Sam H. Schurr, Calvin C. Burwell,
Warren D. Devine, Jr., Sidney Sonenblum.,
Electricity in the American Economy,
Agent of Technological Progress.
NY: Greenwood Press, 1990

Appendix I: The Growth of Electricity Consumption in Historical Perspective

In its analysis of relationships between electricity use and economic gr
this book is concerned essentially with the role of electricity as a fact
production. The central focus is on increases in productive efficien
manufacturing and other economic sectors that result from the use of
nologies that are tied to electricity because of its special attributes ,
energy form.

The book does not deal with the more familiar analytic question o
extent to which the rate of growth of the national economy affects the r
which the use of electricity increases. For the sake of completeness
appendix presents an extended discussion of the latter subject, adapted
a 1986 report prepared under the auspices of the National Academy of
neering.' We have updated some of the data included in that report and
adjusted the text, where needed, to reflect the more recent statistics.*

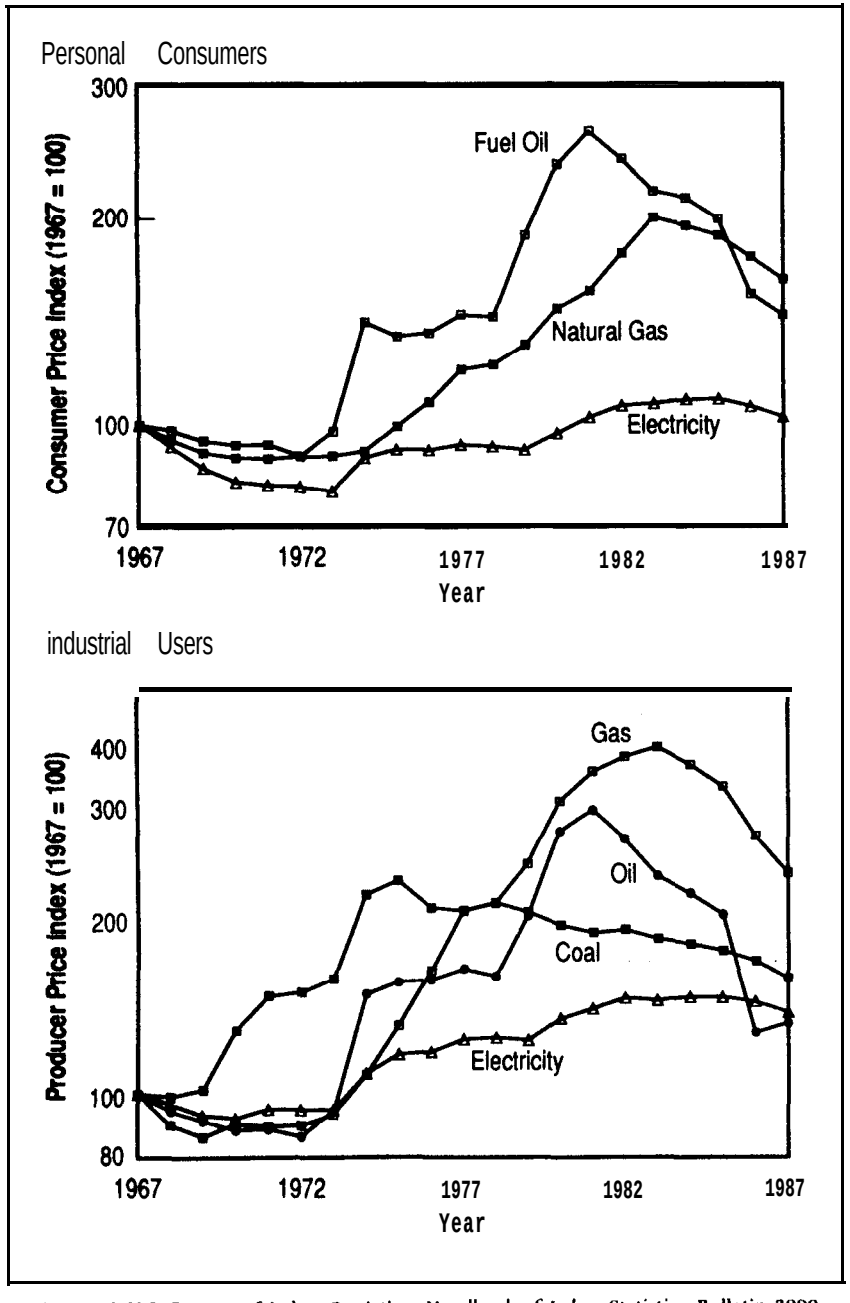
THE LONG-TERM HISTORICAL RECORD

The Growth of Consumption of Electricity and Other Energy Forms

**Electricity is such a versatile energy form that its use and the numbe
applications have grown rapidly throughout the twentieth century. E
ity consumption continues to grow more rapidly than that of other
forms. As a consequence, the proportion of the nation's primary
supply used as electricity has expanded substantially — from near
the** turn **of the** century to 38 percent in 1987. **The** growing import
**electricity as a component of total energy supply can be seen in Figur
which shows the growth in primary energy inputs, in British therm
(Btu), for the production of electricity.**

[illegible] and edited [illegible]

Figure AI.10 Trends in Real Energy Prices, 1967-1987



SOURCES: U.S. Bureau of Labor Statistics, *Handbook of Labor Statistics,* Bulletin 2000

sustained rise in the price of natural gas and the second oil price sho 1979 to 1980. The electric utility industry undertook programs durin period (with federal prodding) to cut back on both oil and natural g generation sources.

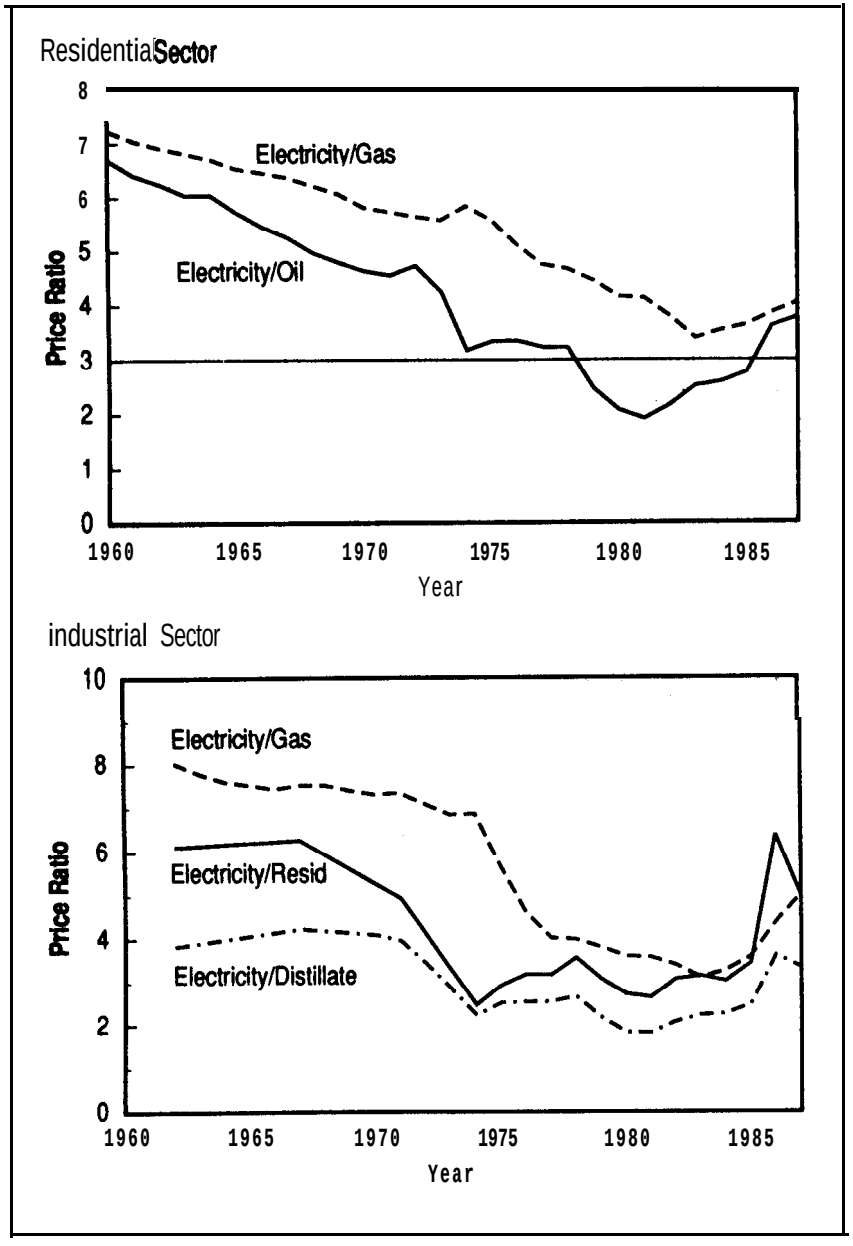
A second fundamental change occurred during this period: the app exhaustion of the economies of scale and improvements in heat rate had led to lower per unit costs of generation over the longer period. I plant construction projects were also being increasingly affected by tion and delays so that the average cost of electricity generation in utility systems has risen as many of these new plants have come on lin additional factor was the sharp increase in environmental regulatior power plants during the 1970s and early 1980s.

Throughout this troubled period, however, electricity price increas average, were only moderate. In real terms, the consumer price index for electricity rose only 18 percent between 1973 and 1983, whil indexes for both fuel oil and natural gas more than doubled. The trends are evident for producers. The producer price index (PPI) for tricity rose 44 percent in real terms from 1973 to 1983, while the ind' petroleum rose 136 percent and the index for natural gas more than tr

Price increases for electricity undoubtedly have led to increases i efficiency of electricity utilization." However, there has also been a toward greater electricity use resulting from the substitution of elect for oil and gas, which have been increasing in price much faster electricity.

Figure AI.11 shows that the ratios of electricity price to the prices and natural gas continued their historical decreasing trend during mu the post-embargo period. Studies have shown that electric resistance ing becomes more cost effective in residences than fuel heating at ex furnace efficiencies when the ratio of electricity price to competin prices reaches'three or below.'" In the aggregate, the ratio of elect price to heating oil price has been below three between 1978 and while the ratio of electricity to natural gas price approached three in but has since turned upward as a result of higher electricity and natural gas prices. Of course, using electric heat pumps, electricity c cost effective at electricity price ratios above three. The same price t are apparent in the industrial sector. Although energy-using technolop this sector are quite diverse, studies have shown that the same cost-eff price ratio thresholds for electricity and oil and electricity and natur were achieved in several materials processing industries in the 1980s.[11]

Figure AI.11 Electricity Price Ratios in the United States, 1960-1987



SOURCES: Based on data from Edison Electric Institute, Statistical Yearbook *of the Electric* Utility *Industry* Washington, D.C.: EEI, various issues); American Gas Association, Gas *Facts* Washington, D.C.: AGA, various issues); US. Bureau of the Census, Annual *Survey* of *Manu-*

Price Elasticities

The basically favorable relative price ratios of electricity to other fuels be weighed against the fact that electricity price increases themselve tend to discourage electricity use. It is not simply a matter of dividing a energy market among electricity and other energy forms; the total n for energy may be diminished as a result of rises in all energy price

Econometricians have tried for years to disentangle the complex of price elasticity, cross-price elasticity (with other energy forms), del price responses, and nonprice factors such as income and changes ir use technology. Powerful statistical tools are employed, but the results much to be desired. The available data base does not yet cover er experience with high energy prices, and, in addition, theory provide: little guidance in this complex task.

Bohi[12] provides a critical review of the methods, data, and results leading econometric analyses of the demand for energy forms. He find even for electricity, which has been subject to extensive study, "there is disagreement about the responsiveness of demand to changes in price incomes, and surprisingly broad gaps in the understanding of the nat this process."[13]

Each sector is considered separately by Bohi. In twenty-five studies residential sector, the spread of long-range, own-price elasticities was to be - 0.45 to - 1.89, with a consensus value of - 1.0 (that is to 10 percent price increase would produce a 10 percent consum decrease). However, after considering the methods and data employed studies, Bohi concludes that the best estimate for long-range resid price elasticity is - 0.70[14] (long-range effects are usually consider achieved in up to ten years).

Five studies on the commercial sector are reported. Some used more one approach, so that there are nine different sets of results. Price el ties ranged frdm - 1.0 to - 1.60. Bohi declines to choose the most value, saying simply that "commercial demand appears to be price elas the long run."[15]

Review of a broad range of industrial elasticity demand studies, used a variety of approaches, yielded a range from - 0.51 to - 1.82 w consensus estimate "around - 1.30." But Bohi notes that "one has diff in placing much confidence in the consensus estimate."[16] His own judg after examining the various studies, is that the price elasticity of indu demand is between -0.5 and - 1.0."

Sweeney" concludes that "the long-run delivered price elastici demand for electricity probably exceeds [that is, is more negative unity but may be as low as -0.7."[19]

Bohi discusses cross-elasticity estimates but does not present numerical values. He notes that problems in the data tend to make estimates of cross elasticities unreliable.

The most that can be safely concluded, therefore, is that own- and cross-price elasticities exist that are nonnegligible, but they are hard to establish precisely. As a result there are counteracting price influences on electricity demand — in particular, electricity's own price and electricity's price movements compared with those of other energy forms. In addition, of course, there are the sizeable effects on the growth in electricity demand produced by the overall growth in the national output of goods and services. The net aggregative effects of all of these forces are assessed in the next section comparing pre- and post-embargo trends in electricity consumption.

CONTINUITY AND CHANGE: PRE- AND POST-EMBARGO TRENDS

The foregoing discussion shows that growth rates of electricity use have slowed in recent years from the high growth rates of earlier periods. GNP growth, averaged over recent years, has also slowed from the higher rates achieved over most of the postwar period.

In light of the strong association that has long been observed between electricity and the GNP, viewing electricity growth rates only with respect to time can give misleading impressions. Nevertheless, the ratio of electricity growth rates to GNP growth rates has been gradually declining (see Table AI.5), a point to which many analysts have drawn attention. Although this trend is consistent in principle with a linear relationship between electricity use and the GNP, the question remains whether the degree and rate of convergence are consistent with the trend that has characterized the entire postwar period.

Electricity price changes are frequently cited as the reason for a shift in the relationship. The econometric studies summarized above show that when the price of electricity increases it tknds to slow the growth of electricity demand. However, the more recent historical period over which these statistical analyses were performed also contained the counteracting influences of rising competing fuel prices, which tend to counterbalance to some degree the effect of the electricity price increases. The extent of the competing fuel price influences on the historical relationship is not well established.

Our examination of the data leads us to believe that by far the most important contributor to the slower growth rates in electricity demand over the last decade has been lower economic growth. Others have come to a similar conclusion. The econometric analysis of Hogan'" shows that the

Table AI.6 Average Annual Growth Rates of Electricity and the Gror National Product (GNP) and Their Ratios Over Selected Postwar Perioc

Period	Electricity growth rate	GNP growth rate	Rati elect and th growtl
1947-1960	8.07	3.52	2.:
1960–1973	6.70	4.17	1.1
1973-1983	1.99	2.04	0.9
1983-1987	3.31	4.07	0.:
1973-1987	2.36	2.44	0.9

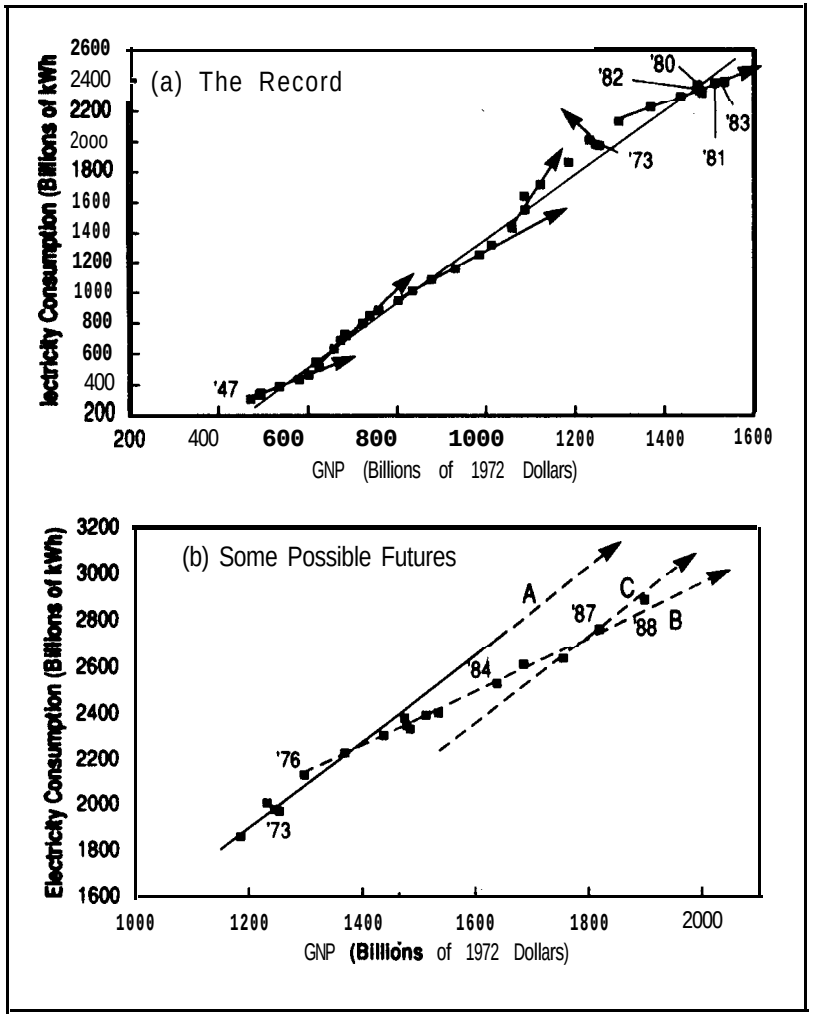
SOURCES: Based on data from Edison Electric Institute, *Statistical Yearbook of the El Utility Industry* (Washington, D.C.: EEI, various issues); U. S. Bureau of Economic Anal *The National Income and Product Accounts of the United States, Statistical Tables,* Supple to *Survey of Current Business* (Washington, D.C.: GPO, various issues).

primary reason, for the lower growth rates in electricity demand durir 1970s was slower economic growth. He attributes only about 30 perce the drop in electricity demand since 1972 to electricity price increases Edison Electric Institute[21] reached similar conclusions regarding the n tude of price effects at the aggregate level. However, Hogan notes th. results capture "only part of the eventual adjustment we can expect i gradual replacement of energy-using equipment."[22] Thus, it can be exp that the energy price changes already experienced will continue to demand growth in the future.

The central question is, of course, what the net effect of all facto price, income, structural change, technological advance, and so forth been on electricity demand in recent years and what these influence: tend for the future. In our judgment, at the present time there is no answer to this /question. Figure AI.12.b identifies three different po interpretations (depicted by lines A, B, and C) of the recent trend in ele ity use as a function of the GNP.

The first interpretation (line A) in Figure AI.12.b is that no shif occurred in the underlying long-term relationship but that the dat recent years represent a "down phase" of the cycle that has persist characterized the long-term relationship. In fact, over the postwar per could have been inferred several times that shifts had occurred in the of the relationship given its cyclic movements (Figure AI.12.a). Neverth these inferences would have been incorrect, as shown by data for s quent years. *In* 1987 and 1988, the growth rate of electricity exceeded of the GNP, and if the cycle continues as before, there will be a long p when the consumption of electricity will exceed trend values. Howe! the growth rate of electricity use in the next few years does not contin

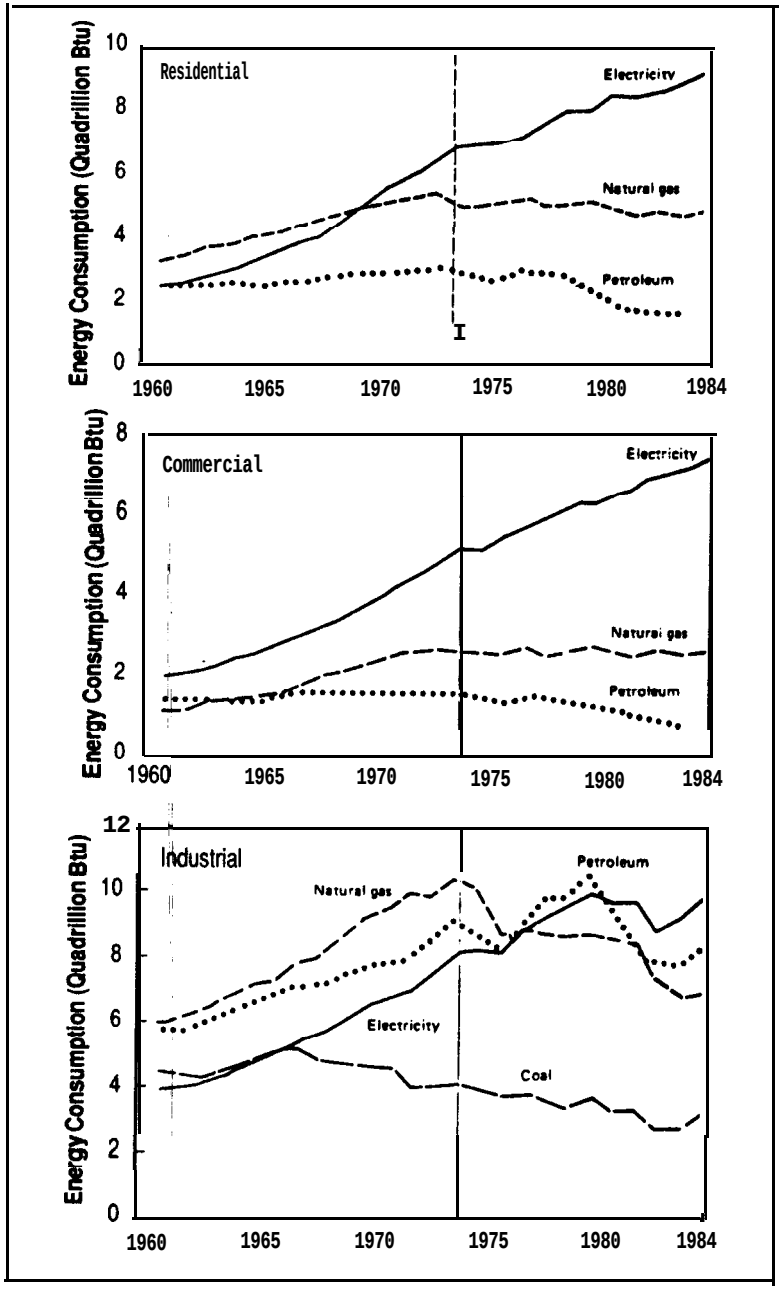
Figure AI.12 Electricity versus the GNP: (a) The 1947-1983 Record, (b) Some Possible Future Relationships



NOTES: The long-term trend line in figure (a) is the same as in Figure A1.4. The lines with the arrowheads in this figure indicate how the trend seemed to be changing at various times in the past based on short-term movements of the data. However, these movements turned out to be aberrations, and there was always a reversion to the underlying long-term trend.

Figure (b) depicts three possible interpretations of the recent past, none of which can be proved or disproved at the present time. Line A is a continuation of the basic long-term trend shown in figure (a); line B is a continuation of the short-term trend starting in 1976; line C is a new trend line. Line C assumes that the decline in average electricity intensity that occurred through 1984 represents a lasting change but that incremental intensities will revert to the basic trend (see text for further discussion and for a historical parallel). Cyclic and random variations (e.g., because of weather) around any future trend line will still occur, but the trend line tops out to be

Figure AI.13 Gross Energy Use by Economic Sector, 1960-1984



SOURCES: U.S. Energy Information Administration, *State Energy Data Report*, DOE/E 0214(83) (Washington, D.C.: U.S. GPO, 1983), and *Monthly Energy*

exceed the growth rate of the GNP (that is, if the "down phase" is not succeeded by an "up phase"), this interpretation must be considered incorrect

A second interpretation is that a permanent shift has occurred in the relationship, one toward a diminished increase in electricity use per dollar increment in the GNP. This interpretation corresponds to a downward shift in the slope of the electricity-GNP trend line, and in fact the relationship can be read in such a way as to support this belief (Figure AI.12.b, line B, which is an extension of the uppermost arrow on Figure AI.12.a).

Still another interpretation is that the increase in the rate of structural change between the industrial and commercial sectors (and within manufacturing) in recent years will neither be corrected nor proceed at the same rate in the future. If in the future the structural shift were to revert to the slower historical postwar rate and the sectoral electricity intensity relationships continue to hold, then the effect on the electricity-GNP trend would be a parallel downward shift in the postwar trend line (an intercept shift), leaving the slope coefficient intact (Figure AI.12.b, line C).[23]

It will be several years before these questions are resolved. The post-embargo years are still too few to provide definitive answers about trend shifts. In the meantime, however, the historical record suggests that the electrification of the economy will continue. Indeed, electricity use has continued to increase in all sectors over the postembargo period while fuel consumption more generally either has been stable or, as in most cases, has fallen, as is shown in Figure AI.13. Furthermore, our examination of the major consuming sectors indicates that substantial potential remains within these sectors for the continued penetration of electricity in many uses.

Generally, the rates of growth in electricity use will depend on the strength and growth of the economy. That much is clear. The exact quantification of this relationship for the current period and its relevance to future trends are important questions that remain to be settled.

Notes

1. National Academy of Engineering, Commission on Engineering and Technical Systems, *Electricity in Economic Growth* (Washington, D.C.: National Academy Press, 1986), Chapter 2, "Historical Perspectives:'

2. A regression is the best relationship of a given functional type between two (or more) correlated variables as judged by a particular statistical criterion, such as the criterion of ordinary least squares.

3. In other words, because of the nonzero intercept in the relationship (which appears as the offset of the regression line from the origin in Figure AI.4), the percentage growths of electricity and the GNP along the regression line are more nearly equal where both quantities are large, as in the later years, than where both quantities are small, as in earlier years.

4. These definitions differ somewhat from the Edison Electric Institute (EEI) sector definitions. However, for our purposes, the differences are not great enough to warrant concern, and so we have used the EEI statistics, with no change, t categories.

5. Gross product originating (GPO), the statistic used for both commerc industrial outputs, is a measure of value added derived from the national and product accounts; it emphasizes the sectoral origin of gross national I (GNP).

6. Solar Energy Research Institute, *A New Prosperity: Building a Sustainable Future* (Andover, MA: Brick House Publishing, 1981).

7. U.S. Energy Information Administration, *Energy Conservation Indicator Annual Report,* DOE/EIA-0441(83) (Washington, D.C.: U.S. GPO, October 198

8. The electricity consumption of the federal government's gaseous di plants for uranium enrichment represented about 20 percent of industrial demand growth in the 1950s but has declined since then, except for a brief i in the early and mid-1970s. Uranium enrichment operations are not expe have an important effect on industrial electricity consumption in the near Excluding electricity consumption for uranium enrichment, the average growth rates of industrial sector electricity demand are 6.8 percent per yea 1950 to 1960, 5.5 percent per year from 1960 to 1973, and 0.7 percent per ye 1973 to 1983.

9. Edison Electric Institute, "What Happened to the 40 Percent?," *Electric I tives* (Spring 1984), 28-31.

10. C. C. Burwell, et al. *Electric Home Heating: Substitution for Oil and Gas,* IEA-82-3(M) (Oak Ridge, TN: Institute for Energy Analysis, Oak Ridge Ass Universities, March 1982).

11. C. C. Burwell, *Industrial Electrification: Current Trends,* ORAU/IEA-83-4(M Ridge, TN: Institute for Energy Analysis, Oak Ridge Associated Universities, ary 1983).

12. D. R. Bohi, *Analyzing Demand Behavior: A Study* of *Energy Elasticities* more, MD: Johns Hopkins University Press for Resources for the Future, 1

13. Ibid., 55.

14. Ibid., Table 7.1, 159.

15. Ibid., 79.

16. Ibid., 90

17. Ibid., Table 7.1

18. J. S. Sweeney, "The Response of Energy Demand to Higher Prices: Whn We Learned?," *AEA Papers and Proceedings 74,* no. 2:31-37.

19. Ibid., 36.

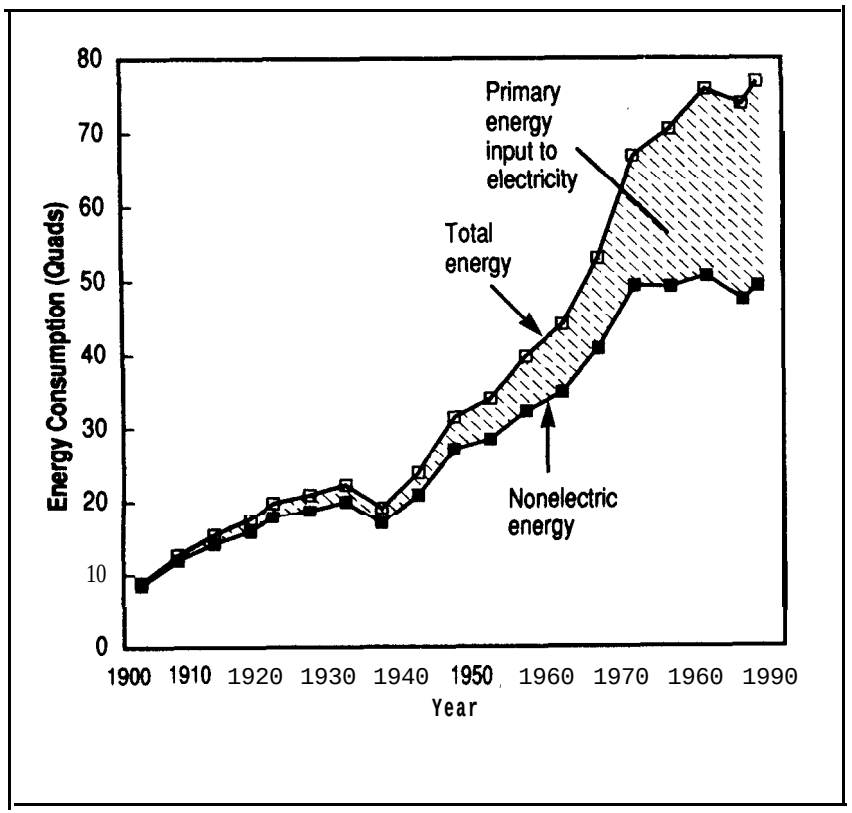
20. W. W. Hogan, *Patterns* of *Energy* Use, E-84-04 (Cambridge: Energy and Er mental Policy Center, Harvard University, May 1984).

21. Edison Electric Institute, "What Happened to the 40 Percent?" 28-31.

22. Hogan, *Patterns of Energy Use, 27.*

23. If this result occurs, it would be a mirror image of the transition fr relationship of the 1920s to that of the 1930s. Incremental electricity intens not change between the two periods, as can be seen from the parallel li regression for the two periods (Figure Al.3). Because the percentage decre the GNP in the years immediately following 1929 were larger than the perc decreases in electricity use, average electricity intensity actually increased ever, as the years passed the trend of the 1930s turned out to be parallel to the 1920s. The net result of the change in average intensity was simply a shift line parallel to itself (mathematically, a shift of the intercept). At the time th shift orrurred, there was of course no way of knowing that this outcome result. Likewise. only time will tell whether the line of the future will fall belo

Figure AI.1 Historical Trends in U.S. Energy Consumption, 1902-1987



SOURCES: U.S. Bureau of Mines, as presented in *Towards* Project Independence: Energy in the Coming *Decade,* prepared for the Joint Committee on Atomic Energy, U.S. Congress, 94th, 1st sess. (December 1975); Edison Electric Institute, *Historical Statistics* of the *Electric Utility Industry,* and Statistical *Yearbook* of the Electric *Utility Industry* (Washington, DC.: EEI, various editions); U.S. Department of Energy, Annual *Energy Review* (Washington, D.C.: GPO. various issues).

Another way of measuring the comparative growth of electrical and nonelectrical energy is by directly comparing the energy delivered by electricity (instead of by the primary energy consumed in its generation) and the energy delivered by other forms (mostly coal and coke, oil products, and natural gas). The average annual growth rates shown in Table AI.1 are based on such data. Clearly electricity consumption has grown at a higher rate than has the consumption of other energy forms throughout the twentieth century, including the 1980s. Nevertheless, the rate of growth of electricity consumption itself fell sharply during the recent past compared with its growth rates in all earlier periods.

Table AI.1 Average Annual Growth Rates in Total Energy, Electric and Nonelectric Energy Consumption for Selected Periods, 1902–1
(Percentage per Year)

Period	Total energy	Electricity	N
1902-1912	6.1	15.5	
1912–1920[a]	2.9	10.8	
1920–1930[a]	1.2	7.3	
1930-1940	0.7	4.6	
1940-1950	3.5	7.9	
1950-1960	2.8	0.1	
1960-1973	4.1	6.7	
1973-1987	0.2	2.4	

SOURCES: U.S. Bureau of Mines, as presented in *Towards Project independence: E the Coming Decade,* prepared for the Joint Committee on Atomic Energy, U.S. Cong 94th Congress, 1st sess. (December 1975); Edison Electric Institute, *Historical Statist Electric Utility Industry Through* 1970, EEI 73-34 (Washington, D.C.: EEI, 1973), and *Yearbook* of the *Electric* Utility *Industry* (Washington, D.C.: EEI, various issues); U.S. ment of Energy, *Annual Energy Review* (Washington, D.C.: GPO, various issues).

[a] Average annual growth rates for total energy and for nonelectric energy were from British thermal units (Btu) of consumption. The growth rate for electricity wa puted from kilowatthour figures. Because of the rapidly improving efficiency of ele power generation in the *early* years, electricity kilowatthours grew much faster tha input for electricity generation. This aspect of the computation is the reason that, f two periods, the growth rate of total energy appears to be lower than the growth r both of its components.

That the rate of growth of electricity use has tended to decline, p larly compared with the early periods of its introduction, is not surp As the base from which growth is measured becomes larger, even growing absolute increments translate into smaller percentage g rates. By the same token, the early rates of growth of a newly em service or industry, such as electricity in the first part of this centu loom large compared to those of already established quantities, s population, GNP, or the use of other energy forms.

Electricity Growth in Relation to the Growth of the Gross National Product

How should the relationship between electricity use and economic g be expressed? Our approach is to look first at the relationship in agg terms, that is, in terms of total electricity made available in the 1 States, regardless of the source, and of the GNP, expressed in co dollars. Later this relationship will also be examined, although only f years following World War II, in terms of the major sectors of elec use: residential, commercial, and industrial. The discussion address nature of the aggregative relationship. changes in this relatio

d sectoral

When standard statistical techniques are used to measure the relationship between annual levels of electricity use and the GNP (in constant dollars), certain regular features of the historical record appear. Perhaps the most significant characteristic of the relationship is its stability over appreciable segments of time. This stability is indicated in Figure AI.2 (with additional detail in Figure AI.3), which displays lines of regression for four periods covering most of the twentieth century to date.' For any point on these lines one may calculate an average electricity intensity, that is, electricity consumption per unit of the GNP. Changes along these lines relate increments in electricity use to increments in the GNP; each period is marked by a stable linear relationship, which, though showing some annual fluctuations, indicates a strong tendency toward a constant incremental intensity of electricity use within each period.

Equally significant is the fact that there are only a few changes in the slope (and level) of the regression line over the long historical record. Clearly discernible changes in slope occurred following World Wars I and II. Even the Great Depression did not result in a change in slope; the level of the regression line did shift upward, however, reflecting the fact that during this period the GNP decreased relatively more than did electricity use. The record of the post-oil-embargo years poses the question of whether we are once again witnessing a change in slope, an issue that is addressed later in this chapter.

The specific findings embodied in Figures AI.2 and AI.3 may be summarized as follows:

(1) From 1902 to 1912, the national economy tended to use an additional 0.29 kilowatthours (kWh) per additional dollar of the GNP, measured in constant (1972) dollars.

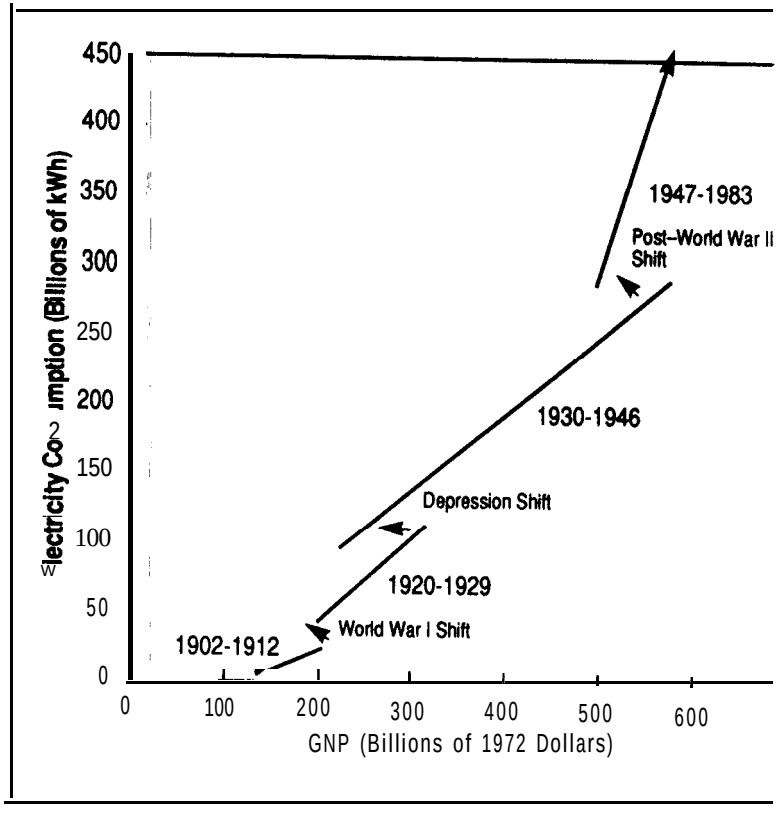
(2) A transition to a new slope occurred between 1912 and 1920; the 1917 observation shown on Figure AI.3 appears to be transitional.

(3) Between 1920 and 1929 the incremental use of electricity per unit of the GNP averaged 0.58 kWh per dollar, twice the value that prevailed between 1902 and 1912.

(4) Following 1929, the GNP dropped by almost one-third, while electricity use declined only slightly. Consequently, average electricity intensity increased. However, the slope of the line for the years 1930 through 1946 did not change significantly from that for the years 1920 through 1929. Thus, the incremental intensity of electricity use remained the same, even though average electricity intensity rose.

(5) Another transition occurred following World War II, and the new trend line has persisted ever since (with a critical question remaining about the most recent past). The new slope (through 19831 shows on the average an increment of 2.12 kWh per additional constant (1972) dollar of the GNP, about three and one-half times that characterizing the relationship observed between 1920 and 1946.

Figure AI.2 Electricity Consumption versus the GNP in the Unite with Lines of Regression by Periods, **1902-1983**

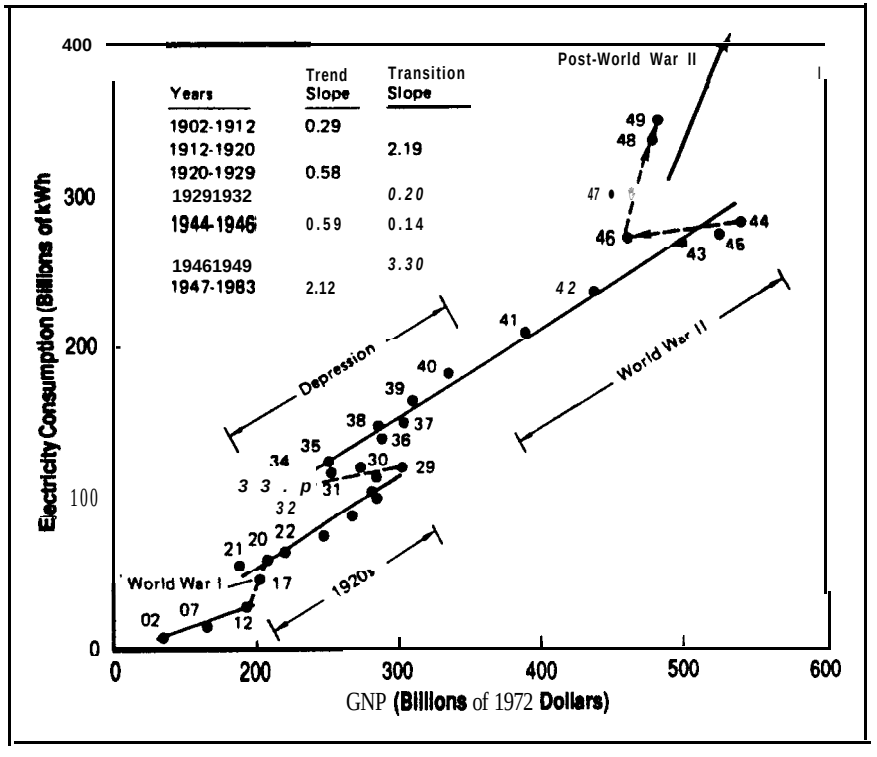


SOURCE: Compilation and figure by Energy Study Center, Electric Power Researc tute, Palo Alto, California.

NOTES: The GNP is expressed in constant (1972) dollars. Data for 1902 through 1 been converted from constant (1958) dollars in U.S. Bureau of the Census, *Historica tics of the United States, Colonial Times to* 1970, Bicentennial Ed., Part 2 (Washingto GPO, 1975), Series Ft-5. 224: for 1929 through 1980 from the Council of Economic ers, *Economic Report of the President* (Washington, D.C.: GPO, February 1984), 222; through 1983 from the Council of Economic Advisers for the Joint Economic Comm Economic *Indicators* (March 1985), 2.

Electricity consumption is expressed as "electricity made available in the United S Conceptually this quantity includes utility generation and nonutility generation (indu self. and co-generation), and net imports. Electricity data sources are Edison Electri tute, *Historical Statistics of the Electric Utility Industry Through 1970,* EEI 73-34 (Was D.C.: EEI, 1973), and *Statistical Yearbook of the Electric Utility Industry,* 1983 (Washin D.C.: EEI, 1984).

Figure AI.3 Electricity Use and the GNP: The Transitions



SOURCE: Compilation and figure by Energy Study Center, Electric Power Research Institute, Palo Alto, California.

NOTES: The GNP is expressed in constant (1972) dollars. Data for 1902 through 1928 have been converted from constant (1958) dollars in U.S. Bureau of the Census, *Historical Statistics of the United States, Colonial Times* to 1970, Bicentennial Ed., Part 2 (Washington, D.C.: GPO, 1975), Series F1-5, 224; for 1929 through 1983 from the Council of Economic Advisers, *Economic Report* of the *President* (Washington, D.C.: GPO, February 1984), 222.

Electricity consumption is expressed as "electricity made available in the United States." This quantity includes utility generation and nonutility generation (industrial self- and cogeneration), and net imports. Electricity data sources are Edison Electric Institute, Historical *Statistics of the Electric Utility Industry Through* 1970, EEI 73-34 (Washington, DC.: EEI, 1973), 9, and Statistical *Yearbook of the Electric Utility Industry* (Washington, D.C.: EEI, 1983).

Appendix I

POST-WORLD WAR II TRENDS

The Growth of Electricity Use and the Gross National Product

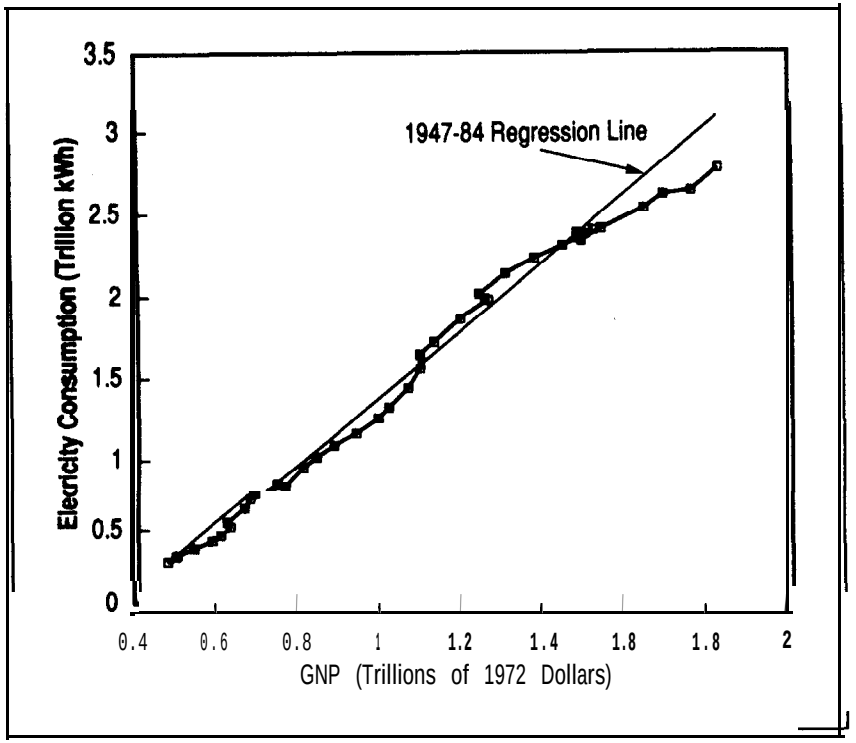
The relationship between increases in electricity use and increase GNP is shown for the post-World War II period in Figure AI.4. The r ship appears to have persisted through the entire period, with the exception of: a break since the mid-1970s. Although observations most recent years fall below the trend line, this fact is still consisten characteristic feature of the relationship, that is, a tendency for in years to exhibit a cyclical pattern around the long-term trend line figure shows.

However, to conclude that the data points after the mid-1970s are more than a manifestation of a persistent cyclic pattern is only one interpreting the record for recent years. There has been a strong, ing trend in the ratio of the annual percentage growth of electricit, that of the GNP, and this fact is frequently cited as evidence that t tionship between the two has changed.

Figure AI.5 shows that the ratio of the five-year moving averages centage electricity growth and percentage GNP growth has fallen f average of 2 before 1973 to about 1 today. This tendency toward gence is consistent with the postwar linear relationship between variables. For example, the electricity use-GNP line of regression for 1983 shows an increment of 2.12 kWh of electricity for every c (1972) dollar increment of the GNP. In the early postwar period average electricity intensity was comparatively low (about 0.6 to 0 per dollar), the high incremental electricity intensity (2.12 kWh per led to much higher electricity growth rates than GNP growth ra average electricity intensity has increased — to 1.57 kWh per c (1972) dollar in 1983 — the relative effect of the incremental ele intensity (2.12 kWh per dollar) has decreased, leading toward a conv in growth rates.[3]

A critical question before us, then, is whether the long-standin World War II trend has been broken by another of the historicall quent transitions, but for the first time toward a decline in the incrc intensity of electricity use. To shed more light on this question, w examine some of the underlying forces that determine electricity relation to national output. Such influences include the trends of ele use in the major consuming sectors, the effects of changes in the c tion of national output, and the effects of changes in energy prices

Figure AI.4 Electricity Consumption versus the GNP in the United States, 1947-1984

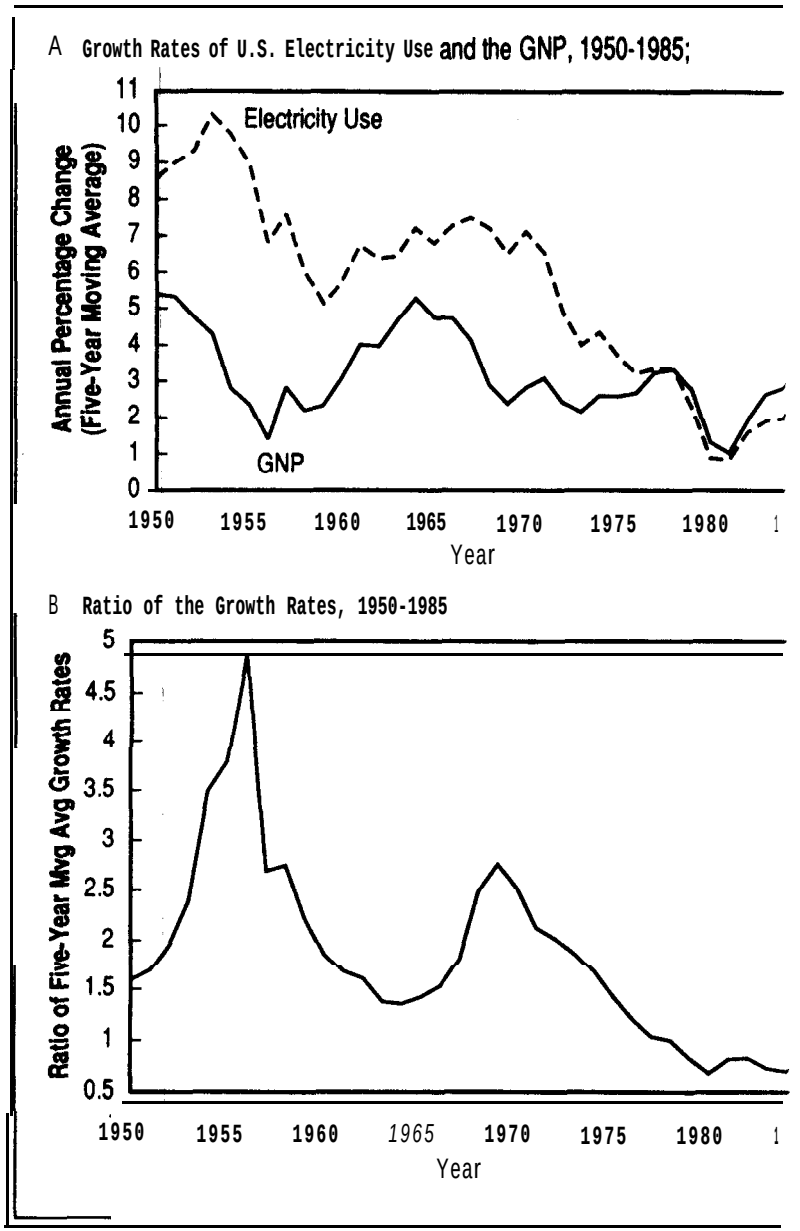


SOURCE: Compilation and figure by Energy Study Center, Electric Power Research Institute, Palo Alto, California.

NOTES: The GNP is expressed in constant (1972) dollars. Data from the Council of Economic Advisers, Economic Report of *the* President (Washington, D.C.: GPO, February 1984), 222; Council of Economic Advisers for the Joint Economic Committee, Economic Indicators (March 1985), 2.

Electricity consumption is expressed as "electricity made available in the United States." This quantity includes utility generation and nonutility generation (industrial self- and co-generation), and net imports. Electricity data sources are Edison Electric Institute, Historical *Statistics of the Electric Utility* Industry *Through 1970,* EEI 73-34 (Washington, D.C.: EEI, 1973), 9, and Statistical *Yearbook* of the *Electric* Utility *industry,* 1987 (Washington, D.C.: EEL 1988).

Figure AI.6 (A) Growth Rates of U.S. Electricity Use and the GNP, 1950-1985; (B) Ratio of the Growth Rates, 1950-1985



SOURCES: Based on data from Edison Electric Institute, ***Statistical Yearbook of the Utility Industry*** (Washington, D.C.: EEI, various issues); U.S. Bureau of Economic Ana *Thr National Income and Product Accounts of the United States* [illegible] *of Current I'*

Electricity Use in the Major Consuming Sectors

Electricity use is ordinarily classified by three major consuming categories:

- Industrial, that is, agriculture, mining, construction, and manufacturing[4]
- Residential, that is, private households
- Commercial and all other activities

Table AI.2 shows the changing importance of each sector as reflected by its percentage of total electricity consumption over the postwar period. The residential sector sharply increased its share of electricity use from one-fifth to about one-third of the total. The commercial sector's share increased sharply during the 1960s, and in 1987 it stood at about 28 percent of the total. The industrial share, starting at 59 percent of the total, dropped dramatically after 1955, to 38 percent of the total by 1983, but it has since increased about a percentage point. (Because the statistics in Table AI.2 include industrial self-generation of electricity, the sectoral shares differ from those shown elsewhere in this book — Chapter 11 in particular — where the data refer only to electricity sales by utilities.)

These postwar trends in sectoral shares of electricity use parallel the underlying trends in the economic measures for each sector. That is, growth in disposable personal income (DPI), the residential sector surrogate for gross product originating (GPO) in the other two sectors and commercial sector growth outpaced that of industrial output over the entire period." In fact, if we examine the relationships between electricity use in these sectors and their respective economic measures, as in Figure AI.6, we find the same stable linear relationship (with cyclical variation) as is seen in the aggregate economy. Also, as in analyzing the aggregate case, one gains a different

Table AI.2 U.S. Electricity Use by Sector, 1950-1987 (Percentage of Total)[a]

Year	Residential	Commercial[b]	Industrial[c]
1950	20.6	20.1	59.3
1955	22.3	17.3	60.4
1960	25.4	18.4	56.2
1965	26.6	22.6	50.7
1970	29.9	24.7	45.4
1975	32.2	26.7	41.1
1980	33.5	27.2	39.3
1983	33.9	28.3	37.8
1987	32.5	28.5	39.0

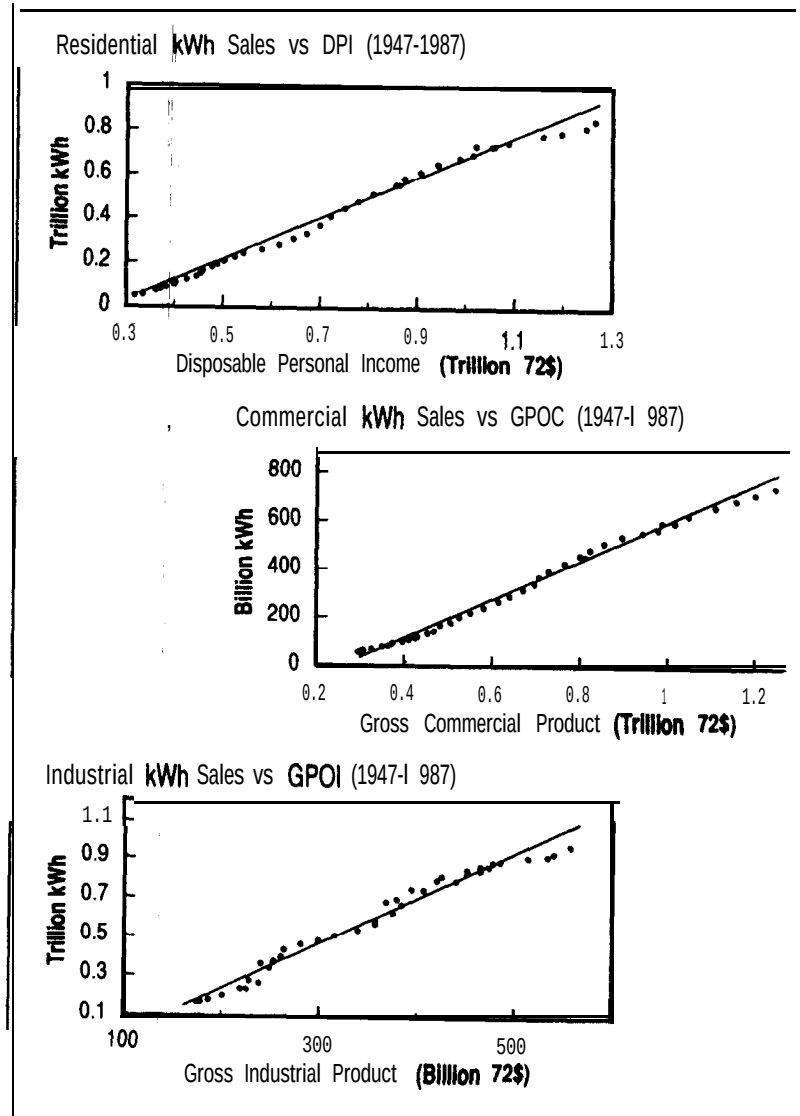
SOURCES; Edison Electric Institute, *Sfatisfical Yearbook of the Electric Utility Industry* (Washington, DC.: EEI, various issues).

[a] Includes industrial self-generation.

[b] Small light and power, street and highway lighting, other public authorities, railroads and railways, and interdepartmental transfers.

[c] [illegible] and power, and industrial self-generation

Figure AI.6 Electricity Use-Economic Output Relationships By Economic Sector, 1947–1987



SOURCE: Compilation and *figure* by Energy Study Center, Electric Power Research Institute, Palo Alto, California.

NOTE: Different scales are used for the three sectors to highlight the linearity of electricity use-economic output relationship within sectors. Based on data from Edison Electric Institute, *Sfatisfical Yearbook* of *the Electric Utility Industry* (Washington, D.C various issues); U.S. Bureau of Economic Analysis, *The National Income and Product of the United States, Statistical Tables* Supplement to [illegible]

perspective when comparing the ratio of the percentage growth rates of electricity use and economic output measures. Figure AI.7 shows the same trend toward convergence between the sectoral percentage growth rates as was observed in the total economy. For further insight into these trends, we examine in more detail the postwar patterns of electricity use within each of the three sectors.

Trends in the Residential Use of Electricity

The trend in residential electricity consumption since World War II falls into three distinct periods, corresponding roughly to the decades of the 1950s, 1960s, and 1970s, as shown in Figure AI.7. During the 1950s, the growth rate of electricity consumption (five-year moving average) was very high but steadily decreasing from about 14 percent to 8 percent per year. During the 1960s, the growth rate slowly accelerated to about 10 percent per year toward the end of the decade. It then dropped in the postembargo period to an average of about 5 percent per year, until the late 1970s and early 1980s when it dropped further, reaching its minimum in 1983 and rising since.

Trends in the Commercial Use of Electricity

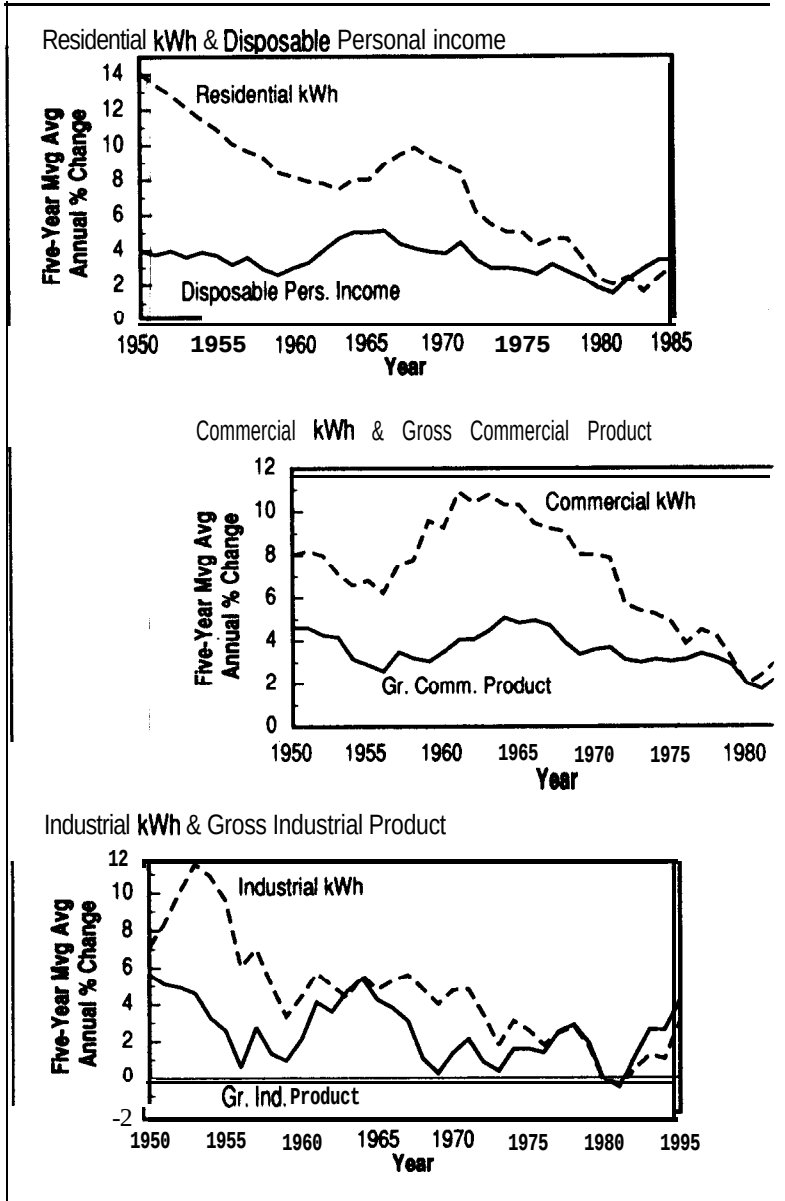
Electricity consumption in the commercial sector has grown faster than that in the other sectors since 1960 (Figure AI.7). The large increase in commercial electricity use between 1960 and 1973 (at a 9.5 percent average annual growth rate) has been attributed to increases in the use of mechanical airconditioning systems and to new standards of building illumination, which resulted in increased lighting requirements.[6] From 1973 to 1980, commercial electricity use continued to increase, although the (five-year moving average) growth rate decreased. Since 1980 this growth rate has been increasing.

The declining growth of commercial sector electricity use during a period when output growth remained relatively strong points to improvements in the efficiency of use. New commercial buildings are generally constructed to be more energy efficient than were older buildings.' Improved lighting systems and the introduction of computerized energy management systems will also increase the efficiency of energy use. On the other hand, the increasing growth rate in recent years probably reflects a trend toward greater use of electric heating and the increased automation of office services.

Trends in the Industrial Use of Electricity

Electricity use in the industrial sector grew at an average rate of 8 percent per year between 1950 and 1960. From 1960 to 1973, the growth rate of industrial electricity use averaged 4.7 percent per year.' By 1980, the five-year moving average growth rate had become negative, but by 1985 it was back to the level of the mid-1970s.

Figure AI.7 Growth Rates of Electricity Sales and of Sectoral Out Indicators, 1950–1985: (a) residential, (b) commercial, (c) industrial



SOURCES: Based on data from Edison Electric Institute, *Statistical Yearbook of th Utility Industry* (Washington, D.C.: EEI, various issues); U.S. Bureau of Economic A *The National Income and Product Accounts of the United States. Statistical Tables*, Su ... ey of Current Bu ... 40

Electricity represents nearly 35 percent of the gross energy (13 percent of net energy) consumed in the industrial sector. Manufacturing accounts for about 85 percent of total electricity use in this sector, with agriculture, mining, and construction activities accounting for the remainder.

The Effects of Structural Change on Electricity Intensity

Measuring Structural Change

Table AI.3 shows that the share of GPO accounted for by industry fell from 38 percent in 1950 to about 32 percent in 1980, to which level it returned in 1987 after falling lower in the interim. Although manufacturing constitutes its most important component, the industrial figures also include agriculture, mining, and construction.

The GPO in the commercial sector, a very broad classification that encompasses all output originating outside the industrial sector, grew from 62 percent to 68 percent between 1950 and 1987. These figures encompass transportation; communications; electric, gas, and sanitary services; wholesale and retail trade; finance, insurance, and real estate; personal services; and government operations.

However, GPO composition is not the only way of looking at structural change. Another perspective is gained by looking at employment trends, shown in Table AI.4. As a share of total employment, industrial sector employment fell from about 45 percent in 1950 to about 27 percent in 1987. Commercial sector employment rose from 55 percent of total employment in 1950 to about 73 percent in 1987.

This information tells us that the commercial sector has been absorbing more of the growing labor force. This trend is especially true of part-time workers. On the other hand, the rapidly increasing share of commercial sector employment relative to output growth in that sector implies that

Table AI.3 Gross Product Originating (GPO) in the U.S. Economy, Selected Years, 1950-1987 (Percentage of Total)

Sector	1950	1960	1970	1980	1987
industrial	38.0	36.0	34.2	32.0	32.1
Agriculture	5.5	4.4	3.2	2.7	2.5
Mining	2.1	1.8	1.8	1.5	3.1
Construction	5.5	fi.3	5.0	3.7	4.6
Manufacturing	24.1)	23.5	24.3	24.1	21.9
Commercial	62.0	64.0	65.8	68.0	67.9

SOURCES: U.S. Bureau of Economic Analysis. The *National Income and Product Accounts of rhe United States, Statistical Tables*, Supplement to Survey of Current *Business* (Washington, D.C.: GPO, various issues).
NOTE: All data have been rounded.

Table AI.4 Employment in the U.S. Economy, Selected Years, 1950– (Percentage of Total)

sector	1950	1960	1970	1980	1987
Industrial	44.9	38.9	34.7	20.7	26.8
Agriculture	10.9	7.0	4.0	3.3	2.8
Mining	1.6	1.1	0.8	1.0	0.7
Construction	5.8	5.3	5.3	5.1	5.7
Manufacturing	26.5	25.4	24.6	19.3	17.6
Commercial	55.1	61.1.	65.3	71.3	73.2

SOURCES: U.S. Bureau of Economic Analysis, *The National Income and Product Acc the United States, Statistical Tables*, Supplement to *Survey of* Current *Business* (Washin D.C.: GPO, various issues). Data series is "Persons Engaged in Production by Industry
NOTE: All data have been rounded.

growth of labor productivity (that is, output per unit of labor inpu been slower in this sector than in the industrial sector.

Of these two different ways of looking at structural change, the significant for analyzing electricity use is the GPO (value-added) me since it provides a measure of total productive activity — embracin labor and capital inputs — within any particular sector. The GPO a shows manufacturing to have generally maintained its share of outpu the postwar period. The shift in output has been from agriculture, n and construction toward selected commercial sector activities. The ing two sections adopt the GPO as the best measure of structural cl

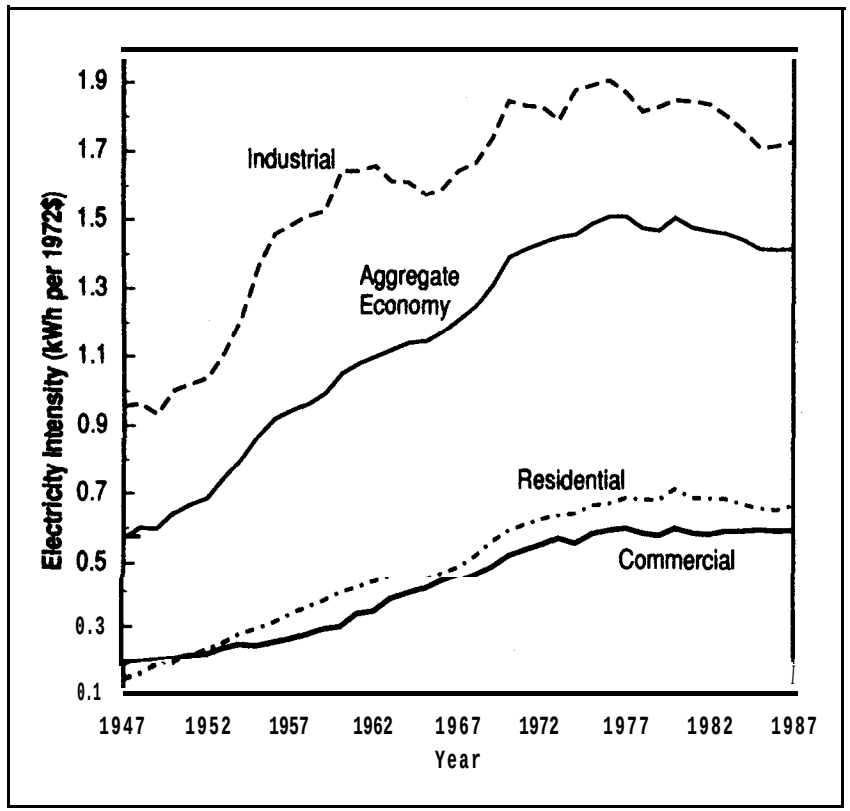
Electricity Intensity of the Sectors

Electricity intensity is defined as total kilowatthours (kWh) of elec consumed divided by the aggregate economic output measure of a that is, a measure of average electricity use per unit of output. constant-dollar GPO is used to measure real output in the industri commercial sectors and constant-dollar DPI is used to measure real i for residential users. Industrial output, at 1.74 kWh per constant dollar, is now (1987) almost three times as electricity intensive as co cial output, at 0.60 kWh per constant (1972) dollar. The residential consumed 0.67 kWh per constant (1972) dollar of DPI in 1987.

For the postwar period as a whole, the intensity of electricity use three sectors has increased, as shown in Figure AI.8. Between 19 1983, industrial electricity intensity increased 80 percent, commerci tor intensity increased more than 180 percent, and residential int increased about 260 percent. Electricity use was growing faster than or income in every sector.

Although there were large increases in average electricity intensit this total period, almost all of the growth occurred prior to 1973. Ind

Figure AI.8 Electricity Intensities in the U.S. Economy, Total and by Sectors, 1947-1987



SOURCES: Based on data from Edison Electric Institute, *Statistical Yearbook* of the Electric Utility Industry (Washington, D.C.: EEI, various issues); U.S. Bureau of Economic Analysis, *The* National *Income and Product Accounts* of *the United States,* Statistical *Tables,* Supplement to Survey of Current Business (Washington, D.C.: GPO, various issues).

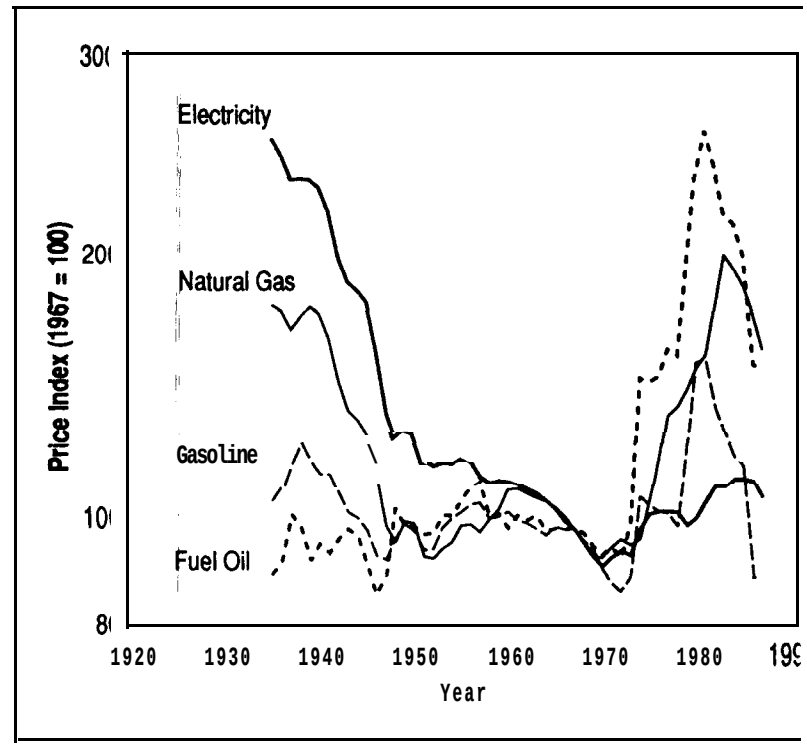
and commercial sector electricity intensities increased slightly in some years after 1973, but by **1983** they had fallen back to their 1973 levels. In the residential sector, electricity intensity was about 8 percent higher in 1983 than in 1973, but it has not shown an appreciable increase since 1977.

Changes in Energy Prices

Price Movements

The trend in energy prices for the forty-year period before 1973, as illustrated in Figure A1.9, was one of generally stable or decreasing prices for most fuels. Electricity prices, in particular, declined throughout the entire

Figure AI.9 Trends in Real Energy Prices to U.S. Personal Consumr 1935-1987



SOURCES: U.S. Bureau of the Census, *Historical* Statistics of *the United* Stares, *Colon* Times *to* 1970, Bicentennial Ed. (Washington, D.C.: GPO, 1975); U.S. Bureau of Labor tics, Handbook of *Labor* Srarisrics, Bulletin 2000 (Washington, D.C.: GPO, 1979), and A *Labor Review* (various issues).

period. The rapid price decline for electricity has been attributed increasing economies of scale in electricity generation and distributio this period and to improvements in the efficiency (heat rate) of gene: Electricity prices were also favorably affected by the stability of pı energy input costs over the period.

Since 1973 a number of forces have combined to reverse the his trend of declining electricity prices. First, there was the great increas prices that accompanied the Arab oil embargo of 1973. This event petroleum product prices up immediately and also adversely affect price of electricity in those regions of the country that depended on o significant portion of their generation requirements. Figure AI.10 con energy price trends over this period for personal consumers and ind users. The 1973 change was followed during the rest of the 1970