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AN INTEGRATED ENERGY PLANNING MODEL FOR TAIWAN: MULTIOBJECTIVE PROGRAMMING AND INPUT-OUTPUT APPROACHES

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AN INTEGRATED ENERGY PLANNING MODEL FOR TAIWAN:
MULTIOBJECTIVE PROGRAMMING AND INPUT-OUTPUT APPROACHES

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
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DOCTOR OF PHILOSOPHY

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AGRICULTURAL AND RESOURCE ECONOMICS

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By

JYH-YIH GEORGE HSU

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ABSTRACT

The main purpose of this study is to investigate the physical and economic aspects of the trade-off between economic goals (e.g., growth and development) and energy goals (e.g., reducing oil dependence or energy consumption). To meet this purpose, a Non-Inferior Set Estimation Input-Output (NISE-IO) model consisting of a combination of multiobjective programming techniques and Leontief input-output analyses is utilized. This model is compared with conventional linear programming, goal programming, input-output, and econometrics approaches. A major innovation of this NISE-IO algorithm is the computation of the maximum possible error, which the analyst may control to obtain an approximation within a desired degree of accuracy. The derived noninferior solutions in the objective space and optimal solutions in the decision space represent simulated scenarios of aggressive, moderate, and conservative policy alternatives. The analyses are focused on the economic performances resulting from these policy alternatives and the energy requirements for supporting these economic performances. The results are presented in graphic and tabular form as reference for Taiwan's energy policy makers.

These solutions aid policy makers in energy planning of issues such as achieving a specified economic growth rate with minimum consumption of energy, the relationship between energy demand/supply and economic development/growth, lowering the elasticity of energy, considerations for "industrial restructuring," and estimating the economic impacts of assumed disruption of energy supply on the Taiwan economy.

The key conclusions of this study show that whichever policy alternative is adopted, electricity (implying nuclear power) and coal should be the priorities for economic development/growth and substitutes for petroleum consumption. To reduce heavy reliance on energy and raw-material imports, the Taiwan economy should shift its industrial structure from labor- and energy-intensive to less-energy-intensive, high-technology, and light-engineering manufacturing such as "electrical machinary industrial blocks."

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Chapter I

INTRODUCTION

1.1 OBJECTIVES

The general objective of this study is to provide Taiwan policy makers with a mechanism for evaluating trade-offs between economic development/growth (measured by sales, income, or employment) and commercial energy use. For purposes of this study, eight types of commercial energy are examined: electricity, coal, coke, motor gasoline, diesel oil, fuel oil, other oil, and natural gas. Fulfillment of this objective requires completion of the following:

(1) A general description of the Taiwan economy with explicit reference to the energy sector's relationship to the other sectors in the economy, including a specific set of current economic energy problems and policy alternatives requiring analysis.

(2) A justification of the energy model for economic analysis and decision making.

(3) A comparative review of alternative methodologies that have been used to investigate Taiwan's energy-economic problems.

(4) Use of a Leontief input-output model to evaluate possible trade-offs between sectoral energy use and sectoral income, and, specifically, the definition and estimation of various types of input-output energy multipliers and coefficients.

(5) Integration of a multiobjective programming technique with a Leontief input-output model to estimate trade-offs between national energy consumption and national GDP, and, specifically, formulation of the input-output model as a mathematical programming problem with a bicriterion objective function.

(6) An analysis of the previously identified issues and policy alternatives, based on the information provided above.

1.2 JUSTIFICATION

1.2.1 Need for Comparative Study

The government of the Republic of China on Taiwan recognizes energy-economic policy as being a critical issue. Consequently, many economic studies on Taiwan's energy sector have been performed, mostly after 1979. These studies range from descriptive analyses to sophisticated energy-economic modelling.

Economic energy analysis is a new field. Before 1970, relatively few economists were interested in energy since it did not seem to be a paramount problem. Most of the substantive studies and journals of energy economics and policy emerged after the OPEC oil embargo of 1973. Many more studies were conducted after the oil price increases in 1979. Since energy-economic analysis is a relatively new field, most energy policy makers have limited experience with the models for energy decision making. They, thus, have difficulty in choosing among the widely diverging recommendations arising from different approaches followed in the various studies. Greenberger (1977, p. 10) notes:

> "Energy research currently is a marketplace of ideas, data, studies, and pronouncements. This is healthy and desirable. <u>But the producer (the modeler) is often out of touch with his ultimate and most important consumer (the decision maker), while this consumer does not understand the wares of the producer</u> (emphasis added). The producer

> does little market research, and the consumer has no reliable shopping service. Under these circumstances, a marketplace will not operate efficiently or to best advantage.
>
> The need for sound energy decisions has never been more pressing than now. Energy modelers have a great deal to offer, but they need better signals from decision makers on the nature of the problems, on the constraints, and on what is and is not critical. <u>Decision makers need a better understanding of the models, their assumptions, strengths, and limitations, and on why they produce the result they do</u> (emphasis added). The need for bridges is great on both sides of the gulf, and the responsibility for creating these bridges is a shared responsibility."

Accordingly, this study provides energy policy makers with a comparative review of some of Taiwan's energy-economic studies and their underlying methodologies. It is the author's hope that this effort to meet the energy-researcher's requirements and responsibilities will lead to more effective communication and more useful cooperation between policy makers and researchers.

1.2.2 <u>Need for New Approaches in Energy-Economic Research</u>

There are at least two major justifications for new approaches to energy-economic research. First, since energy economics is still a relatively new field, new approaches are justified as a means for increasing the diversity and richness of this subject matter. This is especially true in Taiwan. In recent years, former Premier Yun-Suan Sun has designated four areas of science that are of primary importance to the nation. The very first is "energy research and development" (Li, 1982a, p. 5). Accordingly, Article Five of the Energy Management Law explicitly encourages economic analysis related to energy (Energy Committee, 1981b).

Second, different or new approaches to the problem may provide new information not otherwise available for policy decision making. New approaches applied to previously studied problems can reconfirm conclusions from previous studies and, more importantly, might provide new insights and understanding.

Limited information on the relationships between economic growth/development and energy demand/supply is a prevailing problem that has been studied extensively by previous researchers. The main objective of this study is to provide Taiwan energy policy makers with a new mechanism for examining those relationships.

1.3 STRUCTURE OF THE STUDY

To achieve the above objectives, the content of subsequent chapters will be organized as following:

Chapter two is a descriptive analysis of Taiwan's economy with reference to the energy sector's relationship to the other sectors. This analysis is based on historical data, energy statistics published by the government, and other publications. Following this description, a set of current economic energy issues requiring analysis is identified. These issues were derived in consultation with government officials and researchers by the author during the springs of 1983 and 1984.

Chapter three describes the varied uses of energy models for economic analysis and decision making.

Chapter four presents a comparative review of alternative methodologies that have been used to analyze Taiwan's economic energy problems. The strengths and limitations of these models are outlined and compared. The features of the NISE-IO model adopted in this study are also contrasted with alternative approaches.

Chapter five contains the study's empirical results which are then compared with those of other relevant research.

Chapter six analyzes the predefined energy planning issues defined in chapter two. The focus is on the implications of the research findings on economic energy policy decisions.

Chapter seven includes an overall summary and conclusions. The limitations and critical evaluation of this research are then finally made.

Chapter II

TAIWAN ENERGY ECONOMICS AND POLICY

This chapter is organized as follows: In section 2.1, three levels of energy-economic problems are developed through theoretical descriptions. Section 2.2 justifies the focus of this study on the first level of aggregation as developed in section 2.1. Section 2.3 outlines background information relevant to the problem statement. Section 2.4 describes the increasing emergence of energy issues with the development of Taiwan's economy. Section 2.5 contains five current energy-economic issues to be studied. The last section defines the three policy alternatives that will be analyzed in this study.

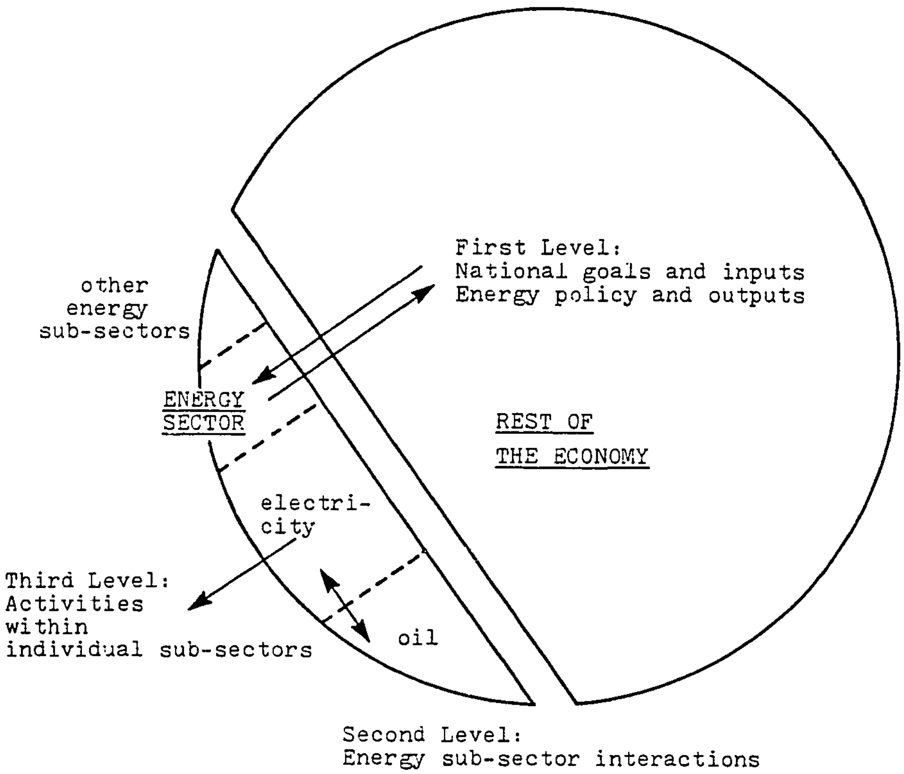
2.1 ENERGY ECONOMICS AND POLICY IN PERSPECTIVE

Energy economics and policy is an interdisciplinary field. An incomplete list of disciplines includes economics, law, politics, engineering, resource geology, biomedical impact, and environmental risk assessment. It also includes analytical methods that are familiar to the operation researcher: optimization algorithms, simulation, decision analysis, and econometric estimation (Manne et al., 1979).

Theoretically, the scope of national energy economics and policy issues can be classified into three different levels (see Figure 2.1). At the highest and most aggregate level, it should be recognized that the energy sector is a part of a larger economic system. Energy planning, therefore, requires analysis of the links between the energy sector and the rest of the economy. Such links involve the input requirements of the energy sector such as capital, labor, and raw materials as well as energy outputs such as electricity, petroleum products, and other forms of energy. The impact on the economy of policies concerning availability of supply, energy prices, taxes, and so on, in relation to national objectives are also included. For example, energy requirements must be considered in order to attain a desirable economic growth.

The second level treats the energy sector as a separate entity composed of sub-sectors such as electricity, petroleum products, and so on. This permits detailed analysis of the sector with special emphasis on interactions among the different energy sub-sectors, substitution possibilities, and the resolution of any resulting policy

Figure 2.1: Hierarchy of Interactions in Integrated National Energy Planning



Source: Munasinghe, 1980, p. 361.

conflicts such as competition between kerosene and electricity for lighting.

The third and most disaggregate level pertains to planning within each of the energy sub-sectors. The electricity sub-sector, for example, must determine its own demand forecasts and long-term investment program.

2.2 JUSTIFICATION: FOCUS OF THIS STUDY

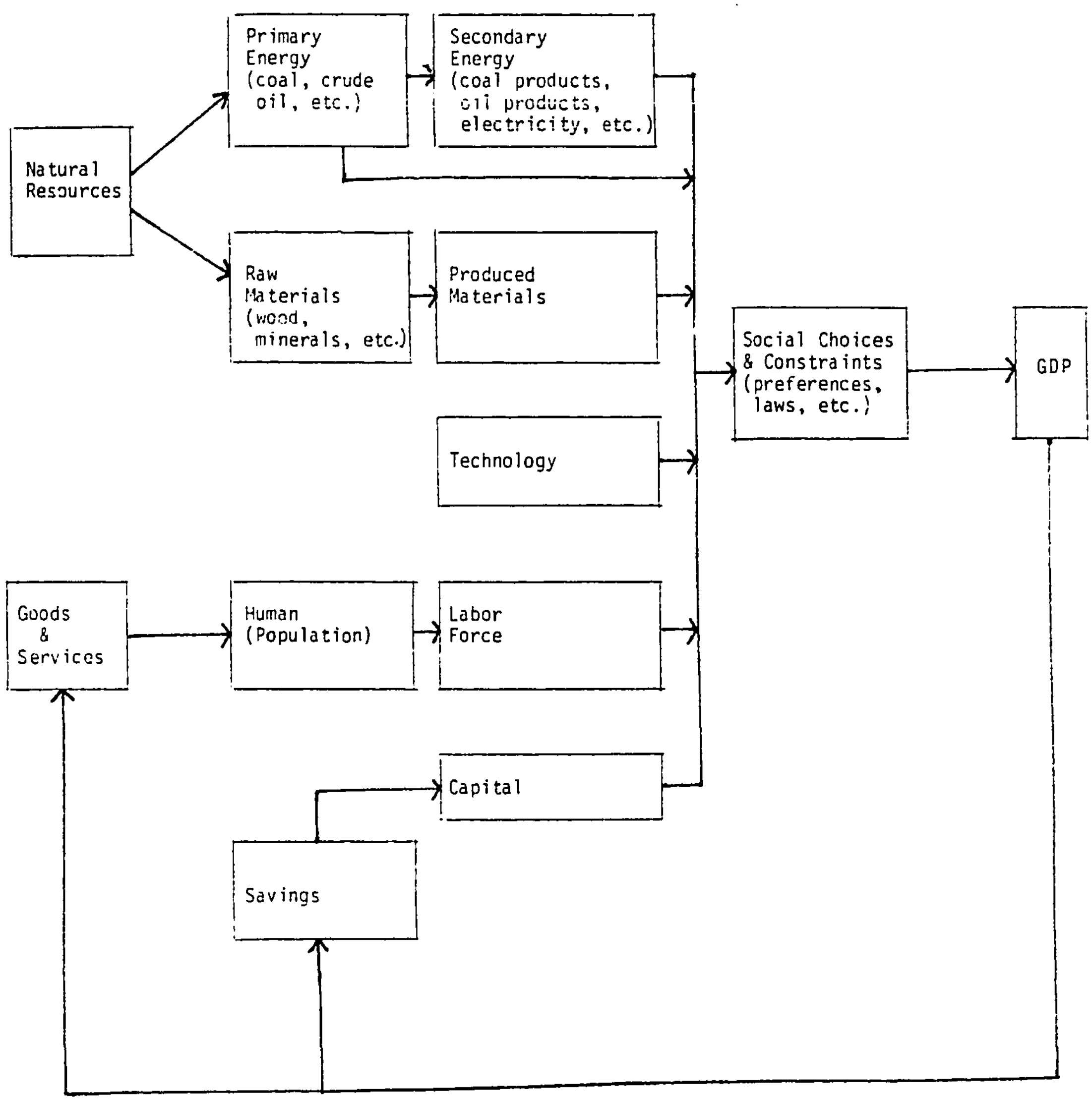
It would be unrealistic for the present study to analyze all issues involved in the above three levels. In this study, the emphasis will be centered on the first level which deals with the energy-economic-policy planning of the links between the energy sector and the rest of the economy. While the more disaggregated levels may be of interest to other researchers, the understanding of the aggregate-level framework has a higher priority than micro-level studies. Reseachers can better perceive these micro issues only after they have identified and quantified those interactions within an overall framework. As Samouilidis and Mitropoulos (1982, p. 222) note: "It has become obvious that the energy system cannot be treated in isolation, but within the context of a broader system which is the economy." Nevertheless, some of the lower-level issues relevant to the findings in this study will also be discussed.

2.3 OVERVIEW: PROBLEM IN PERSPECTIVE

Energy plays a vital role in the economic development of a nation and in the progress of society (Figure 2.2). The growth of industry, mechanized farming, transportation, the improvement of living standards, and military activities are all energy dependent. Since the Arab oil embargo of October 1973, the energy problem has become one of the most persisting issues for both the developed and developing nations.

Today, most nations have to take explicit account of the role of energy when initiating economic development. This is not only due to a fear of increasing energy prices and potential energy cutbacks in the future, but also because energy demand is derived from the structure and growth of the whole economy and population (Samouilidis and Berahas, 1983). As a result, the price and availability of energy could significantly constrain economic production, consumption, and trade. Additionally, the importance of oil to power naval vessels, tanks, trucks, and airplanes is recognized. The security of oil supplies for military purposes is a paramount objective of any national defense policy. All these circumstances are particularly relevant to the Republic of China, one of the countries severely affected by the energy crisis.

Figure 2.2: Economic Roles of Energy



Source: Based on Information Presented in Starr and Field, 1979.

2.4 ENERGY-ECONOMIC ISSUES AND ECONOMIC DEVELOPMENT

Before discussing the Taiwan energy-economic issues, it would be useful first to describe Taiwan's economic development. The two topics are closely related.

Taiwan is an island with a land area of about 13,970 square miles. Although Taiwan is not endowed with rich natural resources and has a high population density (1,280 persons per square mile in 1980), this island has been very successful in pursuit of its economic development goals. As Johnson (1981, p. 15) notes: "Taiwan's economic development strategy is one of the soundest ever created and is (or should be) a model for the underdeveloped nations." Taiwan, the Republic of China, is now sometimes termed a "newly industrializing country" of Asia (Li, 1982a, p. 1).

Since the late 1950s, Taiwan has enjoyed steady economic growth. In 1961 Taiwan's real gross national product (GNP) was $7.2[1] billion while that of 1982 was $47 billion, representing an annual average growth rate of 9.2%. Accordingly, per capita income increased from $584 in 1961 to $2,342 in 1982, an increase more than fourfold. The economic pattern has been transformed from an

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[1] In this study, $1 refers to US$1 which is equivalent to NT$40 (new Taiwan dollars).

agriculture-oriented economy into an industry-oriented one. The total agricultural production value dropped from 31% in 1961 to 7% in 1982 while that of industry rose from 25% to 50% (Table 2.1). Before 1970 Taiwan's industry was mostly labor intensive emphasizing products such as textiles, apparel, and electronic components. Heavy industries, such as petrochemicals, steel, electrical equipment, and automobile industry were subsequently introduced leading to a more energy-intensive economy. As for trade, the total two-way foreign trade (i.e., summation of imports and exports) jumped from $2.1 billion, or 30% of the real GNP in 1961, to $41.1 billion, representing 87.4% of the GNP in 1982. Exports consist mainly of industrial products, such as textiles, electrical-machinery apparatus and plastic products. Imports consist mainly of raw materials and energy. In 1980 the payment for energy importation was $4.8 billion. Oil imports alone cost $4.1 billion, equivalent to 20.8% of total import payments (Chu, 1982a). The heavy dependence on imported oil definitely makes the nation's economy vulnerable to the full impacts of rising oil prices and supply disruptions (Figure 2.3).

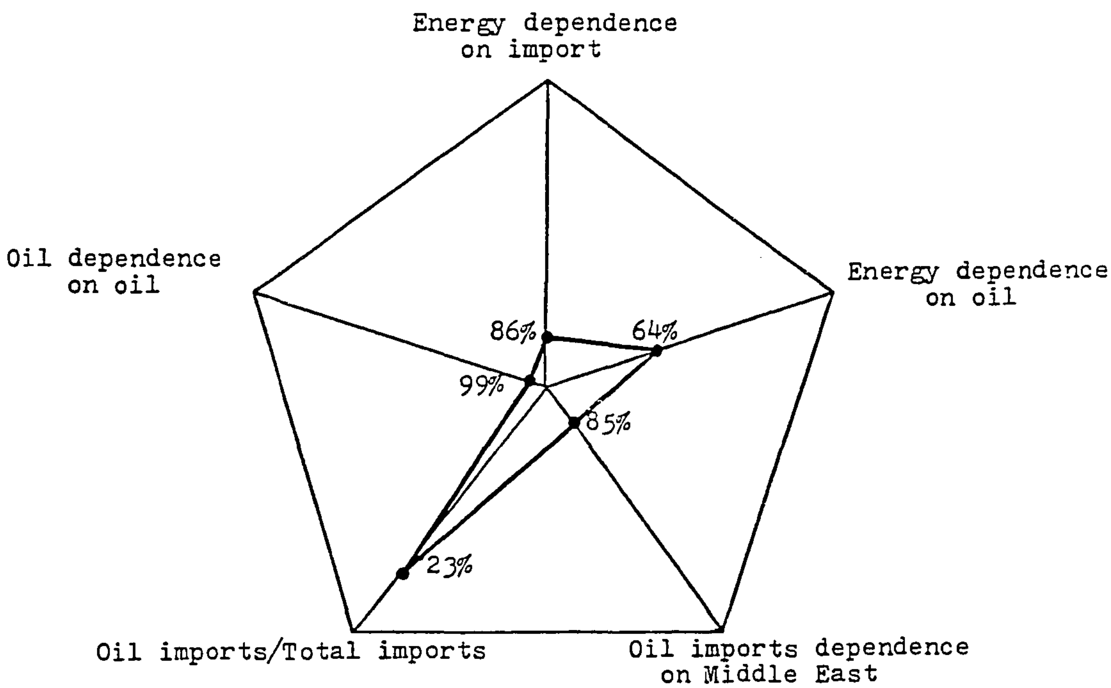
Table 2.1

Structure of the Taiwan Economy (1961 vs. 1982)

Year	Agriculture	Industry	Others	Total
1961	31%	25%	44%	100%
1982	7%	50%	43%	100%

Source: Energy Committee, 1983(a).

Figure 2.3: Energy Dependence/Security Indicators of Taiwan (1982)



Source: Energy Committee, 1983(c), p. 18.

2.5 ISSUES TO BE ANALYZED

This section identifies Taiwan energy-economic-policy issues requiring analysis within the first-level context as outlined in section 2.1.

2.5.1 Determining a Certain Economic Growth Rate with Minimum Consumption of Energy

Kuo (1983, p. 312) notes: "An important concept in energy policy is 'to achieve a certain economic growth rate with a minimum consumption of energy.' Energy policies, therefore, should not be designed only for energy conservation, but also for economic growth." Thus, a policy of saving energy by arresting growth is contrary to the economic objectives and policies of Taiwan. Given this perspective, the problem is to minimize energy consumption while permitting economic growth to recover and continue as it has in the past. This issue forms the main theme of the present study.

2.5.2 Relationship Between Energy Demand/Supply and Economic Development/Growth

The usual measure of economic development and growth is gross domestic production (GDP). The intuitive relationship between energy and GDP suggests energy as an input with GDP as a result or output (production function). It is important to identify and analyze this functional relationship in order to assess development alternatives. Only then can effective energy-economic policies be formulated.

The above-mentioned relationship forms the basis for most energy-economic studies. Because this issue is most complicated and, yet, important, it will continue to be one of the central concerns to energy economists and policy makers. This is true in Taiwan. Although previous researchers have conducted extensive studies ranging from descriptive (Bush, 1972; Chao, 1982a, 1983a; Chen, 1980; Chu, 1981, 1982a, 1982b, 1984; Council for Economic Planning and Development, 1982; Duker, 1983; Energy Committee, 1983a; Sun and Liang, 1980; Yen, 1982) to quantitative (Chang, 1978; Chern, 1984; Chinese Petroleum Corporation, 1980, 1981, 1982; Energy Committee, 1981a, 1983b; Kim, 1983; Lee, 1983; Liang, 1981; Overseas Advisory Associates, Inc., 1982a, 1982b; Taipower, 1979a, 1979b, 1980) the information on the nature of the relationship between energy demand/supply and economy growth/development is limited. This relationship continues to be one of prevailing concerns for further study. Thus, quantitative descriptions are one of the main objectives of this study.

2.5.3 Lower Elasticity of Energy and Oil

Energy elasticity refers to the percentage increase in energy inputs required to raise the gross domestic product by one percent (Kuo, 1983, p. 312). This indicator is used to evaluate the growth relations between economic growth/development and energy consumption.

In Taiwan energy consumption increased from 2.4 million kiloliters of oil equivalent (KLOE) in 1954 to 28 million KLOE in 1982, reflecting an average growth rate of 9.2% per annum. In contrast to the average 8.6% GDP growth rate during the same period, the overall average energy elasticity is 1.07 (Table 2.2). This indicates that the growth rate of energy consumption in Taiwan is greater than the GDP growth rate. Because, as Kuo (1983, p. 312) notes, "to lower energy elasticity becomes a most important task for the entire nation," the third issue to be analyzed in this study is development strategies that can lead to lower energy elasticity.

Note that the elasticity of oil has been significantly higher than the overall energy elasticity (Table 2.2). Even after the 1973 oil embargo, oil elasticity increased to 3.07 in 1975, 2.10 in 1976, and 1.48 in 1977. Only after 1977 has it declined to less than 1.0. Thus, a more specific concern is what can be done to lower the elasticity of oil?

Table 2.2

Energy Indicators of Taiwan (1954 to 1982)

Years \ Items	Internal Final Energy Consumption		Real GDP		The Elasticity Energy	Coal Consumption		The Elasticity of Coal	Oil Consumption		The Elasticity of Oil	Electricity Consumption		The Elasticity of Electricity
	(10^3 KLOE)	Growth Rate (%)	$25,000 (1976 prices)	Growth Rate (%)		10^3 MT	Growth Rate (%)		(10^3 KLOE)	Growth Rate (%)		(Gwh)	Growth Rate (%)	
1954	2,380.1	-	107,656	-	-	2,014.7	-	-	337.3	-	-	1,424.2	-	-
1955	2,614.9	9.87	116,359	8.08	1.22	2,340.4	16.17	2.00	494.0	46.45	5.75	1,531.7	7.55	0.93
1956	2,805.6	7.29	122,767	5.50	1.33	2,396.9	2.41	0.44	626.6	26.84	4.88	1,815.9	18.55	3.37
1957	3,058.3	9.01	131,833	7.38	1.22	2,657.5	10.87	1.47	547.2	-12.67	-	2,133.3	17.47	2.37
1958	3,349.3	9.52	140,706	6.73	1.41	3,004.2	13.05	1.94	666.6	21.82	3.24	2,486.5	16.56	2.46
1959	3,795.0	13.30	151,452	7.64	1.74	3,463.4	15.29	2.00	763.2	14.49	1.90	2,849.2	14.59	1.91
1960	4,041.5	6.50	161,021	6.32	1.03	3,788.8	9.40	1.49	829.2	8.65	1.37	3,241.2	13.76	2.18
1961	4,291.6	6.19	172,093	6.88	0.90	3,931.7	3.77	0.55	920.8	11.05	1.61	3,645.1	12.46	1.61
(1954-1961)	-	8.79	-	6.93	1.27	-	10.02	1.45	-	15.43	2.23	-	14.37	2.07
1962	4,593.0	7.02	185,630	7.87	0.89	4,436.8	12.85	1.63	1,003.6	8.99	1.14	4,228.0	15.99	2.03
1963	4,781.3	4.10	203,020	9.37	0.44	4,701.8	5.97	0.64	1,099.6	9.57	1.02	4,553.5	7.70	0.82
1964	5,425.2	13.47	227,792	12.20	1.10	5,183.8	10.25	0.84	1,187.2	7.97	0.65	5,401.4	18.62	1.53
1965	5,973.1	10.10	253,197	11.15	0.91	4,973.2	-4.06	-	1,676.9	41.25	3.70	5,889.1	9.03	0.81
1966	6,758.7	13.15	275,835	8.94	1.47	5,193.5	4.43	0.50	2,176.7	29.81	3.33	6,730.5	14.29	1.60
1967	7,400.1	9.49	305,278	10.67	0.89	5,018.0	-3.38	-	2,910.7	33.72	3.16	7,757.5	15.26	1.43
1968	8,590.8	16.09	333,119	9.12	1.76	5,065.6	0.95	0.10	3,543.2	21.73	2.38	9,074.0	16.97	1.86
1969	9,230.3	7.44	362,737	8.89	0.84	4,779.0	-5.66	-	4,467.4	26.08	2.93	10,479.4	15.49	1.74
1970	10,116.0	9.60	403,821	11.33	0.85	4,547.2	-4.85	-	5,626.4	25.94	2.69	12,578.6	20.03	1.77
1971	11,266.4	11.37	455,407	12.77	0.89	4,058.9	-10.74	-	6,916.2	22.92	1.79	14,519.8	15.43	1.21
(1962-1971)	-	10.13	-	10.22	0.99	-	0.32	0.03	-	22.34	2.19	-	14.82	1.45
1972	12,912.3	14.61	515,724	13.24	1.10	4,074.6	0.39	0.03	8,221.4	18.87	1.43	16,884.6	16.29	1.23
1973	14,443.3	11.86	582,091	12.87	0.92	3,572.7	-12.32	-	10,093.2	22.77	1.77	18,912.8	12.01	0.93
1974	14,530.4	0.60	588,654	1.13	0.53	3,291.1	-7.88	-	9,870.8	-2.20	-	19,869.3	5.06	4.48
1975	16,120.8	10.95	616,869	4.79	2.29	3,411.8	3.67	0.77	11,323.0	14.71	3.07	22,288.8	12.18	2.54
1976	19,274.6	19.56	701,117	13.66	1.43	3,371.3	-1.19	-	14,571.2	28.69	2.10	25,883.2	16.13	1.18
1977	20,938.2	8.63	769,720	9.78	0.88	3,398.9	0.82	0.08	16,674.8	14.44	1.48	28,907.1	11.68	1.19
1978	24,719.6	18.06	872,854	13.40	1.35	3,968.8	16.77	1.25	18,805.6	12.78	0.95	33,345.0	15.35	1.15
1979	26,827.4	8.53	940,607	7.76	1.10	4,980.4	25.49	3.28	19,536.4	3.89	0.50	37,043.8	11.09	1.63
1980	28,582.2	6.54	1,004,613	6.80	0.96	5,955.8	19.58	2.88	20,511.6	4.99	0.73	39,820.5	7.50	1.10
1981	27,431.4	-4.03	1,059,733	5.49	-	5,520.8	-7.30	-	18,796.0	-8.36	-	39,308.1	-1.29	-
1982	27,968.9	1.96	1,093,095	3.15	0.62	6,357.3	15.15	4.81	18,317.3	-2.55	-	40,105.7	2.03	0.64
(1972-1982)	-	8.62	-	8.26	1.04	-	4.16	0.50	-	9.26	1.12	-	9.68	1.17

Source: Taiwan Energy Statistics, 1982, pp. 10-11.

Two considerations merit special analysis because they are central to the above discussion: "It is important to see how far the high ratio of the growth of energy use to the growth of the gross domestic product was the result of increased energy intensity in individual industries (emphasis added), how far it was the result of a shift in the relative proportions of industries with high energy-intensity and those with low energy-intensity (emphasis added)" (OAAI, 1982a, p. 9). Increased energy intensity in individual industries, measured by the ratio of the increase of energy use to the increase of production (see Table 2.3, fifth column), indicates only one case with a net increase of energy intensity. The small group of "other" industries accounted for 4.6% of the total value added of total manufacturing. This is due to modernization and mechanization which involved increased energy utilization. All the other sectors show a reduction in energy consumption per unit of output. It is clear that between 1974 and 1979 adjustments were already being made in energy use in almost all industries (OAAI, 1982a, p. 11).

The second type of indicator, relative proportions of industries with high energy intensity and those with low energy intensity, one should first identify energy intensities and oil intensities of the principal

Table 2.3

Changes of Energy Use in Individual Manufacturing Industries (1974 to 1979)

Manufacturing Industry	Index of production[a]	Total consumption of energy	Consumption of oil products	Energy consumption per unit of output	Consumption of oil per unit of output	Value added in industry as % of total of manufacturing	
	1974=100	1974=100	1974=100	1974=100	1974=100	1974	1979
Food	173.7	148.7	197.0	85.6	113.4	15.6	13.4
Textiles	168.5	162.4	201.5	96.4	119.6	18.5	15.4
Paper and lumber	205.9	173.8	286.8	84.4	139.3	8.6	8.8
Non-metallic mineral products[b]	191.2	178.1	443.1	93.1	231.7	5.4	5.1
Chemicals	278.5	162.1	283.0	58.2	101.6	15.3	21.2
Basic metals	255.5	234.6	242.2	91.8	94.8	5.1	5.5
Other metal industries	259.7	229.5	232.9	88.3	89.6	24.3	26.0
Others	129.6	173.4	268.7	133.7	207.3	7.2	4.6
Total of manufacturing	208.5	179.9	262.2	86.3	125.8	100.0	100.0

[a]Index of value-added at constant prices.

[b]For non-metallic mineral products the indicator used for production has been the production of cement, which is by far the largest user of energy in the sector concerned. The overall index of production of the sector is 163.2. This gives obviously misleading results.

Source: Overseas Advisory Associates, Inc. (OAAI), 1982(a), p. 10.

(manufacturing) industries of Taiwan. As was shown in Table 2.4, there are certain industries are highly oil and energy intensive. Notable among these are non-metallic mineral products, with cement and glass (particularly the former) as the principal products; paper-making; plastic raw materials; and, more generally, petrochemicals and chemical products. The last are particularly oil intensive. On the other hand, the new, modern, advanced-technology electronic industries are notably low in oil-intensity. The textile industries lie between these two extremes[2] (OAAI, 1982a, p. 9).

As shown in Table 2.3, a shift toward the energy-intensive industries is apparent. For example, chemical production, an energy-intensive activity, though performing well in terms of overall energy consumption per unit output (from 100 in 1974 to 58.2 in 1979), increased in its share of total production (from 15.3% in 1974 to 21.2% in 1979). Basic metal production was also highly energy intensive and also increased its share of total production (OAAI, 1982a, p.11).

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[2] The criterion of energy intensity discussed in this section does not take into account the interdependency among industries, i.e., it implicitly assumes independence of each sector. This problem will be discussed in a later chapter.

Table 2.4

Energy Intensity and Oil Intensity
of Manufacturing Industries
(1979)

	Total energy intensity (KLOE per $25,000 of value added)	Oil intensity (KLOE per $25,000 of value added)
Food, beverages and tobacco	11.8	6.2
Textiles and apparel	24.7	11.2
Wood and paper products	25.9	13.4
Non-metallic mineral products	118.0	50.8
Petrochemicals	40.9	18.2
Synthetic fibers	32.5	13.1
Plastic raw materials	52.6	12.9
Plastic products	14.4	6.0
Other chemicals	25.8	12.9
Iron and steel	61.2	9.6
Other metals and products	43.7	13.0
General machinery	7.3	1.1
Household electric appliances	4.8	1.3
Telecommunication equipment	5.1	0.3
Electric machinery	5.2	0.3
Transportation equipment	3.7	1.0
Other manufactures	36.9	16.7
Average of all manufactures	27.6	10.8

Source: Overseas Advisory Associates, Inc. (OAAI), 1982(a), p. 28.

A key conclusion suggested by OAAI (1982a) is that manufacturing industries contributed to the excess of the growth of energy consumption over the growth of the gross domestic product for two reasons. First, between 1974 and 1979, manufacturing, which is necessarily an energy-intensive activity, increased its aggregate contribution to the gross domestic product from 32.7% to 34.9%. Second, within the total of manufacturing there was indeed a significant shift towards energy-intensive industries (OAAI, 1982a, p. 11).

OAAI (1982a) further suggested that it is important, in the interest of controlling the growth of energy consumption, to examine carefully the rate at which new energy-intensive industries develop. In a later chapter, this study evaluates "optimal" development rates for all sectors in the Taiwan economy, including the energy-intensive industries. "Optimal" here describes the minimization of energy consumption on the one hand with simultaneous maximization of GDP on the other. This will, of course, lower the elasticity of energy, while achieving maximum economic growth.

2.5.4 Industrial Restructuring

An alternative way of expressing the above ideas is to address the "industrial restructuring," constantly emphasized by development economists in Taiwan for the past few years. Industrial restructuring here refers to the shifting of the industrial structure from labor- and energy-intensive to less energy-intensive (or more energy-efficient) and more technology-intensive operations. An economy of this type can achieve a higher level of value added and reduce the heavy burden of energy or raw-material importations. This is essentially what Japan has done in response to the energy crisis of the 1970s:

> "The Japanese, by all rights, since they have no domestic energy resources, should have been devastated by it. Instead, because they have to be nimble, they had seen it coming and had already begun to shift their economy, as a matter of national policy, from a predominantly smokestack one to a high-technology one, weeding out the energy-consuming industries. They went through one brief period of great hardship and now, some 10 years after the Arab-Israeli war of 1973, they have cut back on the percentage of energy used while raising quite dramatically their production" (Halberstam, 1983, p. 7).

This type of strategy should benefit the whole Taiwan economy for similar reasons.

In general, the Taiwan economy is an intermediate economy (Figure 2.4). With limited natural resources, Taiwan is forced to import a large portion of the raw materials and energy resources used by sectors of the economy and, after processing, export the final products and earn the margin of the value added. Basically, Taiwan's economy could be described as both labor and energy intensive. Before the early 1970s, when the international oil price was as low as $2.00 per barrel and the domestic wage rate was relatively low, Taiwan enjoyed rapid economic growth. By early 1974, when OPEC drove up the price of light crude from $2.1 to $9.22 per barrel, and again, in 1979, with the price pushed up from $13.34 to $26.00 per barrel, Taiwan lost one of her advantageous conditions, i.e., cheap inputs of energy and raw materials. Following the energy crises, a pattern of "stagflation" occurred and caused a significant increase in Taiwan's wage rate (see Yen, 1982). Chao (1982a, p. 4) notes that the wage rate within the manufacturing industry has maintained an average annual increase of 18% for the past six years. In contrast, labor productivity for the same period increased only 5.5% per annum. Chao (1982a, pp. 4-5; 1983c, p. 11) further notes: "The increasing labor production cost has weakened the competitive power of our products. On the other hand, other developing countries with lower wage rate have a greater potential for competition. We have gradually lost our favorable condition of low wage rate." "If our industry cannot change its structure in the near future, our dilemma will be getting more and more serious." Moreover, Yen has proposed a cost-reflected pricing policy for necessary adjustments to the domestic economy. He argued that "maintaining unrealistically low energy price[3] would certainly hold structural improvements" (Yen, 1982, p. 9). Li (1982b) notes: "energy saving and energy efficiency call for an adjustment in industrial and economic structure, which, in turn, calls for effective energy policies and strategies." Samouilidis and Berahas (1983, p. 7) also note: "major breakthroughs to solve the energy problems of DIC's (developing and industrializing countries) will require changes in their institutions to promote these changes."

It is, therefore, important to identify the sectors of lesser energy intensity and higher value added in Taiwan and to study how the government can implement policies to achieve this industrial restructuring.

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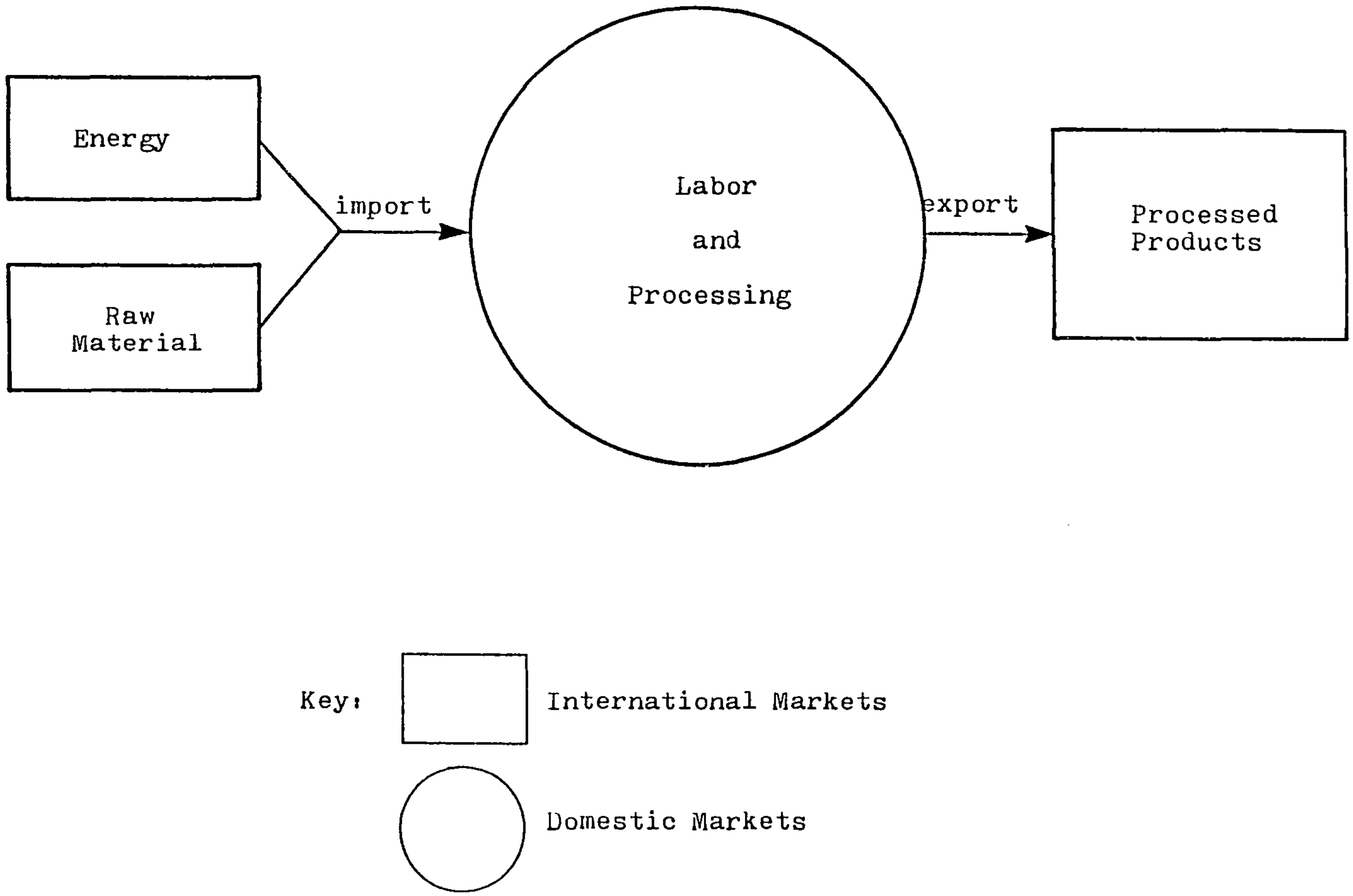
[3] A paper by Liang (1980) pointed out that the prices of petroleum products in Taiwan were lower than those in Korea, Japan, West Germany, France, and the United Kingdom. The underlying reason for these low oil prices has been to help reduce inflation and hence maintain price stability. For detailed discussions see Liang (1980) and Sun and Liang (1980).

Figure 2.4: A Description of the Taiwan Economy



2.5.5 Regarding a Disruption of Energy Supply

In addition to the general issues, a particular concern has been expressed regarding crude oil supply. Because the oil dependency on imports in Taiwan has been so high (above 98% since 1954), energy security indicators (Figure 2.3) also show an extremely vulnerable situation with respect to national energy supply, particularly the supply of oil. This is, of course, an energy-economic-policy issue of paramount importance. What will be the economic impacts to the Taiwan economy if there is a disruption of energy supply? And, how should the government manage an emergent case of this type so as to minimize the economic loss? This study provides the critical analysis necessary to a framework of sound response to these questions.

2.5.6 Summary

The issues outlined all belong to the first aggregate level of energy economics and policy and are of major concern in this study. In summary, they are:

(1) What is the minimum energy supply that should be maintained so as to sustain a desirable or maximum level of economic activities?

(2) What is the relationship between energy demand/supply and economic development/growth?

(3) How can the aggregate elasticity of energy and oil be lowered?

(4) What "industrial restructuring" is required to overcome successfully perturbations in energy supply?

(5) What will be the economic impacts on the Taiwan economy resulting from a disruption of energy supply; and, how should the government manage an emergent case of this type?

Feasible policy alternatives must be weighted by careful consideration of the questions above.

2.6 SIMULATION OF POLICY ALTERNATIVES

Based on the energy-economic situation in 1978, three possible alternatives have been simulated for 1986: The first one is an "aggressive policy." This means that the government is planning a high economic growth rate for the period 1978 to 1986. The second one is a "moderate policy" implying a moderate growth rate. The third is a "conservative policy" indicating a low growth rate of the economy.

Which alternative should the government take, and what are the concerns and consequences of each one?

This study analyzes, in later chapters, these alternatives in terms of two aspects. One is to project the consequences of the economic performance of each policy alternative. The second is to forecast the energy requirements for supporting these economic performance targets. This information should help policy makers make a choice among these alternatives.

Chapter III

ENERGY MODELLING FOR ECONOMIC ANALYSIS AND DECISION MAKING

In order to examine the broad variety of issues related to the energy problem, a large number of energy models (EM) have been developed. These models focus on energy as an economic resource and they are directly or indirectly associated with the decision making process. The purpose of this chapter is to describe and justify the uses of EM.

3.1 ENERGY MODELLING

In three comprehensive studies (Charpentier, 1974; 1975; Charpentier and Beaujean, 1976), 144 energy related models were reviewed and characterized. Samouilidis and Mitropoulos (1982), Ulph (1980), Manne et al. (1979), Sweeney (1978), Brock and Nesbitt (1977), and Greenberger (1977) also discussed the features and the uses of some of the major EM. One can correctly assume that the large number of models developed cover a wide range of application.

EM can be classified into three categories according to their use:

(1) Descriptive--This type of model attempts to replicate some relevant features of the reference system, providing detailed information on the past and present (observable) behavior of the system.

(2) Predictive--This type of model is used to forecast future aspects and features of the reference system, caused either by some contemplated action of the policy maker (conditional forecasting), or by the general dynamics and inertia of the system (unconditional forecasting).

(3) Normative--This type of model is used to project how the reference system should develop given some overall objectives and constraints.

Using this classification, the historical background of EM and their relevant characteristics are evaluated.

Before 1973 most EM dealt with energy demand analysis and forcasting. Energy forecasting studies date back as far as 1866 (Rivett, 1979, p. 38). In the 1950s and 1960s, energy demand forecasting was mainly intended to support investment decisions related to new capacity build-up or expansion of existing capacity. Thus a great number of studies, initiated by the U.S. automobile industry, tried to establish forecasts for gasoline. On the other hand, the peculiarities of the pricing system in the electricity market, e.g., peak load pricing, have always attracted econometricians. Also, see Taylor (1975) for a comprehensive literature survey and critical review on electricity demand analysis.

There are two major characteristics of the EM effort in the period from 1950 to 1970. First, energy commodities were treated in isolation. Each energy form had almost its own market; the question of substitution among energy carriers arose only in special cases. Second, EM reflected a stable energy pattern within a stable economic environment. The changes in the world of energy, mere extrapolations of past trends, were the result of a constant economic growth accompanied by regular technological progress. Thus standard econometric techniques could be used to estimate coefficients of demand functions for both time series and cross sectional data.

3.2 ENERGY MODELS (EM) AND MANAGEMENT SCIENCE

With the beginning of the 1970s, the long period of uninterrupted growth in energy supply/demand that started in the early 1950s came to a halt. Long established trends reversed. Discontinuities became the rule. Erratic patterns and unpredictability characterized this new era. Under these circumstances, previously used EM were no longer reliable forecasting devices. This argument can be supported by the following empirical and theoretical grounds.

On the empirical front, President Nixon announced on November 7, 1973, "It soon become evident that the U.S. would remain heavily dependent upon (oil) imports throughout the 1980s" (Manne et al., 1979, p. 10). This inaccurate projection was based on the Project Independence Evaluation System (PIES) model. Other models in the United States had projected a world price of oil in the range of $13 to $14 per barrel in 1975, a decline over the 1975-1980 period to around $10 and then a slow increase (Pindyck, 1978). Also, in 1866 Professor Jevons forecasted that within 100 years the demand for British coal would be 2,607 million tons a year. In 1966 U.K. coal production was 176 million tons and total energy consumption was 298 million tons of coal equivalent (Rivett, 1979). In addition, the Robbinson commission of the Organization for Economic Co-operation and Development (OECD) stated in 1960 that no persistent shortage of primary energy was likely by 1975 and there was no need to create new sources of energy (Rivett, 1979, p. 38).

On the theoretical front, forecasting can be effective only in a predictable environment--namely, to extrapolate past trends. Structural changes cannot be predicted since an environment cannot be predictable when fundamental changes from established patterns are involved (Samouilidis, 1980).

Although some analysts have proposed new techniques for energy demand forecasting, the values of these approaches is still debatable. For example, Finon and Lapillonne (1983, p. 17) proposed a technico-economic approach which, as opposed to traditional econometric methods, looks in more detail at the determinants of energy demand, such as the number of trips per person, steel output, the number of appliances per household, services industries, etc. Approaches of this type deal with a number of variables each of which is itself difficult to accurately determine and, thus, the accumulated bias can be significant.

As Samouilidis and Berahas (1983, p. 8) note: "The principal question was no more what the energy demand in some future year would be and how different supply options could contribute to satisfy this demand, but rather what a robust, flexible and rational energy policy should be in order to cope with the uncertain future and meet specific economic and social goals." It is under these circumstances, that a new breed of EM made its explosive appearance in the world of management science.

Management science is defined as the application of the methods and techniques of science to problems of management decision making (Lee et al., 1981, p. 3). Its goal is to help managers make better decisions by solving problems more effectively. In pursuing this goal, a number of mathematical techniques (especially operational research) have been developed as tools. These technical models emphasize the managerial role of the decision maker--the objectives of the analyzed system and possible alternatives available to management. These models are normative-oriented, although their approaches per se are positive.

The emphasis of EM have shifted from the "descriptive" and "predictive" models of energy analysis to the "normative" model of energy planning and management. The following characterizes the differences between EM and conventional management science model (Samouilidis, 1980):

(1) Planning horizon--EM generally look further into the future than early decision making models.

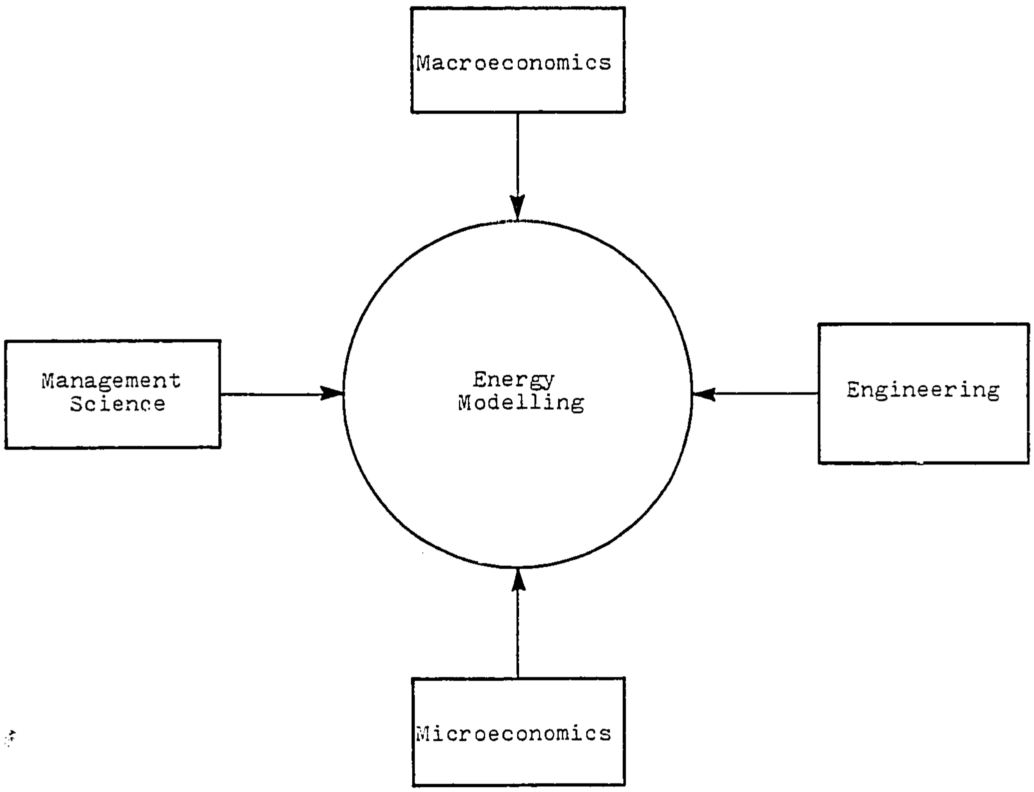
(2) Systems boundaries--Usually decision making models within management science describe the behavior of a firm or an industry. EM usally deal with a higher order of aggregation such as a region or a nation.

(3) Supporting sciences--Whereas industrial models of management science rely heavily on microeconomics and the engineering sciences, EM draw much from macroeconomics (see Figure 3.1).

(4) Model complexity and size--EM tend to be more complex and extensive than the conventional decision-making model.

(5) Model potential users--EM ususally aim at public decision making, whereas conventional management science models address themselves to decision making within a firm. This case makes EM more complicated than the conventional models, e.g., linear programming or goal programming of management science.

Figure 3.1: Energy Modelling and Supporting Sciences



Source: Samouilidis, 1980, p. 621.

As described above, EM broaden the scope and the field of implementation of management science. At the same time, the latter has a rich experience to offer to the former. Energy modellers can therefore benefit from this realm of management science. Accordingly, the main purpose of this study is to incorporate a newly developed model of management science with a conventional input-output model of macroeconomics to investigate the energy-economic issues outlined in chapter two.

3.3 EM AS A TOOL FOR PUBLIC DECISION MAKING

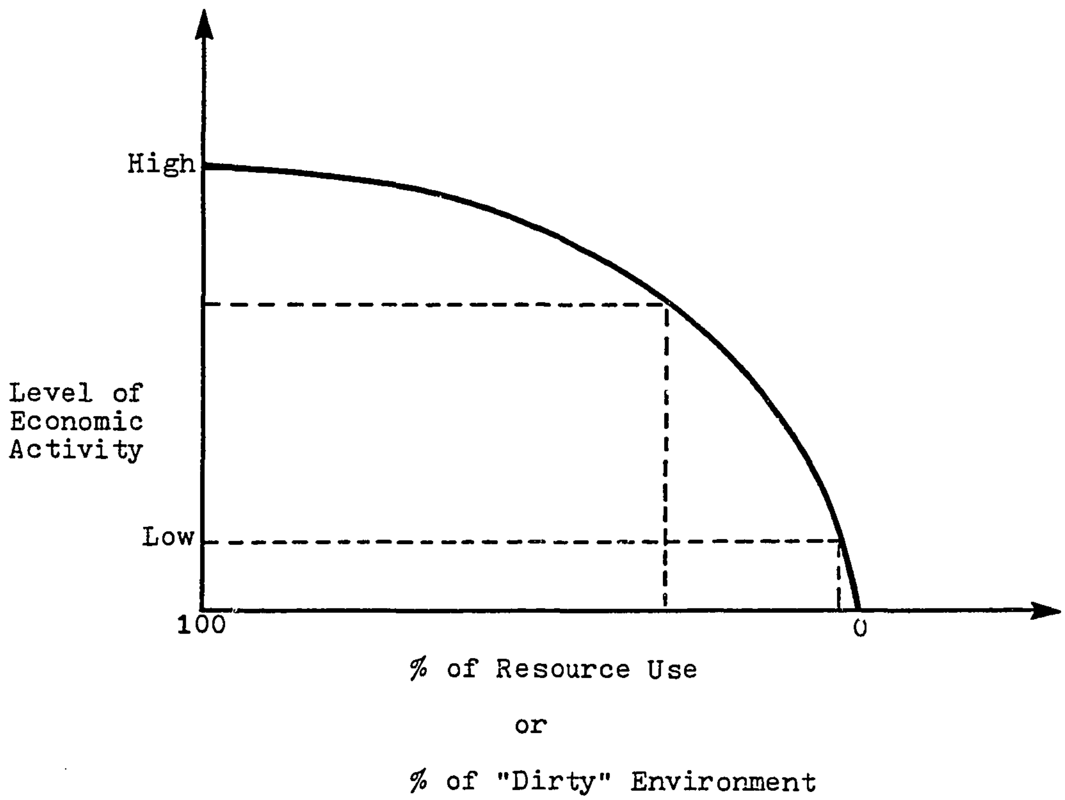
The role of EM is to enhance the understanding and communication of the energy issues involving policy making. EM assist the policy makers to review plausible future configurations of relevant decision variables and parameters. It is therefore important to detail the ways EM can become a tool useful to public decision makers.

As public policy makers and planners face the problems of economic growth under resource or energy constraints, they seek the best possible information on the consequences of their choice among development alternatives. Conceptually, planners are often faced with trade-offs between various levels of ecological purity, resource use, and economic activity. The essence of these trade-offs may be illustrated with the use of a production possibilities curve (Figure 3.2). This curve shows the relationship between levels of environmental cleanliness, resource use (depletion if the resource is not renewable), and economic activity. As shown in Figure 3.2, it is clearly possible to have a pristine (100% clean) environment at the cost of a zero level of economic activity. On the other hand, it is possible to have a "totally dirty" environment but have a high level of economic activity. Further, it is possible to show the relationship between levels of economic activity and resource use. This production or technological relationship simply reflects the use of resources in the production process and shows a proportional relationship between resource use and levels of economic activity (Harris and Ching, 1982).

From a decision maker's standpoint, it would be extremely helpful to quantify some of the above relationships. Then, decision makers would be better able to make informed decisions regarding alternative courses of action.

The job facing the energy modeller is to identify the above-mentioned quantitative relationships by applying energy modelling techniques to the reference system. A formal model of a given reference system can be defined as a

Figure 3.2: Trade-offs between Regional Economic Activity and Either Regional Resource Use or Environmental Pollution



Source: Harris and Ching, 1982.

"system expressed in a formal language, and synthesized from representations of selected elements of the reference system, and their assumed interelationships" (Greenberger et al., 1978, p. 49). This definition implies the following (Samouilidis and Berahas, 1983; Ackoff, 1979a):

(1) A model refers to some system, object, or process.

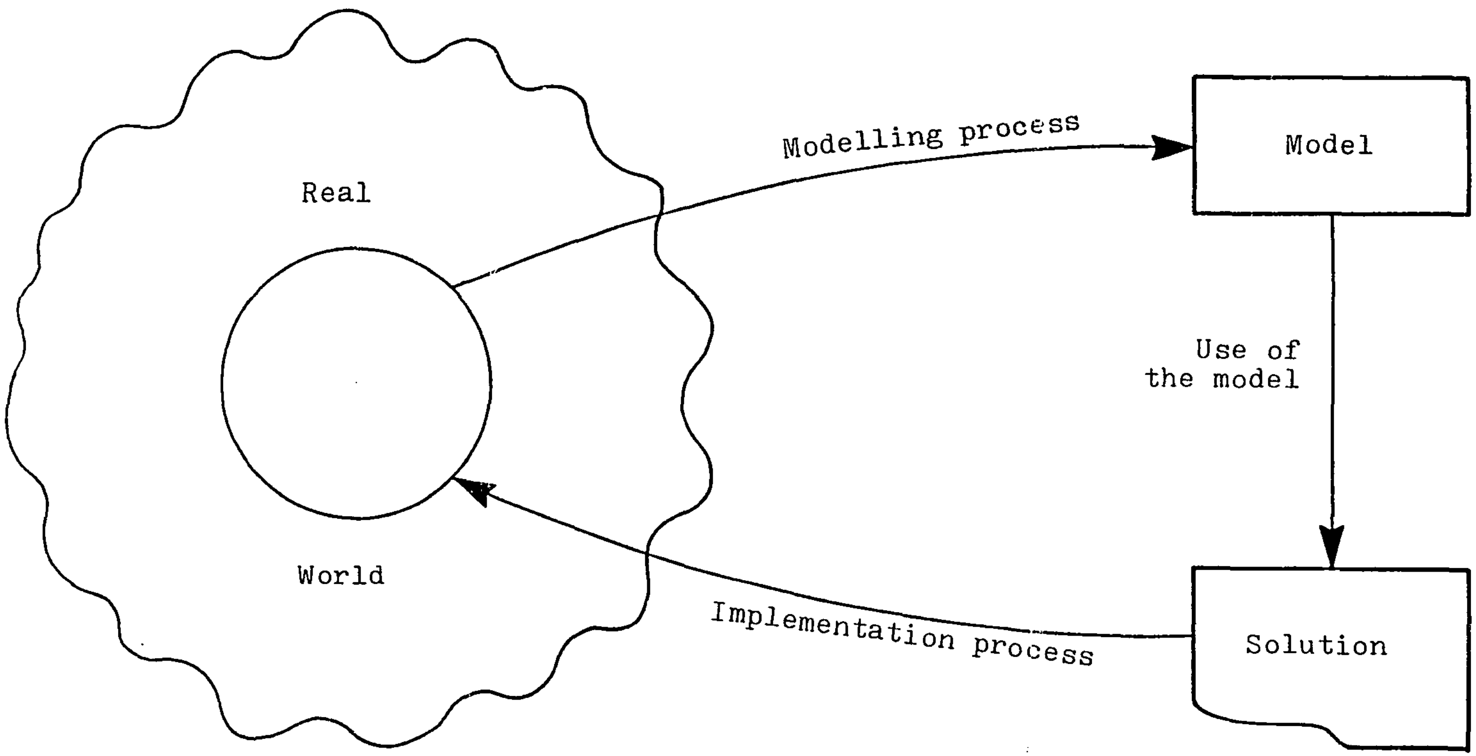
(2) A model represents and approximates selected features of the relevent reference system.

(3) Formal models utilize formal linguistic systems to represent selected features of the reference system.

(4) The optimal solution of a model is not an optimal solution of the problem unless the model is a perfect representation of the problem.

The last point is illustrated in Figure 3.3. Since a model is only an abstraction and simplification of some selected parts and features of the real world, the implementation of the solution given by the model requires the integration of all those elements not included in it. Usually these missing elements and features are the non-quantifiable factors, such as the political issues involved, the behavioral aspects characterizing the reference system, etc. As Koreisha (1980, p. 96) remarks, "failure to consider non-quantifiable factors when assessing the models' results can lead to misleading conclusions."

Figure 3.3: Model versus Problem Solution



Source: Samouilidis and Berahas, 1983, p. 3.

3.4 PROBLEMS AND LIMITATIONS OF EM

Five broad classes of problems and limitations of EM can be identified as follows (Samouilidis and Berahas, 1983; Samouilidis, 1980):

(1) System complexities--involving the difficulties inherent in the nature of the phenomena to be modelled and in expressing these phenomena in formal (usually mathematical) ways (e.g., uncertainty, complexity, addressing the wrong problem, etc.).

(2) Political complexities--involving the difficuties inherent in the political nature of the policy-making process (e.g., conflicting interests, pressure groups, etc.).

(3) Model complexities--involving the difficulties inherent in the complex structure of large-scale models usually developed for addressing policy questions (e.g., detail vs. simplicity, availability of appropriate methodologies, and algorithms, etc.).

(4) Communication complexities--involving difficulties inherent in the lack of communication channels linking the various agents in the modelling process, and communication problems often encountered between analysts and planners

resulting from individual differences, time constraints, and unsatisfactory model documentations.

(5) Data complexities--involving difficulties inherent in the process of capture and management of large quantities of data usually required by policy models (e.g., availability of data, quality of data, data indexing, etc.).

The last point of data complexities is particularly notable because there are alternative ways of measuring energy and handling energy data indexing. Percebois (1979) discussed different interpretations for measuring energy intensity. Smith (1984) presented common problems extensively involved in energy indexing. For example, to measure electricity from a nuclear power plant, the World Bank bases its calculations on the starting point, i.e., total (gross) energy content of nuclear fuel (most of which is lost in the form of heat during the process of generation), whearas the United Nations bases its calculations on the end point, i.e., actual (net) electricity generated. The former is about three times the latter measurement. It is, therefore, important to specify which the energy modeller uses in order to present correct interpretation. Nevertheless, it has been found that many energy-economic studies fail to do so. For example, all the energy models compared in this study (see chapters four and five) did not specify this point. Only the study by Overseas Advisory Associates, Inc. (OAAI) indicated that their data were based on the starting point (gross energy). For the present study, data measurement is also based on the gross energy. This convention rather than net energy is especially useful when oil substitution and reduction are of primary concern.

Indexing problems of energy data are even more complicated than the above-mentioned energy-measuring problems. In general, the index of energy data are in heat (e.g., Btu), weight (e.g., tons of oil equivalent), or in volume (e.g., kiloliters of oil equivalent). To convert different types of energy (e.g., coal, oil, natural gas, etc.) to a common index may cause potential problems (see Griffin and Steele, pp. 6-7, for details). As Smith (1984, pp. 37-38) notes, there is no universal energy index. The index must be chosen carefully to fit the task of interest and to be sure that it is helping to find, not obsuring, the answer to the question at hand. For example, measurement in volume is not as accurate as the other two alternatives, because oil products become altered in volume in the course of refinery process and under different temperatures. However, after considerable thought was given to the question, kiloliters of oil equivalent (KLOE) were adopted for this study. This is justified on the grounds that, first, KLOE has for many years been the unit in which energy consumption has been measured in Taiwan. The desirability of continuity and comparability, and the use of available data are advantageous. Second, one of the primary concerns of the present study is with problems of energy imports and primary energy and the reduction of the dependence on imports of oil. It would be much easier for policy makers concerned to visualize the dimensions of some aspects of the problem if it is presented in terms of oil use.

3.5 AN APPROPRIATE ATTITUDE WITH REGARDS TO EM

Reviewing the difficulties in EM, one can be misled to believe EM can only serve as exercises in academic futility with little practical value. Yet the plethora of models addressing important policy issues is an indication that models and modelling are indeed vital. Without them no formal analysis can be carried out. Thus, it is important to possess an appropriate attitude regarding EM and their use in public policy making.

Hoffman (1978) points out that "there is often a quite unrealistic attitude regarding mathematical models and their use in policy and decision making." The two extremes of this attitude are:

(1) Wariness of decision makers towards models, feeling that the models reduce their role and degrees of freedom, which are essential for their political survival.

(2) Tendencies on the part of analysts to view their models as the ultimate tool, without which it is impossible to make rational decisions.

Problems do exist in developing and using energy policy models since they have inherent limitations. Yet it is obvious that the failures, problems, and limitations of models in policy analysis are integral parts of the failures, problems, and limitations of policy analysis and planning themselves. Therefore, it is essential to have a balanced view of the above-mentioned two extremes: Models are essential as decision aids in the policy making process; yet their contributions may be overshadowed by the political feasibility of the proposed policies.

3.6 VERIFICATION AND VALIDATION

The major uses of EM were described in section 3.1, i.e., descriptive, predictive, and normative. EM also have some indirect but nevertheless very important uses. These include: communication between and among analysts and decision makers, simplification of the issues for enhanced understanding, generation of new points of view and polarization of thinking, attraction of public notice and promotion of public issues. All these contributions and uses of EM are impressive.

The usefulness of EM is largely determined by the process of "verification and validation." Model verification deals with the internal consistency of the model structure and design. It is an attempt to ensure that the model behaves as the modeller intended. Model validation deals with the external consistency of the model, i.e., testing the agreement between the behavior of the model and the real world system being modelled. Verification and validation are important parts of the modelling process, and without them it is not possible to consider the information provided by models as valid and of any value in decision making. Yet it is important to realize that only a few of the conclusions reached during the verification and validation processes are tangible and permanent, due to the volatility of the reference system, and the complex interrelationships involved (Samouilidis and Berahas, 1983).

Chapter IV

COMPARATIVE STUDIES ON SELECTED METHODOLOGIES

As described in chapter three, there are many energy-economic methodologies. In this chapter, the concentration is on the methodologies deemed relevant to the present study:

(1) input-output multipliers and coefficients,

(2) linear programming input-output (LP-IO),

(3) goal programming input-output (GP-IO), and

(4) non-inferior set estimation input-output (NISE-IO).

The purpose of this chapter is to describe the nature and the uses of these models. As explained in chapter one, their different perspectives and uses provide important information to energy policy makers.

In section 4.1, the standard Leontief interindustry model is described. Within this framework, input-output multipliers and coefficients of various types are defined. Careful consideration is then given to energy-economic final demand coefficients as the most appropriate indicators for investigating trade-offs between economic development and energy use on the sectoral-level analysis.

In section 4.2, input-output models are integrated with optimizing techniques for the macro-level analysis. The uses of LP-IO are introduced and, specifically, an LP model by Taipower (1980) and an LP-IO model by the Energy Committee (1981a) are discussed and criticized. The LP-IO model is then extended to multiobjective function analysis. Goal programming (specifically, GP models used by Taipower, 1980, and GP-IO models used by CPC, 1982) and generating techniques are discussed and compared. An alternative (NISE-IO) which will be used as an analytical tool in this study is presented. Finally, a summary and comparison are made in section 4.3.

4.1 THE LEONTIEF INTERINDUSTRY MODEL

4.1.1 The Basic Model

Since Leontief's initial work in the 1930's, many presentations of input-output models have appeared in the literature (Bills and Barr, 1968; Carter, 1974a; Chenery and Clark, 1965; Ching, 1981; Dorfman et al., 1958; Fisher, 1958; Harris and Ching, 1982; Lee et al., 1976; Liew, 1977, 1980; Malinvaud, 1954; O'Malley, 1973; Park, 1982; Penn and Irwin, 1977; Rasmussen, 1957; Richardson, 1972; Sapir, 1976; Yan, 1969). In general, input-output models depict the monetary flow of goods and services throughout the economy.

All sectors in the economy purchase goods from one another and use these goods in the production of a final product. Mathematically, this type of interaction may be expressed as:*

$$
\begin{array}{ccccccccccc}
x11 & + & x12 & +. . . + & x1n & + & y1 & = & X1 \\
x21 & + & x22 & +. . . + & x2n & + & y2 & = & X2 \\
. & & . & & . & & . & & . \\
. & & . & & . & & . & & . \\
. & & . & & . & & . & & . \\
xn1 & + & xn2 & +. . . + & xnn & + & yn & = & Xn
\end{array}
$$

where:

xij = sales from sector i to sector j,
i,j = 1,2,...,n;

yi = final demand for products of sector i,
i = 1,2,...,n;

Xi = total output of sector i,
i = 1,2,...,n.

---

* Because the text of this dissertation has been prepared with a computer on which true subscripts are not available, none have been used. Instead, subscripts are placed on the same level as the variables themselves.

In input-output analysis, linear production activities are assumed, i.e., they utilize production processes that are homogeneous of degree one. As a result, it is appropriate to define the production activity for each sector in terms of a set of input/output coefficients:

$$aij = xij/Xj$$

Thus, the equation system showing the interdependencies of the various sectors may be rewritten as:

$$\begin{array}{l} a11X1 + a12X2 + \ldots + a1nXn + y1 = X1 \\ a21X1 + a22X2 + \ldots + a2nXn + y2 = X2 \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ an1X1 + an2X2 + \ldots + annXn + yn = Xn \end{array}$$

This equation system can be expressed in matrix notation as :

$$AX + y = X$$

where:

X = n x 1 vector of sector outputs,

y = n x 1 vector of final demands, and

A = n x n matrix of technical coefficients.

The matrix A or technical coefficients are sometimes referred to as a production recipe because the column shows the quantity of production or service required from each sector to produce $1.00 of output by the sector heading the column.

Since the general purpose of the Leontief interindustry model is to determine the effects of changes in final demand on the regional economy, one can rearrange the equation system as follows:

$$X = (I-A)^{-1} y$$

where:

I = n x n identity matrix.

This is the basic equation of input/output analysis. The interindustry matrix, $(I-A)^{-1}$, can then be used to determine the economic effects within the context of interindustry multipliers as discussed in the following sections.

4.1.2 Traditional Economic Multipliers

Output, employment, and income multipliers are usually referred as traditional economic multipliers. For example, Bills and Barr (1968) estimated income and employment multipliers for a regional economy.

The output (sales) multiplier is defined as :

$$S = j\ (I-A)^{-1}$$

where:

S = 1 x n vector of output multipliers, and

j = 1 x n sum vector.

Thus the output or sales multiplier is the column sums of the interindustry matrix, $(I-A)^{-1}$. The output multiplier can be interpreted as follows: if the final demand of the kth sector were to increase by one unit, the kth output multiplier would indicate the change in output in the whole economy.

Other input/output multipliers can also be derived. The following equations define the employment multiplier:

$$q = p\ (I-A)^{-1}$$

$$Pi = qi/pi$$

where:

p = 1 x n vector of direct employment coefficients, i.e., the ratio of total employment to total sales for each sector; elements of p are pi.

q = 1 x n vector of total direct and indirect changes in employment; elements of q are q_i. (These are also referred to as employment-final demand coefficients).

P_i = employment multiplier for the ith sector.

The employment multiplier, P_i, shows the total change in regional employment if employment in the ith sector increases by one unit.

Another conventional multiplier is the income multiplier which is defined as:

$$z = w\ (I-A)^{-1}$$

$$Y_i = z_i/w_i$$

where:

w = 1 x n vector of direct income coefficients, i.e., ratio of sectoral income to total sales for each sector; elements of w are w_i.

z = 1 x n vector of total direct and indirect changes in income; elements of z are z_i. (These are also referred to as income-final demand coefficients).

Y_i = income multiplier for ith sector.

The income multiplier, Y_i, shows the total change in regional income if income in the ith sector increases by $1.00.

4.1.3 Energy Multipliers

Ching (1981) and Harris and Ching (1982) argue that there is no reason to focus only upon usual economic multipliers (e.g., sales, income, and employment); resource multipliers are also appropriate. In particular, they discussed water multipliers, water-economic final demand coefficients (e.g., water-income and water-employment final demand coefficients) and their application to regional economics. They argue that if one were interested in the effects of energy utilized by the sectors in the economy, this same multiplier concept would apply. One need only define the direct energy coefficients and then utilize the $(I-A)^{-1}$ matrix to compute the desired direct and indirect effects which would then be used in the computation of the energy multiplier.

The energy multiplier is defined as follows:

$$r = e\,(I-A)^{-1}$$

$$E_i = r_i/e_i$$

where:

e = 1 x n vector of direct energy coefficients, i.e., ratio of total energy used to total sales for each sector; elements of e are ei.

r = 1 x n vector of total direct and indirect changes in energy use; elements of r are ri. (These are also referred to as energy-final demand coefficients).

Ei = energy multiplier for ith sector.

The energy multiplier, Ei, shows the total change in regional energy use if energy use in the ith sector increases by one unit.

This approach is more useful than that of direct energy coefficients, because it counts the total (direct plus indirect) effects on the whole economy arising from particular changes within a specific sector. On the other hand, there are limitations to this approach, i.e., only energy consumption (which is a "cost") is accounted while the "value added" (which is a "revenue") of economic activities is excluded from the model's function. For example, the automobile sector requires significant energy inputs. Within the criterion of the energy multiplier (or energy-final demand coefficients), policy makers might decide to constrain the expansion of this sector to reduce total energy consumption. However, they have to re-evaluate the decision if the value added (direct and indirect effects) of the automobile sector is taken into account.

For this purpose, Harris and Ching (1982) further extend the idea of interindustry multipliers to examine the trade-offs between energy use and economic entities. One such multiplier is the energy/income final demand coefficient which estimates the trade-offs between energy use and sectoral income within an interindustry context, and can be shown as:

$$Ti = ri/zi$$

where:

Ti = 1 x n vector of energy-income final demand coefficient which reflect the total (direct plus indirect) change in energy use per unit total (direct plus indirect) change in income, brought up by sector i.

Accordingly, this model is adopted in this study.

4.1.4 Remarks on Input-Output Model for Energy Analysis

As indicated in previous sections, a strength of input-output models is the ability to explicitly describe the regional economy in the context of sector interdependence. This makes input-output analysis a more desirable research tool than the traditional micro and partial equilibrium macro approaches for energy studies. Energy flows are not concentrated in one sector, industry, or firm, as has been assumed in past economic analysis. Most energy is consumed not as final product but as a "derived" demand by sectors in the economy. In fact, energy is quite similar to other primary inputs, such as capital, to all economic sectors.

Interdependence arising from energy flows is far greater than had been recognized. Researchers have only recently begun to comprehend the complexity of energy transfers and usage throughout the economy. Analysis of the relationship of energy to various components of the economic system requires treatment of those components in the context of the total economic setting of which they are a part (Penn and Irwin, 1977).

4.2 INTERINDUSTRY ANALYSIS INTEGRATED WITH PROGRAMMING TECHNIQUES

The energy/income final demand coefficients emphasize activities at the micro/sectoral level. This approach is most useful when planners are interested in evaluating the development alternatives of a specific sector. It tells the planner how much energy supply should increase/decrease if a proposed stimulating/discouraging strategy is to be implemented in a specific sector.

The energy/income final demand coefficients are also useful to identify the potential sectors that should be or should not be stimulated if minimizing energy consumption and maximizing sectoral value added are the major concerns. However, without other information, meaningful planning cannot be performed. On the basis of interindustry multipliers and coefficients alone, there is no interacting mechanism among sectors to compete for a given amount of resource or energy. That is, within a regional economy, given an increase/reduction of energy supply, one knows the potential sectors that should be stimulated/discouraged by comparing their energy-economic multipliers and coefficients. But one does not know "to what extent" the potential sectors would expand/contract and, thus, one cannot design a meaningful allocation scheme to cope with the change in the energy supply for the economy. To circumvent this problem, input-output models are often integrated with mathematical programming techniques for macro-level studies.

4.2.1 Interindustry Analysis and Linear Programming

Many economic planners have recognized that interindustry analysis can be used within the context of linear programming models. The integration of I/O analysis and linear programming techniques can provide much information not available from separate application of either technique (Harris, 1982). The former provides feasible regional economic production possibilities in the context of industry sector interdependence. The latter enables the analyst to choose the optimal production alternatives.

Researchers have used input-output analysis and linear programming procedures within the regional economy to maximize a desired benefit or minimize a loss. Richardson (1972) enumerates possibilities used for linear programming algorithms and input-output analysis. He suggests that the two models are useful in policy analysis where the interindustry model derives the technical interrelationships between economic sectors and linear programming algorithm strives to achieve a stated objective. Studies by Leung and Hsu (1984), Penn et al. (1976), O'Malley (1973), Richardson (1972) and Dorfman et al. (1958) have used interindustry analysis and linear programming procedures to maximize regional income, final demand or employment subject to a resource constraint such as energy, water or labor availability.

In studying Taiwan's energy-economic problems, both Taipower (1980) and the Energy Committee (1981a) have used linear programming models. Taipower (1980, pp. A9, A53-A55) formulated a model to maximize GDP subject to energy resources availability constraints and sectoral capacity constraints (upper and lower bounds). There are two main problems with this approach. First, on theoretical grounds, this model does not consider the interindustrial relationship between economic sectors. It assumes independence among sectors. This is not true in the real world. Second, on empirical grounds, the right hand side value of the energy resources availability (which are exogenously determined) may be underestimated, as indicated by this Taipower study. As a result, there is no feasible solution to this LP model (Taipower, 1980, p. A-52). While the empirical problems could be identified through the simplex tableaus and remedied by changing values of right hand side elements or relevant coefficients, the failure to include interindustrial constraints is of critical concern. This model, therefore, is not an adequate one for energy planning.

Another LP model developed by the Energy Committee (1981a, pp. 62-90) improves upon the aforementioned model. It is a linear programming input-output (LP-IO) model also set up to maximize gross domestic production. The constraints set include labor and energy resource availabilities, interindusty restrictions, and sectoral capacity bounds. The major results of this study are derived from sensitivity analyses of the economic impacts due to shortages of energy supply, changes of import/export policy, improvement of energy-saving technology and the ratio changes of energy uses for intermediate production to energy uses for final demand.

This model, based on the single-objective of maximizing GDP, provides many significant results and policy recommendations to Taiwan energy-economic policy makers. However, within a regional economy most problems are marked by multiple, sometimes conflicting objectives. The attainment of a single objective as in conventional linear programming is useful, but in reality policy makers are confronted with deriving plans which will try to satisfy to some degree many desired or expressed objectives. This type of procedure is called multiobjective analysis.

4.2.2 Single-Objective Programming vs. Multi-Objective Programming

Multiobjective analysis is one of the mathematical programming techniques called vector optimization. It cannot be characterized as new, since Kuhn and Tucker (1951) and Koopmans (1951) must be credited with its discovery. However, vector optimization theory remained relatively undeveloped from 1951 until the 1960s when multiobjective public investment problems became more common and "trade-off" became a favorite word of managers, planners, and decision makers in both the private and public sectors.

During the past decade, particularly during the latter portion of it, a great deal of effort has been devoted to the development of solution techniques for vector optimization problems (see Cohon and Marks, 1975; Fandel and Gal, 1980; Goicoechea et al., 1976; Hwang et al., 1979; Nijkamp and Spronk, 1981; Rietveld, 1980; Siskos and Hubert, 1983; Zeleny, 1982; Zoint, 1978). The origins of this effort have been varied: techniques have been developed by systems analysts and decision theorists for private and public sector problems, by control theorists for engineering (guidance and design) problems, and by water resource economists and systems analysts for water resource (public sector) planning problems. All of the contributors to the recent development of vector optimization theory shared one or two common goals: the formulation of methods which are theoretically operational and which attempt to avoid the large computational effort associated with multiobjective problem. In the field of economics, multiobjective programming is receiving growing attention and promises to have great potential use in the future.

In considering the roles of the analyst and decision maker in the public decision-making process, multiobjective approaches are superior to conventional single-objective methods. The key point here is that analysts should analyze and decision makers should decide. This point will be developed in subsequent paragraphs.

Single-objective models identify "optimal" solutions--the feasible solution that is best in terms of a single measure of value. Decision makers are given the choice of accepting or rejecting this single solution without learning anything about how the solution compares with other feasible solutions.[5] Since in a public decision-making context, a single objective can be defined only by making important and perhaps controversial value judgments, the analyst is forced by single-objective approaches to usurp a large part of the decision makers' responsibilities (Cohon, 1978, p. 316). As Zeleny (1976, p. 156) notes: "It is important to realize that whenever we face a single attribute, an objective function, an utility function, or any other single aggregate measure, there is no decision-making invovled. The decision is implicit in the measurement and it is made explicit by the search." Zeleny (1981) also discusses prevailing misuses of linear programming for decision making.

Multiobjective analysis, by contrast, emphasizes the range of choices associated with a decision. "It is only when facing multiple attributes, objectives, criteria, functions, etc., that we can talk about decision making and its theory" (Zeleny, 1976, p. 156). The important judgments regarding the relative values of objectives are not made by the analyst; the burden of making these value judgments rests, instead, squarely on the shoulders of the decision makers. Instead of optimizing a single objective function

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[5] Although sensitivity analysis may present alternative solutions, the approach is quite different in nature from that of multiobjectives programming. This point will be elaborated later.

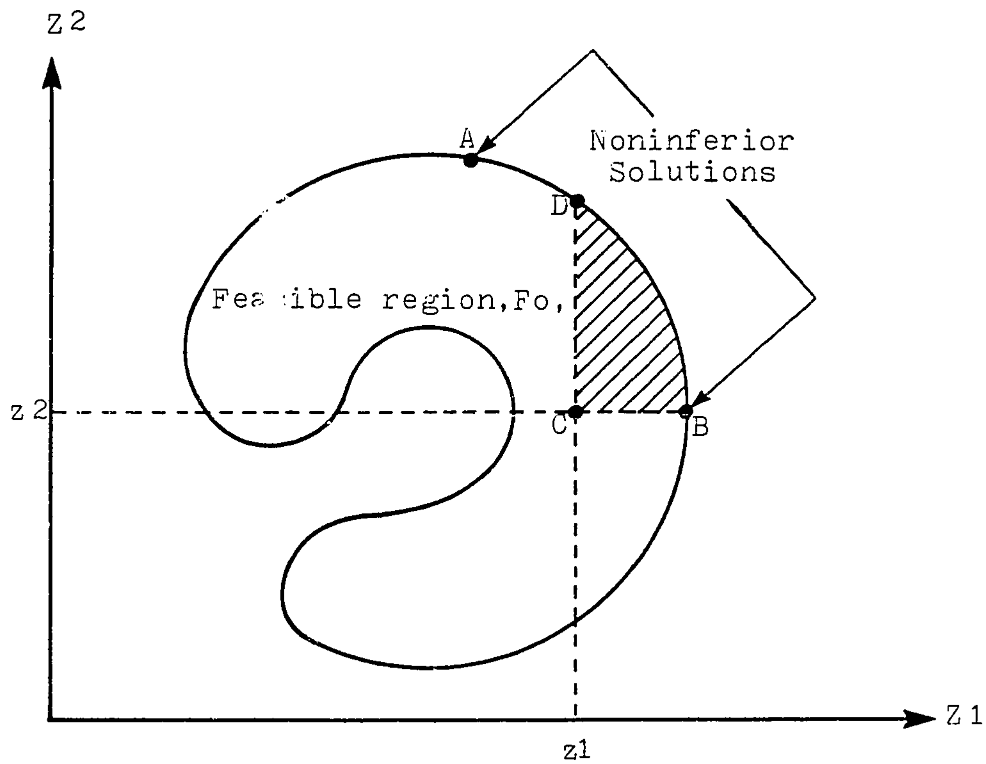
subject to a set of constraints, multiobjective analysis seeks to derive the trade-offs between multiple objective functions subject to constraints or finding the "best" possible values under the given condition. That is to say a single optimum solution may not be sought in multiple objective analysis. Instead, it is a set of "noninferior solutions" or "nondominant solutions," which can be defined in the following way (Cohon, 1978, p. 70):

> "A feasible solution to a multiobjective programming problem is noninferior if there exists no other feasible solution that will yield an improvement in one objective without causing a degradation in at least one other objective."

This definition may be easily explained by Figure 4.1 which is a collection of feasible alternatives in a two-objective problem. The axis of the figure, Z1 and Z2, represent the objective functions. The plot is in objective space rather than in decision space.

In this figure, point C is considered a dominated solution because at point B one gets more Z1 without decreasing Z2. Also at point D one derives more Z2 without decreasing Z1. In contrast, the arc between points A and B are nondominated solutions because as one goes from A to B, an increase in one objective is only derived by a reduction in another objective. Noninferiority is thus shown to have a meaning similar to "Pareto optimality" in economics.

Figure 4.1: Graphical Description of Noninferiority for An Arbitrary Feasible Region in Objective Space



Source: Cohon, 1978, p. 70.

In single objective models, all project effects are measured in terms of a single unit, e.g., all project effects are measured in dollars when maximizing profit. In multiobjective analysis, however, the decision maker pursues results with explicit consideration of the relative value of project impacts, i.e., with multiple objectives, project effects are measured in relative terms of the different objectives (e.g., dollars, Btu, etc.). This is advantageous because arbitrary conversion often contains bias. For example, the basic interindustry transactions, as represented by the input-output table expressed in monetary units, may not be a good representation of energy use by industry because different sectors may pay different prices for the same energy type. Energy flow expressed in physical units is more reliable than arbitary conversion of dollar measures (Leung and Hsu, 1984, p. 117). In addition, original units provide a more intuitive basis for interpretation of the study's results (Harris, 1982).

4.2.3 Goal Programming and Generating Techniques

There are several methods for deriving solutions to multiobjective problems, e.g., goal programming and generating techniques.[6] Goal programming is undoubtedly the

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[6] More than two dozen different techniques for solving

most well-known multiobjective method. It was developed by Charnes and Cooper (1961, pp. 299-310). Based on minimization of the sum of weighted absolute deviations of objectives $zi(x)$ from targets (Ti), a goal programming problem can be formulated as:

$$\min \quad wi\ (di+ei) \tag{4-1}$$

s.t.

$$x\ E\ X \tag{4-2}$$

$$x >= 0 \tag{4-3}$$

$$zi(x)-di+ei = Ti \qquad i = 1,2,\ldots,K; \tag{4-4}$$

$$di,ei >= 0 \tag{4-5}$$

Where wi is the weight or priority attached to the ith goal, di and ei are the positive and negative differences of the ith objective from its target Ti, respectively, x is an n-dimensional vector of decision variables, "E" means "belongs to," and X is the feasible region in decision space. The wi can also be split into two components--one for positive differences (di) and one for negative differences (ei). Neely et al. (1977) provide a good example of goal programming. Others have used goal programming in areas of accounting for control (Ijiri,

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multiple objective programming problems have been developed. For a detailed classification and comparison of some of these approaches, see Cohon, 1978.

1965). Lee (1972) has applied goal programming to problems in production planning, financial decisions, academic planning, and medical care. Goal programming has been applied primarily to private sector problems by Charnes et al. (1968, 1969), Spivey and Tamura (1970), Lee and Clayton (1972), although Lee and Moore (1977) used this method to analyze school busing to achieve racial desegregation and Werczberger (1976) used this method for land-use planning.

In studying the energy-economic problems in Taiwan, Taipower (1980) and CPC (1982) have both used goal programming as their research methodologies. Taipower (1980) has set up two goal programming models. The objective function of the first model is to minimize the targets' deviation of GDP, overall energy elasticity, sectoral energy elasticity, energy supply and industrial (including mineral) production. The constraints set include fifty-six functions which contain targets for GDP, overall energy elasticity, sectoral energy elasticities, total energy demand, sectoral production, population and capacity bounds. The second model is basically a similar model with different goal priorities. It considers overall energy elasticity as having highest priority, followed by other goals such as GDP, etc. Both models exclude interindustry dependency of the type previously noted within the Taipower

(1980) LP model. As a result, the effectiveness of these models for energy policy is again limited.

CPC (1982) developed two goal programming input-output (GP-IO) models which circumvent this problem. Both GP-IO models include an interindustry function as a set of constraints. The first model considers energy supplies in normal situations. The priorities of the desired goals are: (1) GDP, final demand, and energy demand; (2) GDP, energy demand, and final demand. The second model considers energy supplies under disruptive situations. The priorities of the desired goals are: (1) energy demand, followed by GDP and final demand; (2) energy demand, followed by final demand and GDP.

Comparing the above LP models with the GP models, some notable features include:

(1) Economic goals are very often in conflict with each other, e.g., to maximize GDP and to minimize energy demand. In LP approaches, the inclusion of constraint functions on conflicting goals may result in no feasible solution. The above-mentioned LP model of Taipower (1980) is a good example. By contrast, GP approaches do not suffer this type of problem. By introducing deviation variables (di and ei) and given targets (Ti), GP strives for a "compromise

solution" instead of the "optimal or best solution." This compromise solution allows positive and/or negative differences from the desired targets and guarantees feasible answers.

(2) GP provides more alternative solutions than does LP. For example, the CPC (1982) GP-IO models present several alternatives for different situations. When energy supply is normal, GDP is the first priority; when energy supply is short or disruptive, limiting energy demand is the first priority. Different concerns could arise in different situations. GP models respond well to these types of needs. On the other hand, LP has to limit its decision concerns to a single objective, e.g., maximizing GDP. Although the LP-IO model by the Energy Committee (1981a) contains a sensitivity analysis and presents alternative solutions, these alternative solutions are confined to the single objective of maximizing GDP. The meanings of "alternatives" here differ in nature from those of GP.

(3) In LP approaches, all variables in the objective function must be measured in the same unit. This may cause problems or biases as indicated in section 4.2.2. In GP, the problem of arbitrary conversion is avoidable and can provide a more intuitive basis for interpretation of the study's results.

Many practitioners believe that goal programming is multiobjective programming. More accurately, goal programming is just one of the many multiobjective programming techniques developed. There are many other multiobjective programming techniques quite different from goal programming in their nature.

Goal programming does have advantages, e.g., the "pre-emptive" version is easy for practitioners to understand and is quite similar to linear programming analysis. Goal programming also has wide popularity and many computer-aided algorithms have been developed (Lee, 1972; Ijiri, 1965; Arthur and Ravindran, 1978). In addition, goal programming is behaviorally based on the philosophy of "satisficing" and can be viewed as a technical expression of this behavioral theory.

Goal programming, however, is not without its disadvantages. The chief argument against goal programming is that the method may produce dominated solutions. Because the technique relies heavily on decision makers' perceptions of the range of choice and feasibility, a set of goals may lead to an inferior solution. Consider Figure 4.1. The noninferior set is unknown to the decision makers when they set z1 and z2 as the goals for Z1 and Z2, respectively.

Since (z1, z2) is within the feasible region, Fo, the solution to the goal program will give total deviations of zero; i.e., both goals are attained. Unfortunately, (z1, z2) is an inferior solution. If the decision makers stick with their original goals, then they will settle for less than they should.

Another point that makes it difficult to apply goal programming to public decision-making is the ambiguity of specifying target values for some social objectives. For example, highways and reservoirs are not designed or planned to generate a certain quantity of economic efficiency benefits; these benefits are merely an indicator of the project's impact on a single dimension of economic welfare. Other objectives, such as certain formulations of environmental quality or employment, may be more amenable to a goal programming approach (Cohon, 1978, p. 190).

Zeleny (1974a, p. 485) presents arguments against the direct assessment of prior specification of weights for goals. He criticizes the approach on behavioral grounds. He claims that human ability for overall evaluation is limited and the precision of weighting does not reflect the fuzziness of multiobjective decision making. Zeleny (1976) further argues that these weights are not a priori in the possession of the decision maker. Rather, they are, or should be, learned through the decision process and are not independent of the set of feasible alternatives. His criticisms are well-grounded and should disjustify the use of prior specification of weights. Morse (1977) also shows that if naive weights are used, the system may be driven in counter-intuitive and inferior ways.

Since goal programming requires explicit articulation of value judgments, the applicability of this technique is sensitive to the nature of the decision-making process. For those unidentified or inaccessible decision makers, goal programming will cause problems. This will often occur in the public decison-making issues when the question of who should be the decision makers is raised.

Other multiobjective procedures such as generating techniques circumvent problems of this type. Generating techniques do not require the expression of target values for public goals and do not allow preferences to be incorporated into the solution process. That is, prior statements about preferences, priorities, utilities, or any other value judgment about the objectives are deferred until the range of choice represented by the set of nondominated solutions is derived and presented to decison makers. So, decision makers can compare those generated noninferior solutions and select a best-compromise alternative based on their explicit or implicit preferences of the objectives. In this case, the analyst is confined to analytical work per se and leaves the decision to decision makers. Thus, distinct roles would be maintained for the analyst and decision makers, i.e., leaving to the analyst and computer what they do best (generating alternatives) and to decision makers what they do best (evaluating pairs and choosing). In addition, since the preferences of the objectives articulated by the decision makers require a consideration of the range of noninferior solutions, generating techniques rather than goal programming could provide better understanding and control of the decision situation.

Accepted programming analysis stresses sensitivity analysis for the exploration of the range of choice. In goal programming, sensitivity analysis is complicated in part because the actual decision variables have zero coefficients in the objective function; this information makes its way into the objective function only indirectly through the right hand side (Ti) of the policy constraints. These goal constraints in (4-4) have both surplus (di) and slack (ei) variables, and these variables are driven by a set of dependent objective function coefficients, so that for one to change at least one other must change as well.

This is because weights are usually set by making them to one, to insure convex combinations. Even without this restriction, adjusting a single weight alters the relative relationships of the wi (Willis and Perlack, 1980; Morse, 1977).

By contrast, generating techniques are nothing more than systematic sensitivity analysis of the most important value judgments. The emphasis in generating techniques is on the explicit identification of those value judgments, i.e., the weights assigned to each objectives. This notion will be elaborated later by using the empirical results in a later chapter.

Willis and Perlack (1980) evaluate and compare both generating techniques and goal programming under four criteria: computational expense, quantification of trade-offs, quantity of information, and validity of decision maker-analyst interaction. They concluded that goal programming is superior to generating techniques on the basis of computational ease and expense. The generating techniques fared relatively better by the other three criteria. While multiobjective programming likely will grow in importance in empirical applications, generating techniques may become the most important of these approaches because of their intuitive basis, the explicit quantification of trade-offs they supply, and the assistance they provide to the learning process.

4.2.4 The NISE Algorithm

One multiobjective generating technique is the bicriterion algorithm or the non-inferior set estimation (NISE) method. This bicriterion approach was first developed by Cohon, Church, and Sheer (1979). They developed this algorithm for efficiently approximating the set of noninferior solutions of a two-objective problem. In particular, they applied this method on a river basin planning problem. For this study, the NISE model will be incorporated with the input-output model to derive the trade-offs between GDP and energy use in Taiwan.

To demonstrate the NISE algorithm, a simple example with two objectives and two decision variables is presented below (Cohon, 1978):

$$\max Z(X,Y) = (Z1(X,Y), Z2(X,Y))$$

where

$$Z1(X,Y) = 5X - 2Y \qquad Z2(X,Y) = -X + 4Y$$

$$\text{s. t.} \qquad -X + Y \leq 3 \qquad X + Y \leq 8$$

$$X \leq 6 \qquad Y \leq 4$$

$$X \geq 0 \qquad Y \geq 0$$

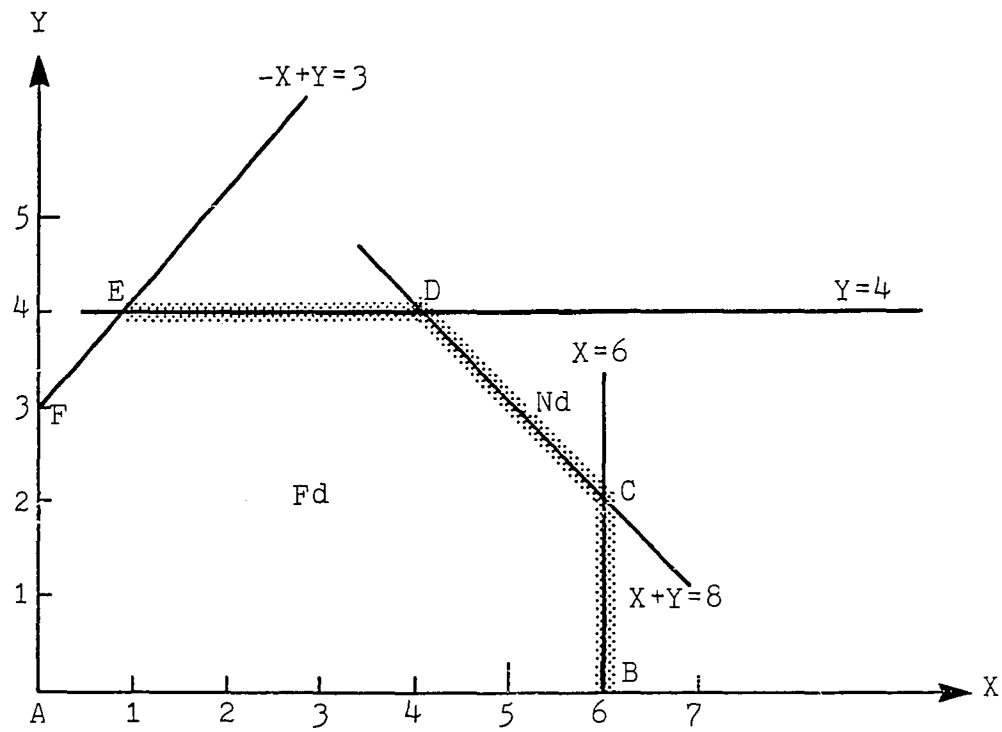
The feasible regions for this problem are drawn in Figures 4.2 and 4.3.

The method begins by optimizing each objective individually, yielding points P1 and P2 in Figure 4.4. This gives for objective Z1 the point (6,0) in the decision space and the point (30,-6) in the objective space; i.e., P1=(30,-6). The optimization of objective Z2 gives (X,Y)=(1,4) in the decision space and point P2=(-3,15) in the objective space. Set S1=P2 and S2=P1. The next solution should be that feasible solution farthest out along the indicated direction (Figure 4.4).

The maximum possible error at this point is F12=17.8, which could be easily computed. For a triangle with sides a, b, and c and altitude d (with c as the base), A= 1/2 cd, or $A= \{ s(s-a)\ (s-b)\ (s-c)\ \}^{1/2}$ where A is the area, s= 1/2 (a+b+c). Since it is known that a=33, b=21, c could be calculated by $c = (a^2 + b^2)^{1/2}$. This gives s=46.6, A=348.9, and F12=d=17.8.

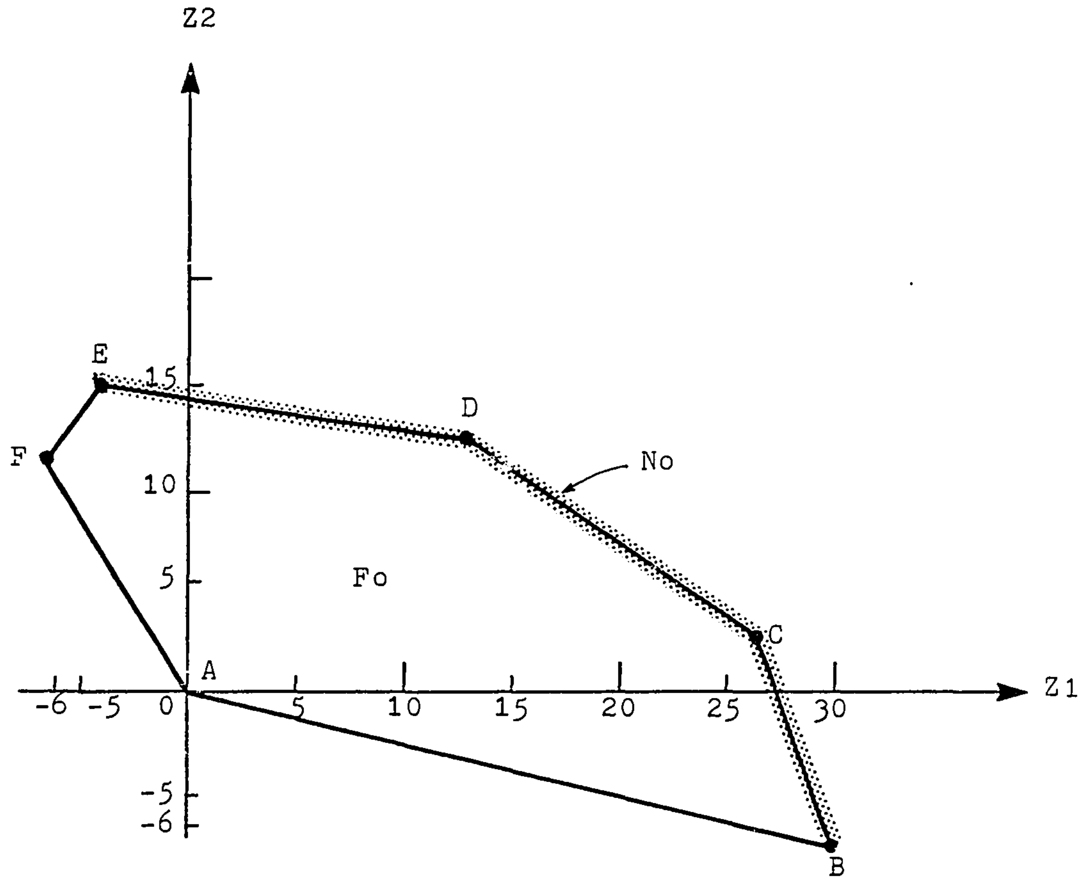
Now, if the maximum allowable error, T, is set at 50% of F12, i.e., T=8.9, the computation is subject to check if the error criterion is met. Obviously, F12>T, so the algorithm continues.

Figure 4.2: Feasible Region (Fd) and Noninferior Set (Nd) in Decision Space



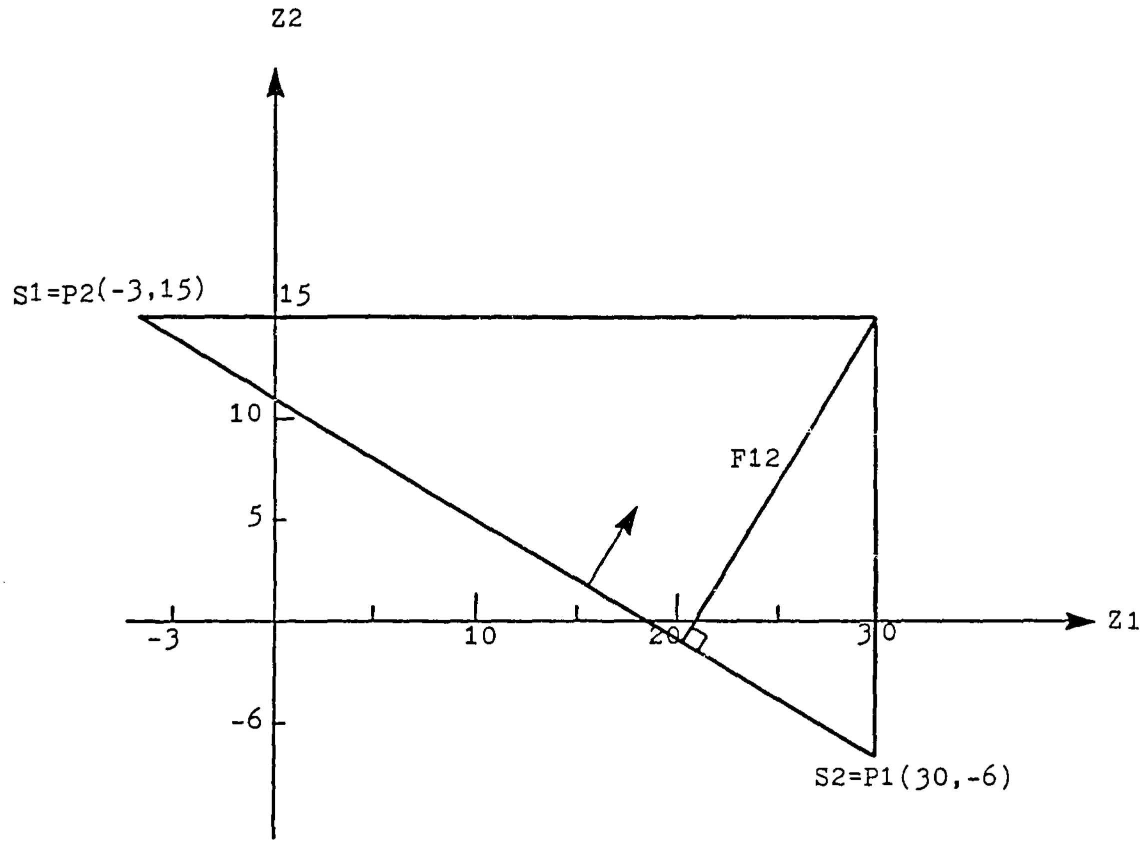
Source: Cohon, 1978.

Figure 4.3: Feasible Region (Fo) and Noninferior Set (No) in Objective Space



Source: Cohon, 1978.

Figure 4.4: NISE Method: Step One and the Computation of the Maximum Possible Error (F12)



Source: Cohon, 1978.

Using a and b as relative weights for the objective function:

$$\max Z\ (X,Y) = bZ1 + aZ2$$

or

$$\max B12 = b\ (5X-2Y) + a\ (-X+4Y) = 72X + 90Y$$

$$\text{s.t.} \quad -X + Y =< 3 \qquad X + Y =< 8$$

$$X =< 6 \qquad Y =< 4$$

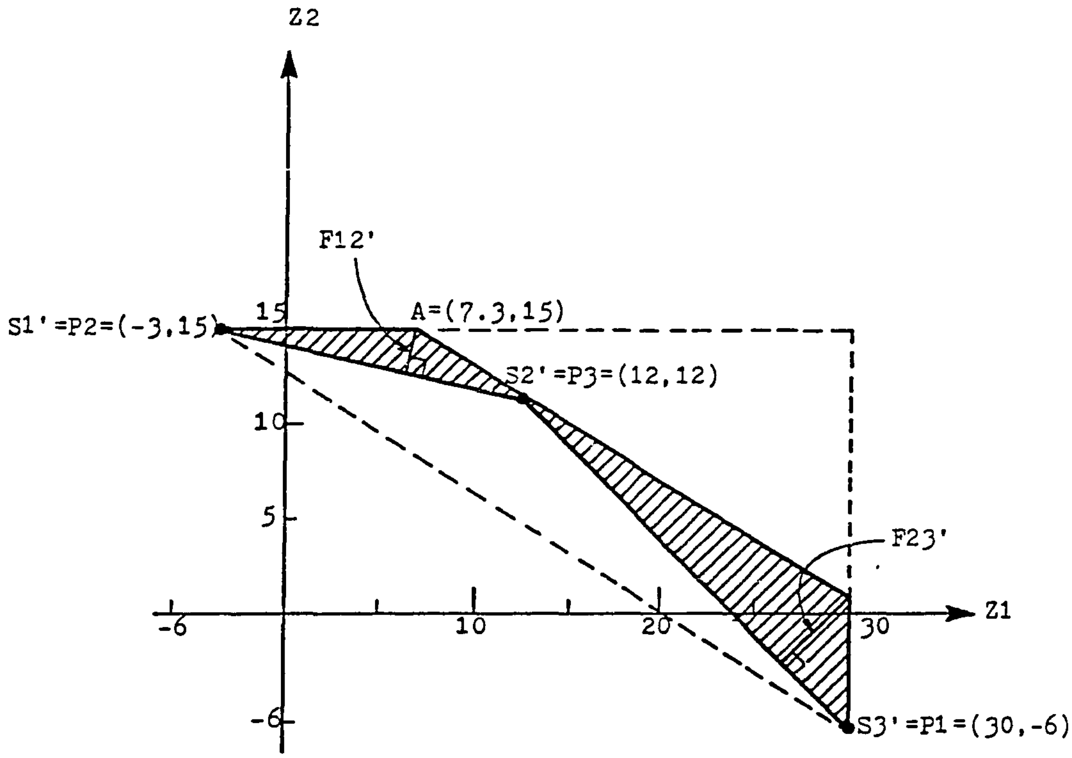
$$X >= 0 \qquad Y >= 0$$

This yields an optimal solution (X,Y) = (4,4) in the decision space and P3= (Z1,Z2) = (12,12) in the objective space, and Z (X,Y) = 648. Then, reorder the noninferior points: S1'=S1=P2, S2'=P3, and S3'=S2=P1, as shown in Figure 4.5.

The linear indifference curve passing through P3 is shown as a line parallel to the line connecting P1 and P2, which was the former lower bound.

The computation of the maximum possible error requires first that the points of intersection of the linear indifference curves be found. This can be done by solving simultaneous equations. Consider point A in Figure 4.5. It is the point of intersection of the line Z2=15 and the line for which an equation can be derived from previous equation: max Z (X,Y) = bZ1 + aZ2. This equation is equivalent to

Figure 4.5: Iteration of the NISE Method



Source: Cohon, 1978.

2Z1 + 33Z2 = 648, where the right-hand side is the value for the weighted objective at P3. Since Z2=15 is known, Z1 can be found equal to 7.3. The sides of the triangle with vertices at P2, P3 and A can now be computed. The new maximum possible error F12' is found equal to 2.1.

The same approach can identify the other maximum possible error F23' = 4.6. Since both F12' and F23' are smaller than "T", the algorithm terminates. This means that a sufficiently accurate approximation of the noninferior set has been identified, given the maximum allowable error "T".

The steps of the bicriterion algorithm are summarized as follows:

Step 1: Set a value of "T" as the maximum allowable error for the run. Then maximize the second objective function Z2(X) subject to X E fd and denote the solution as P1.[7] The first objective function Z1(X) should be maximized subject to X E fd and denote the solution as P2. Let the segments be denoted as S1=P1 and S2=P2. Derive the maximum error as F12.

---

[7] E here means "belongs to." fd means "feasible region."

Step 2: Find where $F_{i,i+1} \leq T$ for $i=1,2,\ldots,n-1$ the approximation of the nondominated solution is completed because the maximum allowable error has been met. Otherwise go to step 3.

Step 3: Find where $F_{i,i+1} > T$ or the $F_{i,i+1}$ that has the greatest error. The problem is solved once again as follows: $\max B_{i,i+1} = (Z2(S_i)-Z2(S_{i+1}))\, Z1(X) + (Z1(S_{i+1})-Z1(S_i))\, Z2(X)$. The above will derive another nondominated solution denoted as P_{n+1}. Proceed to step 4.

Step 4: Since i is the highest value of t such that $Z2(S_i) \geq Z2(P_{n+1})$. The string set is redefined as:

$$S_t' = S_t \qquad t=1,2,\ldots,i$$

$$S_{i+1}' = P_{n+1}$$

$$S_{t+1}' = S_t \qquad t=i+1,\ldots,n$$

The F is redefined as:

$$F_{t,t+1}' = F_{t,t+1} \qquad t=1,2,\ldots,i-1 \quad \text{if } i\geq 1$$

$$F_{t+1,t+2}' = F_{t,t+1} \qquad t=i+1,\ldots,n-1 \quad \text{if } i\leq n-2$$

Compute $F_{i,i+1}'$ and $F_{i+1,i+2}'$. Increment n by one and return to step 2.

4.2.5 Specification of the Non-Inferior Set Estimation Input-Output (NISE-IO) Model

In this study, the multiobjective programming algorithm will incorporate with interindustry analysis to show the potential of cooperative use of these two research methodologies. The bicriterion linear programming for this problem is stated as:

$$\max Z = (\text{GDP, Energy})$$
$$= (G(X), -E(X))$$
$$= (VX, -eX)$$

s.t.

$$RX =< B$$

$$(I-A+M)X >= Fmin$$

$$Xt =< KXt-i$$

where:

GDP = gross domestic product.

V = 1 x n vector of direct income coefficients, i.e., ratio of sectoral income to total sales for each sector.

e = 1 x n vector of direct energy coefficients, i.e., ratio of total energy used to total sales for each sector.

X = $n \times 1$ vector of sector outputs, i.e., the dependent variables of this model.

R = $m \times n$ matrix of direct resource coefficients, i.e., ratio of resources used to total sales for each sector.

B = $m \times 1$ vector of available resources.

I = $n \times n$ unit matrix.

A = $n \times n$ matrix of technical coefficients.

M = $n \times n$ diagonal matrix of import coefficients.

$Fmin$ = $n \times 1$ vector of the minimum levels of final demand.

Xt = $k \times 1$ vector of the output level of constrained sectors in the planning year 1986.

K = $k \times k$ diagonal matrix of the capacity expansion ratios of constrained sectors.

$Xt-i$ = $k \times 1$ vector of the actual production level of each sector in the base year 1978.

In this model, G(X) is the objective to maximize GDP and E(X) is the objective to minimize energy use. E(X) is multiplied by -1 because energy use is to be minimized. The first constraint set requires that total resource use by type not exceed total available resource supply. The second constraint set is derived from the relationship X-AX+MX = F, or X+MX = AX+F, which indicates that the sum of domestic output and importation in each industry sector (which is total supply) must be equal to the intermediate requirement by other sectors and the final demand sector (which is total demand). This is a general equilibrium restriction. The last constraint set limits each sector (except service sectors) to a specified upper bound of capacity expansion.

4.3 A SUMMARY AND COMPARISON

This section summarizes and compares the features of the selected methodologies discussed in this chapter. For sectoral-level analyses, energy/economic final demand coefficients are deemed more useful than the direct energy coefficient for at least two reasons. First, direct energy coefficient implicitly assumes independence among sectors. While it may be an appropriate tool for economic studies within the context of a particular industry or sector, it is not a good criterion for studies within a larger economy involving more than two sectors. Energy-final demand coefficients or energy/income final demand coefficients, by contrast, serve as a more effective tool because they consider direct and indirect effects of energy changes arising from the final demand of the economy.

Second, energy/economic final demand coefficients provide more information and insights from different perspectives than do direct energy coefficients. For example, energy/income final demand coefficients used in this study encompass both cost (energy use) and revenue (income) effects of the economy, and particularly useful for investigating trade-offs between energy consumption and, also, the value added of the sectors.

For macro-level studies, multiobjective programming approaches are deemed more effective than conventional LP methods. Although GP has been the most popular multiobjective programming procedure, generating techniques provide more information and choices for policy makers and have potential uses in empirical economic research. For example, the NISE-IO model utilized in this study is superior to the GP-IO approach in terms of providing nondominant solutions, sensitivity analysis, quantification of trade-offs, quantity of information, and valid decision maker-analyst interaction.

A summary of the models compared and discussed in this chapter is presented in Table 4.1.

Table 4.1

A Comparison of the Selected Methodologies

Model	(1980) LP by Taipower	(1981) LP-IO by Energy Committee	(1980) GP by Taipower	(1982) GP-IO by CPC	(1984) NISE-IO by this study
Number of objectives	one	one	multiple	multiple	multiple
objective	max GDP	max GDP	min goal deviations	min goal deviations	max GDP min Energy
Variables in objective function	decision variables	decision variables	deviation variables	deviation variables	objective variables
Unit measure of objective function	dollar	dollar	different units of deviation variables	different units of deviation variables	dollar & KLOE
Interdependancy among sectors	No	Yes	No	Yes	Yes
Sensitivity analysis	No	Yes	No	No	Yes
Considering energy priority when energy supply falls short	No	No	Yes	Yes	Yes
Nature of solutions	best	best	compromised (could be inferior)	compromised (could be inferior)	noninferior solutions

Chapter V

EMPIRICAL RESULTS AND COMPARISONS

This chapter presents empirical findings of this study and compares them with those of other relevent research.

5.1 INPUT/OUTPUT MULTIPLIERS AND COEFFICIENTS

Table 5.1 presents the various types of input-output multipliers and coefficients discussed in chapter four. The first column denotes the value-added coefficients, Vi. The second column, Mi, gives import dependency coefficients which show the proportional relationship between imports and domestic production. The third column, $Vi(I-A)^{-1}$, is made up of income-final demand coefficients, showing the total (direct plus indirect) income changes in the economy if there is one unit change in the final demand. This column should be always equal to 1.0, assuming Taiwan as a closed economy without international trade. The fourth column, $Vi(I-A+M)^{-1}$, indicates the income-final demand coefficients of an open economy. Trade through importation is reflected in Mi. The fifth column, ei, consists of direct energy coefficients, showing the ratio of total energy used in physical units to total sales for each sector. These coefficients are calculated from the summation of the eight types of commercial energy required to produce sectoral output equal to $25,000. The figures (KLOE) of energy used are calculated at the starting point, i.e., gross energy. They do not show the final destination, i.e., net energy (see discussions in section 3.4). The sixth column, $ei(I-A)^{-1}$, are energy-final demand coefficients, showing total (direct plus indirect) changes in energy use if there is one unit change in final demand. This shows the case for a closed economy. The seventh column, $ei(I-A+M)^{-1}$, is made up of energy-final demand coefficients under an open economy. Figures in this column should be always smaller than or equal to those of column six. The energy multipliers in the eighth column, Ei, are derived from elements of column five, $ei(I-A)^{-1}$, divided by elements of column four, ei. The energy multiplier shows the total change of energy use in the whole economy if the energy use in a specific sector changes by one unit. Again, this column assumes these changes take place in a closed economy. The ninth column, Ei2, by contrast, considers an open economy's energy multipliers, deriving from elements of column seven, $ei(I-A+M)^{-1}$, divided by elements of column five, ei. Figures in this column should be always smaller than or equal to those of column eight. The tenth column, $ei(I-A+M)^{-1}/Vi(I-A+M)^{-1}$, consists of energy/income final demand coefficients derived from elements of column seven divided by elements of column four, reflecting the total (direct and indirect) change in energy use if the total (direct and indirect) value added of the whole economy changes by $25,000. Thus, $ei(I-A+M)^{-1}/Vi(I-A+M)^{-1}$ does not mean that one matrix is divided by the other, but rather that each "element" of one matrix is divided by each corresponding "element" of the other.

Table 5.1

Input-Output Multipliers and Coefficients of the Taiwan Economy (1978 to 1986)

code	sectors	V_i	M_i	$V_i(I-A)^{-1}$	$V_i(I-A+M)^{-1}$	e_i	$e_i(I-A)^{-1}$	$e_i(I-A+M)^{-1}$	E_{i1}	E_{i2}	$e_i(I-A+M)^{-1}/V_i(I-A+M)^{-1}$
01	Agriculture	.55	.27	1.0	.69	1.68	13.51	8.20	8.02	4.87	11.93
02	Fisheries	.54	.04	1.0	.75	20.12	31.35	25.91	1.56	1.29	34.78
03	Coal Industry	.83	.59	1.0	.59	15.55	19.29	11.27	1.24	0.72	19.11
04	Crude Petroleum & Natural Gas	.85	14.07	1.0	.06	5.05	9.24	0.49	1.83	0.10	8.12
05	Other Minerals	.89	.49	1.0	.64	11.71	14.35	8.88	1.23	0.76	13.92
06	Food Products	.35	.11	1.0	.74	5.60	16.67	11.66	2.98	2.08	15.85
07	Fabrics & Apparel	.25	.10	1.0	.69	8.84	32.41	22.79	3.67	2.58	33.24
08	Products of Wood & Bamboo	.40	.03	1.0	.79	3.42	13.94	9.90	4.07	2.89	12.46
09	Paper Industry	.35	.20	1.0	.63	30.92	56.74	40.41	1.83	1.31	63.87
10	Rubber Products	.36	.15	1.0	.65	11.57	31.18	20.20	2.70	1.75	31.12

Table 5.1. (Continued) Input-Output Multipliers and Coefficients of the Taiwan Economy (1978 to 1986)

code	sectors	V_i	M_i	$V_i(I-A)^{-1}$	$V_i(I-A+M)^{-1}$	e_i	$e_i(I-A)^{-1}$	$e_i(I-A+M)^{-1}$	E_{i1}	E_{i2}	$e_i(I-A+M)^{-1}/V_i(I-A+M)^{-1}$
11	Acid & Alkaline	.32	.51	1.0	.45	61.53	88.03	51.33	1.43	0.83	115.31
12	Plastic	.40	.37	1.0	.50	6.56	28.30	13.27	4.31	2.02	26.78
13	Plastic Products	.31	.01	1.0	.72	4.76	24.75	16.09	5.20	3.38	22.48
14	Chemical Fertilizer	.09	.04	1.0	.49	102.10	148.69	123.79	1.46	1.21	250.16
15	Chemical/Artificial Fabrics	.29	.05	1.0	.66	14.14	42.61	30.42	3.01	2.15	46.33
16	Petrochemical Raw Materials	.29	.33	1.0	.41	11.38	36.84	18.91	3.24	1.66	46.39
17	Other Industrial Chemicals	.42	.81	1.0	.40	14.98	36.13	14.85	2.41	0.99	37.24
18	Cements & Products	.42	.00	1.0	.73	103.09	118.98	113.45	1.15	1.10	155.55
19	Glass	.41	.25	1.0	.56	49.13	73.01	51.03	1.49	1.04	91.44
20	Non-Metallic Mineral Products	.41	.12	1.0	.67	30.71	50.77	40.67	1.65	1.32	60.43

Table 5.1. (Continued) Input-Output Multipliers and Coefficients of the Taiwan Economy (1978 to 1986)

code	sectors	V_i	M_i	$V_i(I-A)^{-1}$	$V_i(I-A+M)^{-1}$	e_i	$e_i(I-A)^{-1}$	$e_i(I-A+M)^{-1}$	E_{i1}	E_{i2}	$e_i(I-A+M)^{-1}/V_i(I-A+M)^{-1}$
21	Steel & Iron	.44	.63	1.0	.42	29.06	47.64	23.95	11.64	0.82	56.68
22	Aluminum	.31	.49	1.0	.45	33.94	66.54	34.98	1.96	1.03	77.43
23	Other Metals	.25	.38	1.0	.25	4.45	25.30	6.01	5.69	1.35	23.86
24	Metallic Products	.33	.23	1.0	.53	6.35	32.30	16.00	5.09	2.52	29.93
25	Machinery	.40	.77	1.0	.40	2.24	23.64	7.44	10.55	3.32	18.70
26	Household Electrical Appliances	.45	.08	1.0	.72	3.00	17.96	10.50	5.99	3.50	14.52
27	Electronic Products	.27	.25	1.0	.56	1.25	15.41	6.77	12.29	5.40	12.06
28	Electrical Apparatus	.41	.49	1.0	.49	2.00	20.18	7.62	10.08	3.80	15.58
29	Shipbuilding	.12	.58	1.0	.27	3.62	41.92	13.83	11.59	3.83	51.92
30	Other Transport Equipment	.37	.25	1.0	.58	1.78	20.55	9.35	11.55	5.25	15.99

Table 5.1. (Continued) Input-Output Multipliers
and Coefficients of the Taiwan Economy
(1978 to 1986)

code	sectors	V_i	M_i	$V_i(I-A)^{-1}$	$V_i(I-A+M)^{-1}$	e_i	$e_i(I-A)^{-1}$	$e_i(I-A+M)^{-1}$	E_{i1}	E_{i2}	$e_i(I-A+M)^{-1}/V_i(I-A+M)^{-1}$
31	Other Manufactures	.51	.38	1.0	.60	5.59	18.48	9.81	3.30	1.75	16.35
32	Coal Products	.26	.23	1.0	.38	30.55	43.20	29.42	1.41	0.96	76.84
33	Petroleum Refining Products	.20	.17	1.0	.24	11.43	20.48	11.37	1.79	0.99	46.47
34	Electricity	.49	.00	1.0	.66	9.56	19.70	15.47	2.06	1.62	23.36
35	Constructions	.39	.00	1.0	.78	0.83	28.27	21.50	34.21	26.02	27.72
36	City Water	.49	.02	1.0	.80	28.72	45.94	40.02	1.60	1.39	49.85
37	Communications	.77	.02	1.0	.90	2.14	6.36	4.75	2.98	2.22	5.26
38	Wholesale & Retail Trade	.77	.00	1.0	.94	3.83	8.14	6.76	2.13	1.77	7.19
39	Finance & Insurance	.84	.06	1.0	.91	0.89	3.06	2.17	3.42	2.43	2.39
40	Warehousing	.72	.00	1.0	.92	26.02	33.23	31.55	1.28	1.21	34.31

Table 5.1. (Continued) Input-Output Multipliers and Coefficients of the Taiwan Economy (1978 to 1986)

code	sectors	V_i	M_i	$V_i(I-A)^{-1}$	$V_i(I-A+M)^{-1}$	e_i	$e_i(I-A)^{-1}$	$e_i(I-A+M)^{-1}$	E_{i1}	E_{i2}	$e_i(I-A+M)^{-1}/V_i(I-A+M)^{-1}$
41	Misc. Services	.87	.10	1.0	.87	0.90	4.09	2.77	4.56	3.09	3.18
42	Railway Transportation	.67	.01	1.0	.86	21.12	28.49	25.33	1.35	1.20	29.54
43	Other Land Transportation	.64	.03	1.0	.77	48.44	56.58	51.59	1.17	1.07	66.87
44	Water Transportation	.49	.15	1.0	.68	2.40	12.04	6.65	5.02	2.77	9.84
45	Air Transportation	.41	.37	1.0	.54	1.54	9.07	4.20	5.89	2.73	7.75
46	Undistributed	.00	.05	1.0	.58	4.78	36.20	23.40	7.57	4.89	40.59

Source: Dataset provided by Professor Kao-Chao Lee, based on unpublished data from the Council for Economic Planning and Development and from the Energy Committee.

5.1.1 An Interpretation of I/O Coefficients and Multipliers

For demonstrating the practical meaning of these figures, the first sector, agriculture, is used as an example:

Reading through the first row, V1 = 0.55 means that for each dollar sales for agriculture, the value added in the agricultural sector would increase 55 cents.

M1 = 0.27 means the value of agricultural importation is 27% of the total domestic agricultural production.

$V1(I-A)^{-1} = 1.0$ means, within a closed economy, that for each dollar of sales as agricultural final demand, the total value-added changes in the economy are exactly one dollar (within this one dollar, 55 cents are earned by agricultural sector and the remaining 45 cents are shared by other interrelated sectors).

$V1(I-A+M)^{-1} = 0.69$ means, within an open economy, that for each dollar of agricultural sales, the total income changes in the economy by 69 cents. Thirty-one cents are earned by foreign countries.

e1 = 1.68 means that for a change of $25,000 in agricultural sales, the energy use in the agricultural sector would change by 1.68 KLOE.

$e1(I-A)^{-1} = 13.51$ means, within a closed economy, that for a change of $25,000 in sales within the agricultural sector, total energy use in the whole economy would change by 13.51 KLOE.

$e1(I-A+M)^{-1} = 8.20$ means, within an open economy, that for the change of $25,000 agricultural sales, total energy use in the whole economy would change by 8.2 KLOE. This figure is smaller than 13.51 of $e1(I-A)^{-1}$ because some energy embodied in the import goods is saved by avoiding domestic production.

E11 = 8.02 means, within a closed economy, that the total change of energy use in the economy would be 8.02 if the energy use in the agricultural sector changed by one unit. This figure shows the "indirect effect" of energy use in agriculture. It is relatively high, because the agricultural sector has a significant relationship with the fertilizer sector, which is an energy-intensive activity.

E12 = 4.87 shows the corresponding energy multipliers of an open economy.

$e1(I-A+M)^{-1}/V^{1}(I-A+M)^{-1} = 11.93$ means that in order for the whole economy to increase by $25,000, initiated by the agricultural sales, the energy use in the whole economy would increase by 11.93 KLOE.

5.1.2 Comparison: Various Measurement of Energy Intensities

As discussed in section 4.1.3, when policy makers are facing the choices of developing alternatives in various economic sectors, they consider two points. First, they are concerned about both benefits and costs within the sectors. Second, they want to look into the resultant direct and indirect effects on the whole economy. Based on these considerations, the column coeffients of table 5.1 are compared and their relevance is discussed.

Columns one, three and four of Table 5.1 show the income coefficients (which can be considered benefits) and columns five to nine show the energy coefficients (or costs) of each sector. For example, in one Taipower (1980, pp. 47-50) study, the direct energy coefficient, ei, was used for comparing energy intensity between sectors. Obviously, they missed two points: the sector's benefit side and indirect energy use for producing the increased intermediate inputs required by that sector. Other research by CPC (1981, pp. 39-53) and OAAI (1982a) use ei/Vi as the comparing criterion. Although both benefits and costs are considered in ei/Vi, the indirect value added and energy use for producing the required intermediate inputs are still missing. The quantity $ei(I-A+M)^{-1}/Vi(I-A+M)^{-1}$ avoids these problems by evaluating both benefits and costs within each sector through an interindustry context which considers the total (direct and indirect) effects of both value added and energy use. Therefore, the figures in the tenth column of Table 5.1 are used as the comparing criteria for the sectoral analysis of the present study.[8]

5.2 THE MACRO MODEL: NISE-IO ALGORITHM

As stated in section 4.2, the information of energy/income final demand coefficients provided above is useful for examining the sector-level energy economy, whereas it is limited for regional or national planning. To circumvent this limitation, the macro-level Non-Inferior Set Estimation Input-Output (NISE-IO) model was developed in section 4.2.5 as:

$$\max \quad z = (G(X), -E(X))$$

$$\text{s.t.} \quad RX =< B$$

---

[8] Another relevant indicator is column six $ei(I-A)^{-1}$, or essentially is $ei(I-A)^{-1}/Vi(I-A)^{-1}$, which details the case of a closed economy within an interindustry context. As an island, Taiwan must pay special attention to the possible results of being isolated from the international economy. Any curtailment of shipping resulting from energy embargoes or, possibly, war could cause this to happen. The information listed in column six of Table 5.1 can be used to formulate a contingency plan for such emergencies.

$$(I-A+M)X >= Fmin$$

$$Xt =< KXt-i$$

The computer program utilized to run this model is a NISE subroutine created from a modified LP algorithm. This routine provides new objective function coefficients and new solutions (both objective and decision variables) with each run of the algorithm. The following paragraphs present the empirical results of this algorithm.

5.2.1 Objective Space

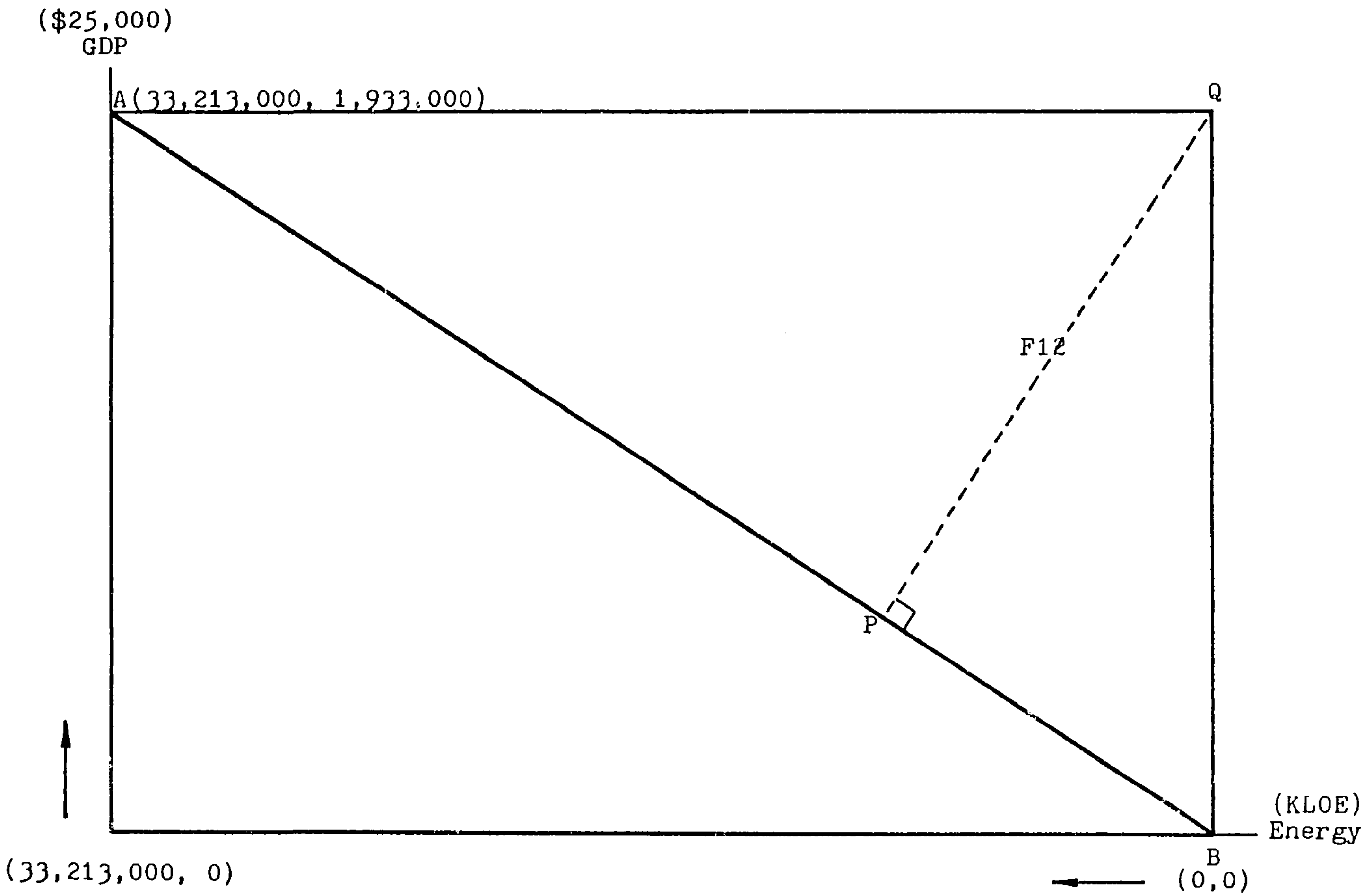
The objectives of this study are to maximize GDP and minimize energy use. Each objective stands for a dimension (axis) and together form an objective space in Figure 5.1. Begin by optimizing each objective individually. This is done by solving an ordinary LP problem. This results in a maximum GDP of 1,933,000 units (one unit is equal to $25,000). At this production level, the energy requirement is 33,213,000 units KLOE. This gives point A in Figure 5.1. On the other hand, minimizing energy use (the second objective) is a zero level of energy consumption and a corresponding zero level of GDP. This is point B (Figure 5.1). The ideal point is at Q, where no energy is used and a maximum level of GDP is attained. This, of course, would never be a real case. The real noninferior set of solutions should occur somewhere within the triangle ABQ.

The algorithm begins by calculating the maximum possible error F12, which is equal to 1.93. If the segment AB is taken as the estimated noninferior set, a range equal to or smaller than F12 might be "missed." The term "miss" denotes the difference between the actual and the estimated noninferior sets. Since this F12 error range is significant, pre-set the allowable error "T" of the present study to 10% of F12, which is 0.193. This "10%" allowable error is arbitrarily chosen; one can control this specification by presetting to any desired range of accuracy.

Next, derive the first nondominated solution as C (Figure 5.2). This gives 1,853,000 units of GPD and 23,556,000 units of energy consumption. The maximum errors in this case are F13 and F23. F13 is calculated as 1.638, which is equivalent to 84.9% of F12; F23 is calculated as 0.250, which is equivalent to 13.0% of F12. Both exceed the maximum allowable error T. So, the algorithm continues.

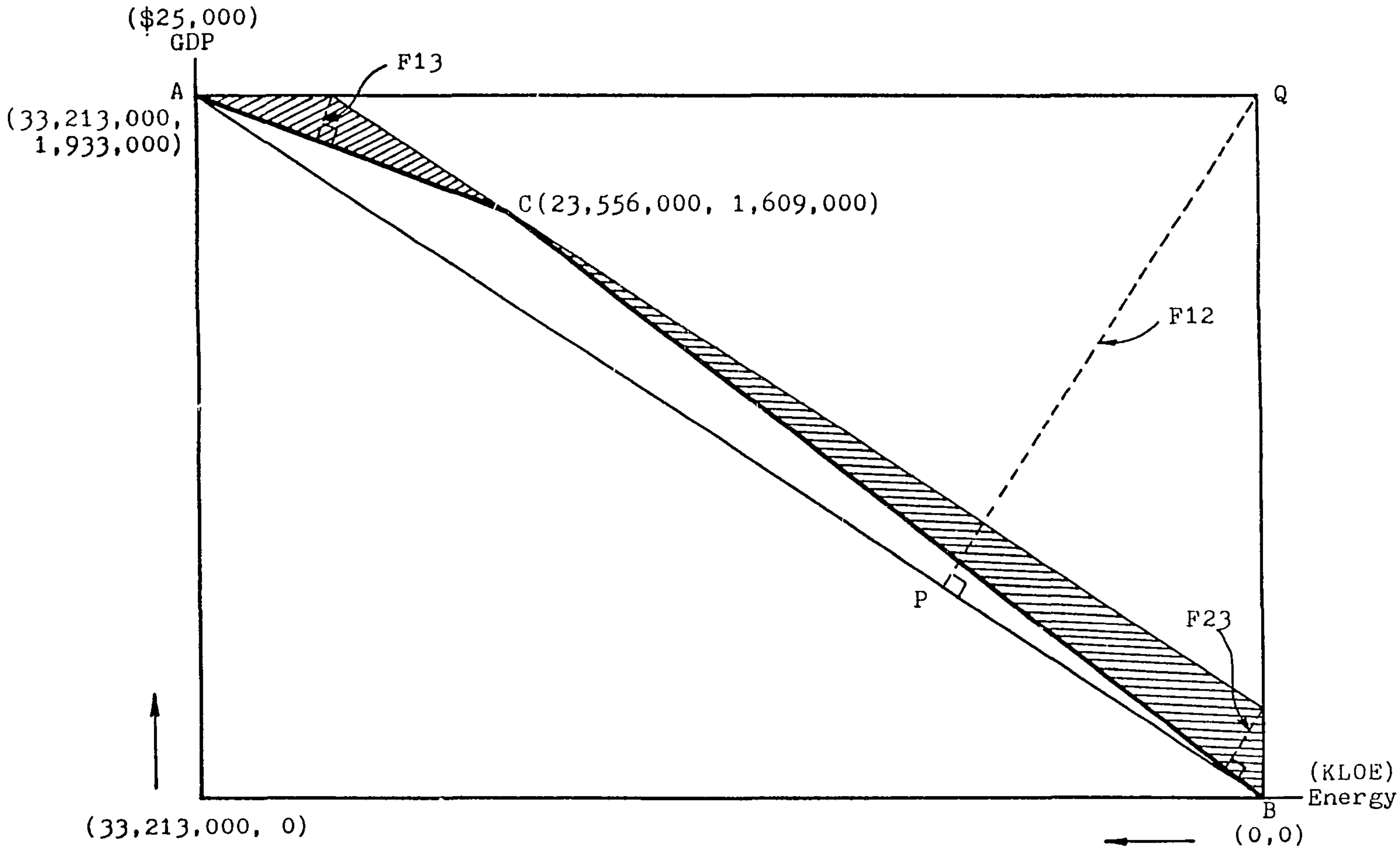
The second iteration runs between points A and C which yields point D (Figure 5.3). This represents levels of 1,853,000 units GDP and 28,592,000 units energy consumption.

Figure 5.1: Initial Step of the NISE-IO Model Results (1986)



Source: Same as Table 5.1.

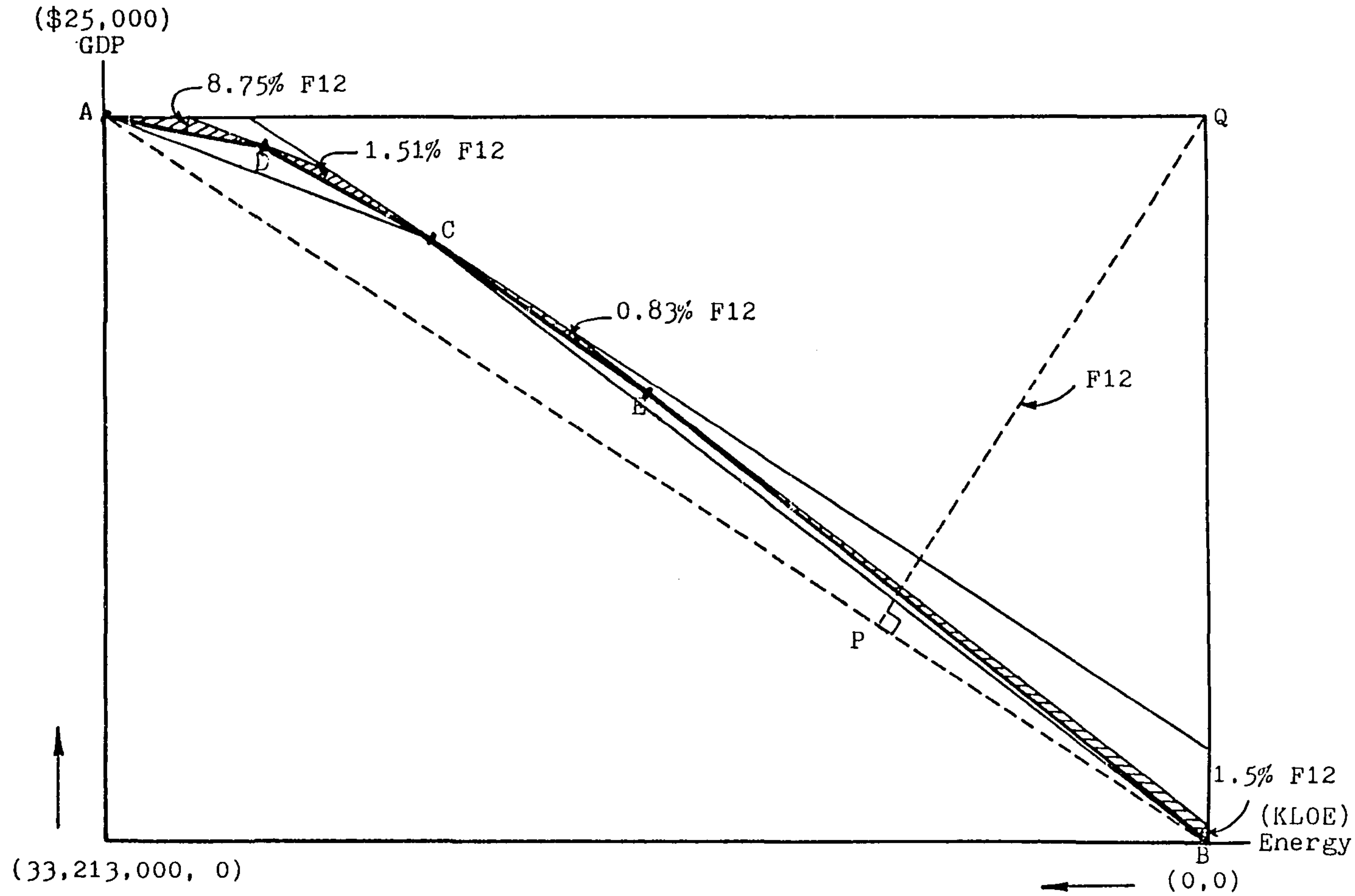
Figure 5.2: First Iteration of the NISE-IO Model Results (1986)



Source: Same as Table 5.1.

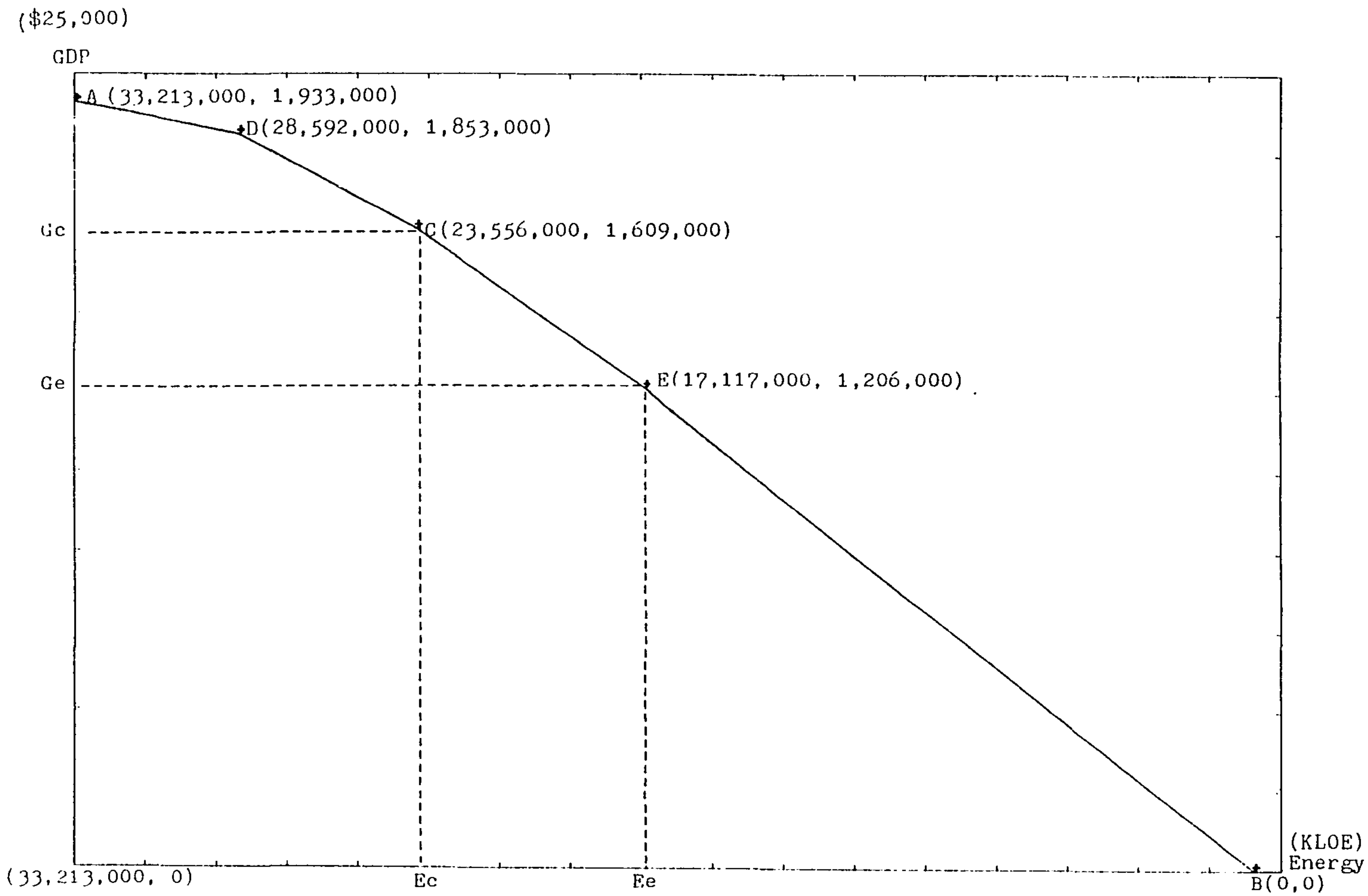
The new maximum errors of this run are 0.169 (8.75% of F12) and 0.029 (1.51% of F12). Both are smaller than the allowable error T, 0.193. Thus, the segments AD and DC are satisfactory noninferior sets estimater. In the same manner, derive the third nondominated solution E (Figure 5.3), which reflcts 1,206,000 units of GDP and 17,117,000 units of energy consumption. The current maximum errors of this run are 0.016 (0.83% of F12) and 0.037 (1.5% of F12). Both meet the allowable error criterion T. This means segments CE and EB are acceptable noninferior set estimations. And on this basis the algorithm is completed. Figure 5.4 presents the whole range of the estimated noninferior set solutions. This solution is for the objective variables and in the objective space.

Figure 5.3: Second and Third Iterations of the NISE-IO Model Results (1986)



Source: Same as Table 5.1.

Figure 5.4: The Results of the NISE-IO Model in Objective Space (1986)



Source: Same as Table 5.1.

5.2.2 Decision Space

Now examine decision variable solutions in the decision space. For each derived nondominated solution of the objective variables, there is a set of optimal solution of the decision variables. Thus, there are four scenarios of decision variable solutions (Table 5.2) which match these derived points A, D, C and E. These scenarios represent the production levels of the forty-six sectors of the Taiwan economy. Using the production level of the base year 1978 as 100%, each sector's projected production level in the analytical year 1986 is plotted in the decision space (Figure 5.5).

Sector slacks (Table 5.2 and Figure 5.6) are derived from the second constraint set $(I-A+M)X >= Fmin$, i.e., $(I-A+M)X = Slack+Fmin$ or $Slack = (X+MX)-AX-Fmin$. Slacks indicate the amount of sector output for either export or a higher level of final consumption.

Table 5.2

Optimal Solutions and Slacks of the Decision Variables: Four Scenarios for Forty-Six Sectors of the Taiwan Economy (1986)

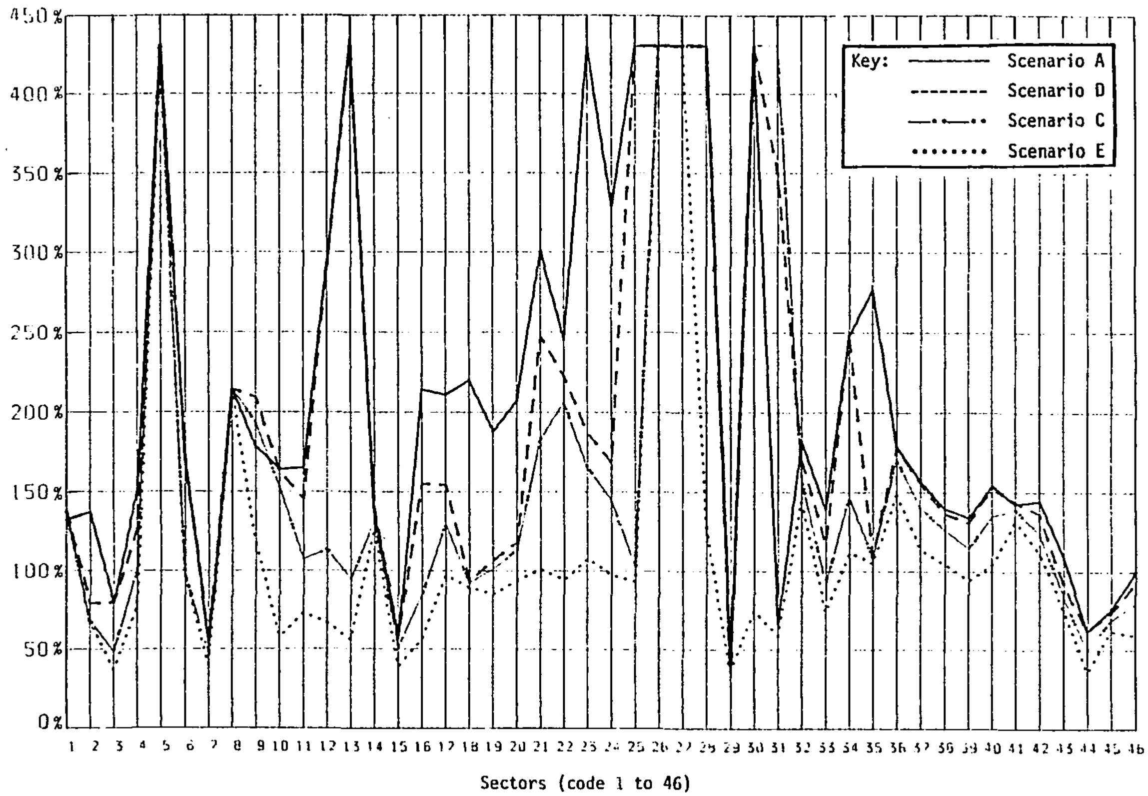
Sector Code[a]	Scenario A			Scenario D			Scenario C			Scenario E		
	Optimal levels			Optimal levels			Optimal levels			Optimal levels		
	Output ($25,000)	Index[b] (%)	Slacks ($25,000)	Output ($25,000)	Index[b] (%)	Slacks ($25,000)	Output ($25,000)	Index[b] (%)	Slacks ($25,000)	Output ($25,000)	Index[b] (%)	Slacks ($25,000)
1	231520.	132.	13395.	240915.	137.	23068.	240915.	137.	57670.	240915.	137.	65199.
2	48190.	137.	19977.	27812.	79.	0.	23933.	68.	0.	23769.	68.	0.
3	3247.	80.	0.	3247.	80.	4958.	1967.	48.	0.	1487.	37.	0.
4	6315.	151.	0.	5291.	127.	0.	4133.	99.	0.	3224.	77.	0.
5	38924.	430.	18859.	38924.	430.	31263.	38924.	430.	40518.	38924.	430.	46051.
6	239269.	171.	107448.	239269.	171.	106040.	135631.	97.	0.	134777.	97.	0.
7	103422.	54.	0.	108911.	57.	0.	91975.	48.	0.	76191.	40.	0.
8	99582.	214.	44535.	99582.	214.	53513.	99582.	214.	56632.	99582.	214.	63881.
9	46628.	178.	0.	54497.	209.	0.	50421.	193.	0.	30864.	118.	0.
10	24443.	164.	0.	24091.	162.	0.	22682.	152.	0.	8605.	58.	0.
11	20213.	165.	0.	17758.	145.	0.	13027.	107.	0.	8976.	73.	0.
12	49124.	293.	115.	49124.	293.	0.	18978.	113.	0.	11158.	67.	0.
13	239294.	435.	163774.	236269.	430.	157584.	51566.	94.	0.	31019.	56.	0.
14	10513.	136.	0.	10726.	139.	0.	10119.	131.	0.	9705.	126.	0.
15	32154.	57	0.	33679.	60.	0.	28649.	51.	0.	21739.	39.	0.
16	51314.	214.	13465.	37153.	155.	0.	20009.	84.	0.	13370.	56.	0.
17	67282.	211.	30317.	49197.	154.	0.	41216.	129.	0.	31065.	97.	0.
18	35132.	220.	0.	14917.	93.	0.	14710.	92.	0.	14226.	89.	0.
19	8744.	188.	0.	4955.	107.	0.	4708.	101.	0.	3953.	85.	0.
20	38286.	207.	0.	21878.	118.	0.	20914.	113.	0.	17507.	94.	0.
21	171668.	301.	0.	141088.	247.	0.	104264.	183.	0.	57461.	101.	0.
22	15003.	246.	0.	13513.	222.	0.	12521.	206.	0.	5733.	94.	0.
23	15871.	430.	15828.	6898.	187.	0.	6084.	165.	0.	3990.	108.	0.
24	131996.	329.	64281.	67213.	168.	0.	57668.	144.	0.	38940.	97.	0.
25	208763.	430.	265607.	208763.	430.	266888.	49673.	102.	0.	45217.	93.	0.
26	93971.	430.	72594.	93971.	430.	74270.	93971.	430.	74562.	93971.	430.	75343.
27	445083.	430.	314973.	445084.	430.	315359.	445084.	430.	315777.	445084.	430.	317212.
28	179420.	430.	147491.	179421.	430.	157649.	179421.	430.	161356.	52001.	125.	0.
29	4462.	43.	0.	3958.	38.	0.	3806.	36.	0.	3742.	36.	0.
30	278522.	430.	245750.	278523.	430.	246737.	278523.	430.	240120.	48305.	75.	0.
31	45883.	67.	0.	237284.	349.	245261.	292730.	430.	320409.	39825.	59.	0.
32	8085.	182.	0.	7541.	170.	0.	7001.	158.	0.	6367.	144.	0.
33	105702.	139.	4475.	88711.	117.	0.	70318.	92.	0.	56567.	74.	0.
34	111185.	248.	30071.	111186.	248.	32997.	65669.	146.	0.	50458.	112.	0.
35	387663.	277.	233335.	153036.	109.	2.	151247.	108.	0.	147684.	105.	0.
36	5088.	178.	0.	5089	178.	0.	4842.	170.	0.	4226.	148.	0.
37	25138.	156.	0.	25008.	155.	0.	22448.	139.	0.	18213.	113.	0.
38	173041.	139.	0.	167617.	135.	0.	155806.	125.	0.	129184.	104.	0.
39	53275.	133.	0.	51996.	130.	0.	45627.	114.	0.	37627.	94.	0.
40	4288.	154.	0.	4250.	153.	0.	3732.	134.	0.	2887.	104.	0.
41	355102.	142.	0.	356506.	143.	0.	344480.	138.	0.	326750.	131.	0.
42	9820.	144.	0.	9226.	135.	0.	8359.	123.	0.	7570.	111.	0.
43	50331.	109.	0.	42012.	91.	0.	38738.	84.	0.	35145.	76.	0.
44	6352.	62.	0.	6465.	63.	0.	5137.	50.	0.	3659.	36.	0.
45	9595.	76.	0.	9309.	74.	0.	8696.	69.	0.	7864.	62.	0.
46	52394.	100.	0.	48843.	93.	0.	41433.	79.	0.	30715.	59.	0.

[a]Same as Table 5.1.

[b]This index column are calculated from 1986 projected output levels divided by the 1978 output levels.

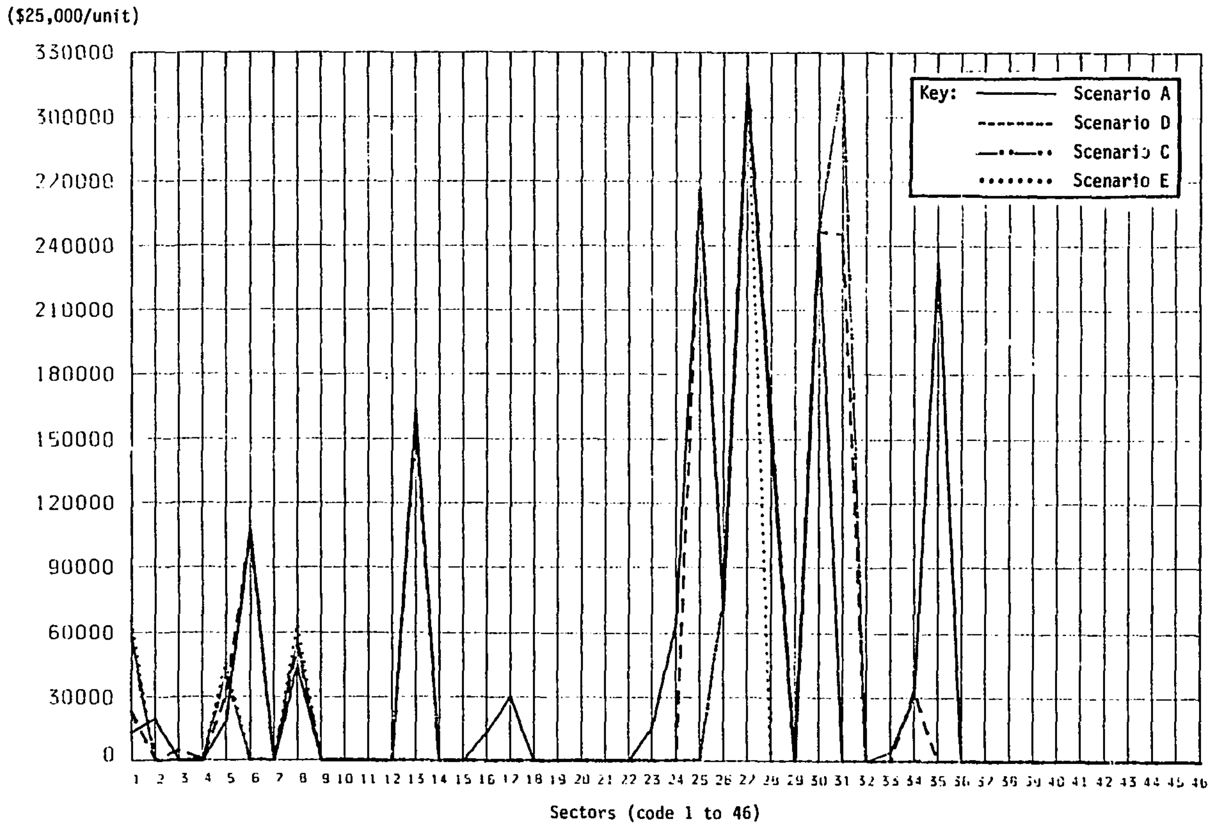
Source: Dataset provided by Professor Kao-Chao Lee, based on unpublished data from the Council for Economic Planning and Development and from the Energy Committee.

Figure 5.5: Optimal Production Levels in Decision Space: Four Scenarios for Forty-Six Sectors of the Taiwan Economy (1986)



Source: Same as Table 5.1.

Figure 5.6: Production Slacks for Export or Higher Levels of Final Consumption: Four Scenarios for 1986



Source: Same as Table 5.1.

5.2.3 Optimal Resource Structure

Based on the production level of each sector in Table 5.2, the optimal resource structure (including labor) for 1986 is derived (see Table 5.3 and Figure 5.7). This is simply calculated as follows:

$$Ei = \Sigma eijXj$$

where:

Ei = total amount of resource type i, in physical units;

eij = required inputs of resource type i for producing one dollar's worth of the jth industry sector, in physical units;

Xj = production level of the jth sector, in dollar units.

Again, Table 5.3 and Figure 5.8 show resource slacks. Since most energy requirements are imported, these slacks (except for labor) do not reflect the amount of energy left from domestic consumption. They can indicate both the reduction in the amount of energy imported from foreign countries and the amounts of disruption in energy supply. Only the labor slack refers wholly to the domestic situation. Note that labor is a binding constraint for alternatives A and D. This implies that (1) labor is

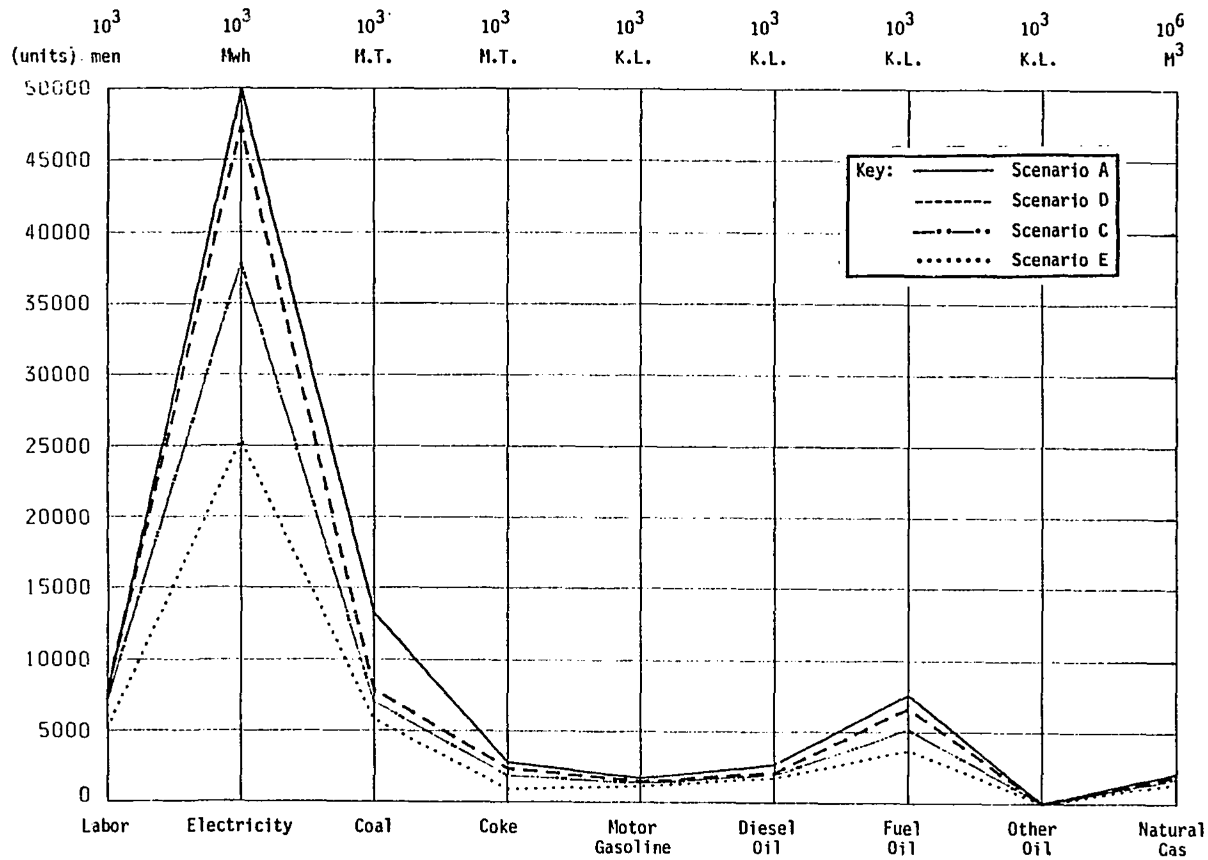
Table 5.3

Resource Requirements and Slacks:
Four Scenarios for 1986

Type of Resource	Scenario A		Scenario D		Scenario C		Scenario E	
	Amount Required	Slacks	Amount Required	Slacks	Amount Required	Slacks	Amount Required	Slacks
Labor (10^3 men)	7,783	0	7,783	0	7,216	567	5,185	2,598
Electricity (10^3 Mwh)	49,972	0	47,398	2,574	37,857	12,115	25,425	24,547
Coal (10^3 M.T.)	13,238	5,281	7,836	10,683	6,978	11,541	5,777	12,742
Coke (10^3 M.T.)	2,810	0	2,359	451	1,812	998	944	1,866
Motor Gasoline (10^3 K.L.)	1,730	2,032	1,456	2,305	1,329	2,432	1,189	2,572
Diesel Oil (10^3 K.L.)	2,734	1,475	2,146	2,063	1,947	2,263	1,761	2,448
Fuel Oil (10^3 K.L.)	7,673	8,441	6,678	9,435	5,183	10,930	3,745	12,369
Others Oil (10^3 K.L.)	20	9	17	12	13	16	9	20
Natural Gas (10^6 M^3)	2,182	1,163	1,938	1,407	1,713	1,632	1,458	1,887

Source: Same as Table 5.1.

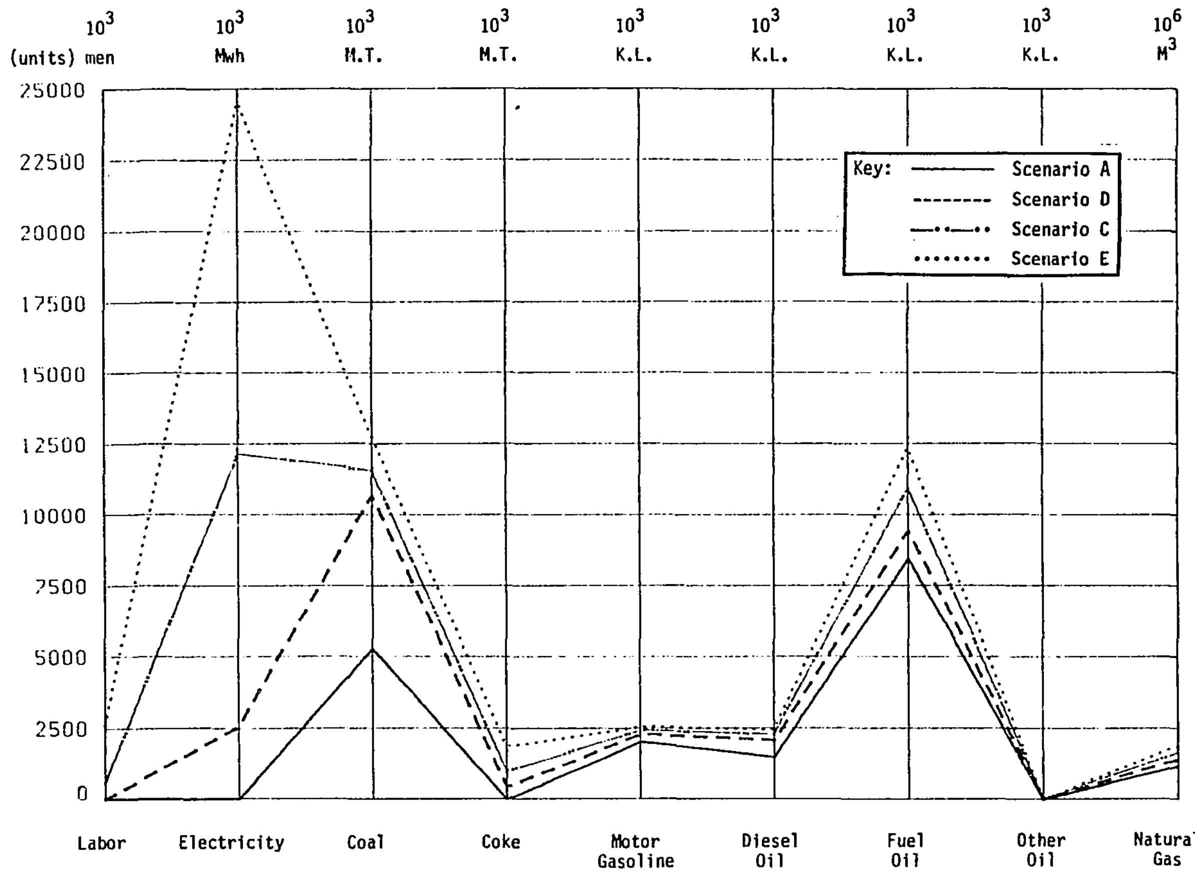
Figure 5.7: Optimal Resources Patterns: Four Scenarios for 1986



Source: Same as Table 5.1.

becoming a scarce resource in Taiwan; and, (2) the less-energy-intensive sectors (e.g., agriculture) are prone to be labor intensive.

Figure 5.8: Resource Slacks: Four Scenarios for 1986



Source: Same as Table 5.1.

5.3 COMPARISON

This section contains a comparison between the NISE-IO model and three other energy models: LP-IO, I/O, and econometrics approaches.

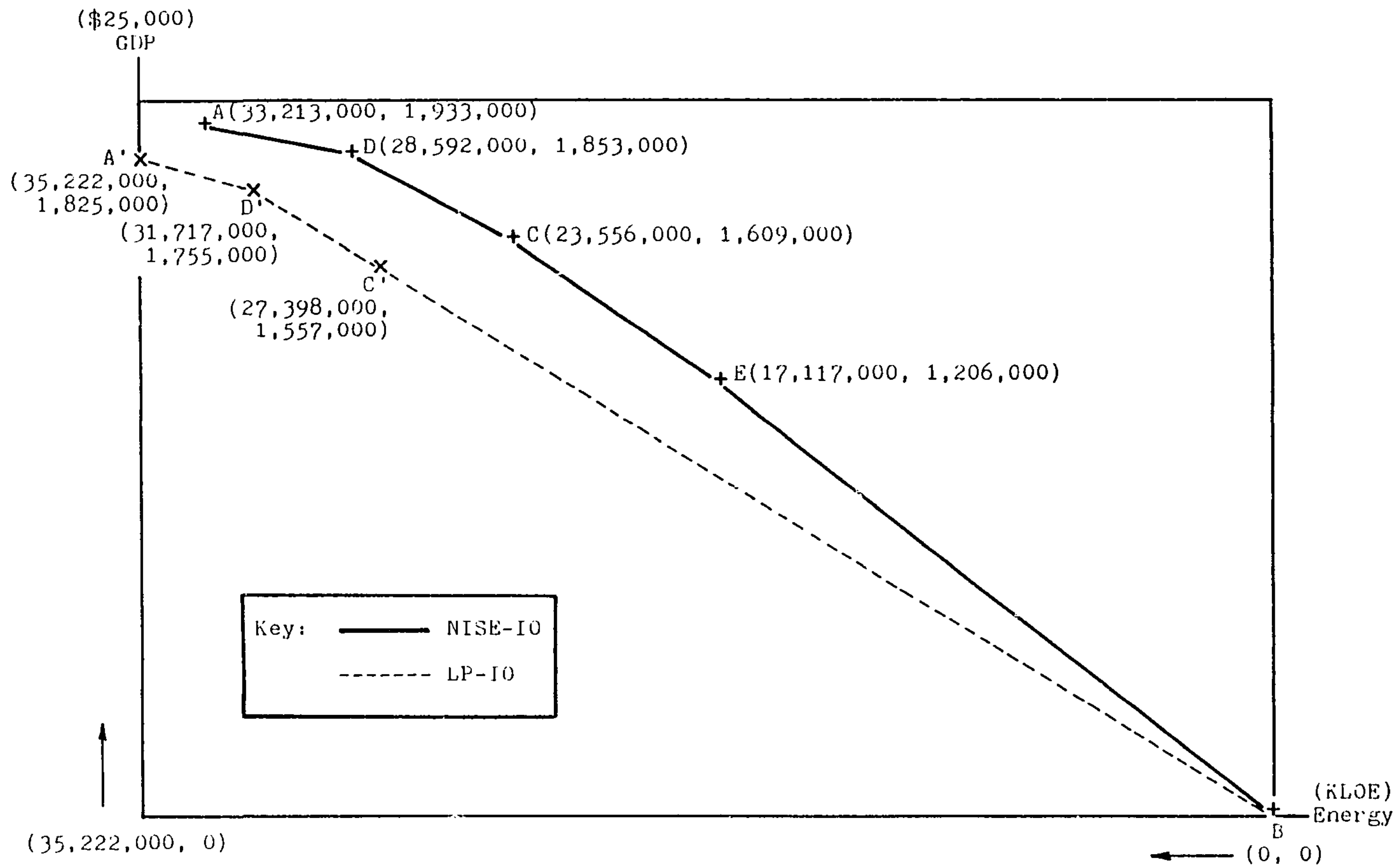
5.3.1 NISE-IO vs. LP-IO

First compare the empirical results of the NISE-IO model with those from the LP-IO model by the Energy Committee (1981a). The two models are closely related.

Figure 5.9 shows points A, D, C and E, as the estimated nondominant solutions and points A', D', and C' as the sensitivity results from the LP-IO model by the Energy Committee (1981a), which reflects that, for the same level of energy consumption, the NISE-IO approach yields a higher level of GDP. As compared and explained in Table 4.1, this is because the NISE-IO model considers energy priorities when energy supply decreases (see also section 6.1).

Another difference is that the NISE-IO model controls the "allowable error" of the whole non-inferior set curve, while the LP-IO model does not. From section 5.2.1 (Figure 5.3), one knows the "possible errors" from segments AD, DC, CE, and EB are 8.75%, 1.51%, 0.83% and 1.5% of F12,

Figure 5.9: Comparison of the Empirical Results between the NISE-IO and the LP-IO Models



Source: Based on Energy Committee, 1981(a), and this study.

respectively. By contrast, in the LP-IO model, this information is not reflected on segments A'D', D'C', and C'B. In addition, Harris (1982) argued that the LP model needs more runs of sensitivity analysis to identify the kinks in the nondominated surface while the NISE model requires fewer runs.

5.3.2 NISE-IO vs. I/O

This section compares the NISE-IO model with an I/O model used by the Chinese Petroleum Corporation (CPC) in 1980. The latter study was to project fifteen types of energy demand up to 1989 by a classical input-output model. The model states (CPC, 1980, p. 13):

$$E = D\,(I-A+M)^{-1}Y$$

where:

E = projected energy demand matrix.

D = energy coefficient matrix.

M = matrix of import coeffcients.

Y = matrix of final demand.

This is a "descriptive" model. Y is first determined by econometric projections. Then, $(I-A+M)^{-1}Y$ produces X, the output level of each sector. E = DX is, therefore, the energy demand level.

The NISE-IO approach is a normative or optimization model. To derive X, more factors are considered than simply the Leontief matrix (I-A+M). Within the constraints, the resource inputs matrix R, the availability of the resource vector B, the minimum consumption level Fmin, and the sector expansion capacities K are all considered. Therefore, there are substantial grounds to argue that the NISE-IO model is more comprehensive than that of the aforementioned CPC I/O model. Consequently, the energy demand pattern derived by this NISE-IO approach should be more pertinent in terms of the models' comprehensiveness.

Because of the differences in classification of the studied energy types (fifteen types for the CPC study vs. eight types for the present study), the actual empirical results of the two studies cannot be compared. More information is needed as to the definition of data classification of the CPC study before one can aggregate the fifteen energy types to the eight types of energy of the present study. It is hoped this research can be extended in the future.

5.3.3 NISE-IO vs. Econometrics-Estimated Functions

This section contains a comparison between the present study and an econometrics study by Chern (1984). Both studies examine the relationship between GDP and energy use.

Chern (1984) utilized an econometrics model to estimate the historical relationship between energy demand and economic growth of fifteen developing countries (including Taiwan, the Republic of China). The estimated function was formed as:

$$\ln(E/POP) = B0 + B1 \ln(GDP/POP) + B1 \ln P + B2 \ln IND + e$$

where:

E = total energy consumption,
POP = population,
GDP = total real gross domestic products,
P = energy price,
IND = share of GDP in the industrial sector,
e = error term, and
Bi = parameters to be estimated.

As Chern notes that his study results are only preliminary and may contain problems of multicollinearity and serial correlation, which need to be further investigated, this section does not intend to compare these empirical results. The emphasis of the comparison are on the methodological aspects.

In the present study, the "trade-offs curve" between GDP and energy is identified in Figure 5.4. Now if one reverses the horizontal axis as shown in Figure 5.10, this curve becomes a production-like function, illustrating the relationship between energy as an input and GDP as an output. This curve with the slope of GDP over energy use declining from point B to E, C, D, and A, is deceptively appears to be a marginal decreasing production function estimated from an econometric approach, e.g., the above-mentioned one by Chern.[9] There are, however, some differences distinguishing the two.

First, due to the linear assumption (constant return to scale), the notion of marginal decreasing productivity does not apply to the NISE-IO model's curve, i.e., $\partial Z/\partial X_i$ cannot be observed.[10] The reason for the decreasing slope of this NISE-IO curve is because of the different GDP/energy efficiency of economic sectors (see section 6.1.1 for

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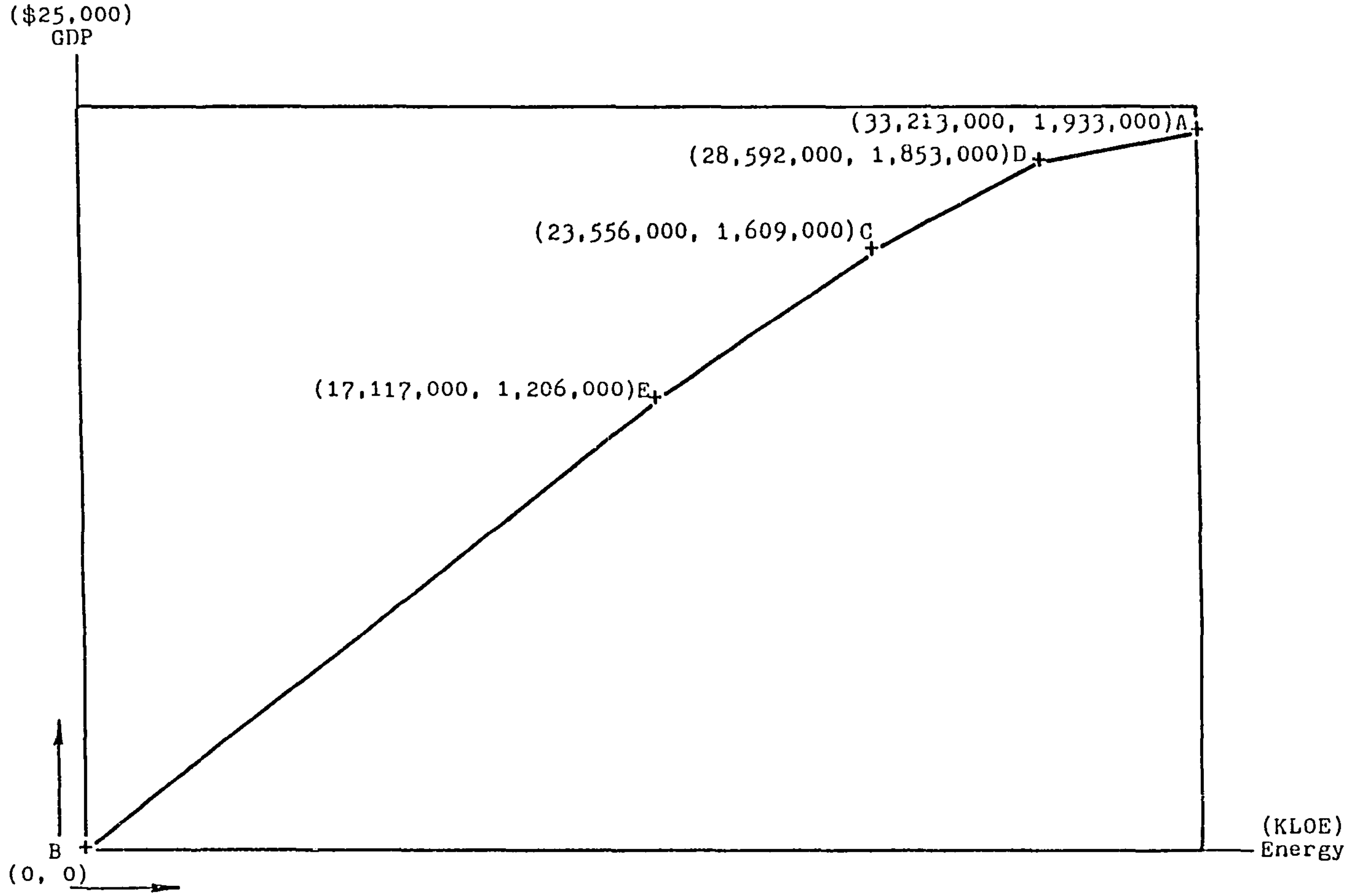
[9] The shape of this NISE-IO curve would be smoother if more kinks are derived by narrowing down the desired degree of accuracy to be less than 10% of F12.

[10] See section 7.2 for the model's assumptions and relaxation of the linear assumption.

Figure 5.10: The Production-Like Function Derived by the NISE-IO Model



Source: Same as Table 5.1.

details), not the law of diminishing productivity.

Second, in econometric approaches, when the BLUS[11] estimator is determined, problems of heteroscedasticity, multicollinearity, autocorrelation, and transmitted error terms may occur.[12] On the other hand, programming approaches avoid multicollinearity problems from exogenous price variables, and its supply responses of inputs can be examined through variation of the input prices from the dual.

Third, the implications of these two approaches differ as follows. Programming techniques form a managerial analysis, indicating "what the economy should be" and "what the optimal solution is"; while the econometric approach is a historical analysis (time series or cross-sectional are both based on historical and/or current data), investigating "what the economy actually is" and "what the best-fit solution is." In addition, this type of programming technique is generally used for studying the supply side, while most econometric approaches have focused on the demand side.

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[11] BLUS stands for Best Linear Unbiased (BLU) with Scalar (S) covariance matrix in the form Q^2I. See Johnston (1972, p. 254).

[12] See Johnston (1972) for discussions of these problems.

Shumway and Chang (1977) derive supply relations from a profit-maximizing LP model for Californian commodities and compare the supply relations with estimates from time-series regressions. They note (pp. 345-346):

> "it is not apparent a priori that the positive estimate should in all cases be more reliable than the LP estimate. Because the positive estimate is based on fitting a linear regression to historical data with least-squared error, one expects it to describe what has actually ocurred in the past and, if past policies and relationships among variables remain stable, to predict more accurately than the LP-derived estimate. Positive estimates may neither accurately describe the past nor accurately predict if one or more of the standard statistical assumptions are violated, e.g., errors in data measurement or aggregation, high correlaton among independent variables, omission of relevant variables, or incorrect anticipation of the form of the relationship.
>
> In contrast, using a combination of historical and synthetic data and imposing a behavioral assumption (typically profit maximization), linear programming describes what "should" have happened rather than what did happen. Perhaps its most important strength is that it can simulate the effects of exogenous forces and policies for which historical observation are not available."

Their conclusion is that (p. 356):

> "Apparently, greater realism in LP's specification of producers' behavioral properties and environment is required to produce real world results that improve substantially on simple econometric models where the latter are also appropriate."

The above quotations lend support to the discussions and comparisons in this section. To compare the present study to that by Shumway and Chang (1977), two points are noted.

First, since this study focuses on the macro-level, the referred "producer" here means "the whole economy." Second, the NISE-IO curve is derived by varying "preferences" between GDP and energy use (see section 6.1 for details), rather than by varying "prices."

5.4 COMPARISON: POLICY ALTERNATIVES

As the noninferior solutions derived from this study are compared with those from the LP model in section 5.3.1, note that point A' (Figure 5.9) stands for a normal case without energy disruption. Since this is the government (Energy Committee) projection, one can thus hypothetically use the 1,825,000 units GDP of point A' as a "normal" or "moderate" performance of 1986 Taiwan economy. Comparing with the derived noninferior solutions from this study, point D which possesses a level of 1,853,000 units GDP (close to the GDP level of point A') represents a possible consequence of a "moderate policy." Similarly, point A which has a higher GDP level (1,933,000 units) represents a possible consequence of an "aggressive policy," and points C and E with lower GDP levels (1,609,000 and 1,206,000 units, respectively) represent possible economic consequences of a "conservative policy" (see also section 2.6). Table 5.4 shows GDP growth of these policy alternatives based on the actual GDP level of 1978. Their policy implications will be discussed in the next chapter.

Table 5.4

GDP Indicators of Policy Alternatives:
Four Scenarios for 1986

		Units ($25,000)[a]	Index (%)	Annual Growth Rate (1978-1986)
1978	Actual Level	1,015,000	100	--
1986	Scenario E[b]	1,206,000	119	2.2%
1986	Scenario C[b]	1,609,000	159	5.9%
1986	Scenario D[c]	1,853,000	183	7.8%
1986	Scenario A[d]	1,933,000	191	8.4%

[a] 1978 prices.

[b] Represents conservative policy.

[c] Represents moderate policy.

[d] Represents aggressive policy.

Source: Same as Table 5.1.

Chapter VI

POLICY IMPLICATIONS AND ALTERNATIVES

This chapter first determines the policy implications of the empirical findings with regard to the five issues defined in chapter two and, then, analyzes the predefined policy alternatives.

6.1 POLICY IMPLICATIONS

In Figure 5.4, the "trade-offs curve" between GDP and energy use is identified. This figure shows that for scenario C to scenario E, the economy trades off (Gc-Ge) units of GDP for (Ec-Ee) units of energy. More accurately, one can investigate trade-offs of energy use for each $25,000. For example, from zero level of GDP to 1,206,000 units (one unit is equal to $25,000) GDP, the economy trades off 14.2 KLOE for each $25,000. This is simply calculated from the energy required level, 17,117,000 KLOE, over the 1,206,000 units GDP. In the same way, from 1,206,000 to 1,609,000 units GDP, 16.0 KLOE is traded off for each $25,000. From 1,609,000 to 1,853,000 units GDP, 20.6 KLOE is traded off for each $25,000. From 1,853,000 to 1,933,000 units GDP, 57.8 KLOE is traded off for each $25,000.

Significant variations can be observed after performing sensitivity analyses based on different scenarios. These sensitivity variations are on the most important factors, i.e., the objective variables of maximizing GDP and minimizing energy use, rather than on other variables such as those of the right hand side as conventional LP does. In other words, sensitivity analyses are on varying the weight (or "slope") between the two objectives. For example, more weight is placed upon the GDP objective for scenario A than that for scenario D. In like manner, more is placed on that for scenario D than that for scenario C, more on that for scenario C than that for scenario E. As a result, segments AD, DC, CE, and EB become steeper and steeper. This point and its implications will be elaborated in subsequent sections.

6.1.1 Achieving a Certain Economic Growth Rate with Minimum Consumption of Energy

Theoretically, when the marginal revenue products of energy inputs to each sector are all equal, the economy achieves its best allocation of energy resources. Conversely, to achieve this ideal situation, energy should be allocated to those sectors efficient in energy use. This point is straightforward to see. The key is to define a realistic amount of energy for allocation and to identify the potential capacity of each sector able to absorb these available energy resources. These aspects are all embodied in the mechanism of the NISE-IO model.

The objective function, max Z = GDP - Energy, directs energy into the efficient sectors. The constraints, setting RX =< B and (I-A+M)X >= Fmin, identify the amount of energy free to be directed for production. RX =< B represents the total supply of resources. After satifying the minimum final consumption, Fmin, the remaining amount of energy is available for production. Each sector, however, has its capacity bounds for production (service sectors are exceptions). This is represented in the third constraint set Xt =< KXt-i. Accordingly, energy is first directed to the most GDP/energy efficient sector until that sector's upper bound is reached. Energy then goes to the second-most efficient sector, and so on.

From the last paragraph, two allocating effects of the NISE-IO model are noted. The allocating effect between final consumption and intermediate production is determined first by the level of Fmin, an exogenous variable, and secondly by allocating effects arising from adjusting the production structure of the economy. This second mechanism is simulated endogenously.

In the present study, the emphasis is on production allocation effects. Fmin is thus set at the lowest possible levels, those used in the LP-IO model by the Energy Committee (1981a). The advantage of this arrangement is that more energy is available for achieving a higher level of production. This also describes the case suitable for contingency planning given energy disruption. On the other hand, the disadvantage of this low Fmin is that for the case of a prosperous economy, people will want to consume more and hence drive Fmin up. Except within a strict communist or socialist country, government may not be able to control the population's level of consumption.

Since the changes of B, Fmin, and/or K will lead to different solutions of the study, to determine appropriate levels for these exogenous variables is critical. To consider different situations, the analyst or the decision maker may want to set several scenarios for these exogenous variables to test and compare the simulation results. The parameters in the model could, then, be easily calculated and provide useful informaton to the issue of "achieving a certain economic growth rate with minimum consumption of energy" (see Table 6.1). In this study, year 1986 has been taken as a demonstration case. Policy implications of the numerical results will be presented and discussed in the following sections, all closely related to this overall subject.

Table 6.1

Achieving a Specified GDP with a Minimum Consumption of Energy (1986)

	G D P		Energy	
	Units ($25,000)[a]	Index (%)	Units (KLOE)	Index (%)
Scenario E	1,206,000	100	17,117,000	100
Scenario C	1,609,000	133	23,556,000	138
Scenario D	1,853,000	154	28,259,000	165
Scenario A	1,933,000	160	33,213,000	194

[a]1978 prices.

Source: Same as Table 5.1.

6.1.2 Relationship between Energy Demand/Supply and Economic Development/Growth

Since the "lead time" and cost of energy project investment are significant, projection of energy supply and demand is an important task. For example, Taiwan Power Company has experienced electricity over-supply problems during the past two years. This year, construction of the fourth nuclear power plant will begin. The estimated cost up to the expected 1994 completion date is 4.5 billion dollars. Will this investment add to the present overcapacity? This type of problem requires an effective tool for projection analysis.

Descriptive, predictive, and normative models discussed in section 3.1 are all capable of making such a projection. For example, the input-output multipliers and coefficients model used in this study and the previously mentioned I/O model by the Chinese Petroleum Corporation (see section 5.3.2) are typical descriptive models. The Leontief matrix, (I-A+M), describes detailed information on the economy. Econometric models such as the one by Chern (see section 5.3.3) are predictive in nature. Based on past behavior, it is predicted that the economy will continue to perform as it has done previously. The NISE-IO model presented in this study is a normative-oriented model. Managerial factors such as Pmin, K, and B are included.

As argued in chapter three, in the field of energy economics and policy, the managerial approach of this study serves as a research tool better than the other approaches. In the process of energy planning, the managerial role of the government should legitimately be taken into account. The energy economy could perform better if government were appropriately involved. However, one point should be borne in mind, i.e., solutions and conclusions of this type of model imply an "optimal," which is generally "better" than the real, situation. In reality, the economy may always perform less than the optimum due to poor management or unmanageable factors. The conclusions arising from these empirical findings imply the direction of government efforts towards a better situation. In other words, the empirical findings derived from this NISE-IO model tend to suggest a higher GDP and/or a lower energy consumption level than the real situations in the economy. This could be verified by checking the model's results with those of the real energy economy. Table 6.2 shows that the derived average annual growth rate of the overall energy consumption from 1978 to 1986 (1.8%) is lower than the actual situation from 1978 to 1982 (3.1%). Oil consumption is particularly lower than the real case, while coal and electricity are about the same. Note that the primary concern of this NISE-IO model is not to predict the real economy, but to see how much the real economy can improve and/or how energy decision makers can better manage energy-economic problems in order to meet specific economic goals. The comparison shown in Table 6.2 implies that the Taiwan economy could achieve a similar level of GDP with less energy consumption provided that it uses more coal and electricity and that it reduces oil use. The economy must be restructured (as suggested by Table 5.2 and Figure 5.5) before this energy situation can be fulfilled. The considerations of economic restructuring are discussed in section 6.1.4.

Table 6.2

Comparison of the NISE-IO Model Results and the Real Energy Economy in Taiwan

Types	Derived Annual Growth Rate (1978 - 1986)[c]	Actual Annual Growth Rate (1978 - 1982)[d]
Electricity	4.5%	4.7%
Coal[a]	12.5%	12.5%
Oil[b]	-7.3%	-0.7%
Overall Energy	1.8%	3.1%

[a]Includes coal and coke.

[b]Includes motor gasoline, diesel oil, fuel oil, and others oil.

[c]Based on the results of Scenario D.

[d]Based on figures of 1978 and 1982 in Table 2.2.

Source: Same as Table 5.1.

6.1.3 Lowering Energy Elasticity

Lowering energy elasticity depends on both non-economic and economic constraints. The non-economic aspects deal with institutional regulations, mechanical techniques for energy conservation or for substitution of energy, etc. and are beyond the scope of this study. The economic aspects are the focus of this section which examines two points (as mentioned in chapter two):

(1) the energy intensity of each sector, and

(2) the proportional weights of energy-intensive sectors as compared with less-energy-intensive sectors.

This study defines, estimates, and justifies the relevance of various types of energy intensity as in chapters four and five.

Table 5.1 reveals that agriculture, machinery, household electrical appliances, electronic products, other transport equipment, and service sectors have relatively low energy/income final demand coefficients, while fisheries, the paper industry, acid and alkaline, chemical fertilizer, chemical petroleum products, cements, glass, non-metallic mineral products, steel and iron, aluminum, and land transportation are relatively energy intensive with high energy/income final demand coefficients.[13] Optimal levels of each sector (including both the energy-intensive and less-energy-intensive ones) have been projected as shown in Table 5.2 and Figure 5.5. From this, the proportionl weights among sectors have been determined. If the government could "direct" the economy toward the optimal production patterns of the scenarios as suggested by this study, the energy elasticity would be lowered to a better position. Directing the economy toward a better structure is the topic of the following section of "industrial restructuring."

A relevant point regarding a lowered energy elasticity should be noted. In the studies by OAAI (1982a; 1982b), one important suggestion is to use nuclear power as a replacement for petroleum consumption in generating electricity. This point is consistent with the findings of the present study. Nuclear energy in this study is represented by sector five, the "Other Minerals" sector. It is one of the highest production sectors with a 430% output level (upper bound of the capacity constraint) compared with that of the base year, 1978, for all scenarios. This

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[13] Most of these high energy/income final demand coefficients sectors are comformable with those energy-intensive sectors defined by the Overseas Advisory Associates, Inc. (OAAI) as discussed in section 2.5.3.

indicates that nuclear energy has been given priority for developing the economy as well as serving as viable means of lowering energy elasticity.

6.1.4 Industrial Restructuring

A lengthy technical discussion would be needed to discuss fully the potential role of each individual sector for industrial restructuring.[14] Instead, this section highlights some conceptual frameworks for policy makers examining industrial restructuring issues. The salient points are as follows:

(1) Interindustry Considerations--Each sector should be evaluated within the larger perspective of the whole economy, not isolated as an independent body. For example, although No.[15]21 "Steel and Iron" and No. 22 "Aluminum" are both relatively energy-intensive activities (with 56.68 and 77.43 units of energy/income final demand coefficients, respectively), they have high levels of production (see Table 5.2 and Figure 5.5). This is because these two products are important intermediate inputs for other

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[14] The potential of each sector for industrial restructuring should be further explored in the future to complement the results of the present study.

[15] "No." means the code of the sector.

energy-efficient sectors of the economy. Their production levels are influenced by the "derived demand" forces from other sectors.[16]

(2) Industrial Blocks--Industrial restructuring should be carried out in terms of whole blocks of industries. For example, No. 25 "Machinery," No. 26 "Household Electrical Appliances," No. 27 "Electronic Products," and No. 28 "Electrical Apparatus" represent the "Electrical Machinery Blocks." Also, Nos. 16 to 24, represent the "Heavy Petrochemical and Metal Blocks." These blocks, formulated as "packages," possess relatively consistent production patterns due to strong ties among these sectors. For example, production levels of the "Petrochemical and Metal Blocks" (from Nos. 16 to 24) all simultaneously fall as energy input falls from scenario A to scenario D (see Table 5.2 and Figure 5.5).

(3) Forward and Backward Linkages--Forward and backward linkages show how strongly each sector is tied with other sectors of the economy. Forward linkages result from increases in the range of supply and increased attractiveness of product prices for buyers in subsequent stages of production due to economies of scale. Backward

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[16] This forward linkage is discussed in a later paragraph in this section.

linkages result from increased factor requirements thus offering greater productive stimuli to the supplier. These two effects together determine the "key" sectors in the economy which, through growth, will promote or generate growth in other sectors of the economy. To determine these linkages and define the key sectors, further research as described in Rasmussen (1957) would be required.

An investigation into the means, e.g., through taxation or financing policy/strategy, for accomplishing industrial restructuring would require further research and is beyond the scope and time constraint of the present study.

6.1.5 Regarding a Disruption of Energy Supply

There are two alternative interpretations of the 1973 Arab oil embargo. To some observers, the political considerations involving the Arab-Israeli conflict were a facade camouflaging the major objective of embargo participants--that of extracting monopoly profits for oil. From this standpoint, the OPEC price increase of 1973-1974 was engineered by the OPEC rulers with or without collusion from the major oil companies. Proponents of this hypothesis point to the fact that oil prices did not drop to preembargo levels after the Arab embargo was lifted. Assuming this view is correct, the consuming nations really do not have a national security problem; they face a monopoly problem. This suggests that the oil exporters would never want to charge a price in excess of the full monopoly price, nor prohibit oil exports.

In contrast, most observers take the view that the oil embargo was a matter of politics, not economics. This means Arab oil exporters may adopt policies that, even though they may inflict some loss on themselves, inflict even greater losses on the consuming nations. The fact that these political motivations sometimes dominate the model of economic self-interest implies the world is dealing at times with a rational, profit-maximizing cartel and occasionally with an "irrational" adversary desiring to inflict greater loss than it sustains. Arguments in support of this viewpoint further emphasize that the Middle East is a most unstable area politically, owing not only to the Arab-Israeli conflict and internal instabilities as demonstrated in Iran, but also the split between radical and conservative regimes and the possibility of eventual Soviet naval intervention in the Persian Gulf. This interpretation of the 1973 Arab oil embargo suggests a real political problem (Griffin and Steele, pp. 20, 28, 193-194).

This study takes the second viewpoint. The long-time conflict between Iran and Iraq has recently become an international problem. Statistics show that from March to May 1984, more than fifteen ships and tankers were attacked in the Persian Gulf. Taiwan's oil import dependence on this area (Middle East) is presently 85% (see Figure 2.3). The tanker teams of Chinese Petroleum Corporation have been sailing through the Persian Gulf for years. Taiwan's concerns about oil disruption from this channel are, therefore, urgent.

Assuming a disruption of energy supply, what will be the impacts on the national economy? Using energy-level scenario D (Figure 5.4) as the 100% level, meaning a "normal" or "moderate" performance of 1986 Taiwan economy, scenarios C and E become 83% and 61%, respectively, indicating energy disruption levels of 17% and 39%. Consequently, GDP drops by 13% and 35% respectively. When energy supply is disrupted, the shocks on the "Heavy Petrochemical and Metal Industries" (Nos. 16-24), "Paper Industry" (No. 9), "Rubber and Products" (No. 10), "Acid and Alkaline" (No. 11), "Plastics" (No. 12), and "Plastic Products" (No. 13) are significant. On the other hand, the "Services Sectors" (Nos. 36-45), "Electrical Machinery Sectors" (Nos. 26-28), and "Agriculture" (No. 1) are insignificantly affected. The degree of shock on each sector depends on the sector's energy intensity and its interrelationships with other sectors. The more energy intensive the sector and the sronger its interrelationships with other energy-intensive sectors, the more impact on its outputs, and vice versa.

After assessing the economic impacts of energy supply disruption, the second step is to recommend to the policy maker a set of implementable strategies for managing this type of problem. In view of the above assessments, the author would like to propose strategies as follow.

From scenario D to scenario C--In this case, GDP drops 13% given a 17% energy supply disruption, reflecting a relatively moderate economic shock. The proposed strategies are (1) to stop exporting any type of energy, especially petroleum products; (2) to reasonably escalate relative prices of energy goods, using higher energy prices to discourage energy consumption in a manner coincident with the expected decrease in supply; and (3) to inform those industries sensitive to energy supply disruption not to expand their capacities in the short run. If the disruption of energy supply does not worsen or last a long time, further drastic measures would not be expected. At present, Taiwan Power Company has four million metric tons of coal in storage, equivalent to nine months national consumption. Chinese Petroleum Corporation has three months refined oil products in storage. As long as the oil embargo or energy supply disruption do not last longer than the amount of stored fuel, the disruption should not be considered a serious problem. A concern is that the psychological factors could serve to deteriorate the pragmatic, planned responses to the problem.

From scenario D to scenario E--GDP drops 35% after a 39% disruption in energy supply. This is a very serious shock. Under these circumstances, energy prices must be fixed and a rationing policy implemented. The prioritization by which energy is allocated to various sectors forms the basis of the rationing policy. The rationed amount for each sector and means to implement the rationing should also be determined on a just and efficient basis. This would call for another, very important study (see Landsberg, 1980, pp. 109-110, 130).

6.2 ANALYSES OF POLICY ALTERNATIVES

This section analyzes predefined policy alternatives based on empirical findings. The focuses are on the economic consequences of and energy requirements for these policy alternatives.

6.2.1 Conservative Policy: Scenarios E and C

Both scenarios E and C have been discussed in section 6.1.5 as cases of energy disruption. Conversely, they could also be considered conservative policy.

Between these two alternatives, scenario E with 1,206,000 units GDP, indicating a total of 19% (or an average of 2.2% annual) GDP growth for the period from 1978 to 1986, seems unrealistic (see Table 5.4). At this GDP level, only agriculture (No. 1, 137%),[17] other minerals (No. 5, 430%), products of wood and bamboo (No. 8, 214%), household electrical appliances (No. 26, 430%), and electronic products (No. 27, 430%) have high production with positive sector surplus, while all other sectors fall to zero sector slacks. There are twenty-seven sectors with production levels less than those of the base year 1978 (see Table 5.2

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[17] Within these parenthesese, "No." means sector and "%" means production level of 1986 in relation to 1978.

and Figure 5.5). This is not realistic. Therefore, scenario E should serve better as a contingency plan rather than a "prior" policy planning option.

Scenario C, with 1,609,000 units GDP, implying a total of 59% (or an average of 5.9% annual) GDP growth for the period from 1978 to 1986 is a good example of a conservative policy (see Table 5.4). At this level of economic activity, other than those five sectors mentioned in the last paragraph, electrical apparatus (No. 28, 430%), other transportation equipment (No. 30, 430%), and other manufacturers (No. 31, 430%) possess high levels of production. Energy requirements at this point are 23,556,000 KLOE. Energy sectors such as coal industry (No. 3, 48%), crude petroleum and natural gas (No. 4, 99%), petroleum raw materials (No. 16, 84%), and petroleum refining products (No. 33, 92%) show production levels below the base year, 1978, indicating energy shortage. On the other hand, "other minerals" (No. 5, 430%), representing nuclear energy, shows very high production. As a result, electricity (No. 34, 146%) also has higher production. Furthermore, coal products (No. 32, 158%) also has a higher production, implying that increase of coal importation is required. These implications conform to the energy situation of the realistic world--nuclear (implying electricity) and coal are substitute for oil, especially with an oil-supply shortage.

6.2.2 Moderate Policy: Scenario D

Scenario D, with 1,853,000 units GDP, represents a relatively prosperous economy, showing a total of 83% (or an average of 7.8% annual) GDP growth for the period from 1978 to 1986 (see Table 5.4). Many other sectors, such as coal production (No. 3, 80%), food products (No. 6, 171%), plastic products (No. 13, 430%), machinery (No. 25, 430%), and electricity (No. 34, 248%) have high production and positive sector slacks. Among these slacks, surpluses in the coal industry and the electricity sector should be interpreted as a higher level of final consumption. As explained in a previous paragraph of this chapter, when a prosperous economy stablizes, people may want to consume more, i.e., a higher level than preset minimum final consumption (Fmin). Since electricity (for general consumers) and coal (for rural consumers) provide the basis for a better standard of living, this inference is sensible and acceptable.

Energy requirements of this moderate policy are 28,592,000 KLOE. Those energy sectors (other than the above-mentioned coal industry, other minerals, and electricity) are still binding constraints of the economy. They are crude petroleum and natural gas (No. 4, 127%), petroleum raw materials (No. 16, 155%), and petroleum refining products (No. 33, 117%). This implies that oil and oil products should be imported only to the level which meets the needs of intermediate production and minimum final consumption.

6.2.3 Aggressive Policy: Scenario A

Scenario A, with 1,933,000 units GDP represents a rapidly growing economy, meaning a total of 91% (or an average of 8.4% annual) GDP growth for the period from 1978 to 1986 (see Table 5.4). Some energy-intensive sectors such as fisheries (No. 2, 137%), petrochemical raw materials (No. 16, 214%), other industrial chemicals (No. 17, 211%), other metals (No. 23, 430%), metallic products (No. 24, 329%), petroleum refining products (No. 33, 139%), and constructions (No. 35, 277%) come into high production with substantial slack surplus. Other energy sectors such as other minerals (No. 5, 430%), coal products (No. 32, 182%), and electricity (No. 34, 248%) are also found at high production levels. Energy requirements of this aggressive policy are 33,213,000 KLOE. If the government is planning an economic policy like scenario A, abundant energy resources should be guaranteed. Energy investments, e.g., a deep water harbor for coal importation and storage space, should be planned. Contracts of energy purchase, e.g., nuclear fuel, coal and oil, should be expanded and arranged in advance.

6.2.4 Concluding Remarks

As elaborated in section 4.2.3, value judgment on the alternative choices in multiobjective generating techniques (e.g., the NISE-IO algorithm in this study) should be made not by the analyst, but by the decision maker after the generating of the model and analysis of policy implications are completed. Therefore, the author does not make conclusions or recommendations about which policy alternative should be adopted. Policy makers should do this based on their implicit or explicit preferences and other relevant information not included in the present study. However, one important point demonstrated here is that electricity (implying nuclear power) and coal should play key roles in the future energy system. Energy planners should plan to implement this strategy no matter which policy alternatives are to be adopted.

Chapter VII

CONCLUSIONS AND LIMITATIONS

This chapter summarizes the main findings and conclusions of this study. Following the summary, the limitations and evaluations of this research are discussed and justified.

7.1 CONCLUSIONS AND RECOMMENDATIONS

This study has utilized a computationally efficient algorithm consisting of an integration of the Non-Inferior Set Estimation (NISE) method and a Leontief interindustry model to investigate trade-offs between national GDP and energy use in Taiwan. On the sectoral level, energy/income final demand coefficients have been used within an input-output context to estimate possible trade-offs between sectoral income and energy use. The information derived from these models' results represents three policy alternatives for energy decision makers to choose among and provides answers to some of the key issues of energy economic problems such as achieving a specified economic growth rate with minimum consumption of energy, the relationship between energy demand/supply and economic development/growth, decreasing the elasticity of energy, considerations for "industrial restructuring," and estimating the economic impacts on the Taiwan economy under assumed disruption of energy supply. To plan for the 1986 Taiwan energy economy, based on the 1978 structure and feasible management factors, the major conclusions and policy recommendations of this study are:

(1) On the national level--From zero level of GDP to 1,206,000 units (one unit is equal to $25,000) GDP, the economy trades 14.2 KLOE for each $25,000. From 1,206,000 to 1,609,000 units GDP, 16.0 KLOE is traded for each $25,000. From 1,609,000 to 1,853,000 units GDP, 20.6 KLOE is traded for each $25,000. From 1,853,000 to 1,933,000 units GDP, 57.8 KLOE is traded for each $25,000 (see section 6.1 and Figure 5.4).

(2) On the sectoral level--"Chemical Fertilizer" trades off the highest total (direct plus indirect) energy use, 250 KLOE, for each total (direct plus indirect) $25,000 income of the economy. Other sectors with high energy/income coefficients are: Cements and Products (156 KLOE/$25,000), Acid and Alkaline (115 KLOE/$25,000), Coal Products (77 KLOE/$25,000), and Aluminum (77 KLOE/$25,000). Considering energy efficiency alone, these sectors should not pursue

aggressive expansion. Coal Products and Aluminum, however, should maintain a sufficient level of production due to their interindustry linkages with other downstream sectors (see Table 5.1 and sections 6.1.3 and 6.1.4).

(3) Achieving a specified economic growth rate with minimum consumption of energy--using scenario E (1,206,000 units of GDP and 17,117,000 KLOE) as the base, achievement of a 33%, 54%, or 60% GDP growth with a minimum consumption of energy would require a 38%, 65%, or 94% increase of energy consumption level, respectively (see section 6.1.1 and Table 6.1).

(4) The relationship between energy supply and economic growth is identified in this study as a production-like function. Its implications, however, are different from those of a positively estimated econometric production function with decreasing marginal productivity (see sections 5.3.3, 6.1.1, and 6.1.2).

(5) The energy/income intensity of each sector and industrial structure of the economy have each been examined for lowering the elasticity of energy. Development of those sectors with relatively low energy/income final demand coefficients such as Agriculture, Machinery, Household Electrical Appliances, Electronic Products, Electrical

Apparatus, Other Transportation Equipment, and Service sectors should be encouraged. On the other hand, expansion of sectors with high energy/income final demand coefficients such as Acid and Alkaline, Chemical Fertilizer, Chemical Petroleum Products, Cements, Glass, and Non-metallic Mineral Products should be curtailed (see Table 5.1 and section 6.1.3).

(6) Industrial restructuring should consider interindustry relationship, industrial blocks, and the forward and backward linkages among sectors. Some sectors such as Steel and Iron as well as Aluminum, though energy intensive, should maintain a desirable production level due to their strong linkages with other sectors (see section 6.1.4).

(7) Assuming a 17% or 39% disruption of energy supply, GDP drops by 13% or 35%, respectively (see section 6.1.5).

(8) If energy disruption is moderate, e.g., 17%, sectors such as Acid and Alkaline, Plastic, Plastic Products, Petrochemical Raw Material, Other Industrial Chemicals, Steel and Iron, Metallic Products and Electicity are significantly affected. In this case, the government should (a) stop exporting any type of energy products; (b) reasonably escalate relative prices of energy goods; and (c)

inform those industries sensitive to energy supply disruption not to expand (or perhaps even to contract) their capacities in the short run (see section 6.1.5 and Figure 5.5).

(9) If the energy disruption is serious, e.g., 39%, most sectors except Agriculture, Products of Wood and Bamboo, Household Electrical Appliances, and Electrical Apparatus suffer severely. At such a time, the government should fix energy prices and implement a rationing policy. An emergency transportation and shipping plan should now be studied so that it can be implemented immediately if conditions so require (see section 6.1.5 and Figure 5.5).

(10) In short, for economy restructuring, to reduce the heavy reliance on energy and raw-material imports, the Taiwan economy should shift its industrial structure from labor- and energy-intensive to less-energy-intensive, high-technology, and light-engineering manufacturing industries such as household electrical appliances and electrical apparatus. Energy-intensive industries should be discouraged and only permitted in those cases in which there is good evidence the products will be competitive at world prices. For energy restructuring, electricity (implying nuclear power) and coal should be priorities for economic development and substitutes for petroleum consumption.

7.2 LIMITATIONS OF THIS STUDY

There are two major limitations in the study--one of scope and the other of the model mechanism itself. The scope of this study is limited to first-level energy economics and policy (see section 2.1), and is tied to the two objectives of maximizing GDP and minimizing commercial energy use. Many other factors are, therefore, beyond the scope of this study. For example, when planning economic development, commercial energy resources must be considered as one part of the total available resources; noncommercial energy, capital, water, soil, etc. are equally important. The whole picture must be examined in order to fully assess economic energy policy. The same arguments extend to the GDP side. Other than GDP, many other concerns such as employment, equity, security, and environmental consequences are also relevant.[18] Because many of these aspects cannot be quantified as economic disciplines, they form the real limitations of the scope of this study (see also sections 3.3 and 3.4).

As to the limitations of the model mechanism, there are at least two types. The first type is inherent in the input-output analysis and cannot be removed. It includes:

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[18] It is hoped that this study can be extended to include three or more objectives along this line in the future.

(1) market equilibrium--in the real world, the market is seldom in equilibrium; (2) perfect competition--the economy may be close to, but not in, perfect competition. Market failures, other externalities and imperfect information characterize any economy (see Layard and Walters, 1978).

The second type of limitations is removable provided more time, manpower, and funding are available. They are:

(1) The constant return to scale inherent in linear production activities. To relax this assumption, more constraint functions may be included in the model. These constraints describe different "recipes" for different production stages of the same product. For example, in the case of marginally decreasing returns to scale, the model may include a variety of processes, each with its own upper bound. The NISE-IO mechanism will then select the most efficient first, using the less efficient processes to attain higher output levels.

(2) Single-technology production. In a conventional input-output model, each sector uses only one technology to produce a single output. As a result, no substitution of inputs (or outputs) is possible. In the real economy, producers substitute inputs as prices change. This behavior could be captured in this model by shifts to alternate

activities to produce goods in response to changes in shadow prices. The energy-intensive sectors may be the first candidates for such detailed analysis.

(3) Homogenous commodities. The output within a given sector is assumed to be homogenous and completely substitutable. But in the real market, every good has different grades, shapes, and sizes. The obvious remedy is to disaggregate commodities. For example, the 1977 ninty-nine sector I/O table of the Taiwan economy can be used in this model to represent a more detailed classification of commodities.

(4) Uniform prices across sectors. The assumption of perfect competition implies that all buyers are price takers and pay the same price for a given commodity. This is not true. For example, in the United States different localities may pay different prices for the same type of energy. A more nearly uniform situation exists in Taiwan, because in most cases a single price for each energy product (petroleum products, electricity, etc.) is set by the government. Because special contracts, quantity discounts, etc. still exist, the effect of nonuniform prices is similar to that of nonhomogeneous commodities. In this study, by using physical units (KLOE) instead of a dollar balance for

the energy sectors, this particular problem is avoided. It still exists, however, for all nonenergy sectors.

(5) Static analysis. This study assumes the structure of the economy remains unchanged from the base year 1978 to the analytical year 1986. This might be questioned because, in particular, no account is taken of the efforts to conserve energy that resulted from higher energy prices. To make the model dynamic, a capital-requirements matrix, a manpower requirements matrix, and a matrix of technological change must be included. Assembling such data would require extensive assistance from related government agencies and would be beyond the time and manpower constraints of the present research.

The time planning horizen (long-run vs. short-run) of the model can be considered another possible limitation of this study. Models dealing with resource allocation and utilization should be long-run models because the formation of and the changes in the economic resources are very slow, e.g., changes like capital, labor, water, and soil. The energy resource, however, is different from the above-mentioned resources in terms of supply changes. Energy is largely imported, and changes may be drastic and very fast due to oil embargoes. This type of economic shock is very different from those arising from other domestic resource changes. A long-run model may not be able to capture this effect. On this basis, short-run models are needed to analyze this problem. As demonstrated in this study, the NISE-IO algorithm serves as a powerful short-run model.

Of course, the importance of the long-run model is recognized, in particular because the Taiwan economy is in a stage of transition (see Galenson, 1979, and Kuo, 1983, for details). Industrial restructuring will occur over a long period of time. In this regard, prices must be taken into account and estimated parameters may need frequent adjustments (e.g., as in Hudson and Jorgenson, 1974). Although the short-run model is useful to evaluate sectoral sensitivity to the disruption of energy supply, a more comprehensive long-run model is needed for a full assessment. In the near future, the author hopes to extend the present study in these directions--both from the static to the dynamic and from the short-run to the long-run.

7.3 EVALUATIONS OF THE NISE-IO MODEL

Despite this formidable list of qualifications and provisos, this NISE-IO model is justified a useful tool. First, the I/O table itself captures an enormous wealth of detail (depending on how many sectors the table includes) concerning the interdependent structure of the economy. The format of the table provides an internal consistency of inputs and output within each sector and balance of production and consumption among sectors. Similarly, the energy flow matrix, R (in physical units), describes a clear picture of how the economy utilizes different types of energy sector by sector. With the mechanism provided by this model, researchers are able to examine major forces in the economy. This type of interindustry analysis is virtually the only practical alternative to a massive econometric model when industrial details are required.

Second, the NISE-IO model is more effective than the conventional LP-IO model because true decision making is involved and because of the consideration on energy priorities when energy supply decreases. Also, it controls "maximum possible error" of the whole noninferior curve while LP-IO does not. In addition, it proved more efficient than LP-IO because the latter needs more runs (sensitivity analysis) to identify the real kinks of the nondominated surface in the objective space (see sections 4.2.2 and 5.3.1).

Third, the NISE-IO mechanisim is superior to goal programming in terms of guaranteeing nondominant solutions and providing more information, choice, and valid decision maker-analyst interaction (see sections 4.2.3 and 4.3).

Another significant benefit of the model is that once the model is set up, it is able to accommodate different points of view quickly and with little effort. It has a definite structure which forecasts different amounts of energy to be used by different scenarios reflected in the values of the right hand side of the model--B, Fmin, and K, the exogenous determinants. The consistent framework of this model allows policy maker to check the actual GDP and production levels of each sector with the results of the model to see if the solutions are logical, consistent, and valid (see sections 4.2.5, 6.1.1, and 6.1.2).

In conclusion, this NISE-IO model is useful for tracing the relationship between economic goals and resource uses, for assessing the relative impacts of fuels and energy shortages in the present economy, and for examining the implications of industrial restructuring in future years.

In addition, with the importation matrix M included in this model, it is capable of investigating the consequences of changing trade policy by imposing artificial diagonal elements in matrix M. By modification to a dynamic model, it can be used to analyze future impacts of present investment and development policy decisions in the energy field. This model is flexible and adaptable enough to explore various issues involved in energy planning and, above all, through its use, decision makers can easily trace the functionings of the mechanism.

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