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Abstract—Shifts among economic sectors within manufacturing have had significant effects on industrial energy demand since 1973. At least one-third of the reduction in U.S. energy intensity for fossil fuels can be attributed to sectoral shifts over this historical period. Shifts among economic sectors will continue to be an important source of uncertainty in forecasting industrial energy demand. Without greater consensus on the major causes of these shifts, analysts will be unable to separate how much of the past shifts can be reversed with changed energy and economic conditions and how much will remain embedded in the economic structure. Standard economic projections anticipate a continuation of the shift away from large industrial energy-using sectors, although at a slower rate. The Wharton economic projections used recently in an Energy Modeling Forum (EMF) study indicated a decline rate of about half that experienced during the 1973-81 period. Even so, this effect alone could contribute as much as 0.5% per annum to the rate of decline in aggregate energy intensity within manufacturing.

1. INTRODUCTION

The reduction in energy intensity since 1973 in many developed countries has been remarkable. In the U.S., for example, energy use has been maintained practically level from 1973 to 1985, while economic activity (GNP) has increased about 30%. This trend of declining use per dollar of output holds for total energy, for fossil fuels, and for electricity. In the case of fossil fuels, this decrease represented an acceleration of the pre-embargo trend of declining fuel intensity. For electricity, on the other hand, the post-embargo trend represented a reversal of the increasing electrification observed before 1973.

A significant portion of this decline was due to shifts among sectors of the economy, among industries (measured at various levels of disaggregation), and among products. At a minimum, these changes in the composition of economic output, or product mix, account for at least one-third of the decline in energy use per unit of output in manufacturing since the embargo. Moreover, this is a conservative estimate because even greater effects can be found when feedstocks are included or for periods encompassing more recent years since 1981.

We assess the current understanding of the sectoral shift effect, i.e. the impact of changes in the composition of economic output on energy demand in the industrial sector. A number of studies on this issue have been conducted by different research organizations. After briefly reviewing these studies, we discuss several explanations advanced to explain the post-embargo trends. Next, we consider why the sectoral shift effect should be explicitly recognized in studying energy demand. And finally, any projection of industrial energy demand will depend critically upon one's perception of future sectoral shift trends. To illustrate this point, we will describe how several possible economic scenarios condition a set of energy demand projections developed in a recent Energy Modeling Forum study. This study is unique in that five different

Table 1. Relative importance of the composition effect (Sectoral Shift) for explaining declines in energy intensities in previous studies of the post-embargo period; abridged from Huntington and Myers.[1] N.A. = not available.

Study	No. of Sectors	% Explained by Sectoral Shift
Myers & Nakamura[2]	2	
Energy 1967-76		6
Energy 1974-76		33
Samuels, Vogt & Evans[3]	448	
Energy, 1975-80		23
Fuels, 1975-80		24
Electricity, 1975-80		8
Marlay[4,5,6]	475	
Energy, 1972-80		36
Energy, 1972-84		53
Fuels, 1972-84		50
Electricity, 1972-84		67
Werbos[7,8]	18	
Energy, 1974-81		33
Energy, 1974-82		75
Jenne & Cattell[9]		
U.K. Energy, 1973-78	9	34
U.K. Energy, 1973-78	104	54
Boyd, MacDonald, Ross & Hanson[10]	20	
Fuels, 1974-81		34
Roop & Belzer[11]	N.A.	
Energy, 1972-77		45
Fuels, 1972-77		45
Fujime[12]		
Japanese Energy, 1974-83	N.A.	33

energy models were exercised using standardized assumptions, thus allowing differences in modeling approaches to be probed more deeply.

2. THE SECTORAL SHIFT EFFECT DURING THE POST-EMBARGO PERIOD

All past studies dealing with this issue have led to the conclusion that the sectoral shift effect has been important in determining the observed energy-output ratio during the post-embargo period. Table 1 summarizes findings regarding the importance of shifts in the composition of output as a determinant of the decline in the ratio. These data are based upon sectoral shifts and energy-intensity changes within manufacturing. Additional shifts may occur between manufacturing and other sectors. It should be emphasized that no two studies are strictly comparable to each other because they are frequently based upon different methodologies, data bases, etc. Studies can differ from each other by employing different levels of industrial aggregation, different indices for aggregating the sectors, or different time periods. In addition, some studies analyzed fuels and electricity separately while others combined them as simply energy.

Trends in Energy Intensity

Despite these fundamental differences in approach, there appears to be a consensus on the approximate magnitude of the effect. Given the results reported in Table 1, many of the studies suggest that perhaps one-third of the decline in the energy-output ratio can be attributed to this effect. Moreover, this estimate can be considered to be a conservative one because these results pertain to purchased fuel and power within manufacturing, the concept usually measured by models of industrial energy demand. When feedstocks, energy use in agriculture, construction, and mining, and the primary energy content of electricity are included, Werbos[7] found the impact of sectoral shifts to be increased substantially. The second study by Werbos differs from his first study in that the estimates refer to all industry (including agriculture, construction, and mining) and incorporate feedstocks and primary energy content of electricity.

The sectoral-shift effect was relatively minor during the few years just prior to the embargo, as revealed by the first entry for Myers and Nakamura[2] in Table 1. In recent years, however, the role of sectoral shift in energy-output trends has become important and increased dramatically after 1981. The post-1981 trend is observable for the Marlay[4,5,6] results, which are based upon a very detailed disaggregation of industry, as well as for several studies conducted by Werbos.[7,8] Unfortunately, data availability often prevents analysts from including these more recent years.

A Two-Sector Decomposition

The study by Boyd *et al*[10] concluded that for fossil fuels, about 80% of the composition effect during the post-embargo period was attributed to shifts between two major manufacturing sectors. Five industries (paper, chemicals, petroleum refining, primary metals, and stone, clay, and glass) share the common features of being highly energy-intensive, as well as producers of raw materials for other industries. These five materials-producing industries were separated from the rest of manufacturing in a two-sector analysis of the decline in aggregate fuel and electricity intensities. This finding suggests that detailed disaggregation of manufacturing may not be necessary to incorporate much of the sectoral shift effect for fossil fuels. Therefore, one may not require a detailed set of economic projections by industry for forecasting fossil fuel consumption in manufacturing. A less expensive, more aggregate economic projection differentiating between the two major sectors may be sufficient for many purposes.

With regard to aggregate electricity intensity, the disaggregation into materials-producing and all other industries accounted for substantially less than the full sectoral shift effect at the two-digit level. This result emphasizes the difference between the energy intensity trends for electricity and fossil fuels.

3. CAUSES OF SECTORAL SHIFTS

There has been substantially more research on documenting the extent of sectoral shift and its importance for energy consumption than on the underlying factors causing this shift. This issue should be given much more emphasis than has been afforded it in the past. Until this is done, it will be impossible to reconcile the wide range of economic projections that are currently available.

Some of the studies cited previously have offered possible explanations for the shift among sectors, although few have investigated the relative importance of these effects. Three explanations deserve explicit consideration here because they have dramatically different implications for future levels of industrial energy demand. These factors are: (1) higher energy prices,

(2) slower economic growth reinforced by other macroeconomic effects such as high capital costs and a strong US dollar during the early eighties, and (3) technological advancements and shifting consumer demand that reduce the use of materials.

Energy Prices

Energy prices have certainly influenced the transformation in the economy to some degree. Higher energy prices make energy-intensive goods and services more expensive than others, shifting consumption away from the first set of products. However, it appears unlikely that this factor can explain most of the dramatic shift among sectors because energy represents a relatively low share of total production costs in most industries.

Slow Economic Growth

It may well be that the indirect effects of rapidly rising energy prices are substantially more important. The oil shocks of the seventies severely depressed economic activity throughout the world. Slow economic growth retards investment more than proportionally. The percentage fall in investment is about twice the decline in real GNP after an oil shock. Since the capital goods used in investment activity are often highly energy-intensive, slow economic growth causes a shift away from energy-intensive sectors.

In recent years, this factor has been reinforced by other macroeconomic influences. The US dollar strengthened sharply and capital costs (interest rates) rose relative to inflation in the early eighties. Both factors appear to have contributed to the shift among sectors, judging from the escalation in this trend after 1981.

The Materials Revolution

The energy-intensive industries tend to produce basic materials for other industries, e.g., steel, chemicals, etc. As incomes rise in developed market economies, consumers have reduced their purchases of goods that have a lower content of such materials in favor of goods and services that are less materials-intensive.[13]

In addition, prior to and during the seventies, long-term technological advancements were reducing the use of basic materials in favor of more versatile, newer ones. This substitution contributed to declining energy intensity overall because the newer materials required less energy per unit of output.[13] Often the decision to use the newer materials has been based upon factors other than energy costs. The importance of this effect can be appreciated by noting that the energy intensity in the basic materials-producing sectors identified previously in the two-sector analysis dwarfs the intensity in the remaining manufacturing industries by a factor of six or seven.

While this factor has been an important force behind declining energy intensity, it is difficult to assess whether it has contributed to the acceleration in this trend during the seventies. Perhaps the energy crisis increased the interest in introducing these new materials, but it would be difficult to quantify such a possibility.

4. IMPLICATIONS OF THE SECTORAL SHIFT EFFECT

A typical economic projection of sectoral activity usually represents a combination of the last two factors, as will be discussed in the final section. However, the relative importance of these two factors is undoubtedly ambiguous, and this uncertainty can have important implications for anticipating energy demand growth.

Energy Demand Futures

The first two explanations (energy prices and slow growth) imply that sectoral shift trends can be dampened if energy prices fall and/or sustained economic recovery (absent high capital costs and a strong dollar) returns. Thus, there exists a degree of reversibility in the process. The changes are not structural or permanent.

The third explanation involves the idea that the shifts will continue unabated by energy market or macroeconomic conditions. In fact, faster economic growth may even accelerate the sectoral shift trends by replacing more rapidly the older materials-producing industries with the newer ones.

Energy-demand projections will be critically affected by assessments of what part of this effect will be reversed over the next decade or two and what part will continue.

Demand Asymmetries

Do energy demands respond to price reductions as strongly as they did to price increases? This issue of demand symmetry has received considerable recent attention due to the oil price collapse. One possible asymmetry, however, has not been widely recognized. If the direct effect of energy prices on sectoral shifts is modest, the effect of falling energy prices on energy demand will depend upon whether or not it is accompanied by a reversal of the macroeconomic trends of the seventies.

The expected stimulus to growth from the oil price collapse has not yet materialized. It may be that the beneficial effects have been hidden by many other economic developments, e.g. the wide swings in exchange rates during the 1980s. The inability to discern clearly these macroeconomic gains raises the possibility that they may not accompany the oil-price reductions of recent years. If this is the case, energy demand may respond less rapidly than would be expected otherwise.

Moreover, energy demand may respond very differently to gradual energy-price changes than to sudden shocks. While past oil shocks have caused economic recessions and contributed to slower economic growth, gradual changes in energy prices may be more easily absorbed by the economy without seriously slowing investment and growth. Thus, dramatic shifts among sectors would not be expected to occur with gradual energy-price changes.

Speed of Energy Demand Adjustments

Energy demand changes within an industry or household evolve slowly over time as new equipment and plant replace older vintages. Full adjustment to an energy-price change often takes many years to realize. This is one reason why the effect of falling energy prices may take several years to be revealed in the trend of energy demand.

While recognizing the importance of the long-run nature of energy-demand adjustments, it should also be emphasized that some adjustments can take place relatively rapidly. In particular, the economy can shift among goods and sectors characterized by varying energy intensities faster than it can replace obsolete equipment and plant within a particular industry. In this sense, there is probably greater short-run flexibility in energy use than commonly supposed. Recognition of the sectoral shift effect in energy demand adjustments emphasizes this flexibility.

5. SECTORAL SHIFT AND ENERGY DEMAND PROJECTIONS

Most U.S. projections of manufacturing output by industry incorporate the effect of both technological advancement and slower growth in the economy. Typically, these projections show that the energy-intensive sectors do not grow as rapidly as the rest of the economy. However, economic growth can influence the rate at which these sectors decline relative to other sectors in the forecasts. Strong economic growth causes a partial recovery in the production of capital goods, reducing the trend away from energy-intensive sectors. Weak growth accelerates the relative decline of these sectors.

The projections from the Wharton Annual Model, maintained by the Wharton Econometric Forecasting Associates (WEFA), are representative of such trends. These projections were used to standardize the industrial energy demand projections of several models compared in an Energy Modeling Forum (EMF) study.[14] This study sought to harness the collective capabilities of different models for developing insights on such issues as interfuel substitution and technological change in energy-using processes. In the process, key differences between models were also explored.

Projected Energy Intensities

Numerous factors can influence industrial energy demand, creating considerable uncertainty about future trends. While energy demand levels cannot be forecasted with precision, the model projections are useful for identifying important trends and effects.

Most data collection, modeling efforts, and projections of industrial energy demand have focused exclusively on purchased energy used for heat and power in manufacturing. By focusing on projections for these particular uses, the EMF working group was able to compare results from models covering similar sectors. However, these uses account for less than half of total industrial use; the balance is used as materials and feedstocks (about 30%), in the agricultural, construction, and mining industries (about 15%), and as self-generated refinery fuels (about 10%). Analysts often exclude these other uses because reliable data are not as readily accessible.

The projections show that energy use per unit of output, or energy intensity, continues to fall through 2010. This trend holds for all models and for a range of energy market and economic conditions. Energy intensity declines by 0.5 to 1.5% per annum from 1985 to 2010.

The projected decline in energy intensity appears more modest than the reduction experienced during the seventies and early eighties. The 1973-85 historical trend incorporated reductions in energy use as energy prices escalated and sectoral shifts continued within the economy. The projections of energy intensity beyond 1985 reflect several conditions: (1) opportunities for energy conservation decline as more plant and equipment are adjusted to past energy price increases, and (2) the shift away from energy-intensive industries slows as economic growth recovers.

Projected Energy Demands

The level of industrial energy demand will also depend upon the level of economic activity as well as these changes in energy intensity. If manufacturing output grows by 2.5% per annum, energy demand levels will increase by 1 to 2% per annum, or by about 40 to 80% of the rate of growth of industrial output. Economic growth would have to fall to 1.5% per annum to keep industrial energy demand from growing, according to these projections.

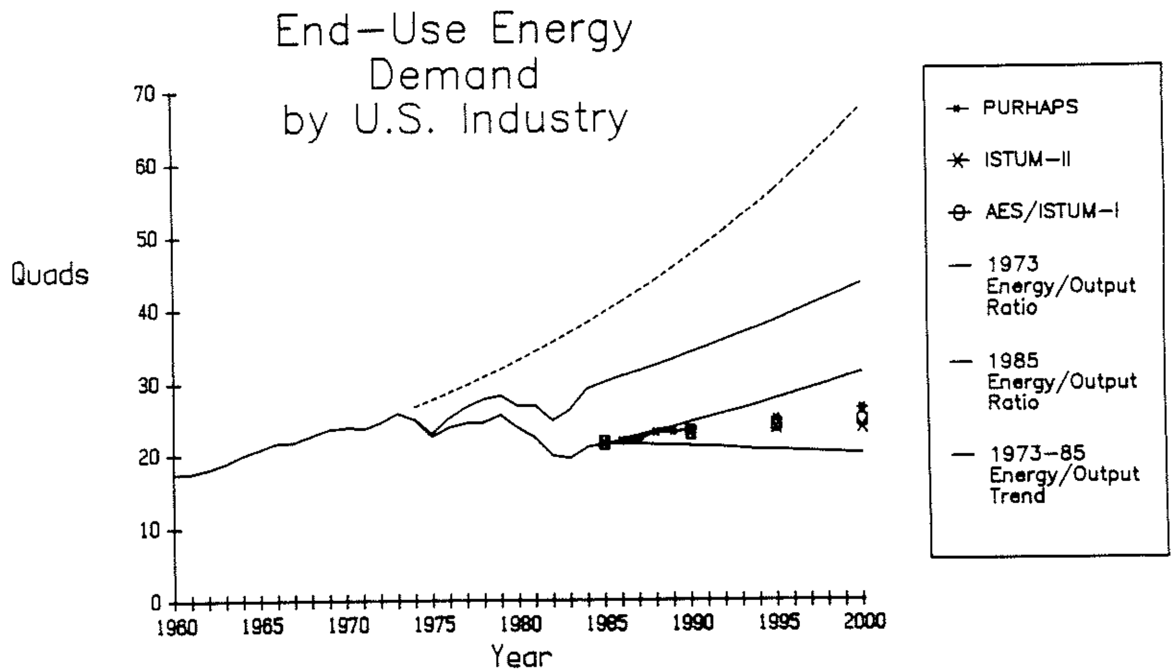

Fig. 1. Model projections of energy demand for U.S. industry .

Industrial energy demand could remain stagnant or even fall with manufacturing growth rates of 2.5% per annum if there is no slowing in the rate of decline in energy intensity. This result can be shown with the aid of Fig. 1, where we plot energy-demand levels from 1960 through 2000. The solid line through 1973 represents the historical trend. The dotted line at the top of the figure depicts energy demand with a continuation of the historical 1960-73 economic growth rate and with the manufacturing energy-output coefficient fixed at its 1973 value. If the same 1973 energy intensity is again fixed but actual economic output is used, energy-demand levels would be represented by the top solid line. In the remaining two lines, we plot actual energy demand levels through 1985 and projected levels after that for two different cases. The upper line in this set is based on the assumption that the energy-output ratio is fixed at its 1985 level. The lower line shows the energy demand trend assuming a constant annual decline in energy intensity at the 1973-85 rate.

As can be seen, the model projections lie between these two latter cases. The energy intensity falls below its 1985 value but declines less precipitously than during the last twelve years. As a result, energy demand levels rise modestly over the projection period. With manufacturing output increasing by 2.5% per annum, energy demand levels would fall only if the energy intensity should continue its 1973-85 rate of decline.

The Effect of Sectoral Shift

The Wharton projections of sectoral output reveal a continuing trend towards less energy-intensive sectors, although at a slower rate than during the historical 1973-85 period. Durable manufacturing, chemicals, and miscellaneous manufacturing grow more rapidly than aggregate industry in these projections, while paper, petroleum refining, and primary metals grow more slowly. The slower decline is due to more widespread economic growth than during the last

Table 2. Effect of sectoral shifts among six major sectors on aggregate fossil-fuel intensity in historical period (1974-81) and projections (1985-2000). Estimates for 1974-81 are based upon the study by Boyd *et al*[10], who used an approach that is most nearly consistent with the projections in the EMF study.[14]

% decline (p.a.) due to	1974-81	1985-2010
Shift among sectors	-1.0	-0.5
Change within sectors	-1.9	-1.5
Aggregate	-2.9	-2.0

twelve years. This growth stimulates the demand for capital goods production, which is very energy intensive relative to other manufacturing sectors.

Shifts among six major manufacturing sectors contribute about 25% of the total decline in fossil fuel use per dollar of output in these projections. When averaged across the four models, aggregate fossil fuels intensity falls by 2% per annum between 1985-2010 (Table 2). Meanwhile, sectoral shift causes aggregate intensity to decline by 0.5% per annum over this same 25-year horizon. The rate of decline due to sectoral shift is about half of that observed for the historical 1974-81 period.

The dampening of sectoral shift contributes importantly to the slower decline in aggregate energy intensity for all manufacturing. Fossil-fuel use per dollar of output declines by 0.9% per annum less than the historical 1974-81 period. The decline due to changes in fuel intensity within the major sectors—shift in product mix, new processes and improved operation of existing facilities—appears to be somewhat slower in these projections than during the 1974-81 period.

The estimates for electricity are more difficult to summarize because two fundamentally different trends can be observed. However, as revealed in Table 3, both types of models indicate that sectoral shift exerts strong pressure towards reducing the aggregate electricity intensity within manufacturing.

Table 3. Effect of sectoral shifts among six major sectors on aggregate electricity intensity in historical period (1974-81) and projections (1985-2000). Estimates for 1974-81 are based upon the study by Boyd *et al*[10], who used an approach that is most nearly consistent with the projections in the EMF study.[14] N.E.—not estimated due to no clear trend.

% decline (p.a.)		1985-2010	
due to	1974-81	PURHAPS	ISTUM2
Shift among sectors	-1.3	-0.5	-0.4
Change within sectors	N.E.	1.3	-0.1
Aggregate	-1.3	0.8	-0.5

The econometric PURHAPS model shows electricity use rising faster than manufacturing output in the future. Electricity intensity increases by 0.8% per annum between 1985-2010, despite the fact that shifts among sectors are causing a 0.5% per annum decline in intensity overall. Increasing electrification occurs because the model projects new applications to more than offset the declines in electricity use arising from more-efficient equipment.

The process-oriented ISTUM2 model, on the other hand, shows electricity use lagging the growth in manufacturing output in the future. Electricity intensity in this model decreases by about 0.5% per annum over the next 25 years. The increasing efficiency of electrical equipment essentially offsets the effect of new applications within a sector. Aggregate intensity is reduced primarily by shifting towards less electric-intensive sectors.

Table 4. Average projected aggregate energy intensities by economic scenarios in EMF 8 study. Materials share (18.9% in 1985) refers to the percent of manufacturing output in paper, chemicals, petroleum refining, and primary metals by year.

% changes and materials share	1995	2000	2010
% change per annum in fuels from 1985:			
High GNP	-1.6	-1.7	-1.6
Reference	-2.2	-2.2	-2.0
Low GNP	-2.9	-2.7	-2.8
% change per annum in electricity from 1985:			
High GNP	0.2	0.2	0.6
Reference	-0.7	-0.5	-0.1
Low GNP	0	0.2	0
Materials share as % of manufacturing output:			
High GNP	19.0	18.3	17.2
Reference	18.4	17.3	15.8
Low GNP	18.0	16.8	14.3

Alternative Economic Scenarios

There remains considerable uncertainty about the extent of future shifts in the economy's structure. For this reason, the EMF study considered several alternative growth paths with different implications for the shift away from the energy-intensive manufacturing sectors. It should be noted that these models focus on industrial energy demand and do not incorporate the effect of higher energy demand on energy prices. If the high U.S. growth were to be accompanied by higher world economic growth, these effects would have to be included in a more comprehensive scenario.

Table 4 reports percent changes in the projected aggregate energy intensity for three different economic scenarios. Averages of the model results are shown for comparison across scenarios, although they disguise important differences among models for any one scenario. Gross output in all manufacturing was projected to grow by 2.6% per annum between 1985 and 2010 in the EMF reference case. Alternative scenarios had real GNP growing by 3.4 and 2.0% per annum in a high GNP and low GNP case, respectively. As indicated previously, higher growth in the Wharton scenarios was viewed as being favorable to energy-intensive sectors through its strong positive effect on investment and the production of capital goods. As a result, faster economic growth retards the shift away from large energy-using industries producing basic materials. As revealed in the lower part of Table 4, the materials share of total manufacturing output declines least rapidly in the high GNP case and most rapidly in the low GNP case.

These alternative economic cases do not change the basic trends observed in the reference case. Fossil fuel intensity declines throughout the 1985-2010 period, while electricity intensity will be rising in the econometric models and falling in the engineering process models. However, the rate of decline in fossil fuel intensity is significantly influenced by these economic scenarios. Over the full 25-year period, the decline in aggregate fuel intensity in manufacturing could range from -1.6 to -2.8% per annum, depending upon the degree of shifting among sectors.

6. CONCLUSIONS

Shifts in the composition of manufacturing output have had an important effect on the trends in industrial energy demand and intensity in the United States. These developments affect not only the speed at which energy demand adjusts to new market conditions, but also the degree to which future energy demands may be reversible in an era of lower energy prices. Uncertainty remains, however, about the factors causing these shifts and the rate at which they occur. This situation leads to a range of possible projections for energy demands and intensities.

Acknowledgement—I would like to acknowledge the contributions of the EMF8 working group whose discussions greatly improved my understanding of the critical issues. Some of this material is drawn from Huntington and Myers[1] and from the EMF summary report[14] on industrial energy demand. Of course, any errors or omissions are mine.

REFERENCES

1. H.G. Huntington, and J.G. Myers, "Sectoral Shift and Industrial Energy Demand: What Have We Learned?" in *Forecasting Industrial Structural Change and its Impact on Electricity Consumption*, A. Faruqui and J. Broehl eds., Battelle Press, Columbus, OH (1987).
2. J. Myers, and L. Nakamura, *Saving Energy in Manufacturing*, Ballinger, NY (1978).
3. G. Samuels, D.P. Vogt, and D.M. Evans, "Shifts in Product Mix versus Energy Intensity as Determinants of Energy Consumption in the Manufacturing Sector" in "Proceedings: Forecasting the Impact of Industrial Structural Change on U.S. Electricity Demand," Electric Power Research Institute, EA-3816, Palo Alto, CA (December 1984).
4. R. Marlay, "Industrial Energy Productivity," unpublished Ph.D. dissertation, MIT (May 1983).
5. R. Marlay, *Science* **226**, 1277 (1984).
6. R. Marlay, "Industrial Electricity Consumption and Changing Economic Conditions" in *Forecasting Industrial Structural Change and its Impact on Electricity Consumption*, A. Faruqui and J. Broehl eds., Battelle Press, Columbus, OH (1987).
7. P. Werbos, "Industrial Electricity Demand: Prospects and Uncertainties" in "Proceedings: Forecasting the Impact of Industrial Structural Change on U.S. Electricity Demand," Electric Power Research Institute, EA-3816, Palo Alto, CA (December 1984).
8. P. Werbos, "Industrial Structural Shift: Causes and Consequences for Electricity Demand" in *Forecasting Industrial Structural Change and its Impact on Electricity Consumption*, A. Faruqui and J. Broehl eds., Battelle Press, Columbus, OH (1986).
9. C, Jenne, and R. Cattell, *Energy Economics* **5**, 114 (April 1983).
10. G. Boyd, J. MacDonald, M. Ross, and D. Hanson, *Energy Journal* **8(2)**, 77 (1987).
11. J. Roop, and D. Belzer, "Changes in Energy Use in the U.S. Economy, 1972-77: An Input-Output Analysis," Pacific Northwest Laboratory, Richland, WA (February 1986).
12. K. Fujime, "Japan's Energy Supply-Demand Achieved in 1984 and Background," *Energy in Japan* **75**, 1, Institute of Energy Economics, Tokyo, Japan (July 1985).
13. R.H. Williams, E.D. Larsen, and M.H. Ross, *Ann. Rev. Energy* **12**, 99 (1987).
14. Energy Modeling Forum, "Industrial Energy Demand," Stanford University, Stanford, CA (December 1986).