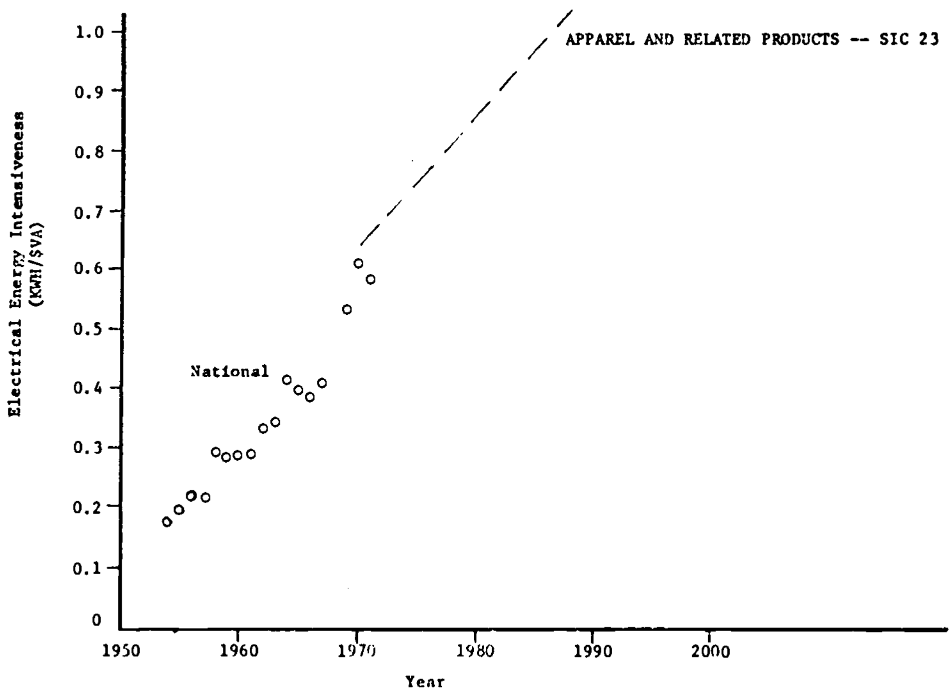
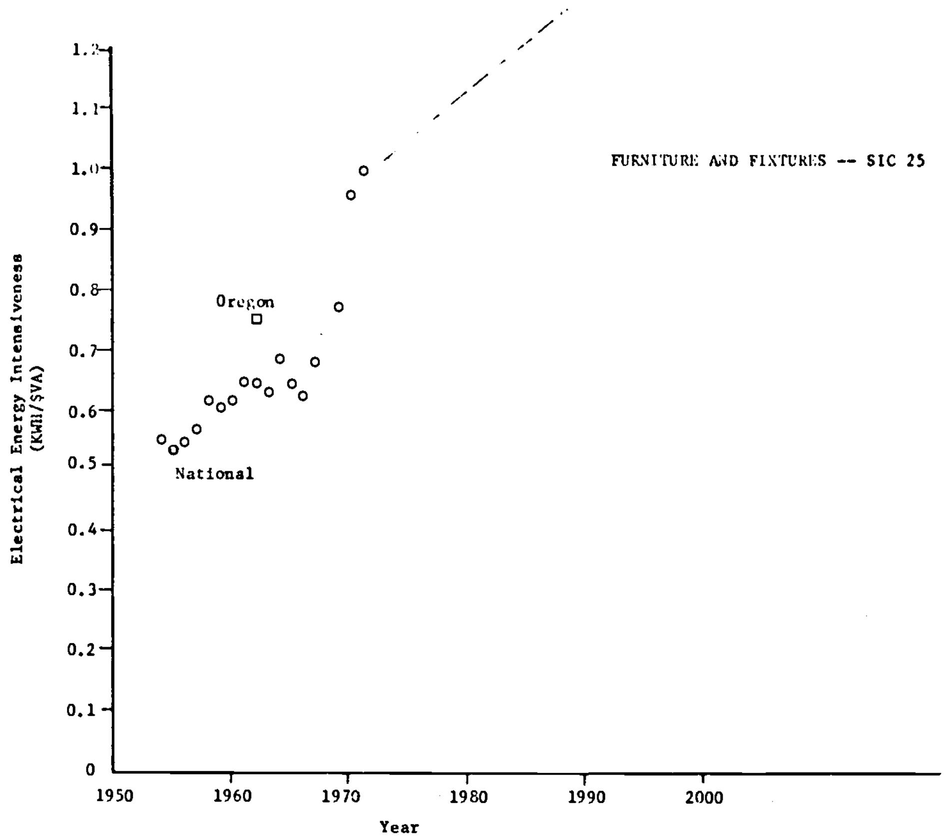


Figure III-2. Electrical energy intensiveness, SIC's 22 and 23.



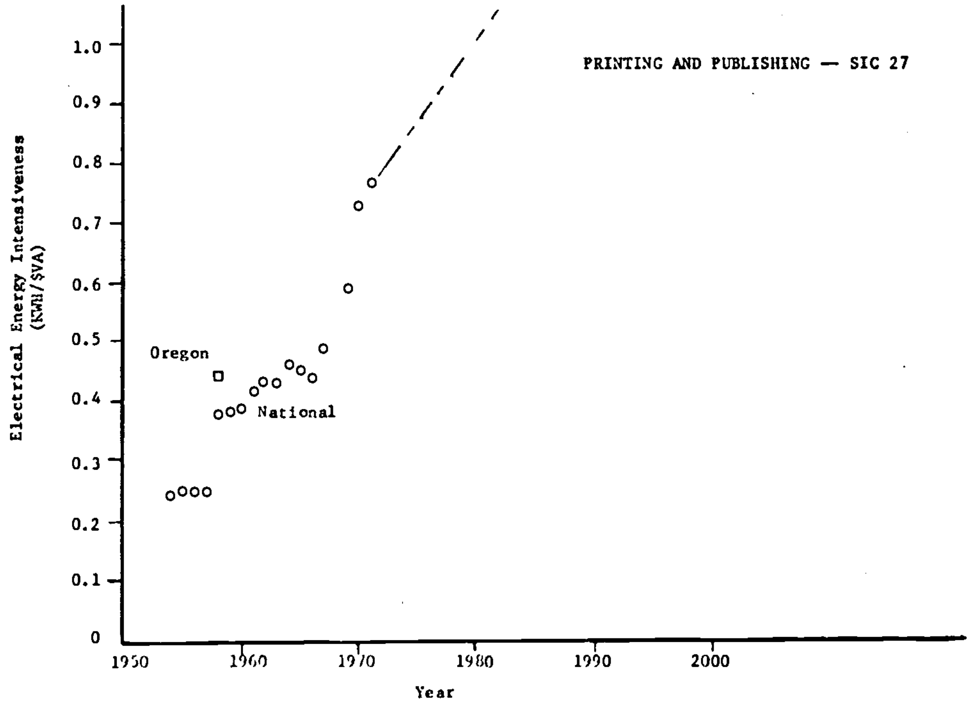
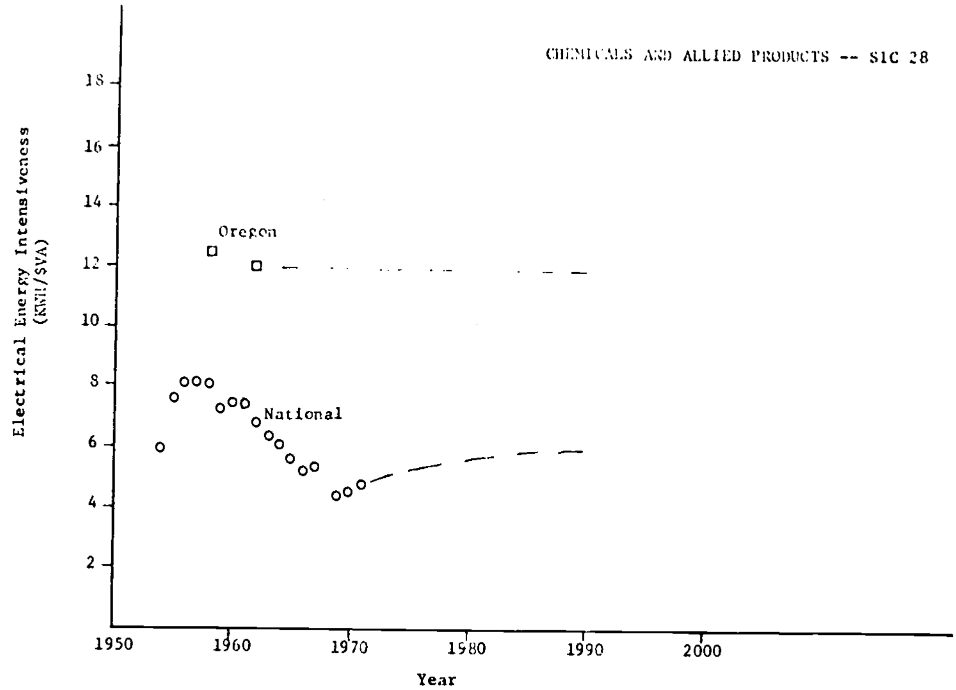


Figure III-3. Electrical energy intensiveness, SIC's 25 and 27.



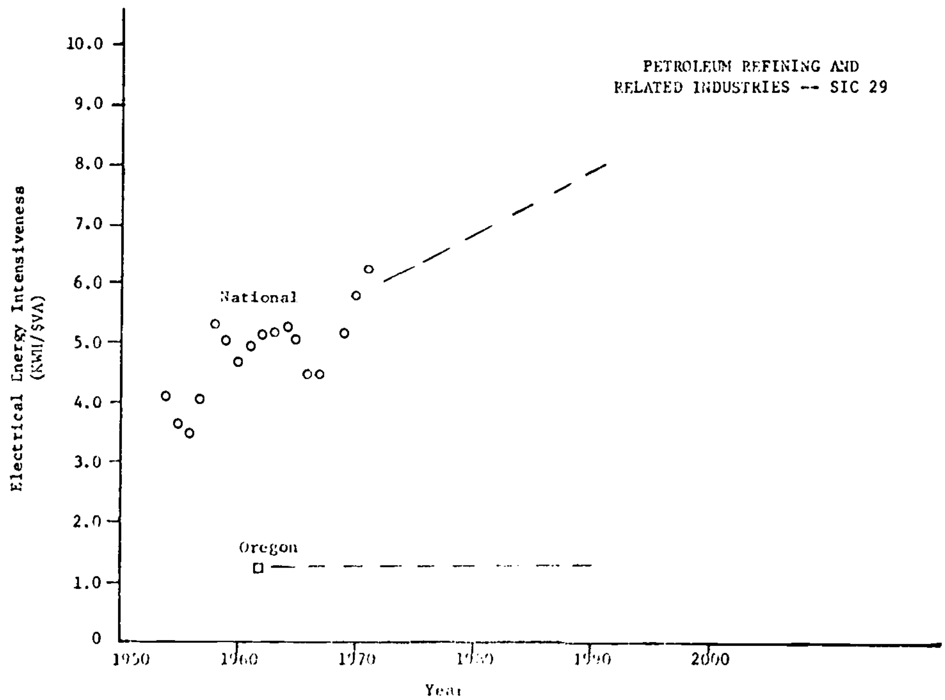
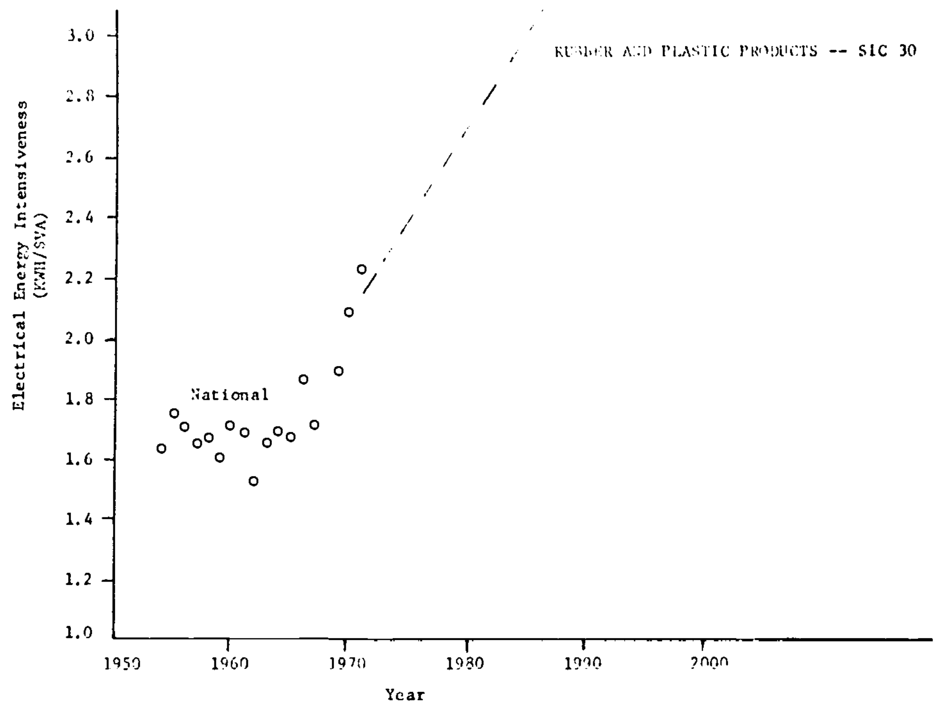


Figure III-4. Electrical energy intensiveness, SIC's 28 and 29.



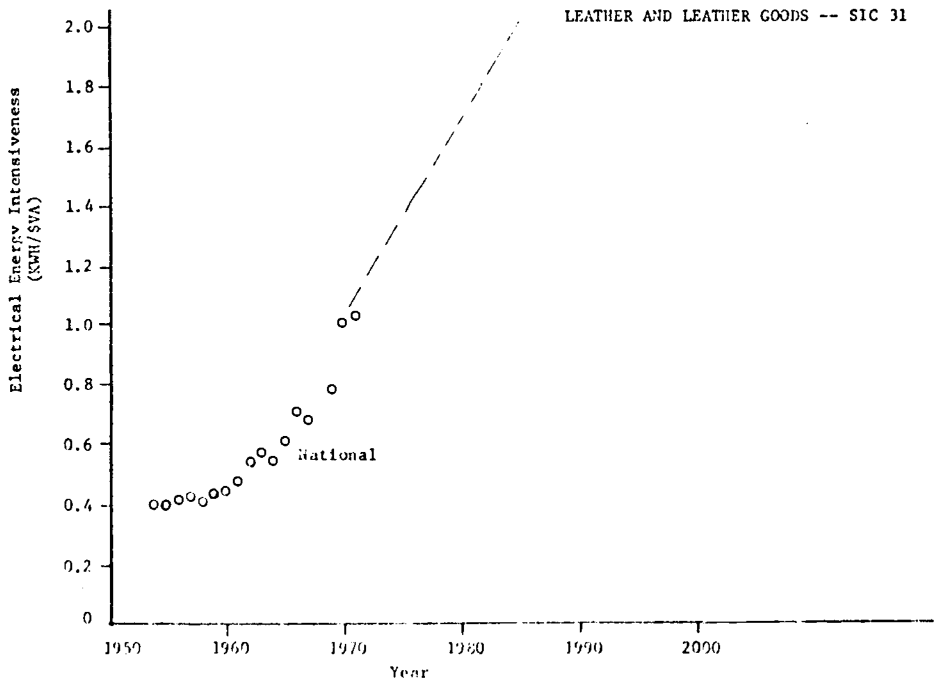
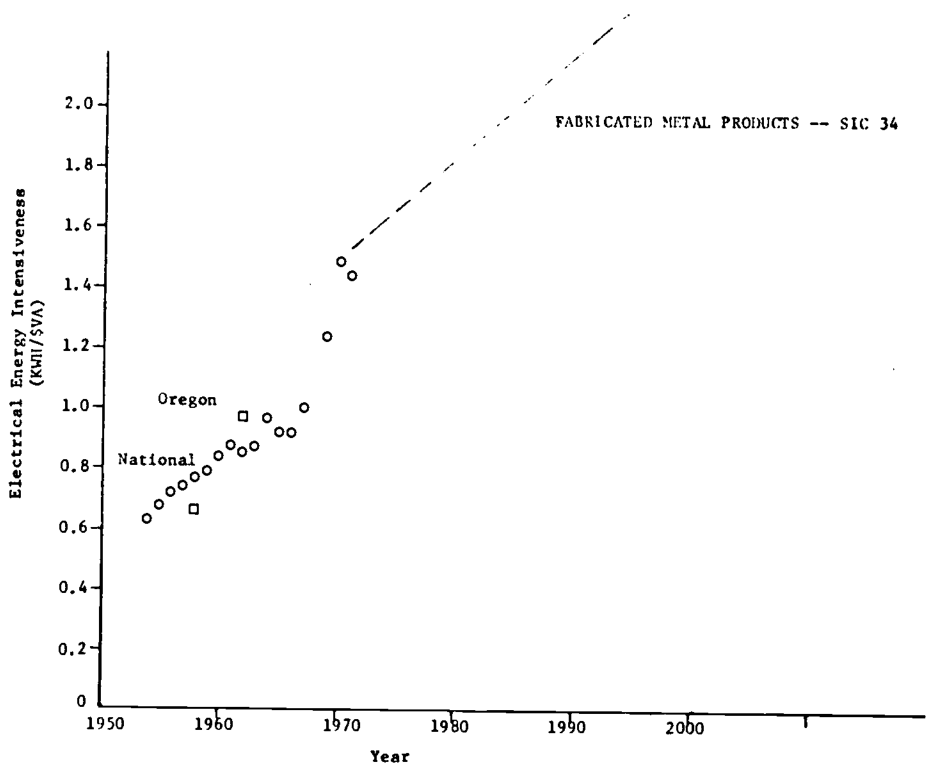


Figure III-5. Electrical energy intensiveness, SIC's 30 and 31.



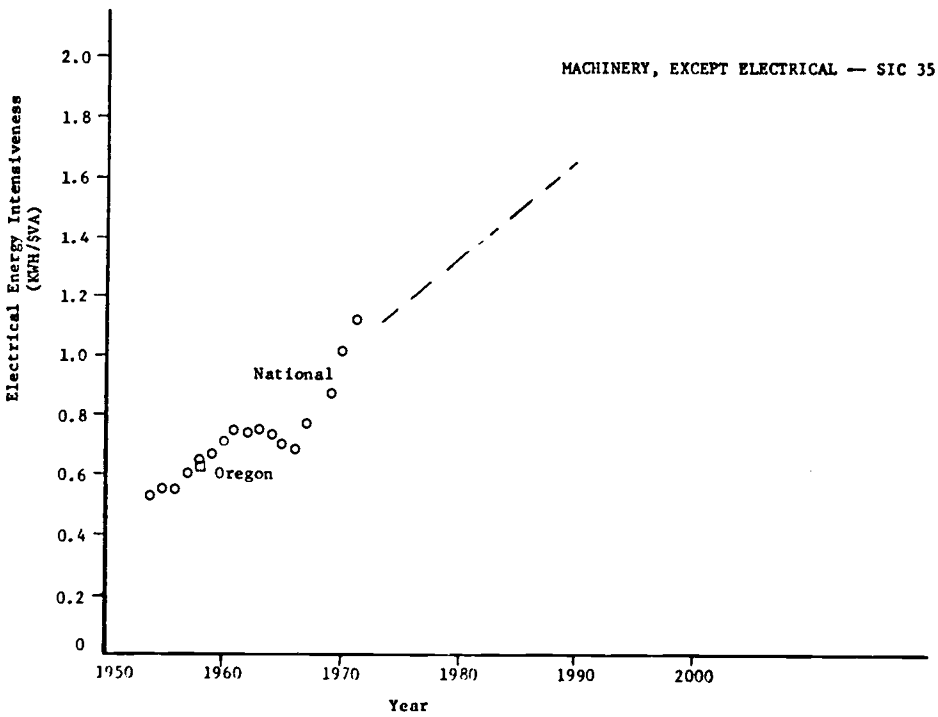
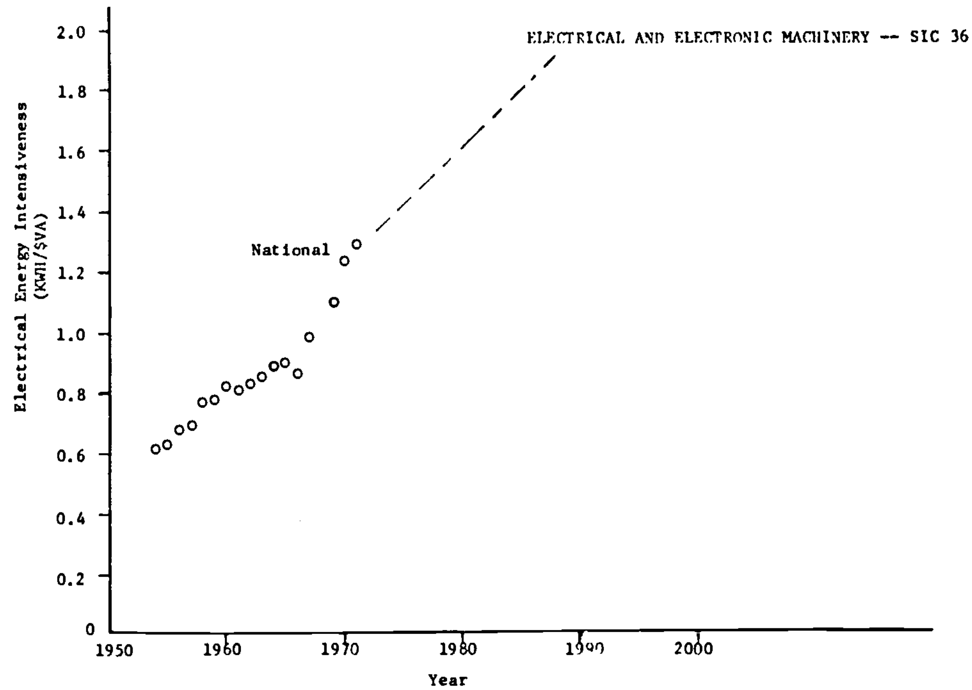


Figure III-6. Electrical energy intensiveness, SIC's 34 and 35.



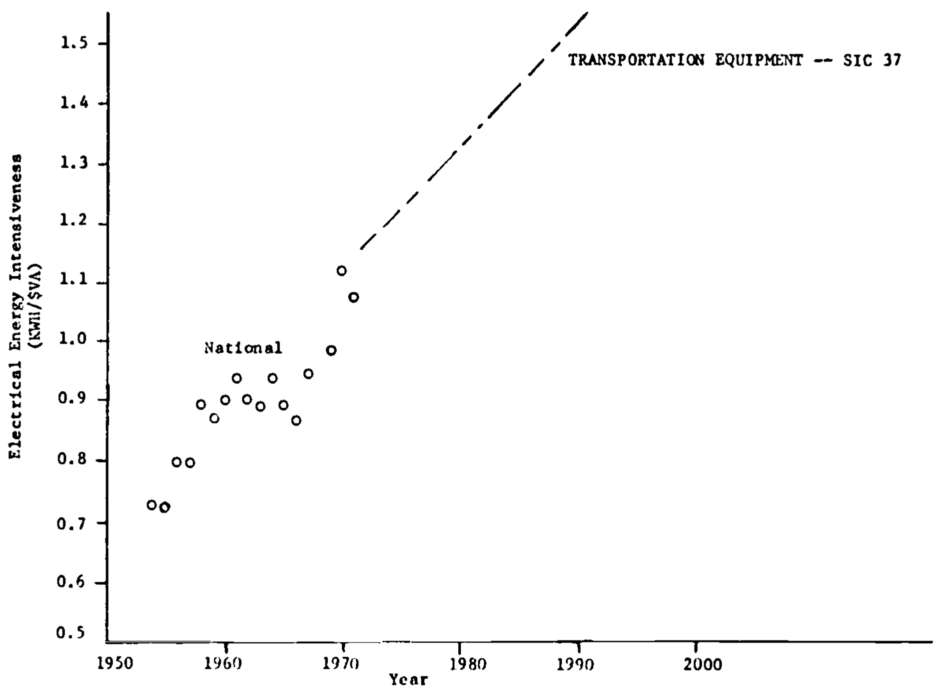


Figure III-7. Electrical energy intensiveness, SIC's 36 and 37.

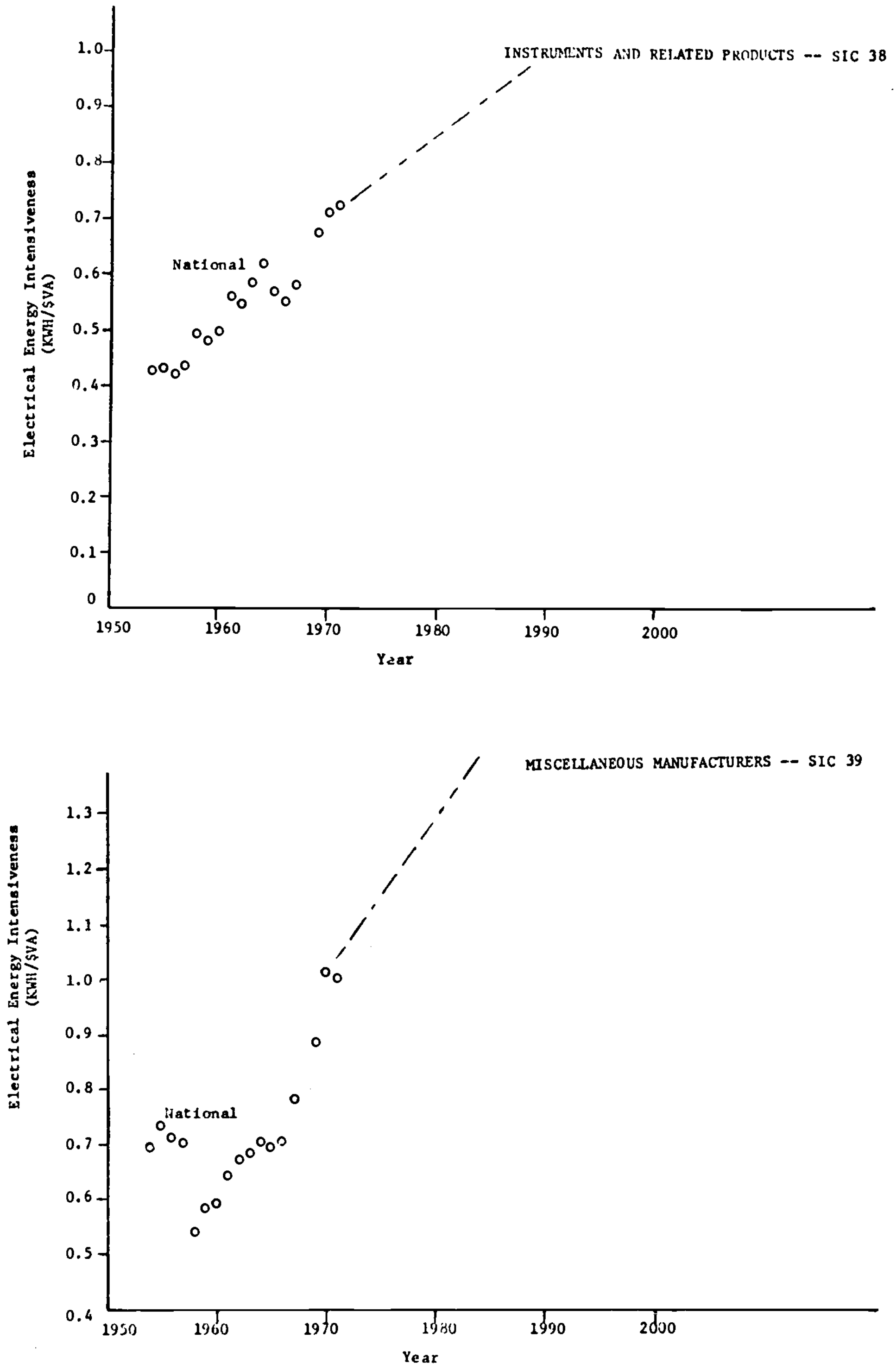


Figure III-8. Electrical energy intensiveness, SIC's 38 and 39.

APPENDIX IV. Sample Model Output--Case I

	COMMERCIAL SECTOR					TRANSPORTATION SECTOR				
YR	INT,KWH/ECA	EC.ACTIVITY	DEMAND,KWH	PC CH	PC	INT,KWH/ECA	EC.ACTIVITY	DEMAND,KWH	PC CH	PC
0	1.01680E 04	5.67866E 05	5.77406E 09	0	21.9	1.42000E 03	9.50630E 04	1.34989E 08	0	.5
1	1.06067E 04	5.81776E 05	6.17875E 09	6.9	22.2	1.45920E 03	9.75085E 04	1.42284E 08	5.4	.5
2	1.10455E 04	5.96027E 05	6.58341E 09	6.7	22.4	1.49840E 03	1.00017E 05	1.49865E 08	5.3	.5
3	1.14842E 04	6.10626E 05	7.01259E 09	6.5	22.6	1.53760E 03	1.02590E 05	1.57742E 08	5.3	.5
4	1.19230E 04	6.25584E 05	7.45884E 09	6.4	22.8	1.57680E 03	1.05229E 05	1.65925E 08	5.2	.5
5	1.23617E 04	6.40908E 05	7.92274E 09	6.2	22.9	1.61600E 03	1.07936E 05	1.74425E 08	5.1	.5
6	1.28005E 04	6.56607E 05	8.40490E 09	6.1	23.1	1.65520E 03	1.10713E 05	1.83252E 08	5.1	.5
7	1.32393E 04	6.72691E 05	8.90592E 09	6.0	23.2	1.69440E 03	1.13561E 05	1.92418E 08	5.0	.5
8	1.36780E 04	6.89163E 05	9.42644E 09	5.8	23.4	1.73360E 03	1.16482E 05	2.01934E 08	4.9	.5
9	1.41167E 04	7.06050E 05	9.96713E 09	5.7	23.5	1.77280E 03	1.19479E 05	2.11812E 08	4.9	.5
10	1.45555E 04	7.23344E 05	1.05286E 10	5.6	23.6	1.81200E 03	1.22553E 05	2.22065E 08	4.8	.5
11	1.49942E 04	7.41063E 05	1.11117E 10	5.5	23.7	1.85120E 03	1.25705E 05	2.32706E 08	4.8	.5
12	1.54330E 04	7.59215E 05	1.17170E 10	5.4	23.8	1.89040E 03	1.28939E 05	2.43746E 08	4.7	.5
13	1.58717E 04	7.77812E 05	1.23452E 10	5.4	23.9	1.92960E 03	1.32256E 05	2.55201E 08	4.7	.5
14	1.63105E 04	7.96865E 05	1.29973E 10	5.3	24.0	1.96880E 03	1.35658E 05	2.67084E 08	4.7	.5
15	1.67492E 04	8.16385E 05	1.36738E 10	5.2	24.1	2.00800E 03	1.39148E 05	2.79410E 08	4.6	.5
16	1.71880E 04	8.36382E 05	1.43757E 10	5.1	24.1	2.04720E 03	1.42728E 05	2.92193E 08	4.6	.5
17	1.76268E 04	8.56869E 05	1.51038E 10	5.1	24.2	2.08640E 03	1.46400E 05	3.05448E 08	4.5	.5
18	1.80655E 04	8.77859E 05	1.58590E 10	5.0	24.3	2.12560E 03	1.50166E 05	3.19192E 08	4.5	.5
19	1.85043E 04	8.99362E 05	1.66420E 10	4.9	24.3	2.16480E 03	1.54029E 05	3.33442E 08	4.5	.5
20	1.89430E 04	9.21392E 05	1.74539E 10	4.9	24.4	2.20400E 03	1.57991E 05	3.48213E 08	4.4	.5
21	1.93817E 04	9.43962E 05	1.82956E 10	4.8	24.5	2.24320E 03	1.62056E 05	3.63523E 08	4.4	.5
22	1.98205E 04	9.67084E 05	1.91681E 10	4.8	24.5	2.28240E 03	1.66225E 05	3.79391E 08	4.4	.5
23	2.02592E 04	9.90773E 05	2.00723E 10	4.7	24.6	2.32160E 03	1.70501E 05	3.95835E 08	4.3	.5
24	2.06980E 04	1.01504E 06	2.10093E 10	4.7	24.6	2.36080E 03	1.74887E 05	4.12873E 08	4.3	.5
25	2.11367E 04	1.03991E 06	2.19802E 10	4.6	24.7	2.40000E 03	1.79386E 05	4.30526E 08	4.3	.5
26	2.15755E 04	1.06538E 06	2.29861E 10	4.6	24.7	2.43920E 03	1.84001E 05	4.48815E 08	4.2	.5
27	2.20142E 04	1.09144E 06	2.40280E 10	4.5	24.8	2.47840E 03	1.88734E 05	4.67759E 08	4.2	.5
28	2.24530E 04	1.11821E 06	2.51072E 10	4.5	24.8	2.51760E 03	1.93589E 05	4.87381E 08	4.2	.5
29	2.28917E 04	1.14560E 06	2.62249E 10	4.5	24.9	2.55680E 03	1.98570E 05	5.07703E 08	4.2	.5
30	2.33305E 04	1.17366E 06	2.73822E 10	4.4	24.9	2.59600E 03	2.03678E 05	5.28748E 08	4.1	.5
31	2.37692E 04	1.20241E 06	2.85805E 10	4.4	25.0	2.63520E 03	2.08918E 05	5.50540E 08	4.1	.5
32	2.42080E 04	1.23187E 06	2.98210E 10	4.3	25.0	2.67440E 03	2.14292E 05	5.73103E 08	4.1	.5
33	2.46467E 04	1.26204E 06	3.11052E 10	4.3	25.0	2.71360E 03	2.19805E 05	5.96462E 08	4.1	.5
34	2.50855E 04	1.29295E 06	3.24344E 10	4.3	25.0	2.75280E 03	2.25459E 05	6.20644E 08	4.1	.5
35	2.55243E 04	1.32463E 06	3.38101E 10	4.2	25.1	2.79200E 03	2.31259E 05	6.45676E 08	4.0	.5
36	2.59630E 04	1.35707E 06	3.52337E 10	4.2	25.1	2.83120E 03	2.37209E 05	6.71585E 08	4.0	.5
37	2.64018E 04	1.39031E 06	3.67067E 10	4.2	25.1	2.87040E 03	2.43311E 05	6.98399E 08	4.0	.5
38	2.68405E 04	1.42437E 06	3.82308E 10	4.2	25.1	2.90960E 03	2.49570E 05	7.26149E 08	4.0	.5
39	2.72793E 04	1.45926E 06	3.98075E 10	4.1	25.1	2.94880E 03	2.55990E 05	7.54864E 08	4.0	.5
40	2.77180E 04	1.49501E 06	4.14386E 10	4.1	25.2	2.98800E 03	2.62576E 05	7.84577E 08	3.9	.5

FOOD PRODUCTS,SIC 20

YR	INT,KWH/ECA	EC.ACTIVITY	DEMAND,KWH	PC CH	PC
0	1.27000E 00	2.60100E 08	3.30327E 08	0	1.3
1	1.31350E 00	2.65832E 08	3.49171E 08	5.7	1.3
2	1.35700E 00	2.71691E 08	3.68685E 08	5.6	1.3
3	1.40050E 00	2.77679E 08	3.88890E 08	5.5	1.3
4	1.44400E 00	2.83799E 08	4.09806E 08	5.4	1.3
5	1.48750E 00	2.90054E 08	4.31455E 08	5.3	1.2
6	1.53100E 00	2.96446E 08	4.53859E 08	5.2	1.2
7	1.57450E 00	3.02980E 08	4.77042E 08	5.1	1.2
8	1.61800E 00	3.09657E 08	5.01025E 08	5.0	1.2
9	1.66150E 00	3.16482E 08	5.25835E 08	5.0	1.2
10	1.70500E 00	3.23457E 08	5.51494E 08	4.9	1.2
11	1.74850E 00	3.30586E 08	5.78029E 08	4.8	1.2
12	1.79200E 00	3.37872E 08	6.05466E 08	4.7	1.2
13	1.83550E 00	3.45318E 08	6.33831E 08	4.7	1.2
14	1.87900E 00	3.52929E 08	6.63153E 08	4.6	1.2
15	1.92250E 00	3.60707E 08	6.93459E 08	4.5	1.2
16	1.96600E 00	3.68657E 08	7.24779E 08	4.5	1.2
17	2.00950E 00	3.76782E 08	7.57143E 08	4.5	1.2
18	2.05300E 00	3.85086E 08	7.90581E 08	4.4	1.2
19	2.09650E 00	3.93573E 08	8.25125E 08	4.4	1.2
20	2.14000E 00	4.02247E 08	8.60808E 08	4.3	1.2
21	2.18350E 00	4.11112E 08	8.97663E 08	4.3	1.2
22	2.22700E 00	4.20173E 08	9.35725E 08	4.2	1.2
23	2.27050E 00	4.29433E 08	9.75028E 08	4.2	1.2
24	2.31400E 00	4.38898E 08	1.01561E 09	4.2	1.2
25	2.35750E 00	4.48571E 08	1.05751E 09	4.1	1.2
26	2.40100E 00	4.58457E 08	1.10075E 09	4.1	1.2
27	2.44450E 00	4.68561E 08	1.14540E 09	4.1	1.2
28	2.48800E 00	4.78888E 08	1.19147E 09	4.0	1.2
29	2.53150E 00	4.89442E 08	1.23902E 09	4.0	1.2
30	2.57500E 00	5.00229E 08	1.28809E 09	4.0	1.2
31	2.61850E 00	5.11254E 08	1.33872E 09	3.9	1.2
32	2.66200E 00	5.22522E 08	1.39095E 09	3.9	1.2
33	2.70550E 00	5.34038E 08	1.44484E 09	3.9	1.2
34	2.74900E 00	5.45807E 08	1.50042E 09	3.8	1.2
35	2.79250E 00	5.57837E 08	1.55776E 09	3.8	1.2
36	2.83600E 00	5.70131E 08	1.61689E 09	3.8	1.2
37	2.87950E 00	5.82696E 08	1.67787E 09	3.8	1.1
38	2.92300E 00	5.95539E 08	1.74076E 09	3.7	1.1
39	2.96650E 00	6.08664E 08	1.80560E 09	3.7	1.1
40	3.01000E 00	6.22078E 08	1.87246E 09	3.7	1.1

LUMBER+WOOD PRODUCTS,SIC 24

YR	INT,KWH/ECA	EC.ACTIVITY	DEMAND,KWH	PC CH	PC
0	2.81000E 00	6.23000E 08	1.75063E 09	0	6.6
1	2.88450E 00	6.26123E 08	1.80605E 09	3.2	6.5
2	2.95900E 00	6.29261E 08	1.86198E 09	3.1	6.3
3	3.03350E 00	6.32415E 08	1.91843E 09	3.0	6.2
4	3.10800E 00	6.35585E 08	1.97540E 09	3.0	6.0
5	3.18250E 00	6.38771E 08	2.03289E 09	2.9	5.9
6	3.25700E 00	6.41973E 08	2.09091E 09	2.9	5.7
7	3.33150E 00	6.45191E 08	2.14945E 09	2.8	5.6
8	3.40600E 00	6.48425E 08	2.20854E 09	2.7	5.5
9	3.48050E 00	6.51675E 08	2.26816E 09	2.7	5.3
10	3.55500E 00	6.54942E 08	2.32832E 09	2.7	5.2
11	3.62950E 00	6.58225E 08	2.38903E 09	2.6	5.1
12	3.70400E 00	6.61524E 08	2.45029E 09	2.6	5.0
13	3.77850E 00	6.64840E 08	2.51210E 09	2.5	4.9
14	3.85300E 00	6.68173E 08	2.57447E 09	2.5	4.8
15	3.92750E 00	6.71522E 08	2.63740E 09	2.4	4.6
16	4.00200E 00	6.74888E 08	2.70090E 09	2.4	4.5
17	4.07650E 00	6.78271E 08	2.76497E 09	2.4	4.4
18	4.15100E 00	6.81671E 08	2.82961E 09	2.3	4.3
19	4.22550E 00	6.85087E 08	2.89484E 09	2.3	4.2
20	4.30000E 00	6.88521E 08	2.96064E 09	2.3	4.1
21	4.37450E 00	6.91973E 08	3.02703E 09	2.2	4.0
22	4.44900E 00	6.95441E 08	3.09402E 09	2.2	4.0
23	4.52350E 00	6.98927E 08	3.16160E 09	2.2	3.9
24	4.59800E 00	7.02431E 08	3.22978E 09	2.2	3.8
25	4.67250E 00	7.05951E 08	3.29858E 09	2.1	3.7
26	4.74700E 00	7.09490E 08	3.36795E 09	2.1	3.6
27	4.82150E 00	7.13046E 08	3.43795E 09	2.1	3.5
28	4.89600E 00	7.16621E 08	3.50857E 09	2.1	3.5
29	4.97050E 00	7.20213E 08	3.57982E 09	2.0	3.4
30	5.04500E 00	7.23823E 08	3.65169E 09	2.0	3.3
31	5.11950E 00	7.27451E 08	3.72418E 09	2.0	3.3
32	5.19400E 00	7.31097E 08	3.79732E 09	2.0	3.2
33	5.26850E 00	7.34762E 08	3.87109E 09	1.9	3.1
34	5.34300E 00	7.38445E 08	3.94551E 09	1.9	3.0
35	5.41750E 00	7.42146E 08	4.02058E 09	1.9	3.0
36	5.49200E 00	7.45866E 08	4.09630E 09	1.9	2.9
37	5.56650E 00	7.49605E 08	4.17268E 09	1.9	2.9
38	5.64100E 00	7.53362E 08	4.24972E 09	1.8	2.8
39	5.71550E 00	7.57139E 08	4.32743E 09	1.8	2.7
40	5.79000E 00	7.60934E 08	4.40581E 09	1.8	2.7

PAPER+ALLIED PRODUCTS, SIC 26

YR	INT,KWH/ECA	EC.ACTIVITY	DEMAND,KWH	PC CH	PC
0	1.00000E 01	1.85900E 08	1.85900E 09	0	7.1
1	1.01100E 01	1.93023E 08	1.95146E 09	5.0	7.0
2	1.02200E 01	2.00419E 08	2.04828E 09	5.0	7.0
3	1.03300E 01	2.08098E 08	2.14965E 09	4.9	6.9
4	1.04400E 01	2.16071E 08	2.25579E 09	4.9	6.9
5	1.05500E 01	2.24350E 08	2.36690E 09	4.9	6.9
6	1.06600E 01	2.32947E 08	2.48321E 09	4.9	6.8
7	1.07700E 01	2.41872E 08	2.60496E 09	4.9	6.8
8	1.08800E 01	2.51140E 08	2.73240E 09	4.9	6.8
9	1.09900E 01	2.60762E 08	2.86578E 09	4.9	6.8
10	1.11000E 01	2.70754E 08	3.00536E 09	4.9	6.7
11	1.12100E 01	2.81128E 08	3.15144E 09	4.9	6.7
12	1.13200E 01	2.91899E 08	3.30430E 09	4.9	6.7
13	1.14300E 01	3.03084E 08	3.46425E 09	4.8	6.7
14	1.15400E 01	3.14697E 08	3.63160E 09	4.8	6.7
15	1.16500E 01	3.26754E 08	3.80669E 09	4.8	6.7
16	1.17600E 01	3.39274E 08	3.98987E 09	4.8	6.7
17	1.18700E 01	3.52274E 08	4.18149E 09	4.8	6.7
18	1.19800E 01	3.65772E 08	4.38194E 09	4.8	6.7
19	1.20900E 01	3.79786E 08	4.59162E 09	4.8	6.7
20	1.22000E 01	3.94338E 08	4.81093E 09	4.8	6.7
21	1.23100E 01	4.09448E 08	5.04030E 09	4.8	6.7
22	1.24200E 01	4.25136E 08	5.28019E 09	4.8	6.8
23	1.25300E 01	4.41425E 08	5.53106E 09	4.8	6.8
24	1.26400E 01	4.58339E 08	5.79340E 09	4.7	6.8
25	1.27500E 01	4.75901E 08	6.06773E 09	4.7	6.8
26	1.28600E 01	4.94135E 08	6.35458E 09	4.7	6.8
27	1.29700E 01	5.13068E 08	6.65450E 09	4.7	6.9
28	1.30800E 01	5.32727E 08	6.96807E 09	4.7	6.9
29	1.31900E 01	5.53139E 08	7.29590E 09	4.7	6.9
30	1.33000E 01	5.74333E 08	7.63863E 09	4.7	6.9
31	1.34100E 01	5.96339E 08	7.99690E 09	4.7	7.0
32	1.35200E 01	6.19188E 08	8.37142E 09	4.7	7.0
33	1.36300E 01	6.42913E 08	8.76290E 09	4.7	7.0
34	1.37400E 01	6.67546E 08	9.17209E 09	4.7	7.1
35	1.38500E 01	6.93124E 08	9.59977E 09	4.7	7.1
36	1.39600E 01	7.19682E 08	1.00468E 10	4.7	7.2
37	1.40700E 01	7.47257E 08	1.05139E 10	4.6	7.2
38	1.41800E 01	7.75889E 08	1.10021E 10	4.6	7.2
39	1.42900E 01	8.05617E 08	1.15123E 10	4.6	7.3
40	1.44000E 01	8.36485E 08	1.20454E 10	4.6	7.3

NON-RESOURCE-BASED MANUFACTURING

YR	INT,KWH/ECA	EC.ACTIVITY	DEMAND,KWH	PC CH	PC
0	8.83913E 00	7.60100E 08	6.71863E 09	0	25.5
1	8.86298E 00	7.95563E 08	7.05106E 09	4.9	25.3
2	8.88683E 00	8.32680E 08	7.39989E 09	4.9	25.2
3	8.91068E 00	8.71530E 08	7.76592E 09	4.9	25.0
4	8.93453E 00	9.12192E 08	8.15000E 09	4.9	24.9
5	8.95838E 00	9.54750E 08	8.55301E 09	4.9	24.8
6	8.98223E 00	9.99295E 08	8.97589E 09	4.9	24.7
7	9.00607E 00	1.04592E 09	9.41961E 09	4.9	24.6
8	9.02992E 00	1.09472E 09	9.88520E 09	4.9	24.5
9	9.05377E 00	1.14579E 09	1.03737E 10	4.9	24.5
10	9.07762E 00	1.19925E 09	1.08863E 10	4.9	24.4
11	9.10147E 00	1.25520E 09	1.14242E 10	4.9	24.4
12	9.12532E 00	1.31376E 09	1.19885E 10	4.9	24.4
13	9.14917E 00	1.37506E 09	1.25806E 10	4.9	24.4
14	9.17301E 00	1.43921E 09	1.32019E 10	4.9	24.4
15	9.19686E 00	1.50636E 09	1.38538E 10	4.9	24.4
16	9.22071E 00	1.57664E 09	1.45377E 10	4.9	24.4
17	9.24456E 00	1.65020E 09	1.52553E 10	4.9	24.5
18	9.26841E 00	1.72719E 09	1.60083E 10	4.9	24.5
19	9.29226E 00	1.80777E 09	1.67983E 10	4.9	24.6
20	9.31611E 00	1.89211E 09	1.76271E 10	4.9	24.7
21	9.33995E 00	1.98039E 09	1.84968E 10	4.9	24.7
22	9.36380E 00	2.07279E 09	1.94092E 10	4.9	24.8
23	9.38765E 00	2.16950E 09	2.03665E 10	4.9	24.9
24	9.41150E 00	2.27071E 09	2.13708E 10	4.9	25.1
25	9.43535E 00	2.37666E 09	2.24246E 10	4.9	25.2
26	9.45920E 00	2.48754E 09	2.35301E 10	4.9	25.3
27	9.48305E 00	2.60360E 09	2.46901E 10	4.9	25.5
28	9.50690E 00	2.72507E 09	2.59070E 10	4.9	25.6
29	9.53074E 00	2.85221E 09	2.71837E 10	4.9	25.8
30	9.55459E 00	2.98528E 09	2.85232E 10	4.9	26.0
31	9.57844E 00	3.12456E 09	2.99285E 10	4.9	26.1
32	9.60229E 00	3.27034E 09	3.14028E 10	4.9	26.3
33	9.62614E 00	3.42292E 09	3.29495E 10	4.9	26.5
34	9.64999E 00	3.58262E 09	3.45722E 10	4.9	26.7
35	9.67384E 00	3.74977E 09	3.62747E 10	4.9	26.9
36	9.69768E 00	3.92472E 09	3.80607E 10	4.9	27.1
37	9.72153E 00	4.10783E 09	3.99344E 10	4.9	27.3
38	9.74538E 00	4.29948E 09	4.19001E 10	4.9	27.5
39	9.76923E 00	4.50008E 09	4.39623E 10	4.9	27.8
40	9.79308E 00	4.71003E 09	4.61257E 10	4.9	28.0

YR	IRRIGATION, REGION 1 INT,KWH/ECA	EC.ACTIVITY	DEMAND,KWH	PC CH	PC	IRRIGATION, REGION 2 INT,KWH/ECA	EC.ACTIVITY	DEMAND,KWH	PC CH	PC
0	2.26000E 02	2.07447E 05	4.68830E 07	0	.2	1.06600E 02	9.24000E 04	9.84984E 06	0	.0
1	2.26000E 02	2.14514E 05	4.84802E 07	3.4	.2	1.06600E 02	9.55478E 04	1.01854E 07	3.4	.0
2	2.26000E 02	2.21822E 05	5.01318E 07	3.4	.2	1.06600E 02	9.88029E 04	1.05324E 07	3.4	.0
3	2.26000E 02	2.29379E 05	5.18397E 07	3.4	.2	1.06600E 02	1.02169E 05	1.08912E 07	3.4	.0
4	2.26000E 02	2.37193E 05	5.36057E 07	3.4	.2	1.06600E 02	1.05649E 05	1.12622E 07	3.4	.0
5	2.26000E 02	2.45274E 05	5.54319E 07	3.4	.2	1.06600E 02	1.09249E 05	1.16459E 07	3.4	.0
6	2.26000E 02	2.53630E 05	5.73203E 07	3.4	.2	1.06600E 02	1.12971E 05	1.20427E 07	3.4	.0
7	2.26000E 02	2.62270E 05	5.92731E 07	3.4	.2	1.06600E 02	1.16819E 05	1.24529E 07	3.4	.0
8	2.26000E 02	2.71205E 05	6.12924E 07	3.4	.2	1.06600E 02	1.20799E 05	1.28772E 07	3.4	.0
9	2.26000E 02	2.80445E 05	6.33805E 07	3.4	.2	1.06600E 02	1.24914E 05	1.33159E 07	3.4	.0
10	2.26000E 02	2.89999E 05	6.55397E 07	3.4	.1	1.06600E 02	1.29170E 05	1.37695E 07	3.4	.0
11	2.26000E 02	2.99878E 05	6.77724E 07	3.4	.1	1.06600E 02	1.33570E 05	1.42386E 07	3.4	.0
12	2.26000E 02	3.10094E 05	7.00813E 07	3.4	.1	1.06600E 02	1.38121E 05	1.47237E 07	3.4	.0
13	2.26000E 02	3.20658E 05	7.24688E 07	3.4	.1	1.06600E 02	1.42826E 05	1.52252E 07	3.4	.0
14	2.26000E 02	3.31582E 05	7.49376E 07	3.4	.1	1.06600E 02	1.47692E 05	1.57439E 07	3.4	.0
15	2.26000E 02	3.42878E 05	7.74905E 07	3.4	.1	1.06600E 02	1.52723E 05	1.62803E 07	3.4	.0
16	2.26000E 02	3.54559E 05	8.01304E 07	3.4	.1	1.06600E 02	1.57926E 05	1.68349E 07	3.4	.0
17	2.26000E 02	3.66638E 05	8.28603E 07	3.4	.1	1.06600E 02	1.63306E 05	1.74084E 07	3.4	.0
18	2.26000E 02	3.79129E 05	8.56831E 07	3.4	.1	1.06600E 02	1.68870E 05	1.80015E 07	3.4	.0
19	2.26000E 02	3.92045E 05	8.86021E 07	3.4	.1	1.06600E 02	1.74623E 05	1.86148E 07	3.4	.0
20	2.26000E 02	4.05401E 05	9.16206E 07	3.4	.1	1.06600E 02	1.80572E 05	1.92489E 07	3.4	.0
21	2.26000E 02	4.19212E 05	9.47418E 07	3.4	.1	1.06600E 02	1.86723E 05	1.99047E 07	3.4	.0
22	2.26000E 02	4.33493E 05	9.79694E 07	3.4	.1	1.06600E 02	1.93084E 05	2.05828E 07	3.4	.0
23	2.26000E 02	4.48261E 05	1.01307E 08	3.4	.1	1.06600E 02	1.99662E 05	2.12840E 07	3.4	.0
24	2.26000E 02	4.63532E 05	1.04758E 08	3.4	.1	1.06600E 02	2.06464E 05	2.20091E 07	3.4	.0
25	2.26000E 02	4.79324E 05	1.08327E 08	3.4	.1	1.06600E 02	2.13498E 05	2.27589E 07	3.4	.0
26	2.26000E 02	4.95653E 05	1.12018E 08	3.4	.1	1.06600E 02	2.20771E 05	2.35342E 07	3.4	.0
27	2.26000E 02	5.12539E 05	1.15834E 08	3.4	.1	1.06600E 02	2.28292E 05	2.43360E 07	3.4	.0
28	2.26000E 02	5.29999E 05	1.19780E 08	3.4	.1	1.06600E 02	2.36070E 05	2.51650E 07	3.4	.0
29	2.26000E 02	5.48055E 05	1.23860E 08	3.4	.1	1.06600E 02	2.44112E 05	2.60223E 07	3.4	.0
30	2.26000E 02	5.66726E 05	1.28080E 08	3.4	.1	1.06600E 02	2.52428E 05	2.69088E 07	3.4	.0
31	2.26000E 02	5.86033E 05	1.32443E 08	3.4	.1	1.06600E 02	2.61028E 05	2.78256E 07	3.4	.0
32	2.26000E 02	6.05998E 05	1.36955E 08	3.4	.1	1.06600E 02	2.69920E 05	2.87735E 07	3.4	.0
33	2.26000E 02	6.26642E 05	1.41621E 08	3.4	.1	1.06600E 02	2.79116E 05	2.97538E 07	3.4	.0
34	2.26000E 02	6.47990E 05	1.46446E 08	3.4	.1	1.06600E 02	2.88625E 05	3.07674E 07	3.4	.0
35	2.26000E 02	6.70066E 05	1.51435E 08	3.4	.1	1.06600E 02	2.98457E 05	3.18156E 07	3.4	.0
36	2.26000E 02	6.92893E 05	1.56594E 08	3.4	.1	1.06600E 02	3.08625E 05	3.28994E 07	3.4	.0
37	2.26000E 02	7.16498E 05	1.61929E 08	3.4	.1	1.06600E 02	3.19139E 05	3.40202E 07	3.4	.0
38	2.26000E 02	7.40908E 05	1.67445E 08	3.4	.1	1.06600E 02	3.30011E 05	3.51792E 07	3.4	.0
39	2.26000E 02	7.66148E 05	1.73150E 08	3.4	.1	1.06600E 02	3.41254E 05	3.63777E 07	3.4	.0
40	2.26000E 02	7.92249E 05	1.79048E 08	3.4	.1	1.06600E 02	3.52880E 05	3.76170E 07	3.4	.0

YR	IRRIGATION, REGION 3 INT,KWH/ECA	EC.ACTIVITY	DEMAND,KWH	PC CH	PC	RESIDENTIAL SECTOR INT,KWH/ECA	EC.ACTIVITY	DEMAND,KWH	PC CH	PC
0	2.76052E 02	1.21957E 06	3.36666E 08	0	1.3	1.35480E 04	6.92978E 05	9.38846E 09	0	35.6
1	3.03657E 02	1.26112E 06	3.82949E 08	13.7	1.4	1.40282E 04	7.08109E 05	9.93347E 09	5.8	35.7
2	3.31263E 02	1.30408E 06	4.31995E 08	12.8	1.5	1.45177E 04	7.23571E 05	1.05046E 10	5.7	35.7
3	3.58868E 02	1.34851E 06	4.83938E 08	12.0	1.6	1.50160E 04	7.39370E 05	1.11024E 10	5.7	35.8
4	3.86473E 02	1.39445E 06	5.38918E 08	11.4	1.6	1.55221E 04	7.55514E 05	1.17271E 10	5.6	35.8
5	4.14078E 02	1.44196E 06	5.97083E 08	10.8	1.7	1.60350E 04	7.72011E 05	1.23792E 10	5.6	35.9
6	4.41684E 02	1.49108E 06	6.58586E 08	10.3	1.8	1.65537E 04	7.88867E 05	1.30588E 10	5.5	35.9
7	4.69289E 02	1.54188E 06	7.23586E 08	9.9	1.9	1.70769E 04	8.06092E 05	1.37656E 10	5.4	35.9
8	4.96894E 02	1.59441E 06	7.92251E 08	9.5	2.0	1.76035E 04	8.23693E 05	1.44999E 10	5.3	36.0
9	5.24499E 02	1.64872E 06	8.64754E 08	9.2	2.0	1.81322E 04	8.41679E 05	1.52614E 10	5.3	36.0
10	5.52104E 02	1.70489E 06	9.41278E 08	8.8	2.1	1.86616E 04	8.60057E 05	1.60501E 10	5.2	36.0
11	5.79710E 02	1.76297E 06	1.02201E 09	8.6	2.2	1.91907E 04	8.78836E 05	1.68655E 10	5.1	36.0
12	6.07315E 02	1.82303E 06	1.10716E 09	8.3	2.2	1.97181E 04	8.98025E 05	1.77074E 10	5.0	36.0
13	6.34920E 02	1.88514E 06	1.19691E 09	8.1	2.3	2.02427E 04	9.17634E 05	1.85754E 10	4.9	36.0
14	6.62525E 02	1.94936E 06	1.29150E 09	7.9	2.4	2.07634E 04	9.37670E 05	1.94692E 10	4.8	35.9
15	6.90130E 02	2.01577E 06	1.39114E 09	7.7	2.4	2.12791E 04	9.58144E 05	2.03885E 10	4.7	35.9
16	7.17736E 02	2.08444E 06	1.49608E 09	7.5	2.5	2.17889E 04	9.79065E 05	2.13328E 10	4.6	35.8
17	7.45341E 02	2.15545E 06	1.60655E 09	7.4	2.6	2.22920E 04	1.00044E 06	2.23018E 10	4.5	35.8
18	7.72946E 02	2.22889E 06	1.72281E 09	7.2	2.6	2.27874E 04	1.02229E 06	2.32953E 10	4.5	35.7
19	8.00551E 02	2.30482E 06	1.84513E 09	7.1	2.7	2.32746E 04	1.04461E 06	2.43128E 10	4.4	35.6
20	8.28157E 02	2.38334E 06	1.97378E 09	7.0	2.8	2.37528E 04	1.06742E 06	2.53542E 10	4.3	35.5
21	8.55762E 02	2.46453E 06	2.10905E 09	6.9	2.8	2.42217E 04	1.09073E 06	2.64192E 10	4.2	35.3
22	8.83367E 02	2.54849E 06	2.25125E 09	6.7	2.9	2.46807E 04	1.11454E 06	2.75076E 10	4.1	35.2
23	9.10972E 02	2.63531E 06	2.40070E 09	6.6	2.9	2.51295E 04	1.13888E 06	2.86194E 10	4.0	35.1
24	9.38577E 02	2.72509E 06	2.55771E 09	6.5	3.0	2.55680E 04	1.16374E 06	2.97546E 10	4.0	34.9
25	9.66183E 02	2.81793E 06	2.72263E 09	6.4	3.1	2.59959E 04	1.18916E 06	3.09131E 10	3.9	34.7
26	9.93788E 02	2.91393E 06	2.89583E 09	6.4	3.1	2.64132E 04	1.21512E 06	3.20952E 10	3.8	34.5
27	1.02139E 03	3.01320E 06	3.07766E 09	6.3	3.2	2.68200E 04	1.24165E 06	3.33011E 10	3.8	34.4
28	1.04900E 03	3.11585E 06	3.26852E 09	6.2	3.2	2.72164E 04	1.26876E 06	3.45311E 10	3.7	34.2
29	1.07660E 03	3.22200E 06	3.46881E 09	6.1	3.3	2.76025E 04	1.29647E 06	3.57857E 10	3.6	33.9
30	1.10421E 03	3.33176E 06	3.67896E 09	6.1	3.3	2.79787E 04	1.32478E 06	3.70655E 10	3.6	33.7
31	1.13181E 03	3.44527E 06	3.89940E 09	6.0	3.4	2.83452E 04	1.35370E 06	3.83710E 10	3.5	33.5
32	1.15942E 03	3.56264E 06	4.13059E 09	5.9	3.5	2.87025E 04	1.38326E 06	3.97030E 10	3.5	33.3
33	1.18702E 03	3.68401E 06	4.37301E 09	5.9	3.5	2.90509E 04	1.41346E 06	4.10624E 10	3.4	33.0
34	1.21463E 03	3.80951E 06	4.62715E 09	5.8	3.6	2.93909E 04	1.44433E 06	4.24500E 10	3.4	32.8
35	1.24223E 03	3.93929E 06	4.89353E 09	5.8	3.6	2.97229E 04	1.47586E 06	4.38669E 10	3.3	32.5
36	1.26984E 03	4.07350E 06	5.17269E 09	5.7	3.7	3.00473E 04	1.50809E 06	4.53140E 10	3.3	32.3
37	1.29745E 03	4.21227E 06	5.46519E 09	5.7	3.7	3.03648E 04	1.54102E 06	4.67926E 10	3.3	32.0
38	1.32505E 03	4.35577E 06	5.77162E 09	5.6	3.8	3.06756E 04	1.57467E 06	4.83038E 10	3.2	31.8
39	1.35266E 03	4.50416E 06	6.09258E 09	5.6	3.8	3.09803E 04	1.60905E 06	4.98489E 10	3.2	31.5
40	1.38026E 03	4.65761E 06	6.42871E 09	5.5	3.9	3.12794E 04	1.64418E 06	5.14290E 10	3.2	31.2

YR	TOT.DEMAND,KWH	PC CHANGE
0	2.634949E 10	0
1	2.784586E 10	5.68
2	2.940938E 10	5.61
3	3.104226E 10	5.55
4	3.274068E 10	5.49
5	3.452476E 10	5.43
6	3.637861E 10	5.37
7	3.831028E 10	5.31
8	4.032183E 10	5.25
9	4.241533E 10	5.19
10	4.459286E 10	5.13
11	4.685655E 10	5.08
12	4.920859E 10	5.02
13	5.165124E 10	4.96
14	5.418687E 10	4.91
15	5.681793E 10	4.86
16	5.954753E 10	4.80
17	6.237087E 10	4.75
18	6.531034E 10	4.70
19	6.835048E 10	4.65
20	7.150049E 10	4.61
21	7.476380E 10	4.56
22	7.814403E 10	4.52
23	8.164502E 10	4.48
24	8.527089E 10	4.44
25	8.902597E 10	4.40
26	9.291489E 10	4.37
27	9.694258E 10	4.33
28	1.011142E 11	4.30
29	1.054354E 11	4.27
30	1.099119E 11	4.25
31	1.145499E 11	4.22
32	1.193559E 11	4.20
33	1.243368E 11	4.17
34	1.294997E 11	4.15
35	1.348522E 11	4.13
36	1.404021E 11	4.12
37	1.461578E 11	4.10
38	1.521277E 11	4.08
39	1.583210E 11	4.07
40	1.647469E 11	4.06