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CHAPTER 1

Output

THOMAS A. EDISON'S PEARL STREET, NEW YORK, steam-electric station which opened in 1882, was the first plant to produce and distribute electricity commercially. His incandescent lamp provided the first opportunity for the extensive use of electricity, and the industry grew rapidly. As it advanced technically, production costs fell to a point where electric energy began to displace coal, oil, and other fuels as a source of power and heat as well as light; in two generations electricity became basic to economic life.

1 Electric Light and Power: The Nature of its Output

The conventional unit of output in the electric light and power industry is the *kilowatt-hour*. The kilowatt is a unit of electric power equal to about one and one-third horsepower; the kilowatt-hour represents then the generation or use of this power for one hour. Output may be considered from either the manufacturing or the distributive angle; i.e., the actual generation of kilowatt-hours whether at a steam or hydroelectric plant or their distribution to ultimate consumers. Representing its 'service' function, distribution is a no less essential part of the industry's activity than manufacturing, for its product, electric energy, is usually delivered to the consumer by the producer. Since we wish to take account of the distributive service, our unit of measurement is the kilowatt-hour sold (i.e., distributed) to ultimate consumers, rather than the kilowatt-hour generated.[1]

[1] Because data on sales to ultimate consumers are lacking for the early years of the period under review, we fall back on statistics of kilowatt-hours generated. The difference

It is in the distributive or service aspect of the industry that quality differentiation appears. Technically (in terms of kilowatt-hours) the *generated* product of the electric light and power industry may seem homogeneous. For example, at first glance there appear to be no physical differences between the kilowatt-hour generated for the large industrial consumer and for the small domestic consumer. Actually, however, the industrial kilowatt-hour is usually transmitted at much higher voltage than the domestic. In general, the widely varying conditions under which electricity is *distributed* to various consumer groups gives rise to marked price differentials.[2] These price differentials indicate differences in the 'quality' or kind of service rendered various consumer groups wide enough to justify the treatment of each service as a separate output entity. A weighting scheme serves to assign appropriate degrees of importance to the various components of output. In constructing our index, we use actual prices as weights, thereby applying the judgment of the market.

The 'market' for the products of public utilities has a rather special character. Because it is generally accepted that the traditional market mechanism is inadequate to determine utility prices, they are subject to review by state agencies. Considerable controversy has arisen whether the rates charged, with the approval of public service commissions, approximate the competitive ideal. The use of differential rates as price weights in constructing indexes must therefore be qualified. Those who contend, for instance, that the rates offered domestic and industrial consumers discriminate against the former, and that therefore the importance

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between the two totals is accounted for mainly by losses in transmission and intra-industry consumption; there seems to have been little secular change in the relation between current generated and sales.

[2] That these price differentials may be associated with variations in the conditions under which electricity is distributed to consumer groups is clear from a consideration of the general principles governing the rates charged. It may of course be difficult in practice to allocate the costs of servicing among consumers 'equitably' but it is evident, for instance, that a utility company, in an effort to reduce over-all unit costs by minimizing the time during which its plant remains idle, will seek to encourage 'off-peak' consumption by offering lower rates for current used during slack hours.

In the extensive literature dealing with the technical aspects of setting rates, rate differentials arising from variations in the 'load factor' and 'diversity factor' for each group are emphasized. Both factors are designed to aid in measuring the proportions of capital equipment per unit of output required to service the needs of groups consuming varying quantities of electricity at peak and off-peak periods.

assigned to each class of service in a price-weighted index is not proportionate to the 'true' costs underlying the respective services, may protest.

For the purpose of this study it is unnecessary to examine this argument. Though we have used the established rates as weights in constructing indexes of output, we have also constructed unweighted indexes for each, i.e., output indexes in which sales to the various consumer groups are given equal weight, and their differential unit costs to both the utility company and the consuming public are ignored. The price-weighted and unweighted indexes of output reveal different aspects of the changing volume of utility output. For example, the weighted index reflects changes in the character of utility service consumption; the unweighted does not, but it is better suited for comparisons of utility output with, say, productive capacity.

An indication of the differences in average rates paid by different consumer groups is afforded by the distribution of electric light and power sales as reported in the 1937 Census of Electric Light and Power (Table 1). Nonfarm commercial service is the largest

TABLE 1
Electric Light and Power, 1937
Distribution of Sales

	QUANTITY		REVENUE		AVERAGE UNIT PRICE
	Mil. kwh.	% of total	$ mil.	% of total	¢ per kwh.
Farm	2,671	2.6	71.2	3.3	2.66
Residential	667	0.7	24.8	1.1	3.72
Rural	981	1.0	31.1	1.4	3.18
Commercial	1,024	1.0	15.2	0.7	1.48
Domestic, nonfarm	16,815	16.7	726.4	33.5	4.32
Commercial, nonfarm	70,218	69.7	1,200.3	55.4	1.71
Small (retail)	17,339	17.2	595.1	27.5	3.43
Large (wholesale)	52,879	52.5	605.2	27.9	1.14
Municipal street & highway lighting	2,036	2.0	73.9	3.4	3.63
Steam rr. & electric rw.	6,446	6.4	56.5	2.6	0.88
Other	2,612	2.6	39.2	1.8	1.50
Total to ultimate consumers	100,798	100.0	2,167.4	100.0	2.15

Data taken chiefly from *Electric Light and Power Industry, 1937* (Bureau of the Census, Washington, D. C., 1939), p. 20. The Census presentation has been changed in minor respects. Interdepartmental sales, included in the Census total for 1937 but not in preceding Census years, were excluded in order to attain comparability with earlier Census data. For the same reason, the division of kwh. sales into Farm, Domestic, and Small and Large Commercial service was retained, although it differs somewhat from a new classification adopted by the Bureau of the Census in 1937.

Commercial service was divided into Small (retail) and Large (wholesale) on the basis of the comparable totals ascertained by the Edison Electric Institute and published in annual statistical bulletins; e.g., in *Statistical Bulletin 10*, p. 20, it is indicated that sales to Large commercial consumers in 1937 made up 75.307 percent of the Commercial service kwh. total and 50.418 percent of the corresponding revenue total. Applying these percentages to the Census sales and revenue totals for Commercial service, nonfarm, we obtain the division shown above for Small and Large Commercial service.

component, accounting for nearly 70 percent of total sales in 1937. However, it includes both the low-valued large commercial service sold at wholesale rates and the relatively high-valued service sold to small commercial users at essentially retail rates. Large commercial service, representing mainly sales for power purposes and including use in electro-thermal and electro-chemical processes of an industrial character, accounted for more than half of all kilowatt-hours sold in 1937, although it contributed less than a third to total revenue. The low rates enjoyed by large industrial consumers of electricity, averaging about 1.1 cents per kilowatt-hour in 1937, reflect the economies associated with large scale production. Such consumers, including manufacturers of chemicals and paints, electrical equipment, rubber products, iron and steel products, textile and leather products, are representative of the entire range of modern manufacturing activity, for electric energy is ideal for the power needs of motors whose speeds must be adjusted precisely. Large industrial consumers, whose power needs are usually sustained throughout the day and do not compete with domestic peak demand in the evening, frequently take advantage of the low rates offered to encourage off-peak consumption. Their low rates reflect also discounts given for long term contracts.

The only cheaper service was that rendered street railways and electrified divisions of steam railroads, to which a small amount of current (6.4 percent of total sales) was sold, for traction purposes, at a rate less than 9 mills per kilowatt-hour, yielding 2.6 percent of the 1937 revenue total.

Small commercial sales at retail rates, averaging about 3.4 cents per kilowatt-hour in 1937, constituted as big a share of total revenue as large commercial sales, though accounting for only 17.2 percent of total sales. They are made to shops, offices, small factories, repair shops, and various other small industrial establishments, and the current is used mainly for lighting rather than power purposes. In recent years, however, air-conditioning has begun to balance seasonal demands in the electric consumption of stores, theaters, hotels, and other commercial establishments, thereby tending to reduce costs.[3]

Most sales other than commercial are made for lighting purposes and yield a higher revenue per unit. The largest are for domestic service, and are at the highest rate, 4.3 cents per kilowatt-hour. In 1937 they constituted one-sixth of total sales and as much as one-third of total revenue. Farm service, including the relatively high-revenue residential and rural services and low-revenue commercial service (for power and irrigation purposes) accounted for 2.6 percent of total sales and 3.3 percent of total revenue. Electricity sold for street and highway lighting, at 3.6 cents per kilowatt-hour, accounted for 2.0 percent of total sales and 3.4 percent of total revenue.

If price is a guide, we are evidently dealing with several distinct categories of electric service. In the range of differential prices domestic and large industrial consumers are the extremes; our index of output, so far as it gives separate weight to each, will be directly affected by changes in the ratio of electricity sold at high rates for domestic and lighting purposes to electricity sold at relatively low rates for industrial power purposes. We distinguish three general groups to which the Census classification of data lends itself: electricity consumed for (1) lighting and household use mainly, (2) the power needs of industrial users, and (3) the traction needs of electric railways and steam railroads.

2 *Source and Character of the Data*

Our basic source is the Census of Electrical Industries, taken quinquennially 1902–37 by the United States Bureau of the Census. The 1942 Census canvass was deferred because of wartime exigencies. We supplement the Census data with reports of the Edison Electric Institute and the Federal Power Commission.

In 1937 the Bureau of the Census defined the electric light and power industry to include:

"all establishments which were engaged during any portion of the calendar year 1937 in the generation and distribution of electric energy to public or private consumers; or in the generation of current for sale to other light and power companies for distribution; or in the distribution of cur-

[3] John D. Wilson, The Electric Power Industry and the Defense Program, *Survey of Current Business*, Jan. 1941, p. 15.

rent generated by plants under other ownership; or in the transmission of electric energy for private or public use. The statistics do not include establishments which consume all current generated, such as manufacturing and mining companies, railroads, railways, hotels, and other enterprises not in the nature of public utilities, unless a portion of their generated output is sold commercially." [4]

This definition indicates that the Census recognizes the dual character of the output of the industry: generation of current and its distribution to ultimate consumers, even when not done by the same establishment.

The 1937 Census classified its reporting sources as privately owned electric utilities, municipally owned electric utilities, cooperatives and power districts, federal and state projects, and 'other'. 'Other' includes plants selling current but owned by:

"manufacturing and mining companies, railways and railroads, together with some publicly owned properties such as United States national parks, State colleges, and municipal plants, not included in the 'Municipally owned electric utilities group', which are not primarily engaged in the manufacture and/or sale of electric energy." [5]

The Census states that the coverage of the industry as defined in 1937 is somewhat more inclusive than that of earlier censuses in that 'federal and state projects' and 'cooperatives and power districts' are reported. The resulting discontinuity in the series is believed to be negligible because such projects were of slight importance before 1937.[6] They may be regarded as evidence of the industry's natural growth rather than as a heterogeneous element in the series.

A more serious break in Census coverage, which the Census Bureau does not explain, arises from the lack of a uniform treatment, since 1917, of electric light and power departments of electric railway companies. In Section 5 we discuss this discontinuity and seek to adjust for it.

We do not itemize output by type of plant ownership. However, privately owned electric utilities accounted in 1937 for nine-tenths

[4] Electric Light and Power Industry, Census of Electrical Industries, 1937 (Washington, D. C., 1939), p. 2; designated below as *ELP*, with the year.

[5] *Ibid.*, p. 16.

[6] Even in 1937 they accounted for the sale of no more than 874.6 million kilowatt-hours to ultimate consumers or about 0.8 percent of the industry total, 103,070.4 million kilowatt-hours, including interdepartmental sales (see *ELP, 1937*, pp. 20–2).

of total sales to ultimate consumers. Except when otherwise noted, we are concerned with activities carried on for the most part by them. But, to facilitate comparisons of output and input, we do make indexes for both fuel-burning and hydro-electric plants.

As in the censuses since 1902 there have been many changes in the reported data — with respect to coverage, degree of detail, and reliability — we present our output estimates in two time segments, 1902–17 and 1917–42. During each the data are of reasonable homogeneity and sufficiently comparable to admit the construction of indexes. In the earlier period output is measured by kilowatt-hours generated; in the later, by kilowatt-hours sold to ultimate consumers. After discussing the movements of the output index for each period, we splice the segments and consider the four decades as a whole.

3 *The Early Years: 1902–1917*

The statistical record begins in 1902, when the electric light and power industry was already 20 years old. Partial surveys were made in 1890 and 1898, but the Census of 1902 was the first complete canvass on a nationwide basis.[7] Central electric stations reported their output in terms of kilowatt-hours *generated*, and the total, 2,507 million, was based largely on estimates. Meters were not in very general use in 1902 and current was often sold at a flat rate for a specified demand.[8] More current may actually have been generated, for we do not know how much was lost by overloading, thefts, and losses. As measurement by meter spread, the output totals reported became more accurate. But as late as 1917, "a large number of the smaller central stations did not make any attempt to measure the quantity of current produced, so that the figures which they have returned are merely their best estimates, based on the extent and nature of their business." [9] The totals for

[7] The 1890 Census was confined to New York State and St. Louis; its results are compared with the 1902 statistics for New York State in the *1902 Census of Electric Light and Power Stations* (p. 15). The *Fourteenth Annual Report of the Commissioner of Labor, 1899*, contains the results of the 1898 survey, in which 320 of the 460 known municipal plants and only 632 of the 2,572 commercial plants were canvassed.

[8] About three-quarters of all central stations reported having meter equipment, but the Census states that many were not fully equipped and sold part of their current at flat rates (*ELP, 1907*, p. 85).

[9] *ELP, 1917*, p. 72.

current generated reported in the early Census volumes were checked carefully, however, by Census agents and they remain our sole indicators of output in these years (Table 2).

TABLE 2

Electric Light and Power, 1902–1917
Unweighted Index of Output (1902:100)

	1902[a]	1907	1912	1917
Kwh. generated mil.[b]	2,507	5,862	11,569	25,438
Sales, $ mil.[c]	84.2	169.6	287.1	502.1
Av. revenue per kwh. generated, ¢ per kwh.	3.36	2.89	2.48	1.97
Unweighted output index	100.0	233.8	461.4	1,014.6

[a] The 1902 Census covered the fiscal year ending June 30; in subsequent censuses reports were requested for calendar years.

[b] The figures for kilowatt-hours generated in 1902 and 1907, although presented by the Census as comparable with the data on kilowatt-hours generated in later years, may include a small amount of current purchased from other companies. Such duplication could have arisen in the case of companies that did not meter current and that reported all sales as kilowatt-hours generated. See Table 3, notes a and b.

[c] Revenue from sale of electric service plus estimated value of free services.

Kilowatt-hours generated, and the output index based on it, increased tenfold 1902–17. The index, however, is unweighted, for there is no quantitative evidence on the changing proportions of electricity going to various consumer groups. The average revenue from each kilowatt-hour generated fell steadily from 3.36 cents to 1.97 cents. Such a marked decline may reflect rapid downward revision of rate schedules as well as increases in the proportion of total current going to large industrial consumers at low unit rates.

Some information on the changing proportions of current for light and power uses may be gleaned from Census revenue data (Table 3). In 1902 more than four-fifths of the electric service revenue of all central electric stations came from the sale of current for domestic and street lighting. Electric power for stationary motors contributed a little over one-tenth. The emphasis on the use of electricity for lighting purposes merely reflected the conditions under which the industry was born. The Edison direct current systems installed in the wake of the Pearl Street experiment were designed to provide current for incandescent lamps in buildings within short distances of the central station. As no other use for electricity was then envisaged, except to supply arc-lights for street illumination, central stations were usually operated during evening hours alone.

TABLE 3

Electric Light and Power, 1902–1917

Distribution of Income from Electric Service, by Consumer Groups

	1902		1907		1912		1917	
	$ mil.	%	$ mil.	%	$ mil.	%	$ mil.	%
Light (domestic, rural, & st. lighting)	70.1	84.6	125.8	77.1	...	...	283.3	60.6
Power (for stationary motors)	9.9	12.0	28.5	17.5	...	...	161.2	34.5
Rail (sales to electric st. rw. mainly)	2.8	3.4	8.9	5.5	...	...	23.0	4.9
Total income from electric service	82.9 [a]	100.0	163.2 [b]	100.0	269.1 [c]	100.0	467.5 [d]	100.0

[a] We excluded as duplicatory $1.3 mil. of income estimated to have been received from other central electric stations for intra-industry sales of electric power. 'Light' includes $151 th., the estimated value of service rendered without charge (*ELP*, *1907*, pp. 76, 94).

[b] We excluded $6.4 mil. of income estimated to have been received from other central electric stations for intra-industry sales of electric power. 'Light' includes $338 th., the estimated value of service rendered without charge (*ELP*, *1907*, pp. 76, 94).

[c] In 1912 no classification of income by consumer groups was reported. As for preceding years, we deducted from total revenue reported for that year the amount spent by central electric stations for purchased current (*ELP*, *1917*, pp. 110, 115) as representing duplicated income. But the $18.1 mil. deducted for 1912 may be somewhat larger than is strictly warranted, for the central stations may have bought some electric power outside the industry. For instance, electric railway companies received $36.5 mil. in revenue from sales of electric service, but we do not know how much was sold to central electric stations (*ER*, *1912*, p. 18).

[d] In 1917 central electric stations reported $502.1 mil. as income received from electric

	MILLIONS OF DOLLARS
Commercial lighting	241.1
Street	36.7
Power	161.2
Other public service corporations	57.5
Estimated value of free service	5.6
Total	502.1

service (*ELP*, *1917*, p. 116). For the $57.5 mil. of income from sales to 'other public service corporations' we followed a Census suggestion (*ELP*, *1917*, p. 82), allocating two-fifths or $23.0 mil. to sales to street railways, and considering the remainder to represent intra-industry sales to be deducted from the income total.

Central stations became increasingly interested in encouraging other off-peak uses for electricity. Their success is indicated by the fall in the percentage of total revenue derived from sales for lighting from 84.6 in 1902 to 60.6 in 1917. The sale of electric power for the traction needs of the rapidly expanding electric railway system was one opportunity for central stations to diversify the demand for electricity. Revenue from electric railways was included with revenue from sales to other central stations in censuses before 1917, but in Table 3 we have allowed for such intra-industry exchanges.

The percentage of total revenue from sales to electric railways rose moderately — from 3.4 in 1902 to 4.9 in 1917.[10]

A much bigger field for off-peak use since 1902 has been the supply of power for industrial purposes, represented in Table 3 as power for 'stationary motors'. By 1907, when revenue from the sale of electricity for lighting purposes had fallen to about three-quarters of the total, revenue from the sale of industrial power was 17.5 percent. The Census of Electric Light and Power noted the remarkable increase in the uses of electricity other than for illumination, especially in the supply of power for motor service, which was seen to offer favorable opportunities for creating daytime loads. The restriction of electric service to the evening hours was abandoned in large cities, although twenty-four hour service did not become general until after World War I.[11] When domestic and industrial loads overlapped, special concessions were offered industrial consumers who would agree to confine their use to specific periods, by rearranging the working day, if need be. Among the newly discovered uses for electric power (other than in manufacturing) that might serve to diversify and increase the demand for electricity, the 1907 Census mentioned the introduction of electric motors in refrigeration, in the operation of New York City's high-pressure water system for fire-protection, and in the charging of storage batteries for the operation of electric automobiles. Another factor was the development of household heating and cooking appliances — electric irons, toasters, percolators, etc. While it was recognized that electric heating and cooking could "not yet compare in general cheapness with older methods", the possibility that electricity might be applied to household tasks induced many companies to extend their operations to day circuits. Tuesday, the traditional ironing day, was sometimes chosen for a trial, in the hope that daily consumption would be encouraged (*ELP, 1907*, pp. 113–6).

In the next five years the industrial use of electric power continued to make enormous strides. Central stations within urban areas

[10] In 1912 electric railways canvassed by the Census of Electric Railways purchased one-third of their power requirements (*Census of Electric Railways, 1917*, p. 39); purchased power has since made up progressively larger proportions of total electric railway consumption.

[11] C. W. Thompson and W. R. Smith, *Public Utility Economics* (McGraw-Hill, 1941), p. 38.

were consolidated and transmission systems interconnected, greatly extending the area served by utilities. Particular progress was made in the technology of transmission. Voltages of 100,000 became commonplace, where only a few years before 10,000 or 15,000 volts had been regarded as extreme. Central stations were in a position to offer service to outlying industrial plants.

The 1912 Census did not cite any quantitative evidence of the growing industrial use of electric power beyond noting that the horsepower capacity of stationary motors served by central stations increased 843 percent 1902–12, and total revenue from light, heat and power 241 percent. However, in listing the new industries in which the electric motor had been successfully adopted, it pointed out that the electric drive introduced great flexibility into the balancing of successive industrial processes; its constant and uniform speed improved the quality of product and frequently led to marked increases in productivity. It cited the following special uses for electric energy:

"For driving printing machinery, because of its qualities of cleanliness, variation in speed, safety, and economy; for running elevators, where electrical devices for securing control in speed and direction of movement are more simple and effective than when any mechanical drive is used; for operating woodworking machinery, requiring essentially a high rate of speed; in stores, markets, and jewelry shops, and by opticians; in shipyards and erecting works, in conjunction with machine tools that can be carried to various portions of floor or yard; for driving fans and exhausters, bellows, etc; by bakers and confectioners, with whom perfect cleanliness is highly desirable; in pumping water for irrigation; in lumbering operations, enabling portable mills to be operated anywhere on the cut; in small refrigerating apparatus; on docks, to move and load merchandise; in building operations, to raise material; in cash-carrier systems in stores; for driving laundry machinery; in hotels, and so forth, for quarry work, in drilling."[12]

The industrial adoption of electric power did not increase the sales of central stations immediately, for some plants generated their own power. However, the power sales of central stations gradually increased, for their generating costs were on the whole less than those of most isolated industrial electric systems. Rate schedules were issued offering big differentials to wholesale power consumers.

[12] *ELP, 1912*, pp. 147–8.

Average rates for central station service in thirty large cities in 1913–14 ranged from 9.4 cents per kilowatt-hour for service to small residences to 3.2 cents for industrial consumers.[13]

A further impetus was given the purchase of electrical energy during World War I by the difficulties some industries experienced in getting dependable supplies of fuel; [14] by 1917 more than one-third of total central station revenue came from the sale of power. For the first time the Census requested reports on kilowatt-hours consumed for light, power, and rail needs as well as revenue (Table 4).

TABLE 4

Consumption of Electric Light and Power, 1902 and 1917

	LIGHT	POWER	RAIL	TOTAL
1917				
Kwh. sold, mil.[a]	5,112	13,175	2,986	21,273
Revenue, $ mil.[b]	283.3	161.2	23.0	467.5
Av. revenue per kwh. sold, ¢	5.54	1.22	0.77	2.20
1902				
Revenue, $ mil.[b]	70.1	9.9	2.8	82.9

[a] *ELP, 1917*, p. 82. Of total sales to 'other public service corporations' two-fifths were regarded as sales to electric railways, as suggested by the Census.
[b] From Table 3.

The average unit revenue from electricity consumed in lighting in 1917 was about seven times higher than for rail use. The spread between the rates for light and power use was narrower, their ratio being 4.5.

Such wide price divergences in electric sales in 1917 suggest marked bias in our output index which, for 1902–17, accords no separate weight to the three classes of electricity sales. As we have shown, in 1902–17 power sales increased more rapidly than sales for lighting uses. On this score alone an index that gives the same weight to the power and light components will *overstate* the growth in output. In the absence of the quantity data required for a weighted index, we resort to a device designed to reveal the degree of overstatement in our unweighted index.

[13] *Ibid.*, p. 170. Weighting the rates for large and small residences, large and small retail stores, drug stores and saloons, and for five groups of industrial users by their average monthly consumption yields an average rate for all industrial consumers of 3.6 cents per kilowatt-hour, about half that for all other (lighting) uses (6.9 cents per kilowatt-hour).

[14] *Census of Manufactures, 1929*, I, 111. In areas of acute power shortage, electric light and power companies were allowed in 1917 to make priority distributions of power in accordance with rules established by the War Industries Board, Power Section (Bernard Baruch, *American Industry in the War;* Prentice-Hall, 1941; p. 298).

To construct a weighted index of electric light and power output, certain assumptions concerning the prices charged the three consumer groups in 1902 had to be made. We do not know what these prices were, but we can infer that the price 'spread' was narrower in 1902 than in 1917, because sales for industrial uses were promoted when central stations realized that they could thereby reduce overall unit costs. As this realization deepened, the expansion of power sales in this early period was undoubtedly accompanied by rate declines greater than in those for domestic lighting.[15]

This reasoning suggests that we may make two assumptions with respect to the prices obtaining in 1902 that may serve to mark off reasonable limits. The first is that the spread remained the same; i.e., that the prices charged each class changed in the same proportion between 1902 and 1917. For example, if p_0, p'_0, and p''_0 represent the average prices charged for light, power, and rail service respectively in 1902, and p_1, p'_1 and p''_1 the corresponding prices in 1917, we assume that $\frac{p_0}{p'_0} = \frac{p_1}{p'_1}$ and $\frac{p'_0}{p''_0} = \frac{p'_1}{p''_1}$. Since we know the three revenue totals for each class in 1902 (i.e., p_0q_0, $p'_0q'_0$, and $p''_0q''_0$) and total quantity sold $(q_0 + q'_0 + q''_0)$[16] we have the six equations necessary to determine p_0, p'_0, p''_0, q_0, q'_0, and q''_0. Based on these values (App. Table A1) the 1917 index (1902:100), computed by the Edgeworth formula, is 658.2.

The second assumption, which would lie at the opposite extreme of probability, should allow for the maximum degree of change in the price ratios 1902–17, subject to the limitation that the price divergence in 1902 was less than in 1917. Such is the case if we assume that the same price was charged for all three classes of service in 1902.[17] The weighted index of output in 1917, based on

[15] Some confirmation may be had from the sample study of rates in 30 large cities in 1913–14, which indicates that the ratio of average rates for lighting use to those for power use was about 1.9, as compared with 4.5 in 1917; see note 13 above.

[16] Actually we have only total kilowatt-hours generated in 1902 (2,507.1 million) but from the 1917 ratio between current generated (25,438.3 million kilowatt-hours) and sold (21,273.1 million) we estimate the sales to be 2,096.6 million kilowatt-hours. The computations are described in Appendix Tables A1 and 2.

[17] The three classes of service have been ordered so that $\frac{p_1}{p'_1} > \frac{p'_1}{p''_1} > 1$. When the condition $\frac{p_1}{p'_1} > \frac{p_0}{p'_0}$ and $\frac{p'_1}{p''_1} > \frac{p_0'}{p''_0}$ is imposed, the maximum change in the price ratios will be associated with the case in which $\frac{p_0}{p'_0} = \frac{p'_0}{p''_0} = 1$. The latter ratios

the 1902 quantities and prices under this assumption, is 708.5. The indexes yielded by either assumption are considerably lower than the output index for 1917 (1902:100) based on unweighted quantities of kilowatt-hours generated: 1,014.6. In the absence of information concerning which assumption is preferable as a realistic representation of the 1902 price situation, we strike an average between the indexes yielded by the two — 683.3.

The intermediate (unweighted) indexes for 1907 and 1912 should now be similarly adjusted. By an even distribution of the upward 'bias' to which the unweighted index is subject 1902–17, we obtain the 'weighted' indexes of output in Table 5. Though crude, the adjustment indicates the magnitude of the difference between a price weighted and an unweighted index; the weighted index also rises rapidly, but considerably less than the unweighted.

TABLE 5
Electric Light and Power, 1902–1917
Unweighted and Weighted Indexes of Output (1902:100)

		1902	*1907*	*1912*	*1917*
1	Unweighted index	100.0	233.8	461.4	1,014.6
2	Estimated ratio of weighted to unweighted index *	1.000	.891	.782	.673
3	Weighted index (1 × 2)	100.0	208.3	360.8	683.3

* The cumulated divergence between the unweighted and weighted index was evenly distributed over the period 1902–17 by a straight-line interpolation of the difference between the ratio of the indexes in 1917 (.673) and in 1902 (1.000).

4 *Recent Trends, 1917–1942*

For the years since 1917 output can be measured more precisely than for earlier years because adequate price and quantity data are at hand for the broad consumer groups. However, the Census data must first be adjusted to include the light and power departments of electric railway companies. Such departments, whose activities correspond to those of central electric stations, were regarded by Census canvassers as belonging to the electric light and power industry and were incorporated with the statistics for the latter whenever possible. But frequently, when their accounts could not be segregated from those of the parent electric railway companies, the

cannot fall below unity, for if they did, the ranking of the three classes of service would be altered, a contingency we may rule out on the ground that the price differences characterizing the three classes are based on stable, not random, quality differences. These quality differences may, in the limiting case considered here, be reduced to zero.

departments were canvassed by the Census of Electric Railways and were excluded from the Census of Electric Light and Power.

Since electric railways have varied widely in the extent to which they have been able to separate the accounts of their subsidiary electric light and power departments, we examined the reports of the Census of Electric Railways to ascertain the amount of the light and power department electric sales not canvassed by the Census of Electric Light and Power (Table 6). The sales of light and power departments included in the electric railway industry have declined steadily since 1917, when their sales made up 8.9 percent of total kilowatt-hours sold. In 1932, the last year in which the Census classified such departments under the electric railway industry, their sales constituted a negligible part of the total. This decline may perhaps be attributed to improved accounting practices and to a tendency for electric railways to establish separate subsidiary corporate bodies to sell and distribute their surplus power. In any case, we wish to eliminate the effects of such shifts and have totals for all electric light and power departments of electric railways to add to totals for plants canvassed by the Census of Electric Light and Power.[18]

Since 1917 electric light and power output has grown rapidly: every quinquennial period, except 1927–32, registered big advances over the preceding, cumulating to 577 percent for the 25 years, or at an annual rate of nearly 8 percent.[19]

In 1917 sales for power use made up 62.3 percent of total sales, the largest share ever reached. In that crucial war year industrial activity attained peak levels with consequent demands on electric power. Sales for light, including residential consumption (in 1917 confined chiefly to illumination), commercial consumption, and municipal consumption for street lighting, contributed one-quarter, and rail use the remaining 13.4 percent.

As already noted, the price differentials for these classes of use

[18] In treating the relation of output to employment, we have to ignore the output of electric railway light and power departments because employment data for them are lacking. However, productivity trends will not be greatly affected, since both output and employment are subject to the same omissions. See Ch. 2, Sec. 3.

[19] In National Bureau business cycle chronology, 1927 and 1932 are trough years, but 1917, 1922, 1937, and 1942 are either mid-expansion or peak years, and the last four years taken as points of observation may therefore serve to indicate general secular movement. In Section 5 we refine our present observations by considering annual data.

TABLE 6

Electric Light and Power, 1917–1942

Sales for Light, Power, and Rail Use

	1917				1922				1927			
	LIGHT	POWER	RAIL	TOTAL	LIGHT	POWER	RAIL	TOTAL	LIGHT	POWER	RAIL	TOTAL
	PLANTS INCLUDED IN CENSUS OF ELECTRIC LIGHT AND POWER											
Q	5,122.5 [a]	13,174.8	2,985.8 [b]	21,283.1	9,781.7 [e]	18,613,4	4,557.2 [f]	32,952.3	23,132.4 [g]	33,707.8	6,772.2	63,612.5
R	282.8 [a]	161.2	23.0 [b]	467.0	561.6 [e]	334.8	48.4 [f]	944.9	1,141.3	461.5	64.2	1,667.0
P	5.521	1.224	0.771	2.194	5.742	1.799	1.063	2.867	4.934	1.369	0.948	2.621
	ELECTRIC RAILWAY LIGHT AND POWER DEPARTMENTS [c]											
Q	544.9	1,390.8	155.1	2,090.8	768.6	1,334.5	234.7	2,337.7	23.9	16.6	2.3	42.8
R	30.1	17.0	1.2 [d]	48.3	44.1	24.0	2.5	70.6	1.4	0.4	*	1.8
P	5.521	1.224	0.771	2.310	5.742	1.799	1.063	3.022	5.779	2.374	1.164	4.210
	ALL CENTRAL STATIONS AND ELECTRIC RAILWAY LIGHT AND POWER DEPARTMENTS											
Q	5,667.4	14,565.6	3,141.0	23,374.0	10,550.2	19,947.8	4,791.9	35,290.0	23,156.3	33,724.4	6,774.5	63,655.3
R	312.9	178.2	24.2	515.3	605.8	358.8	50.9	1,015.5	1,142.7	461.9	64.2	1,668.8
P	5.521	1.224	0.771	2.205	5.742	1.799	1.063	2.878	4.935	1.370	0.948	2.622
	1932 [c]				1937 [h]				1942 [i]			
	PLANTS INCLUDED IN CENSUS OF ELECTRIC LIGHT AND POWER											
Q	27,589.5	33,151.3	5,155.1	65,896.0	38,860.6	55,491.2	6,446.4	100,798.2	59,121.2	92,584.3	6,628.0	158,333.5
R	1,276.4	498.9	45.8	1,821.1	1,466.5	644.4	56.5	2,167.4	1,908.2	888.5	53.6	2,850.3
P	4.626	1.505	.888	2.764	3.774	1.161	.877	2.150	3.228	.960	.809	1.800
	ALL CENTRAL STATIONS AND ELECTRIC RAILWAY LIGHT AND POWER DEPARTMENTS											
Q	27,592.7	33,155.4	5,157.2	65,905.2	38,860.6	55,491.2	6,446.4	100,798.2	59,121.2	92,584.3	6,628.0	158,333.5
R	1,276.6	499.0	45.8	1,821.3	1,466.5	644.4	56.5	2,167.4	1,908.2	888.5	53.6	2,850.3
P	4.626	1.505	.888	2.764	3.774	1.161	.877	2.150	3.228	.960	.809	1.800

* Less than $50,000.

Notes to Table 6

The data, except those for 1942, are from successive quinquennial reports of the Census of Electric Light and Power and the Census of Electric Railways, 1917–37. Data for 1942 are from the Edison Electric Institute *Statistical Bulletin 10* (May 1943).

Quantity (Q) data are in terms of mil. kwh; revenue (R) data in mil. dollars; price (P) data in cents per kwh.

A word of explanation is necessary for the use of the classification of electric sales by Light, Power, and Rail Use, which was superceded in 1927 by a more detailed classification of electric sales. 'Light' includes the sub-categories entitled in the 1927 and later reports 'Farm service', 'Domestic service', 'Small light and power (retail) commercial service', and 'Municipal street lighting'. The Census noted that 'an appreciable fraction' of the energy reported as sold to users of commercial service for 'small light and power' may be used for power purposes, though the 'major portion is undoubtedly used for lighting' (*ELP, 1927*, p. 31).

'Power' includes the 1927 classifications 'Large light and power (wholesale)' and 'Other service'. The latter was included with Power sales because the average rate for such service was closer to that of power than of light. Undoubtedly some slight amounts of current are included in power consumed for lighting purposes, but by far the greater part is utilized for mechanical power and electro-thermal and electro-chemical processes.

The Rail component in 1927 and later years includes current sold to both electric railways and steam railroads. In 1917 and 1922, however, sales to other electric light and power companies were included in the Rail component and, as explained in note d below, had to be excluded to avoid duplication (see also *ELP, 1922*, p. 3).

[a] We included 9.95 mil. kwh., valued at $5.1 mil., reported as 'free service' by municipal plants (*ELP, 1917*, pp. 82, 115, 116); see note d.

[b] In 1917 the Census included sales to railways with sales to other electric utility companies, but indicated that railway sales made up about two-fifths (*ELP, 1917*, p. 83). To avoid duplication we excluded sales to other electric utilities.

[c] Data for electric railway light and power departments were taken from successive reports of the Census of Electric Railways. For 1917 and 1922 revenue data alone were reported; the corresponding quantity data were therefore estimated by applying to the reported revenue figures the appropriate revenue per kwh. averages obtained for plants in the electric light and power industry. Quantity and revenue data were reported in 1927 and 1932; in 1932 sales were: Light, 3.1 mil. kwh. valued at 5.2¢. per kwh; Power, 4.1 mil. kwh. valued at 1.9¢. per kwh; Rail, 2.1 mil. kwh. valued at 0.2¢. per kwh. By 1937 no electric light and power departments were retained in the electric railway industry (*Census of Electric Railways, 1922*, p. 233; *1927*, p. 168; *1932*, p. 80).

[d] In 1917 the sales of current by electric railway light and power departments to other electric railways were included with sales to other light and power companies. The two categories were separated on the basis of the ratios prevailing in 1922 when sales of current to light and power companies amounted to $9.6 mil. and sales to other electric railways to $2.5 mil. (*ibid., 1922*, p. 233).

[e] We included 4.55 mil. kwh., valued at $4.7 mil., reported as 'free service' by municipal plants (*ELP, 1922*, pp. 77, 83, 130). Examination of the Census data makes it evident that municipal plants in 1917 and 1922 included a large part of such service in the figure they reported for quantity sold, but did not include its estimated value in their sales.

For the sake of consistency and simplicity, we regarded all free service of municipal plants as sales and included its estimated value in the revenue totals. This treatment is in close accord with Census usage in 1927 and presumably later years, when the sales for municipal street lighting reported by municipal plants included all service 'for which a charge was made by the light and power department'. Probably in 1927 and later years municipal plants were more careful in reporting the necessary charges for lighting service rendered parent municipalities.

[f] In 1922 the Census included 4,557.2 mil. kwh. sold to electric railways with sales to other electric utilities, valued at $48.4 mil. The size of the electric railway component was indicated in the 1927 report, p. 27; see also *ELP, 1922*, pp. 77, 83, 130.

[g] In 1927 electric plants reported 3,192.9 mil. kwh., valued at $154.7 mil., but did not specify the class of service. The Census indicated that such service was probably consumed by those receiving domestic service and by small commercial users of light and power. Accordingly, we included such service in 'Light' (*ELP, 1927*, p. 31).

[h] The 1937 Census data included interdepartmental sales, which we excluded to attain comparability with earlier Census data. The 1937 Census did not separate Commercial service into Small (retail) and Large (wholesale) service. Since this division is essential for our threefold classification, we based it on comparable totals ascertained by the EEI (see Table 1, note).

[i] In the absence of Census data for 1942 we reproduced the corresponding data reported in EEI *Statistical Bulletin 10*, May 1943, p. 20. The EEI total for all sales may be taken as fairly comparable with that of the Census, for while the data are 'based on reports covering 94% of the electric utility companies and 40% of the municipal and cooperative utilities', the published totals are described by the EEI as providing 100% coverage (*ibid.*, p. 1). In 1937, however, the EEI totals fell somewhat short of those reported by the Census (see Table 21).

varied widely, ranging from 0.8 cent per kilowatt-hour for rail consumption to 5.5 cents for lighting. This range narrowed (Chart 2) as the average rate for light declined from a peak of 5.7 cents per kilowatt-hour in 1922 to 3.2 cents in 1942. The rate for rail use changed little, ranging from 0.8 cent to 1.0 cent throughout the 25 years. After 1917 the rate for industrial power declined considerably less than that for light, falling from 1.8 cents per kilowatt-hour to 1.0 cent. The major price decline and the greatest expansion since 1917 were in current for light (Chart 1).[20] From 1917 current consumed mainly for light rose steadily to well over one-third of the sales total throughout the 'thirties; current for power dropped from 62 to 58 percent in 1942.

In contrast, from 1902 to 1917, power sales far out-stripped light sales.[21] This relation was altered, as we shall see, by the profound changes in domestic consumption after World War I.

[20] Trends in average revenue per unit do not, of course, necessarily coincide with trends in utility rates, for the former are greatly affected by shifts in the quantities of kilowatt-hours consumed at various rate levels.

[21] Based on Assumption A in Appendix Table A1, power sales increased at least 1,796 percent 1902–17; light 372 percent. Assumption B yields an even greater divergence in the respective percentage increases.

Though domestic use of electricity increased rapidly in the first two decades of the century, it lagged behind power sales. Undoubtedly the growth in the number of domestic users of electricity was rapid before 1920 but not as rapid as it would have been had illumination not been the only large domestic use of electricity.[22] Moreover, many remarkable gains in lamp efficiency greatly reduced the quantity of current required per unit of illumination. The efficiency of incandescent lamps may be measured in terms of the lumen, defined by the National Bureau of Standards as "the luminous flux on a unit surface all points of which are at a unit distance from a uniform point source of one candle". In 1880 the average carbon lamp sold had an efficiency rating of 1.7 lumens per watt. The efficiency of successive carbon lamps rose slowly to 3.4 lumens per watt in 1900; then jumped when the vacuum tungsten lamp, which in 1910 was rated at 8.3 lumens per watt, was introduced. The average vacuum tungsten lamp sold in 1920 was nearly three times as efficient as its 1900 predecessor.[23]

In 1920, when illumination constituted the major domestic use for electricity, the average annual domestic consumption was estimated to be 339 kilowatt-hours per customer. Through the successful introduction of many low-cost electrical appliances that have revolutionized the modern dwelling, illumination began to lose its dominant position. By 1942, when lighting was estimated to account for merely one-third of total electricity consumed in the household, annual domestic consumption had risen threefold, to 1,022 kilowatt-hours per customer.[24]

In 1927 the Census took note of the changing character of domestic consumption by discarding the classification of sales for light, and making four classes of high-valued service: farm, domestic, small commercial (retail), and municipal street lighting (Table 7). Of these, domestic service is the largest and highest-valued. Domestic service tripled from 1927 to 1942, while total sales rose about 150 percent. The average rate for domestic consumption declined from 6.7 cents to 3.7 cents per kilowatt-hour. The average rate for all sales declined less — from 2.6 cents to 1.8 cents — but this smaller decline reflects in part the increas-

[22] Domestic consumers were estimated to be 8 million in 1920 (Edison Electric Institute; *Statistical Bulletin 9*, 1942, p. 23).

[23] H. B. Neill, *Forty-Eight Million Horses* (Lippincott, 1940), p. 67.

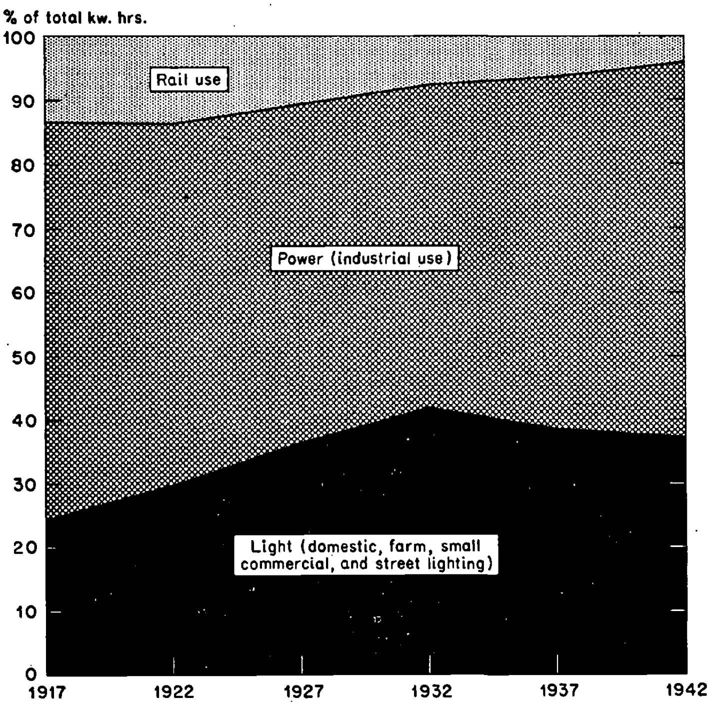
[24] *Statistical Bulletin 10* (Edison Electric Institute, 1943), pp. 22, 23.

ing share of the high-valued domestic component in the sales total.

Another high-valued component of electric consumption that increased at a higher than average rate after World War I is farm service, which more than tripled from 1927 to 1937. This increase,

CHART 1

Changing Composition of Electric Consumption 1917-1942

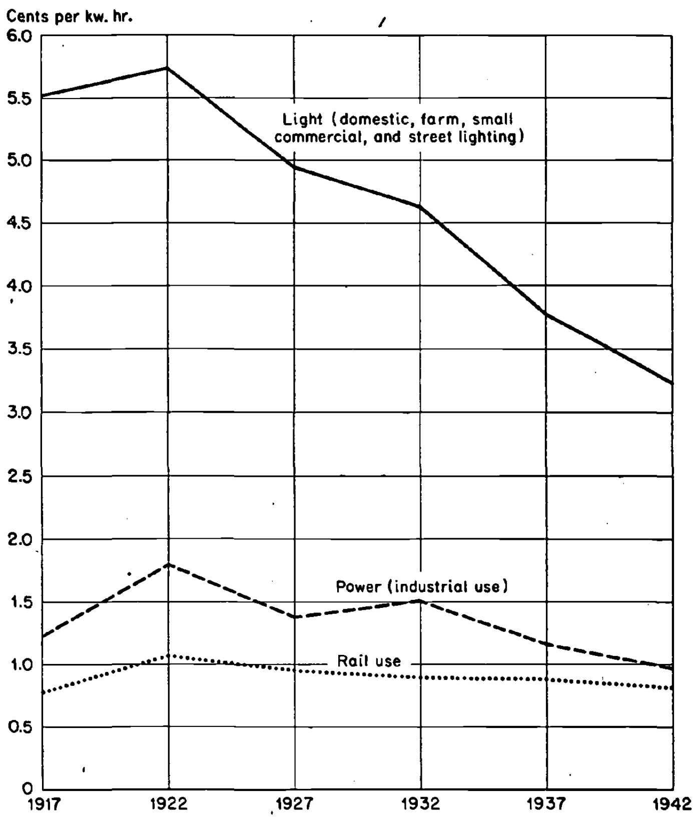


Based on Table 6.

associated with an increase in the average price paid for farm service — from 2.1 cents to 2.7 cents per kilowatt-hour in 1937 and 2.6 cents in 1942 — is itself a reflection of the extension of electrification to remote rural dwellings. In the past, farm service has included a larger proportion of what is essentially a commercial service, namely, the supply of low revenue electricity for farm power and irrigation purposes. Indeed, the initial farm service projects were designed primarily for western farming enterprises that required inexpensive power for irrigation systems. In recent years, however, the rapid growth of electric consumption for domestic use in farm dwellings, a higher-valued farm service, has raised the average price of *all* current supplied to farms, for both domestic and commercial uses.

CHART 2

Electric Light and Power, 1917–1942
Trends in Average Revenue per Kilowatt Hour



Based on Table 6.

Small commercial sales of light have expanded as rapidly as total sales but not as rapidly as domestic. In 1942 domestic and small commercial sales were each about one-sixth of total sales, but small commercial sales constituted a lower proportion of total revenue, costing an average of 2.8 cents per kilowatt-hour as compared with the domestic rate of 3.7 cents. The only component of the light category that lagged behind total sales was municipal street light-

TABLE 7

Electric Light and Power, 1927–1942

Sales to Ultimate Consumers

Quantity, mil. kwh; Revenue, $ mil; Price, ¢ per kwh.

	1927			1932			1937 (comparable with 1932) [b]			1937 (comparable with 1942) [c]			1942 [c]		
	Q	R	P	Q	R	P	Q	R	P	Q	R	P	Q	R	P
Light	*23,156*	*1,143*	*4.935*	*27,593*	*1,277*	*4.626*	*38,861*	*1,466*	*3.774*	*39,299*	*1,487*	*3.783*	*59,721*	*1,908*	*3.228*
Farm	836	17	2.071	1,504	43	2.844	2,671	71	2.665	1,670	38	2.258	2,890	75	2.596
Domestic	8,421 [a]	566	6.718	11,791	650	5.511	16,815	726	4.320	17,691	760	4.295	26,937	990	3.676
Small commercial (retail)	12,157 [a]	482	3.968	12,061	492	4.078	17,339	595	3.432	18,075	616	3.410	27,233	767	2.817
Municipal st.	1,743	77	4.434	2,236	92	4.116	2,036	74	3.628	1,863	73	3.905	2,061	76	3.671
Power	*33,724*	*462*	*1.370*	*33,155*	*499*	*1.505*	*55,491*	*644*	*1.161*	*53,762*	*622*	*1.157*	*92,584*	*888*	*0.960*
Large commercial (wholesale)	33,488	457	1.364	32,384	483	1.493	52,879	605	1.144	51,360	583	1.136	88,378	828	0.937
Other, public authorities, etc.	236	5	2.127	771	16	2.012	2,612	39	1.500	2,403	39	1.615	4,206	60	1.431
Rr. & rw. use	*6,774*	*64*	*0.948*	*5,157*	*46*	*0.888*	*6,446*	*56*	*0.877*	*5,712*	*48*	*0.836*	*6,628*	*54*	*0.809*
St. & interurban	6,256	59	0.941	4,395	39	0.882	4,888	42	0.869	4,428	37	0.836	4,256	35	0.830
Electrified steam rr.	518	5	1.031	762	7	0.921	1,558	14	0.901	1,284	11	0.838	2,372	18	0.771
Total	63,655	1,669	2.622	65,905	1,821	2.764	100,798	2,167	2.150	98,773	2,156	2.183	158,334	2,850	1.800

The sources are those indicated in Table 6. The sum of the subtotals here and in succeeding tables may not in all instances equal the totals because the figures have been rounded.

The data for 1927 and 1932 include sales of electric light and power departments classified in the electric railway industry, but they were small.

[a] In 1927 electric plants reported 3,192.9 mil. kwh., valued at $154.7 mil., which were not distributed by class of service. As the Census indicated that such service probably went to domestic consumers and small commercial consumers, we divided it according to the relative importance of these two classes: 40.9 percent of the undistributed kwh. sales and 54.0 percent of the undistributed revenue to domestic, the remainder to small commercial users (*ELP., 1927*, p. 31).

[b] The 1937 Census data included interdepartmental sales which we excluded to attain comparability with earlier Census data. Moreover, it did not divide Commercial service into Small (retail) and Large (wholesale) service. We did this on the basis of comparable totals provided by the Edison Electric Institute (see note to Table 1).

[c] In the absence of Census data after 1937 we reproduce the corresponding data reported by the Edison Electric Institute (*Statistical Bulletin 10*, May 1943, p. 20), which may be accepted as more or less comparable. While the EEI describes its data as providing 100 percent coverage, its published totals for 1937 (reproduced here to provide a basis of comparison with the 1942 EEI data) fall somewhat short of those reported by the Census. However, the agreement is close enough to warrant the use of the EEI material to extend the trends indicated by Census data. The greatest discrepancy between the two sets of data for 1937 affects farm and domestic service, which after 1937 were revised to retain in domestic service small amounts of farm residential service formerly included in farm service.

ing, which has not exceeded its 1932 level. The decline in its rate has been moderate, and in 1942 the average rate was 3.7 cents.

The sole other electric service whose sales have declined secularly is rail use (Chart 1). The decline, due entirely to the falling off in the consumption of power purchased by street and inter-urban railway companies, whose traffic has been declining for many years (Table 7), is counteracted in part by rapid gains in the use of electric power by electrified divisions of steam railroads, which has more than quadrupled since 1927 and shows signs of soon outranking the consumption of power by street railways.

There has been no marked relative increase in the service rendered large commercial users of electric power since 1917 (Table 6 and Chart 1), although the decline in the consumption of power for rail use has contributed to an increase in the shares of all other components. Certainly, power consumption lagged somewhat behind light. From 1917 to 1942, which represent not too dissimilar phases of cyclical activity, power consumption increased some 535 percent, or at an average annual rate of 7.7 percent. While this is a vigorous rate of expansion, the growth of the light component has been more rapid since 1917, averaging 9.8 percent annually, in large part reflecting the change in the volume and character of domestic consumption.

We are now in a position to assess the precise effects of these shifts in the composition of electric output on our estimates of the total. The estimates are based on 1917–27 and 1927–37 so that we may utilize to the full the most detailed sets of comparable data. During 1917–27 (Table 8), when the low-valued services lagged behind the high-valued, light sales registered increases equivalent to 15.1 percent annually; the corresponding gains in power and rail sales were little more than half as much. The weighted index, the resultant of these widely disparate movements, gained 12.8 percent annually, the unweighted, 10.5 percent.

The changes since 1927 (Table 9) follow the trends of the preceding 10 years, although the classification of output is more detailed. On balance, the high-valued services have continued to gain more rapidly than the low-valued; for each five years 1927–42 the weighted index, based on 1927, has reached higher levels than the unweighted. However, the two indexes diverged more in the depression year 1932, when the commercial, industrial, and rail

TABLE 8

Electric Light and Power, 1917–1927

Indexes of Output based on Sales to Ultimate Consumers

(millions of kilowatt-hours)

	1917	1922	1927
Light	5,667	10,550	23,156
Index (1917:100)	100.0	186.2	408.6
Power	14,566	19,948	33,724
Index (1917:100)	100.0	137.0	231.5
Rail	3,141	4,792	6,774
Index (1917:100)	100.0	152.6	215.7
Total	23,374	35,290	63,655
Indexes of Total Output			
Unweighted (1917:100)	100.0	151.0	272.3
Weighted (1917:100) *	100.0	168.0	333.1
Weighted (1902:100) *	683.3	1,148.2	2,276.3

* The computation of the weighted indexes of output is described in detail in Appendix Table A3.

TABLE 9

Electric Light and Power, 1927–1942

Indexes of Output based on Sales to Ultimate Consumers

(millions of kilowatt-hours)

	1927	1932	1937	1942 [a]
Light				
Farm	836	1,504	2,671	2,890
Index (1927:100)	100.0	180.0	319.6	552.9
Domestic	8,421	11,792	16,815	26,937
Index (1927:100)	100.0	140.0	199.7	304.1
Small commercial	12,157	12,061	17,339	27,233
Index (1927:100)	100.0	99.2	142.6	214.9
Municipal street lighting	1,743	2,236	2,036	2,061
Index (1927:100)	100.0	128.3	116.8	129.2
Power				
Large commercial	33,488	32,384	52,879	88,378
Index (1927:100)	100.0	96.7	157.9	271.7
Other, public authorities, etc.	236	771	2,612	4,206
Index (1927:100)	100.0	326.5	1,106.1	1,936.3
Rail				
Street & interurban	6,256	4,395	4,888	4,256
Index (1927:100)	100.0	70.2	78.1	75.1
Electrified steam rr.	518	762	1,558	2,372
Index (1927:100)	100.0	147.1	300.8	555.6
Total	63,655	65,905	100,798	158,334
Indexes of Total Output				
Unweighted (1927:100)	100.0	103.5	158.4	253.8
Weighted (1927:100) [b]	100.0	113.4	166.7	259.4
Weighted (1902:100) [b]	2,276.3	2,581.4	3,794.6	5,904.4

[a] The 1942 indexes were based on the Edison Electric Institute data for 1937–42 as shown in Table 7, then spliced to the corresponding 1937 Census indexes.

[b] The construction of the weighted indexes is described in Appendix Table A4.

power services registered absolute declines from the levels attained in 1927; in 1937 and 1942 this divergence was narrowed. Indeed, in 1937–42 Edison Electric Institute data indicate somewhat greater increases in the low-valued services than in the high-valued, the unweighted index rising 60.3 percent, and the weighted, 55.6 percent. But for 1927–42, as a whole, the movements of the two indexes confirm the tendencies displayed in the preceding decade, namely, that the high-valued residential and lighting services grow more rapidly than the low-valued industrial power services. Expansion of all electric services except municipal street lighting and sales to electric railways has been remarkably sustained during the 25 years.

The movements of the weighted and unweighted indexes since 1917 are in contrast to the movements in the early years (Table 10 and Chart 3). When both indexes are based on 1917 and plotted together, the weighted index, which gives greater weight to the high-valued services, gains less rapidly before 1917 and more rapidly after 1917, indicating a shift in emphasis within the industry since 1917 in favor of the high-valued services.

TABLE 10
Electric Light and Power, Five-Year Intervals, 1902–1942
Unweighted and Weighted Output Indexes

	1902	1907	1912	1917	1922	1927	1932	1937	1942
				UNWEIGHTED					
1902:100	100.0	233.8	461.4	1,014.6	1,531.9	2,763.2	2,860.9	4,375.5	7,014.0
1917:100	9.9	23.0	45.5	100.0	151.0	272.3	282.0	431.2	691.2
				WEIGHTED					
1902:100	100.0	208.3	360.8	683.3	1,148.2	2,276.3	2,581.4	3,794.6	5,904.4
1917:100	14.6	30.5	52.8	100.0	168.0	333.1	377.8	555.3	864.1

Tables 5, 8, and 9.

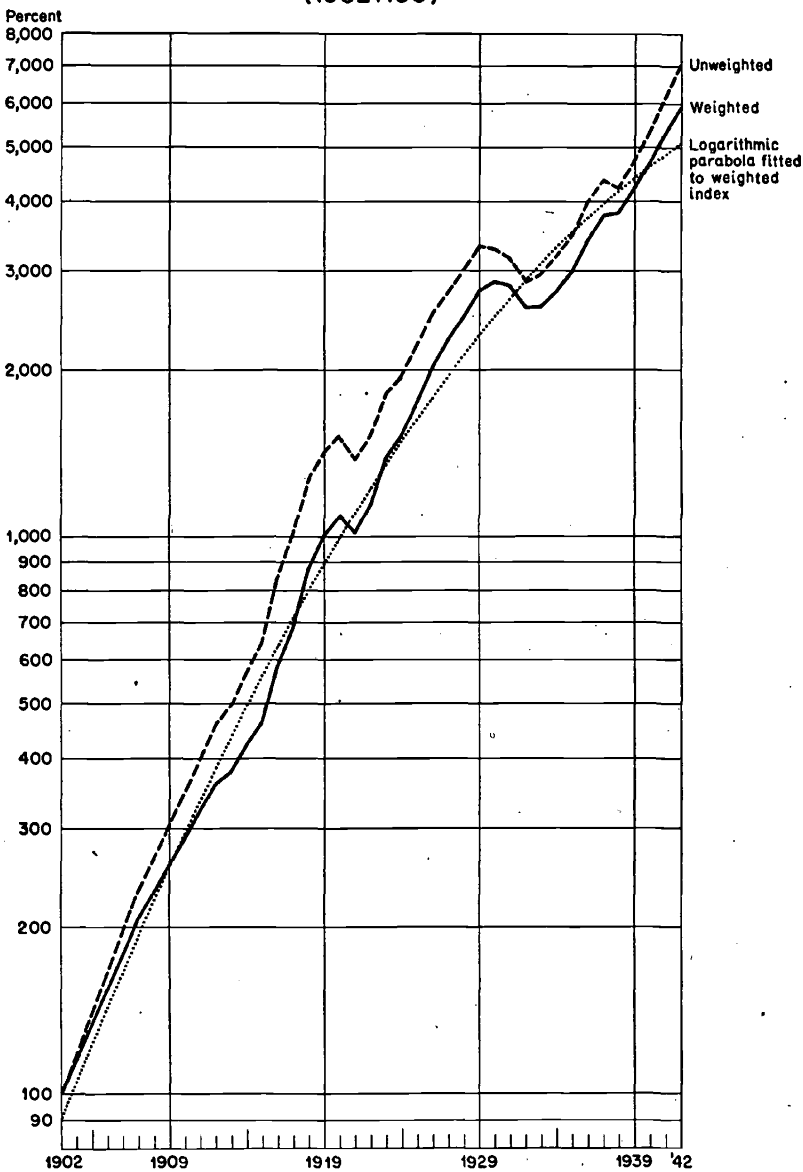
In this respect three distinct stages may be discerned. Before 1902, despite the absence of statistical records, the industry's growth can be attributed to the extension of domestic electric lighting rather than to the industrial use of current for either light or power — a natural consequence of the invention of the incandescent lamp. (In 1902, for instance, revenue from lighting made up more than four-fifths of the gross revenue of central electric stations.) From 1902 to 1917, sales of electricity for industrial power uses grew most rapidly; since 1917, sales for domestic consumption have made the greatest gains.

5 *Final Indexes of Output, 1902–1942*

With the aid of Census material we established quinquennial benchmarks in tracing the movement of total electric light and power out-

CHART 3

Electric Light and Power, 1902–1942
Unweighted and Weighted Indexes of Output
(1902:100)



Based on Table 13 and Appendix D.

Ratio scale

put. Before analyzing the over-all estimates we must interpolate annual values to avoid any possible distortion of secular trends arising from the cyclical factors affecting the Census year indexes.

For recent years two collections of annual data are suitable for purposes of interpolation: those of the Edison Electric Institute and the Federal Power Commission. As the latter does not present output totals for the several classes of service, we examine first the material published by the former, i.e., the price and quantity data, by class of service, for utilities reporting to the Edison Electric Institute since 1933 and to the Institute's predecessor, the National Electric Light Association, 1926–33 (Table 11). A weighted output index, constructed from these data (Table 12), was used to interpolate the weighted Census output index after 1926 (App. Table A5). For 1912–27 the annual interpolation was based on Federal Power Commission data (App. Table A6).

The interpolated entries reveal that the growth in output since the turn of the century (Chart 3), was not entirely uninterrupted, though the movements in the 1920–21, 1929–33, and 1937–38 contractions appear as rather minor retardations of the broad upward sweep. Total output rose nearly sixtyfold during the forty years since 1902; i.e., at an average annual rate of 10.7 percent.

The few interruptions to the industry's expansion were brief. But despite the relative youth of the industry, it would be surprising if its rate of growth showed no signs of slackening after four decades, and Chart 3 offers some visual evidence that growth during the last two decades has been less rapid.

A measure of the rate of retardation in the growth of electric light and power output is afforded by fitting a logarithmic parabola to the movements of the output index. Such a fitted curve, of the type $y = ka^x b^{x^2/2}$, has the virtue of yielding a single parameter b, which measures the degree of retardation or acceleration. The curve fitting process enables us to examine the secular changes in the rate of growth undisturbed by random or cyclical factors. Thus, the curve traced by a logarithmic parabola fitted to the output index yields an annual rate of increase that declines from 17.8 in 1900 to 14.4 in 1910, to 11.1 in 1920, to 7.9 in 1930 and to 4.7 in 1940. In other words, the fitted trend is subject to retardation at an annual rate of 0.3 percent.[25] The annual rate of growth at the close of the

[25] The equation of the fitted curve is: $y = 69.966(1.0898)^x(.99705)^{x^2/2}$, x centered at 1927. The curve fitting process is discussed in Appendix D.

TABLE II

Electric Light and Power, Edison Electric Institute Data, 1926–1942

Annual Sales

Quantity, mil. kwh; Price, ¢ per kwh.

	FARM	DOMESTIC	SMALL COMMERCIAL	MUNICIPAL ST. LIGHTING	LARGE COMMERCIAL	OTHER	ST. & INTERURBAN RW.	ELECTRIFIED STEAM RR.	TOTAL
1926									
2	723	6,727	9,485	1,589	31,993	196	4,951	426	56,089
p	2.994	6.976	4.506	4.281	1.488	2.873	0.962	1.026	2.710
1927									
2	861	7,538	10,766	1,741	34,540	262	5,039	504	61,251
p	3.014	6.796	4.478	4.436	1.461	2.196	0.952	1.027	2.712
1928									
2	1,387	8,420	11,692	1,911	37,715	312	4,991	560	66,988
p	2.634	6.602	4.447	4.344	1.403	2.462	0.932	0.993	2.664
1929									
2	1,602	9,526	13,106	2,038	42,971	412	5,049	590	75,294
p	2.538	6.302	4.240	4.334	1.375	2.505	0.916	1.014	2.575
1930									
2	1,789	10,702	13,944	2,226	40,148	508	4,997	591	74,906
p	2.610	6.001	4.128	4.287	1.411	2.436	0.922	1.017	2.658
1931									
2	1,879	11,373	13,544	2,330	36,937	664	4,549	626	71,902
p	2.700	5.744	4.168	4.261	1.475	2.220	0.921	1.074	2.748
1932									
2	1,579	11,494	12,106	2,033	30,964	926	4,040	568	63,711
p	2.984	5.572	4.138	4.418	1.532	1.951	0.908	1.088	2.847
1933									
2	1,632	11,359	11,589	1,893	33,858	926	3,991	668	65,918
p	2.848	5.492	4.071	4.390	1.383	2.077	0.879	0.997	2.662

1934									
2	1,858	12,233	12,278	1,896	36,944	945	4,237	692	71,082
p	2.648	5.304	3.994	4.316	1.352	2.020	0.859	0.965	2.577
1935									
2	1,692	13,496	13,588	2,078	40,865	842	4,194	841	77,596
p	2.860	4.990	3.821	3.823	1.300	1.891	0.869	0.945	2.464
1936									
2	2,138	14,992	15,612	2,222	48,655	908	4,401	1,116	90,044
p	2.772	4.649	3.601	3.636	1.194	1.896	0.850	0.860	2.271
1937 (*comparable with earlier years*)									
2	2,389	16,876	17,558	1,909	53,546	1,453	4,450	1,265	99,446
p	2.844	4.386	3.445	3.887	1.149	2.087	0.844	0.843	2.193
1937 (*comparable with later years*)									
2	1,670	17,691	18,075	1,863	51,360	2,403	4,428	1,284	98,773
p	2.258	4.295	3.411	3.905	1.136	1.615	0.836	0.838	2.183
1938									
2	1,577	19,371	19,137	1,929	43,140	2,451	3,989	1,449	93,043
p	2.468	4.143	3.303	3.853	1.202	1.640	0.840	0.828	2.313
1939									
2	1,882	21,084	20,722	2,002	51,108	2,538	3,918	1,847	105,100
p	2.418	3.999	3.188	3.768	1.120	1.607	0.831	0.781	2.174
1940									
2	1,991	23,318	22,373	2,048	59,557	2,720	3,974	1,936	117,917
p	2.485	3.842	3.081	3.713	1.060	1.673	0.824	0.778	2.065
1941									
2	2,352	25,124	24,628	2,110	76,061	3,093	3,960	2,118	139,446
p	2.738	3.734	2.944	3.646	0.997	1.591	0.820	0.778	1.908
1942									
2	2,890	26,937	27,233	2,061	88,378	4,206	4,256	2,372	158,334
p	2.596	3.676	2.817	3.671	0.937	1.431	0.830	0.771	1.800

For 1926–37 the quantity and price data are from the Edison Electric Institute *Statistical Bulletin 6*, May 1939, pp. 1–2. After 1937 the farm classification was narrowed somewhat and the domestic classification widened. Both sets of data are shown for 1937, to provide an overlap.

The data for 1937–42 are from *Statistical Bulletin 10*, May 1943, pp. 20–1.

TABLE 12
Electric Light and Power, Edison Electric Institute Data, 1926–1942
Indexes of Output, Unweighted and Weighted (1927:100)

	UNWEIGHTED	WEIGHTED	INTERPOLATED WEIGHTED (Census)
1926	91.6	90.1	90.1
1927	100.0	100.0	100.0
1928	109.4	110.4	109.5
1929	122.9	124.3	122.3
1930	122.3	129.6	126.6
1931	117.4	128.6	124.6
1932	104.0	118.0	113.4
1933	107.6	118.6	113.6
1934	116.0	127.3	121.4
1935	126.7	139.4	132.4
1936	147.0	159.6	150.9
1937	162.4	177.0	166.7
1938	152.9	177.7	167.4
1939	172.8	196.9	185.4
1940	193.8	217.9	205.2
1941	229.2	247.5	233.1
1942	260.3	275.4	259.4

The unweighted output index is based directly on the kwh. sales totals in Table 11. The construction of the weighted index and the interpolated Census index of output are discussed in note to Appendix Table A5.

TABLE 13
Electric Light and Power, 1902–1942
Unweighted and Weighted Output Indexes (1929:100)

	UNWEIGHTED	WEIGHTED		UNWEIGHTED	WEIGHTED
1902	3.0	3.6	1926	75.8	73.5
			1927	82.8	81.7
1907	7.0	7.5	1928	90.3	89.5
			1929	100.0	100.0
1912	13.8	13.0	1930	98.6	103.5
1913	14.9	13.6	1931	94.5	101.9
1914	17.2	15.2	1932	85.7	92.7
1915	19.3	16.6	1933	88.8	92.8
1916	25.4	21.1	1934	95.8	99.2
1917	30.4	24.5	1935	104.6	108.2
1918	38.2	31.4	1936	120.0	123.4
1919	43.0	36.0	1937	131.1	136.3
1920	45.8	39.3	1938	126.4	136.8
1921	41.4	36.3	1939	142.1	151.6
1922	45.9	41.2	1940	159.1	167.7
1923	54.5	50.0	1941	185.7	190.5
1924	58.7	54.9	1942	210.2	212.0
1925	66.6	63.5			

Appendix Tables A5, 6, and 7.

fourth decade, while high compared with that of most industries in this period, is little more than one-third as high as at the turn of the century.[26]

6 Quality of Electric Light and Power Output

We cannot end our discussion of the measurement of electric light and power output without examining one particular type of 'bias' to which indexes of output are subject; they do not reflect changes in quality which may affect the unit of measurement.

The kilowatt-hour sold to ultimate consumers cannot be regarded as unaffected by temporal changes in quality, i.e., changes that are not reflected in our final index.[27] Quality changes have affected the units that measure the output of both generation and distribution. Although they are difficult to evaluate, it is instructive to enumerate them.

The original Edison system prevailed until about 1900, when it was recognized that alternating current could be transmitted over much longer distances than direct current, because of the ease with which its voltage (or electrical pressure) could be stepped up. The merits of the two systems were hotly debated in the closing years of

[26] The use of the logarithmic parabola for curve fitting purposes means assuming that an industry's pattern of growth will usually in time increasingly reflect the effect of retardation, an assumption borne out (though not for every industry) by the work of A. F. Burns in *Production Trends in the United States Since 1870* (National Bureau of Economic Research, 1934). Granted the assumption, it is tempting to extrapolate the fitted curve to establish what might presumably be regarded as the peak year of the industry's growth, after which time the factors making for contraction may be expected to outweigh those making for expansion. Such a procedure is of course subject to all the dangers implicit in the extrapolating process and could hardly serve as a basis for prophecy, for curve fitting analysis is valid only as a convenient means of summarizing an industry's development during some period of observation.

However, if we set the ratio of annual y values ($ab^{x+.5}$) equal to 1 and solve for x, 1955 is the hypothetical peak year. The degree of remoteness (or proximity) of the presumptive peak year derived as above may itself serve to indicate the degree of maturity achieved by an industry within the years observed. But it is a very crude indicator of maturity because it may be shifted by choosing different periods for the fitted curve.

[27] An index of output will be subject to a downward bias if the quality of the product improves over time and the improvements are not reflected by an adequate system of weights. An adequate weighting system is possible only if the aggregate of units produced can be grouped into classes whose average prices may be said to reflect quality differences. The output index even so will reflect only those quality changes which involve shifts in the relative importance of different classes; quality changes within classes must continue to go unrecorded.

the 19th century. Proponents of direct current maintained that the high voltages required in the transmission of alternating current constituted a great danger to the householder.[28] Whatever the dangers, they were soon overcome, and the lower costs attending the transmission of alternating current soon assured it the dominant position.

Direct and alternating current are not interchangeable except by a troublesome conversion process. For some present-day uses alternating must be converted into direct current (for instance, in charging storage batteries); for others (e.g., constant speed motors, time clocks, etc.), alternating current may be preferable. On the other hand, for many domestic and industrial needs alternating current may be of no qualitative gain (or loss) to the consumer. In any case, since the change from direct to alternating current was in large part made in the early years of the industry, our computed index, which begins in 1902, remains relatively unaffected.[29]

In the distributive phase of the electric light and power industry, many qualitative changes have taken place, most of which may be registered by weights assigned to the various types of service. However, the greater reliability of present-day service due to technical advances in the construction and maintenance of modern transmissions systems cannot be measured in this way. The interconnecting of transmission systems, which has been going on within and between regions since the introduction of alternating current, has also contributed greatly to minimizing the possibilities of interrupted service due to breakdowns in individual systems. But how much it is difficult to say, as we know little about the reliability of service achieved in the early years of the period under review. A similar improvement in the quality of service rendered comes from 24 hour daily service.[30]

[28] During the so-called 'war of the currents', alternating current was adopted by the New York State Prison authorities for electrocutions. Advocates of direct current were quick to point out that this confirmed their warnings concerning the dangers of alternating current to human life! (J. W. Hammond, *Men and Volts;* Lippincott, 1941; p. 109.)

[29] In cities where there is still a demand for direct current, the current usually originates and is transmitted as alternating current and converted at or very near the point of consumption.

[30] The American Gas and Electric Company described conditions in its Steubenville plant in the early days as follows: "On Saturday nights . . . then peak load time . . . the instruments often showed that the 500 kilowatt turbines were turning out from 650 to 750 kilowatts per unit. This overloading condition finally resulted in the complete

The interconnection and extension of transmission systems has, in addition, lengthened the average distance over which a kilowatt-hour travels from origin to destination. Such a lengthening might perhaps be regarded as an advance in the average quality of service rendered, but if so, it is a quality change that, conceptually at least, may be measured by an adequate weighting system. At any given period many qualitative differences may exist among types of electrical service rendered different consumers, although there may have been little technical change in the quality of the delivered kilowatt-hour. All such quality differences are due to differences in the conditions under which the product is distributed to ultimate consumers, not to differences in the physical nature of the product. For example, the extension of a transmission system may bring current to remote consumers not previously served by electrical utilities; i.e., a higher-valued service (such as the rural electrification services) whose distribution presumably entails greater costs and that may therefore command a higher price is initiated.[31] In other words, we regard, in effect, one kilowatt-hour as no 'better' for having traveled further than another kilowatt-hour, unless there is a significant price differential. If there is, a suitable weighting scheme should be used to get a weighted output aggregate. We regard the weighting procedure used here as adequate to account for probably most of the changes affecting quality of service, as these have been reflected in differential prices. However, to the extent that we cannot take into account improvements affecting *all* classes of service — improvements leading mainly to greater reliability — our index of output understates the actual growth.

7 *Relation of Electric Utility Output to Total Power Consumption*

The output indexes considered here are for plants producing electric

destruction of one of the 500 kilowatt turbines. The voltage at peak load was generally 90 volts (110–115 volts normal) and there were frequent interruptions. In order to keep the lights on in the business district it was sometimes necessary to kill all of the other circuits, including some and often all of the street lighting circuits. Interruptions were also frequent during the daytime." (From Utility Corporations: Sen. Doc. 92, 70th Cong., 1st Sess., XXII, p. 715; quoted by N. S. Buchanan, The Origin and Development of the Public Utility Holding Company, *Journal of Political Economy*, Feb. 1936, XLIV, 33.)

[31] If unit costs are reduced by the extension of transmission, rates to all ultimate consumers may in time be lowered. The rate differential between various consumer groups is usually maintained, however, when certain groups require disproportionate amounts of capital equipment to service their needs. See note 2.

current for sale to others. Considerable amounts of electricity are generated, however, by industrial and commercial establishments for their own use.[32]

In 1939 the utility industry, as defined here, generated 129.6 billion kilowatt-hours,[33] or about four-fifths of the total electricity generated in all industrial establishments. This percentage would probably not be greatly altered if the kilowatt-hours generated in nonindustrial establishments (hotels, hospitals, etc.) could be included. Manufacturing accounted for most of the electric energy generated outside the electric utilities — 28.8 billion kilowatt-hours. Indeed, the fact that large manufacturing plants could, if necessary, generate their own electricity has at all times been a competitive challenge to the utilities. Generation of electricity in other industries is relatively small; mining generated about 2.1 billion kilowatt-hours, electric and steam railroads 1.8, and agriculture, 0.9.[34]

In 1939 manufacturing plants canvassed by the Bureau of the Census reported purchases of 45.1 billion kilowatt-hours, or about three-fifths of their total electric power consumption. Similarly, the horsepower of electric motors owned by manufacturing plants and driven by purchased energy constituted 65 percent of total electric motor horsepower operated by manufacturing plants. Despite their heavy investment in the production of electricity, manufacturing plants now depend more on purchased electricity. The reverse was true in 1899, when the horsepower of electric motors

[32] The Federal Power Commission and the Bureau of the Census define the electric utility industry similarly as plants "generating electric energy for public use". The FPC coverage is somewhat wider, including the total production of electric railways and electrified steam railroads; the Census, holding strictly to its definition, includes only the portion of rail-generated power that is for sale. E.g., the FPC kilowatt-hour total generated in 1937 was 121.8 billion; the Census total, 121.1 billion. The divergence between the two totals would be greater did the FPC not exclude plants whose sales are less than 10,000 kilowatt-hours per month (*Electric Power Statistics, 1938;* Federal Power Commission, Washington, D. C., 1939; p. 40).

[33] Obtained by multiplication of the total for the industry, as defined by the Federal Power Commission (130.3 billion kwh.), by the ratio .994, which expresses the relation between Census and FPC kilowatt-hour coverage in 1937.

[34] *Census of Manufactures, 1940*, I, 283; *Statistical Abstract, 1942*, p. 837; *Electric Power Statistics, 1939*, p. 5; *Census of Agriculture, 1940*, III, 456. In the case of agriculture, the Census figure for the number of farm dwellings supplied by home electric power plants (179.1 th.) as of April 1, 1940 was multiplied by the 1939 annual electric consumption average for farms in areas "where irrigation may be involved" (5.2 th. kwh; *Statistical Bulletin 11;* Edison Electric Institute, 1944, p. 30).

driven by self-generated energy constituted more than three-fifths of total electric motor horsepower (Table 14 and Chart 4).

TABLE 14

American Manufacturing, Selected Years, 1899–1939
Horsepower of Electric Power Equipment (thousands)

		1899	1904	1909	1914	1919	1925	1929	1939
1	All electric motors	475	1,517	4,583	8,392	15,613	25,093	33,844	45,291
2	Driven by purchased energy	178	428	1,669	3,707	8,965	15,116	21,794	29,213
3	Driven by plant-generated energy	297	1,089	2,913	4,685	6,647	9,976	12,050	16,078
4	Percent line 2 is of line 1	37.5	28.2	36.4	44.2	57.4	60.2	64.4	64.5
5	All prime movers	9,633	12,605	16,393	17,858	19,432	19,243	19,328	21,240
6	Total power equipment (2 + 5)	9,811	13,032	18,063	21,565	28,398	34,360	41,122	50,453
7	Percent line 1 is of line 6	4.8	11.6	25.4	38.9	55.0	73.0	82.3	89.8

Census of Manufactures, 1939, I, 275. The ratio of the horsepower of all electric motors to the sum of the horsepower of all prime movers and of electric motors driven by purchased energy (line 7) may be regarded as a measure of the degree of electrification of manufacturing plants. Electric motors run on self-generated power are represented in the total (line 6) by their required prime mover equipment.

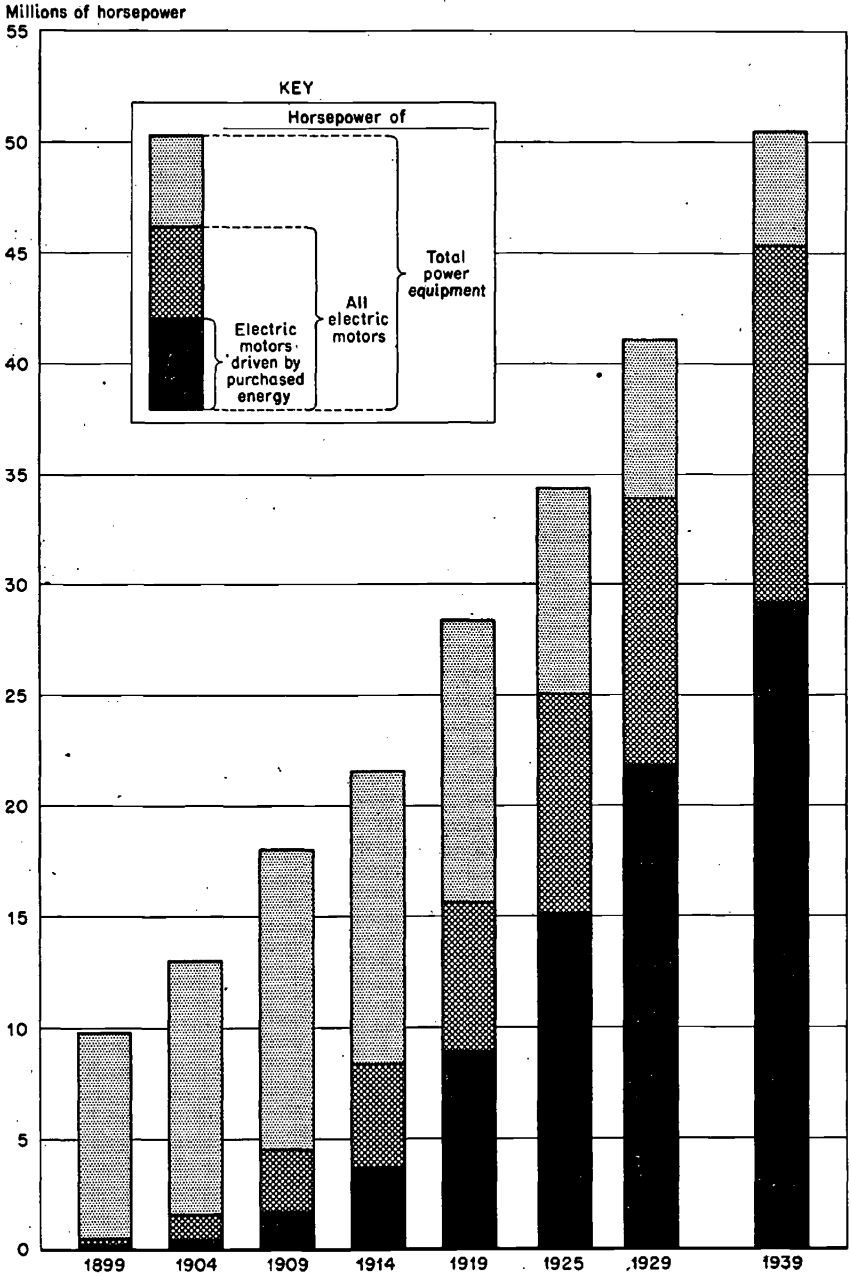
Table 14 reflects also the shift to electricity from steam and other forms of mechanical power. For example, the horsepower of electric motors in 1899 constituted only 4.8 percent of the horsepower of total manufacturing power equipment (i.e., the sum of all prime mover horsepower and of electric motors driven by purchased energy). The corresponding percentages for 1919 and 1939 were 55.0 and 89.8.

The growing electrification of American manufacturing is evident in the gains registered by the horsepower of electric motors driven by purchased and self-generated energy. Both series increased rapidly, even after 1919, when the horsepower of all prime movers increased little. The greatest gains were in the horsepower of electric motors run on purchased electricity, for which the average annual rate of growth equivalent to the 1899–1939 percentage increase was 13.6 percent; the average annual gain in the horsepower of motors run on self-generated energy was 10.5 percent.[35] The greater tendency for American industry to rely upon purchased electric power is evidence of the ability of the electric utilities to reduce the costs of supplying the power needs of industry. The indi-

[35] The following comment by the Bureau of the Census is pertinent: "In general, those industries in which the processes lend themselves readily to machine operation made the largest growth between 1919 and 1929 in the use of motors on purchased energy, while those industries which utilize process heat in large quantities showed the strongest tendency toward the generation of their own heat and power" (*Census of Manufactures, 1929*, I, 41). Between 1929 and 1939, reliance on purchased and self-generated power increased at the same rate.

CHART 4

Manufacturing, 1899–1939
Source of Electric Energy



Based on Table 14.

cations are that the utilities' proportion of the nation's total power production may continue to grow, though less rapidly. The reasons lie in the economies of large scale production, of which public utilities are peculiarly fitted to take advantage. New customers make possible fuller utilization of productive capacity, which in turn reduces costs, and may lower rates. But the relation of output to utilization of capacity is merely one aspect of the relation of output to the input of resources, a subject treated in detail in Chapter 2.

CHAPTER 2

Relation of Output to Input

THE EFFICIENCY with which the resources entering into the production process are used may be measured by indexes of productivity, which compare output and input aggregates. To measure productivity fully, input aggregates must reflect all the various resources consumed in an industry, i.e., the services of labor and capital, and the services and goods contributed by other industries. Technical difficulties make it hard to construct an over-all input aggregate that would weight properly the various resources and put them on a common denominator. In lieu of a single index, movements of output and of the use of a single resource are compared by means of *partial* productivity indexes. These must be interpreted carefully and all observed gains in efficiency not attributed to any single factor, for gains in productivity are of course due to the interaction of many factors.

1 Fuel Input in the Production of Electric Light and Power

In the electric and gas utilities we have the relatively rare opportunity of ascertaining the volume of goods purchased from other industries as raw materials. For the electric light and power industry such materials include coal, coke, oil, and other fuels (Table 15). Detailed data on the quantities of the various fuels consumed are available since 1917; before that date we must rely on fuel costs, adjusted for changes in prices. Bituminous coal is the chief fuel, constituting about four-fifths of total fuel consumption (in units of bituminous equivalent) during most of the period since 1917. As in other fuel consuming industries, anthracite has declined, and natural gas and fuel oil have increased in relative importance.[1] While the consumption of gas has increased most rapidly, 1,334 percent 1917–42 (taking into account breaks in the continuity of data in Table 15), in 1942 it was only 11.5 percent of total fuel consumption in terms of coal equivalent, according to the Federal Power Commission. The percentage increase for fuel oil was 126.1, considerably below the average, as total fuel consumption increased 222.4 percent; fuel oil contributed 4.5 percent (in terms of coal equivalent). Anthracite consumption increased only 26.5 percent — to 4.0 percent of 1942 fuel requirements. Bituminous coal increased 219.4 percent, constituting the remaining 80.1 percent.

Total fuel consumption in the electric light and power industry has risen twelvefold since 1902; it declined once, in 1927–32.[2] The indexes of output (both weighted and unweighted) rose more rapidly, and the indexes of output per unit of fuel, the quotient of the output and fuel input indexes, more than fivefold. The greater part of the productivity increase occurred in 1912–32.

In computing an index of output per unit of fuel we may use either the price-weighted or unweighted output index as the numerator. In the present instance as indicated in Table 15, there is little numerical difference between the movements of the unweighted index of kilowatt-hour per unit of fuel and the index of weighted output per unit of fuel, although they differ conceptually. Since most of the shifts among the high- and low-priced components of electric output are not directly related to changes in fuel input, an unweighted output aggregate is perhaps better suited for comparison with fuel input than a price-weighted aggregate.

An exception may be noted for hydro-electric plants using fuel to meet peak demands, i.e., high-valued demands, and for fuel-burning

[1] See Barger and Schurr, *The Mining Industries, 1899–1939: A Study of Output, Employment and Productivity* (National Bureau of Economic Research, 1944), p. 41.

[2] From our knowledge of the quantity movements of fuel consumption in the electric light and power industry we can adjust the index of gross output considered in Chapter 1 and get an index of net output, i.e., net of fuel consumption, for the industry. The construction of such an index of net output, interesting methodologically, is considered in detail in Appendix C.

TABLE 15

Electric Light and Power, 1902–1942

Indexes of Fuel Input and Output per Unit of Fuel (1927:100)

	1902	*1907*	*1912*	*1917*	*1922*	*1927*	*1932*	*1937* [a]	*1937* [a]	*1942* [a]
Anthracite, mil. sh. t.				2.44	1.84	2.00	1.56	2.02	1.90	2.79
Bituminous, mil. sh. t.				19.38	24.49	35.68	26.00	40.47 }	42.87	65.64
Coke, mil. sh. t.				.06	.04	.03	.15	.09 }		
Fuel oil, mil. bbl.				6.16	11.86	7.15	7.87	13.90	14.14 [b]	15.28
Gas, mfd., bil. cu. ft.				} 14.20	20.17	6.16	1.94	4.88 }	171.27	238.74
Gas, natural, bil. cu. ft.						59.36	96.36	159.45 }		
Total fuel consumption (bit. equiv.) [c], mil. sh. t.	6.41	12.34	17.90	24.04	30.20	42.22	33.89	52.49	52.77	77.94
Bil. kwh. generated	2.51	5.86	11.57	25.44	40.29	74.69	79.66	121.10	121.84	189.18
Kwh. generated per sh. ton of bit.	391.0	475.1	646.5	1058.2	1334.1	1769.2	2350.5	2309.0	2309.0	2427.4
Indexes										
Fuel input [d]	15.2	29.2	42.4	56.9	71.5	100.0	80.3	124.3	124.3	183.6
Weighted output [d]	4.0	8.3	14.4	27.2	47.0	100.0	113.5	166.8	166.8	259.6
Weighted output per unit of fuel [d]	26.3	28.4	33.9	47.8	65.7	100.0	141.4	134.2	134.2	141.4
Kwh. per unit of fuel	22.1	26.9	36.5	59.8	75.4	100.0	132.9	130.6	130.6	137.3

Data for 1902–37 are, except when otherwise indicated, from successive Census of Electric Light and Power reports; for 1937–42, from the Federal Power Commission, as explained in note a. The Census data are for the industry as defined by the Census of Electric Light and Power, i.e., they *exclude* electric light and power departments of electric railways.

[a] Data for 1937 and 1942 are from the FPC, whose coverage is somewhat wider than the Census, as indicated by the divergence between the two sets of data for 1937.

[b] Includes negligible amounts of gasoline.

[c] Appendix Table B1.

[d] The fuel input index reflects the bituminous equivalent consumption of plants canvassed by the ELP Census. The unweighted and weighted output indexes to which such input corresponds are constructed precisely as indicated in Chapter 1 and Appendix A, but exclude the output of electric light and power departments of electric railways. The resulting indexes of output per unit of fuel are probably very slightly affected by the omission of railway plants. All indexes were computed in this and succeeding tables on the basis of 5-figure accuracy and rounded.

plants resorting to obsolescent equipment to meet peak demands. For these plants, the increase in high-valued output is accompanied by a greater than average increase in fuel consumption and the resulting unweighted output per unit of fuel index would reflect a decline in fuel efficiency due entirely to shifts in type of consumption. The use of a weighted output index, giving greater weight to increases in high-valued output, would, for such plants, reduce or eliminate the drop in fuel efficiency due to shifts in demand, but may on the other hand introduce other, extraneous movements. For instance, if the use of market prices overweights the high-valued service, the index of weighted output per unit of fuel will overstate the fuel efficiency of plants using obsolescent equipment in peak load or emergency periods (see Sec. 2). In any case, however, as noted below, both the weighted and unweighted output indexes so far considered are for both fuel-burning and hydro-electric plants, and are therefore not strictly comparable with our index of fuel input, which, for the most part, relates to fuel-burning plants alone.

With annual data on fuel consumption and generated power collected by the Federal Power Commission and the Edison Electric Institute since 1920 we can interpolate an index of fuel input annually, on 1929 as base (App. Table B3); it rises rather steadily. The 275 percent increase in fuel input 1902–17 was equivalent to an average annual growth of 9.2 percent; in the succeeding 25 years, the annual rate was much lower, 4.8 percent. The average annual growth during the 40 years was 6.4 percent; output increased at the rate of 11 percent. The over-all annual rate of rise in the index of unweighted output per unit of fuel was 4.7 percent, but was not maintained during the entire period. In the decade after 1932 particularly, it did not rise much, indicating that the output and input indexes rose at almost the same rate.

How were the savings in fuel brought about and why did they not appear in the recent period? The index of output, based as it is on the output of the industry as defined by the Census of Electric Light and Power, includes the output of hydro-electric plants whose fuel consumption is typically of an auxiliary nature. To ascertain trends in fuel saving, we construct a measure of output per unit of fuel input for fuel-burning equipment alone. As we shall see, it is the decreasing percentages of total output that hydro stations have accounted for in 1932–42 that retards the upward movement of the output per unit of fuel index just considered.

The most useful indexes of the efficiency of fuel consumption in the branches of the industry that use fuel may be constructed by considering separately the output generated by the several kinds of steam and water power equipment. The Census and other agencies have separated fuel- and water-generated output in recent years. For the preceding years a segregation of output data by kind of plant will obviously not suffice, for many plants use both hydro and fuel-burning equipment in order that "maximum advantage . . . be taken of available stream flow at any given time, fuel being used only for providing the additional energy to meet the demand. On the other hand, during periods of low water, a possible deficiency can be carried by steam plants" (*ELP*, *1937*, pp. 37–8).

In 1937 the few plants in the industry that rely solely on hydro-electric equipment, including those which had on hand idle generating equipment other than hydro-electric, contributed 14.2 percent of total electricity generated in the industry as compared with 62.0 percent generated by *all* plants with hydro-electric equipment.[3]

In Table 16 we present all evidence available in Census reports bearing on the segregation of output into the proportions associated with the use of hydro-electric and of fuel-burning equipment. On the basis of this evidence we estimate that power generated by hydro-electric equipment ranges above 30 percent during most of the period since 1902 and constituted about a third in recent years. It rose rapidly in the early period, reaching an all-time peak, 44.6, in 1917 (when local fuel shortages were widespread). Despite the fluctuation in the relative importance of water power in the industry, in absolute terms hydro-electric power has increased more than 8,700 percent since 1902. Such a percentage, however, is not any too accurate because the estimates of the use of water power in the early period are derived indirectly. As indicated in the source note to Table 16, the estimates of the hydro-electric percentage of total generated power 1912–22 are based upon the assumption of a constant relation between that percentage and the proportion of total power generated in plants with hydro-electric equipment of 1,000

[3] *ELP*, *1937*, p. 41.

TABLE 16

Electric Light and Power, 1902–1942

Output Generated by Fuel-Burning and Hydro-electric Equipment

	1902	1907	1912	1917	1922	1927	1932	1937	1937 *	1942*
Bil. kwh. generated	.51	5.86	11.57	25.44	40.29	74.69	79.66	121.10	121.84	189.18
Fuel-burning equip.	1.76	3.44	6.81	14.09	25.06	45.97	46.09	75.32	77.35	125.00
Hydro-electric equip.	.75	2.42	4.76	11.34	15.23	28.72	33.57	45.78	44.49	64.18
Percent generated by hydro-electric equip.	29.8	41.3	41.2	44.6	37.8	38.4	42.1	37.8	36.5	33.9
Plants with more than 1,000 hp. of hydro-electric equip.										
Bil. kwh.	...	...	5.85	13.92	18.70	39.58	45.08	67.70	...	...
Percent generated	...	...	50.5	54.7	46.4	53.0	56.6	55.9	...	...
Horsepower of prime movers, mil.	1.84	4.10	7.53	12.94	20.30	35.71	47.97	50.22	...	...
Hydro-electric	.44	1.35	2.47	4.28	5.82	9.84	13.53	15.23	...	...
Percent hydro-electric is of total hp.	23.7	32.9	32.8	33.1	28.7	27.6	28.2	30.3	...	...

All data, except for 1937–42, from successive quinquennial Census reports. The Census began to publish figures on current generated by fuel-burning and hydro-electric equipment in 1927. For the years before 1927 the figures on the percentage generated by hydro-electric equipment (and the resultant division of current generated into the two components shown above) were estimated as follows: The movement of the percentage figure 1922–27 was presumed to follow the movement of the percentage figure as ascertained by the Federal Power Commission for a slightly larger sample than that covered by the Census. E.g., for 1922 and 1927 the FPC estimates of the percentage of total generated current to be attributed to hydro-electric equipment were 36.0 and 36.6 respectively (see Table 20).

The estimates for 1912 and 1917 are based on the assumption that the percentage moved in accordance with the percentage of the total generated by establishments with hydro-electric equipment of 1,000 hp. and over.

Finally, the estimates for 1902 and 1907 are based on a similar assumption with respect to the hydro-electric percentage of total horse power of prime movers in the industry. See the text for a discussion of the qualifications to which the method described here is subject.

* Data since 1937 on the fuel-burning and hydro-electric division of total current generated are from successive issues of *Electric Power Statistics*, published by the FPC, which, as noted in Chapter 1, note 32, has a somewhat different coverage than the Census.

horsepower and more. Though since 1912 the Census has called the latter 'hydro-electric', it is evident that a considerable proportion of the current from them is generated by fuel-burning equipment. In 1937, when only 37.8 percent was from hydro-electric equipment, for instance, they reported 55.9 percent of total current generated in the industry. Again, a small proportion of water power was generated by plants with hydro-electric equipment of less than 1,000 horsepower. However, for 1912–22 the current generated by plants with hydro-electric equipment of more than 1,000 horsepower remains our best indicator of the changing importance of water power.

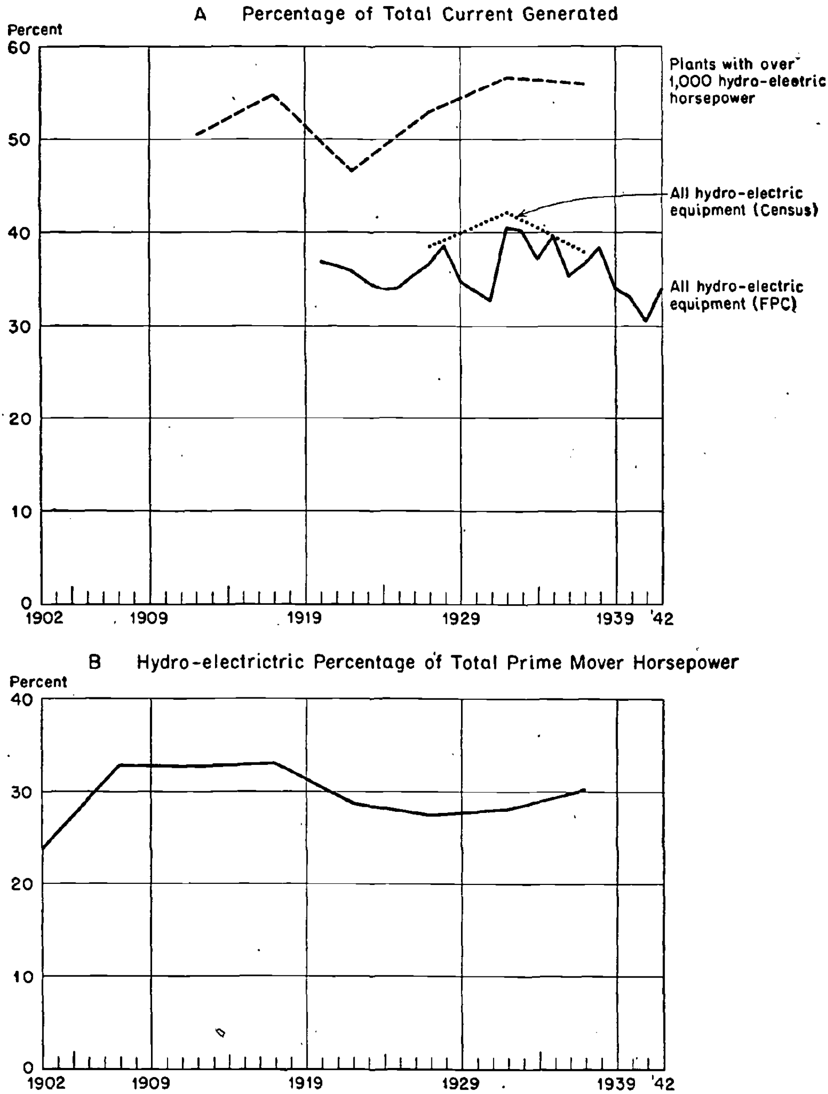
For 1902–12 our estimates of the hydro-electric percentage of total generated power rest upon the assumption of a constant relation between that percentage and the hydro-electric proportion of the total horsepower of all prime movers in the industry. As any correspondence of movement between these two ratios is extremely crude at best, a wider margin of error must surround these early estimates than those for later years (Chart 5). It is evident from the annual Federal Power Commission series that the portion of total current generated by hydro-electric equipment is subject to violent annual fluctuations which do not seem to have any easily defined cyclical pattern. Variations in rainfall make for great extremes in waterpower potential, of which only a portion may be utilized. During drought and other emergency periods, hydro-electric stations must fall back on fuel-burning equipment. Since 1932 the hydro-electric trend seems to have been definitely downward. In 1902–17 the trend seems to have been upward, but it is difficult to define the trend between 1917 and 1932; it seems to be generally upward from a low point in the early 'twenties.

Unsatisfactory and inconclusive as the evidence on the changing importance of water power is, the separation of hydroelectric and fuel-burning generation in Table 16 enables us to construct an index of output per unit of fuel that for some purposes is a better indicator of gains in the efficiency of fuel consumption than was the index previously considered (Table 17).

Unit fuel requirements have declined steadily since 1902, from over 7 pounds of coal per kilowatt-hour to 1.25 pounds (bituminous equivalent) in 1942. These findings agree fairly well with independent calculations published by the National Resources Com-

CHART 5

Electric Light and Power, 1902-1942
Changing Importance of Water Power



Based on Table 16.

mittee in 1939 (Table 17). The estimates for the early years of the century, which, as noted above, are subject to a wide degree of error, diverge most. For example, the National Resources Committee figure is 6.4 pounds of bituminous equivalent per kilowatt-hour in 1902; our estimate, 7.3 pounds.[4]

TABLE 17

Electric Light and Power, Fuel-Burning Equipment, 1902–1942
Unit Fuel Consumption Requirements

		1902	1907	1912	1917	1922	1927	1932	1937	1942
1	Bil. kwh. generated by fuel-burning equipment	1.76	3.44	6.81	14.09	25.06	45.97	46.09	75.32	125.00
2	Fuel consumed, bil. lb. of bit. equiv.	12.8	24.7	35.8	48.1	60.4	84.4	67.8	105.0	155.9
3	Lb. per kwh. generated									
	a Line 2 ÷ 1	7.28	7.17	5.26	3.41	2.41	1.84	1.47	1.39	1.25
	b NRC estimate	6.4	5.4	4.5	3.47	2.51	1.84	1.50	1.44	...

Lines 1 and 2 assembled from Tables 15 and 16, and line 3b is from *Energy Resources and National Policy* (National Resources Committee, Washington, D. C., 1939), p. 375.

Chart 6 traces the quinquennial estimates of unit fuel requirements, interpolated to yield an index of output per unit of fuel for fuel-burning equipment, annually since 1920 (App. Table B3). In marked contrast to the output per unit of fuel indexes in Table 15, the output per unit of fuel index for fuel-burning equipment does not falter after 1932, and registers an increase every year since 1920. The over-all gain was 472 percent 1902–42, equivalent to an average annual rate of 4.4 percent. However, as may be seen from Chart 6, the rate of advance has slackened in recent years, the annual rate in the last twenty years being about 3 percent. The output per unit of fuel index for fuel-burning equipment does not diverge greatly from that for fuel-burning and hydro equipment taken together but is characterized by a somewhat more sustained upward trend.

It is interesting to speculate on future gains in the efficiency of fuel consumption in the electric utilities. The industry still has far to go before reaching a ceiling beyond which no further advances are technically possible. Such a ceiling can be determined by converting the 1942 total of kilowatt-hours into the equivalent quantity of British thermal units, using the customary relation of one kilowatt-hour equal to 3,412 Btu.[5]

[4] The National Resources Committee estimates for unit fuel requirements 1902–17 are from *Statistical Studies of Progress in Fuel Efficiency* by F. G. Tryon and H. O. Rogers (Transactions, Second World Power Conference, Berlin, 1930), Vol. 6, pp. 344–5. The authors apparently used much the same sources and methods as we, but do not publish the details.

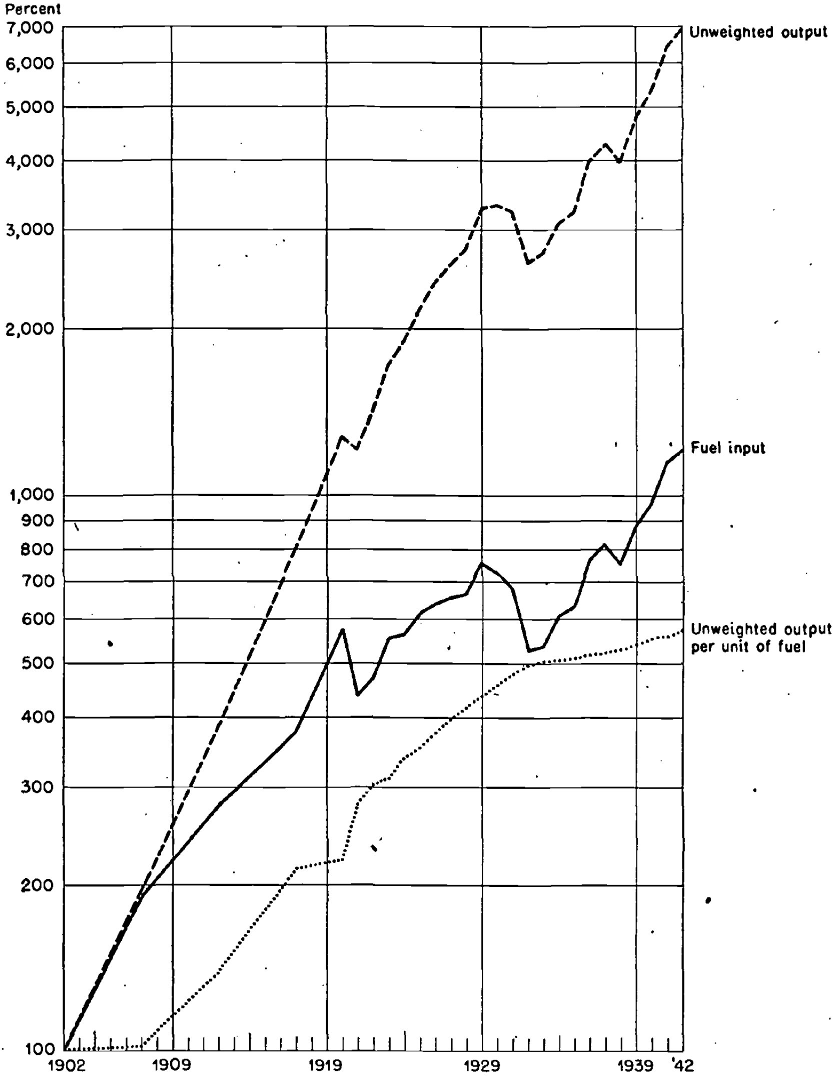
[5] The British thermal unit is defined as the amount of heat required to raise the temperature of one pound of water one degree (Fahrenheit).

CHART 6

Electric Light and Power, 1902–1942

Fuel-Burning Equipment Only; Annual Indexes of Unweighted Output, Fuel Input, and Unweighted Output per Unit of Fuel

(1902:100)



Based on Appendix Table B3. Ratio scale

Thus the 125 billion kilowatt-hours generated by the fuel-burning equipment of plants reporting to the Federal Power Commission represented 426.5 trillion Btu., or 20.1 percent of the 2,119.8 trillion

Btu. embodied in the 77.9 million short tons of bituminous coal consumed as fuel. For plants reporting to the Census in 1937, 18 percent of the Btu. heat content of the fuel consumed was realized in the generation of 75 billion kwh. by fuel-burning equipment. The corresponding figure for 1902 was 3.4 percent. Its steady rise since 1902 paralleled the movement of the ratio of kilowatt-hours generated per unit of fuel: 1907, 3.5; 1912, 4.8; 1917, 7.4; 1922, 10.4; 1927, 13.7; 1932, 17.1.

As only one-fifth of the heat value of its fuel was realized in 1942, it is obvious that the industry's opportunities to heighten the efficiency of its fuel consumption are far from exhausted.

These gains in the efficiency of fuel consumption are due primarily to successive improvements in the quality of capital equipment, secondarily to the use of capital equipment in units of increasing capacity. Higher boiler pressures and higher steam temperatures contribute greatly to fuel efficiency. And machines and parts that can cope with the much greater stresses demanded by high speeds, pressures, and temperatures can now be constructed with chrome, nickel, and molybdenum alloys and modern welding processes. In the early years of the century the reciprocating steam engine, whose efficiency declined with units of a capacity greater than 10,000 kilowatts, was replaced by the steam turbine, whose efficiency increased greatly with expansions in capacity. Some steam turbines today have capacities of more than 200,000 kilowatts. The increasing size and speed of turbo-generators has led to the adoption of hydrogen as a cooling medium; lighter than air and an efficient conductor of heat, it cuts 'windage' or air-friction losses.

A more recent fuel-saving innovation is 'superposition': a new high pressure turbine is combined with an old low pressure unit which, instead of being scrapped, utilizes the exhaust steam of the high pressure turbine. Fuel is also saved by the use of pulverized coal and automatic devices controlling the fuel and air supply to the boiler.[6]

[6] Recent developments in fuel-saving technology are discussed in *Technological Trends and National Policy* (National Resources Committee, Washington, D. C., 1937), pp. 256–61; Charles W. E. Clarke, Steam Power Developments, *Iron and Steel Engineer*, March 1938, pp. 15–38; A. C. Monteith, Trends in Electrical Apparatus Development, *Electrical Engineering*, June 1940, pp. 221–6.

2 *Relation of Electric Output to Capital Input*

Modern production processes make large demands on the services of fixed capital; in this Section we attempt to compare the output of the electric light and power industry with the industry's 'capital input'. The latter may perhaps be defined, in monetary terms, as the value of the capital assets employed in production.[7] Though book values of fixed capital assets may perhaps be obtained from the utility accounting records generally available, they must be deflated to take account of changes in underlying prices. But how can we ascertain the physical counterpart of capital values when the diverse types of capital equipment used in production have no accepted common unit of physical measurement? One possible procedure is to deflate capital values by an index recording price changes in capital goods. For instance, from 1902 to 1937 the book value of electric light and power plant as reported to the Census by central electric stations rose from $504.7 million to $12,637.9 million, about 2,400 percent. Book values are a mixture of original costs and revaluations to something approximating current price levels. The level of prices underlying book values in 1902, to judge from construction costs in 1902 and in the preceding decade or two, was apparently about 40 percent of those generally prevailing in the '20's and early '30's. Prices underlying book values in 1937 were probably at about the level of construction costs in the '20's and early '30's. It was during those years that the bulk of the assets in existence in 1937 were created; and it was to the price level of those years that many pre-World War I assets were later raised.[8] Deflat-

[7] Among other related monetary measures of capital input we might perhaps include interest payments and profits accruing to stockholders' equity (as the money reward for the services of capital) though changes in their volume may be due to factors other than changes in capital input, however defined. Depreciation charges might also be regarded as a measure of capital input. Strictly speaking, such charges are designed to measure the capital *consumed* in the production process, rather than the capital *employed;* but changes in them may be taken as a rough index of changes in capital invested and thus in capital employed.

[8] An index of construction prices (1929:100), computed by Simon Kuznets in *National Product since 1869* (National Bureau of Economic Research, 1946) is averaged at 40.8 for the decade 1894–1903, and at 42.4 for the decade 1884–93. A similar index of the price of producer durable goods stands at 46.0 for 1894–1903 and at 47.3 for 1884–93. An index of construction costs in the electric light and power industry, available since 1911 from the *Engineering-News Record* (April 23, 1942, p. 132), and based on electric utility materials and labor costs in the Atlantic, North Central, South Central, Plateau, and Pacific regions, yields an average figure of 188 for 1921–29 and 189 for 1930–36.

ing the 1902 and 1937 book values to take the price rise into account, 150 percent under the above assumptions, we get a figure for the deflated value of electric light and power capital assets in 1937 about 1,000 percent higher than in 1902. In the same period weighted output rose some 3,700 percent; output per unit of deflated capital assets therefore rose about 280 percent. However, it is difficult to assess the accuracy of such an estimate. For one thing, the reported book values are difficult to interpret (aside from the large area of dispute that surrounds public utility valuations) because of changes in the Census instructions defining book values and the absence of any uniform system of accounting for all reporting companies. Moreover, because of the time lags involved, book values cannot be regarded as equal to replacement values. Finally, reliance on an index of capital prices as a deflation factor introduces an error impossible to evaluate.

For the electric light and power industry there is an alternative, albeit none too good, measure of capital input that does not have to be adjusted for fluctuations in prices: the rated kilowatt capacity of the industry's total stock of generating equipment. An index reflecting movements in the level of total rated capacity does not, of course, measure the total capital of the industry, though we may expect that the relation between total capital and total kilowatt capacity will be close. A more serious drawback is that the great quality changes in electric generators are not reflected in an unweighted total of rated capacity. However, an index of rated kilowatt capacity allows us to examine a particularly significant output-input relation — between generated output and generating capacity, commonly expressed as a ratio between generated output and 'potential' or 'optimum' output, the product of the annual kilowatt capacity and the number of hours in the year. Optimum output so calculated cannot of course be regarded as a realistic production goal that can be fulfilled, even in a technical sense, unless we assume an unchanging peak load demand and adjust for the hours consumed in repairs and maintenance. Nevertheless, the ratio of generated to 'optimum' output constitutes a useful measure

Note 8 concluded:

The assumption of a 150 percent price increase in the prices underlying electric utility book values, 1902–37, is probably generous, and even makes some allowance for the possibility that revaluations during the '20's (reflected in the 1937 figure) overstated reproduction costs.

of one aspect of the changing 'efficiency' (or *degree*) of the use of capital equipment in the industry.

The percentage of actual to optimum output rose from 23.6 in 1902 to 47.1 in 1942 (Tables 18 and 19, and Chart 7). This doubling was not distributed evenly over the period, most of the gain occurring between 1912 and 1917, and after 1932. As we saw in Chapter 1, the early years of the century were a period of experimentation when the demand for current for power supply emerged in the course of efforts to lower over-all unit capital costs. The consequent increases in off-peak consumption of current for power tended in time to raise the ratio of generated to optimum output.[9]

In Table 19 we express the relation between current generated and installed capacity in column 9 as 'kilowatt-hours generated per kilowatt of capacity', interpolated annually since 1920. We converted the latter, a ratio between output and a measure of capital input, into an index of unweighted output per unit of capital equipment (col. 11). The annual index is, of course, very sensitive to cyclical forces, reaching peak levels in years of good business: 1920, 1923, 1929, 1937, and 1942. The contraction period 1929–32 in particular brought it to an all-time low; in 1932 the percentage of actual to potential output was 26.3, a level no higher than that attained very early in the century (Chart 8).

In another index of output per unit of capital equipment, the output component is the weighted index of output rather than the unweighted current generated total. The output aggregate used in an output-input measure is weighted or unweighted, depending on the meaning one wishes to assign to it. For instance, in discussing how to measure the fuel efficiency of fuel-burning equipment, we compared fuel consumption with an *unweighted* current generated total, because for the most part shifts in high- and low-priced electric consumption do not seem to have much relation to changes in fuel input. In the case of generating capacity, however, in addition to the definite meaning one may attach to the ratio of actual (unweighted) generated output to optimum output, there is a close conceptual relation between changes in generating capacity and shifts among the light and power components of electric output.

[9] The percentage ratio of actual to optimum generation has been variously described: the Federal Power Commission refers to it as the "plant factor"; the Census as "a percentage of maximum possible output" (*ELP, 1922,* p. 80).

TABLE 18

Electric Light and Power, 1902–1942

Ratio of Kilowatt-hours Generated to Optimum Output

		1902	*1907*	*1912*	*1917*	*1922*	*1927*	*1932*	*1937*	*1942*
1	Generator capacity installed as of Dec. 31, mil. kw.	1.21	2.71	5.16	8.99	14.31	25.81	34.62	36.48	45.59 *
2	Optimum output, bil. kwh.	10.62	23.73	45.25	78.80	125.39	226.11	303.29	319.57	399.37
3	Bil. kwh. generated	2.51	5.86	11.57	25.44	40.29	74.69	79.66	121.10	188.03 *
4	Percent kwh. generated is of optimum output	23.6	24.7	25.6	32.3	32.1	33.0	26.3	37.9	47.1

Lines 1 and 3 for 1902–37, from successive quinquennial Census reports, are for the electric light and power industry as defined by the Census; i.e., they exclude electric light and power departments of electric railway companies.

Optimum output (line 2), the product of kw. capacity as of December 31 (line 1) and 8,760, the number of hours in the year, is a rather artificial measure (see text discussion) and may be rendered somewhat more realistic if the December 31 installed capacity figure is adjusted, as the Federal Power Commission does, to represent the average mid-year installed capacity (see Table 20).

* Based on FPC data published in *Electric Power Statistics, 1940* and *Production of Electric Energy and Capacity of Generating Plants, 1942*, adjusted to the Census coverage level by application of the correction factors, .9824 and .9939, to the 1942 FPC figures for kw. capacity and kwh. generated respectively. The correction factors were based on the 1937 relation, e.g., of Census to FPC data; the FPC 1937 figure for kw. capacity was 37.13 mil. kw; for kwh. generated, 121.84 billion.

TABLE 19

Electric Light and Power, 1902–1942

Annual Interpolation, Indexes of Output per Unit of Capital Equipment (1929:100)

	Bil. kwh. generated Census	Bil. kwh. generated FPC	Interpolated ratios (1 ÷ 2)	Bil. kwh. generated interpolated census	Capacity mil. kw. Census	Capacity mil. kw. FPC	Interpolated ratios (5 ÷ 6)	Capacity (mil. kwh.) interpolated census	Kwh. generated per kw. of capacity (4 ÷ 8)	Percent actual is of optimum output (4)1000 / (8)8760	Indexes of output per unit of capital equipment based on Unweighted output	Indexes of output per unit of capital equipment based on Weighted output
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1902	2.5			2.5	1.2			1.2	2068	23.6	68.6	81.4
1907	5.9			5.9	2.7			2.7	2164	24.7	71.8	75.9
1912	11.6			11.6	5.2			5.2	2240	25.6	74.3	68.9
1917	25.4			25.4	9.0			9.0	2828	32.3	39.9	75.0
1920		43.3	.848	36.7		14.4	.897	12.9	2849	32.5	94.6	85.0
1921		40.9	.848	34.7		15.3	.897	13.7	2528	28.9	83.9	74.2
1922	40.3	47.5	.848	40.3	14.3	16.0	.897	14.3	2815	32.1	93.4	81.2
1923		55.6	.867	48.1		17.4	.909	15.8	3038	34.7	100.8	90.5
1924		58.9	.885	52.1		19.5	.921	17.9	2905	33.2	96.4	89.1
1925		65.8	.904	59.4		23.5	.932	21.9	2712	31.0	90.0	85.5
1926		73.7	.922	68.0		25.4	.944	24.0	2837	32.4	94.2	91.8
1927	74.7	79.4	.941	74.7	25.8	27.0	.955	25.8	2894	33.0	96.0	95.9
1928		86.6	.946	81.9		29.7	.957	28.4	2882	32.9	95.6	95.4
1929		95.9	.951	91.3		31.6	.958	30.3	3013	34.4	100.0	100.0
1930		94.7	.957	90.5		34.1	.959	32.7	2772	31.6	92.0	96.0
1931		90.7	.962	87.3		35.4	.961	34.0	2568	29.3	85.2	90.8
1932	79.7	82.4	.967	79.7	34.6	36.0	.962	34.6	2301	26.3	76.4	81.1
1933		84.7	.972	82.4		36.2	.966	35.0	2353	26.9	78.1	80.4
1934		90.8	.978	88.8		35.8	.970	34.7	2557	29.2	84.9	86.6
1935		98.5	.983	96.8		36.1	.974	35.1	2754	31.4	91.4	93.3
1936		112.2	.989	110.9		36.6	.978	35.8	3100	35.4	102.9	104.5
1937	121.1	121.8	.994	121.1	36.5	37.1	.982	36.5	3319	37.9	110.2	113.2
1938		116.7	.994	116.0		39.0	.982	38.4	3024	34.5	100.4	108.1
1939		130.3	.994	129.5		40.3	.982	39.6	3271	37.3	108.6	116.0
1940		145.0	.994	144.1		41.6	.982	40.9	3523	40.2	116.9	124.3
1941		168.2	.994	167.1		44.1	.982	43.3	3859	44.0	128.1	133.3
1942		189.2	.994	188.0		46.4	.982	45.6	4124	47.1	136.9	141.0

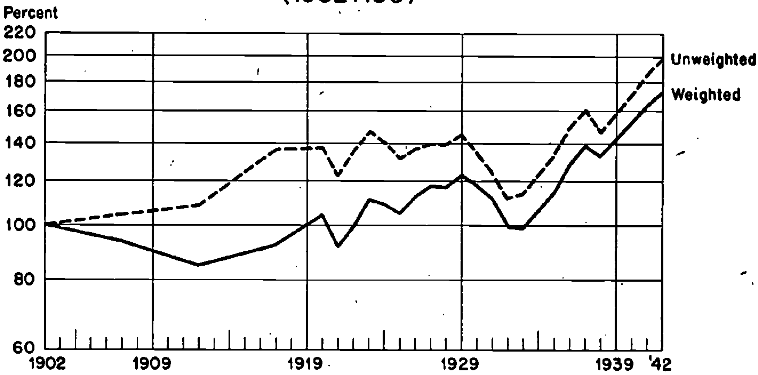
The annual interpolation follows the procedure adopted in preceding tables in which the Census sample (excluding electric light and power departments of electric railway companies) is interpolated by data from the Federal Power Commission sample. Columns 1 and 5 are from Table 18. The FPC data (col. 2 and 6) are from *Electric Power Statistics, 1940*, and *Production of Electric Energy and Capacity of Generating Plants, 1942*, both published by the Federal Power Commission.

The index of unweighted output per unit of capital equipment (col. 11) is column 9 expressed as an index (1929:100).

The index of weighted output per unit of capital equipment (col. 12) was obtained by dividing the annual interpolated index of weighted output (Table 21) by an index of capital input based on column 8 (1929:100).

CHART 7

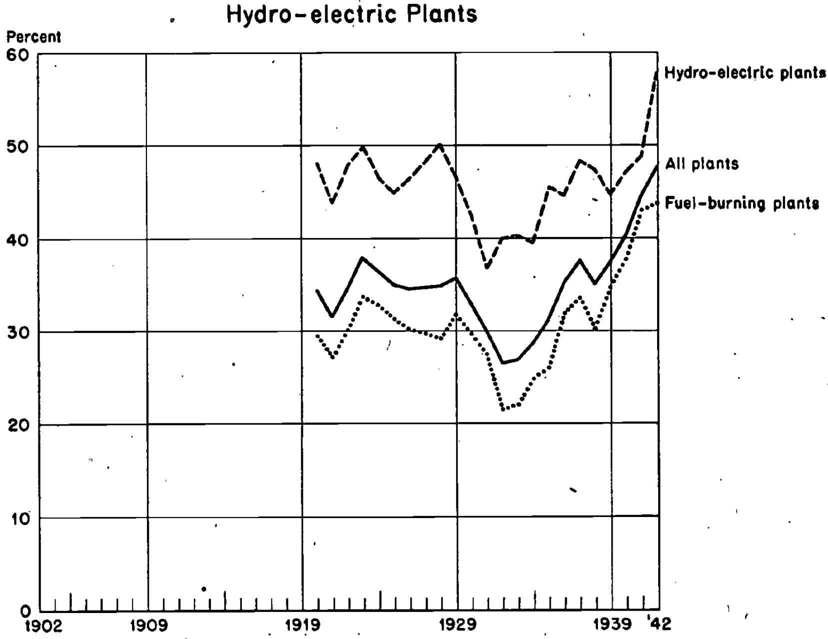
Electric Light and Power, 1902–1942
Indexes of Output per Unit of Capital Equipment
(1902:100)



Based on Table 19.

CHART 8

Electric Light and Power, 1920–1942
Actual Kilowatt Hours Generated as Percentage of Total Optimum Output in Fuel-Burning and Hydro-electric Plants



Based on Table 20.

For example, if we apply measures of output per unit of capital equipment to two plants, A and B, of equal technical efficiency but with different markets, both may during a given period register the same increase in generated output. However, plant A, with a large proportion of current designed for high-valued domestic consumption, would require more capital equipment. And plant B, having a higher proportion of low-valued sales for industrial power consumption requiring less over-all kilowatt capacity, would register a bigger increase in the *unweighted* index of output per unit of capital equipment. A *weighted* output aggregate, giving greater weight to the output gain of plant A, would tend to restore the balance between the efficiency ratings of the two plants.

In 1920–42, when high-valued consumption of current for household use was gaining more rapidly than power consumption, the output per unit of capital equipment index based on a *weighted* output aggregate advanced 65.9 percent, equivalent to an average annual rate of 2.3 percent; the *unweighted* index advanced at an annual rate of 1.7 percent. In 1902–20, when this relation was reversed, the unweighted index rose 37.7 percent and the weighted registered practically no advance; indeed in 1902–12 capital 'input' evidently increased more rapidly than the index of weighted output, for the index of weighted output per unit of capital equipment *declined* 15.3 percent. Even the unweighted index rose rather moderately, 8.3 percent, equivalent to an average annual advance of 0.8 percent.

Hydro-electric plants operate at higher levels of efficiency of capital use than fuel-burning plants (Table 20 and Chart 7). From 1920 to 1942 the average percentage of actual to optimum output was 45.9 for hydro-electric plants and 30.9 for fuel-burning plants; the divergence, however, has narrowed somewhat since 1932.[10]

The indexes of output per unit of capital equipment, which may be said to measure the 'efficiency' of the use of capital equipment, should not carry any *causal* implications, i.e., they do not measure the efficiency gain *due* to the use of capital equipment. As already noted, generating capacity as a measure of capital input ignores the very real quality changes in units of generating equipment of equal

[10] The high utilization of capital equipment by hydro-electric stations is required by their high fixed costs; e.g., water-power generation is generally regarded as suitable only for areas affording a high load factor (cf. *Technological Trends and National Policy*, p. 260).

TABLE 20

Electric Light and Power, 1920–1942

Percentage Actual is of Optimum Output, Fuel-Burning and Hydro-electric Plants

	ALL PLANTS			FUEL-BURNING PLANTS			HYDRO-ELECTRIC PLANTS		
	Capacity (mil. kw.) mid-year av.	Bil. kwh. generated	Plant factor	Capacity (mil. kw.) mid-year av.	Bil. kwh. generated	Plant factor	Capacity (mil. kw.) mid-year av.	Bil. kwh. generated	Plant factor
1920	14.4	43.3	34.4	10.6	27.4	29.5	3.8	15.9	48.1
1921	14.8	40.9	31.5	11.0	26.0	27.1	3.9	14.9	43.8
1922	15.6	47.5	34.7	11.5	30.4	30.1	4.1	17.1	47.8
1923	16.7	55.6	38.0	12.3	36.3	33.7	4.4	19.2	49.9
1924	18.5	58.9	36.4	13.6	39.0	32.8	4.9	19.8	46.5
1925	21.5	65.8	34.9	15.8	43.5	31.3	5.7	22.2	44.9
1926	24.5	73.7	34.4	18.0	47.6	30.1	6.4	26.1	46.5
1927	26.2	79.4	34.6	19.3	50.3	29.7	6.9	29.0	48.1
1928	28.4	86.6	34.8	20.8	53.2	29.2	7.6	33.4	50.2
1929	30.7	95.9	35.7	22.6	62.7	31.8	8.1	33.2	46.7
1930	32.8	94.7	32.9	24.3	62.9	29.6	8.6	31.7	42.4
1931	34.7	90.7	29.8	25.5	61.1	27.4	9.2	29.6	36.7
1932	35.7	82.4	26.4	26.2	49.1	21.4	9.5	33.3	40.0
1933	36.1	84.7	26.8	26.5	50.7	21.9	9.7	34.1	40.2
1934	36.0	90.8	28.8	26.3	57.1	24.8	9.7	33.7	39.5
1935	35.9	98.5	31.3	26.2	59.4	25.9	9.8	39.0	45.6
1936	36.3	112.2	35.3	26.2	72.7	31.7	10.1	39.5	44.6
1937	36.9	121.8	37.7	26.3	77.3	33.5	10.5	44.5	48.3
1938	38.1	116.7	35.0	27.3	71.9	30.1	10.8	44.8	47.3
1939	39.7	130.3	37.5	28.4	86.3	34.6	11.2	44.0	44.7
1940	41.0	145.0	40.4	29.4	97.2	37.7	11.5	47.8	47.2
1941	42.9	168.2	44.8	30.9	116.9	43.2	12.0	51.3	48.9
1942	45.3	189.2	47.7	32.6	125.0	43.8	12.6	64.2	57.9

Based on data in *Electric Power Statistics, 1920–40*, pp. IV, V; and *Production of Electric Energy and Capacity of Generating Plants, 1942*, p. II, both published by the Federal Power Commission. The FPC uses the term 'plant factor' to express the ratio of actual to optimum output, that is, the quotient of current generated and the product of the mid-year average kw. capacity and 8,760, the number of hours in the year. The average mid-year kw. capacity is the "capacity in service at the end of the preceding year, plus one-half of the increase or decrease during the year under consideration"; for 1920, however, the figure is for December 31.

size. Indeed the increase in the efficiency of fuel consumption discussed in the preceding section may be attributed almost entirely to improvements in various kinds of capital equipment. They are not reflected in the kilowatt capacity aggregates arbitrarily taken here as a measure of capital input. We must fall back on the injunction made at the outset of this chapter: partial productivity indexes of the kind treated here compare output and input aggregates without any assumption of a direct causal relation. The indexes of output per unit of capital equipment just considered compare the output (weighted and unweighted) of the electric light and power industry with a partial and imperfect measure of one aspect of capital input; the upward trend in the ratio of output to input so defined reflects an increase in efficiency rather remotely related to capital input and more closely related to a secular change in the demand and price situation that allows a given quantity of capital to be more fully utilized. Thus the demand for current on the part of all consumers has been considerably extended, diversified, and balanced as the result of a host of institutional changes, including rate adjustment, education, and technological progress. As the proportion of actual to optimum output in 1942 was somewhat less than one-half, there is evidently room for further improvement.

3 *An Index of Electric Output per Unit of Labor*

Labor input in the electric light and power industry can be measured without any great difficulty, though there are minor breaks in seasonal comparability in the employment totals reported in the various Census inquiries (see Table 21, note to col. 1).

The employment statistics include employment associated with the generation and distribution of current, maintenance of transmission lines, meter installation, meter reading, bill collecting, etc., but presumably omit workers engaged exclusively in construction activities, as their omission was specifically requested by the Census in all years except 1932. However, as suggested by the rapid rise of the employment index in the first three decades of the century, but not since (Table 21 and Chart 9), the employment series (and the resulting indexes of output per unit of labor) may have been affected by changes in the rate of construction undertaken in the industry after 1902. The Edison Electric Institute has published data indicating that construction expenditures in the 'thirties were

TABLE 21

Electric Light and Power, 1902–1942

Annual Indexes of Employment, Manhours, and Output per Unit of Labor (1929:100)

	EMPLOYMENT CENSUS (th.) (1)	BLS INDEX OF ELECTRIC LIGHT & POWER EMPLOYMENT IN PRIVATE COMPANIES (2)	EMPLOYMENT IN PRIVATE ELECTRIC LIGHT & POWER COMPANIES (th.) (3)	INTERPOLATED RATIOS (1 ÷ 2) (4)	INTERPOLATED RATIOS (1 ÷ 3) (5)	INTERPOLATED CENSUS EMPLOYMENT (th.) (6)	AV. HOURS WORKED PER WEEK (7)	EMPLOYMENT INDEX BASED ON 6 (8)	MANHOUR INDEX BASED ON (6 × 7) (9)	WEIGHTED OUTPUT INDEX (10)	OUTPUT PER UNIT OF LABOR INDEXES BASED ON Employment (11)	OUTPUT PER UNIT OF LABOR INDEXES BASED ON Manhours (12)
1902	30.3					30.3		10.4		3.3	31.4	
1907	47.6					47.6		16.3		6.8	41.6	
1912	79.3					79.3		27.1		11.8	43.3	
1917	105.5		94.7		1.115	105.5	46.3	36.1	35.9	22.3	61.6	62.0
1918			102.3		1.113	113.9	45.7	39.0	38.2	28.6	73.4	74.8
1919			108.1		1.112	120.2	45.2	41.1	39.9	33.0	80.3	82.8
1920			119.0		1.110	132.1	44.6	45.2	43.3	36.2	80.0	83.6
1921			123.4		1.109	136.8	45.6	46.8	45.8	33.6	71.7	73.3
1922	150.8		136.1		1.108	150.8	45.9	51.6	50.8	38.4	74.4	75.6
1923			177.6		1.100	195.4	45.6	66.9	65.4	47.3	70.8	72.4
1924			192.0		1.092	209.8	45.9	71.8	70.7	52.8	73.6	74.7
1925			198.4		1.085	215.2	46.1	73.6	72.9	61.9	84.0	84.9
1926			224.6		1.077	241.9	44.9	82.8	79.7	72.6	87.7	91.1
1927	251.0		234.7		1.069	251.0	45.8	85.9	84.4	81.7	95.1	96.8
1928			250.6		1.072	268.7	45.6	91.9	90.0	89.5	97.3	99.5
1929		100.0	271.8		1.075	292.3	46.6	100.0	100.0	100.0	100.0	100.0
1930		...	279.9		1.078	301.8	47.0	103.3	104.2	103.5	100.2	99.4
1931		...	259.8		1.081	281.0	47.1	96.1	97.2	101.9	106.0	104.9

1932	244.6	82.9	225.6	2.950	1.084	244.6	44.0	83.7	79.0	92.7	110.8	117.4
1933		77.3		2.969		229.5	42.0	78.5	70.8	92.9	118.3	131.2
1934		79.8		2.988		238.4	38.8	81.6	67.9	99.3	121.7	146.1
1935		81.4		3.007		244.8	39.3	83.7	70.6	108.3	129.3	153.3
1936		86.7		3.026		262.3	40.1	89.8	77.2	123.4	137.5	159.8
1937	281.3	92.4		3.045		281.3	40.3	96.3	83.2	136.3	141.6	163.8
1938		89.5		3.045		272.5	39.9	93.2	79.8	136.9	146.8	171.5
1939		89.0		3.045		271.0	39.6	92.7	78.8	151.6	163.6	192.5
1940		91.1		3.045		277.4	39.7	94.9	80.9	167.8	176.8	207.6
1941		92.7		3.045		282.2	39.8	96.6	82.5	190.6	197.4	231.1
1942		86.5		3.045		263.4	40.1	90.1	77.5	212.1	235.4	273.6

The final indexes presented here are based on the Census coverage, which excludes electric railway companies. The interpolating method follows those used in preceding tables. The data underlying columns 1, 2, 3, 7, and 10 were obtained as follows:

(1) Data from successive Census of Electric Light and Power reports include salaried employees and wage earners. The figure for 1937 is for the number employed on June 30; employment on December 31, 1937, also requested, totaled 276.8 th. As seasonal fluctuations in employment are not of wide amplitude, the comparability of the series is not greatly affected by the fact that not all the Census employment totals are for the mid-year. E.g., in 1902 and 1907 annual average employment figures were reported, i.e., "the number that would be required, at continuous employment, for the twelve months" (*ELP, 1907*, p. 191). The figures for 1912 and 1917 are for the number employed on September 16 and 29 respectively, or the nearest typical day; for the remaining years, as of June 30.

(2) Based on reports for private plants representing about 95 percent of the industry, according to the BLS. The employment totals exclude corporation officers and executives (*Survey of Current Business*, 1942 Supplement, p. 46, 194; *Monthly Labor Review*, March 1943, p. 632).

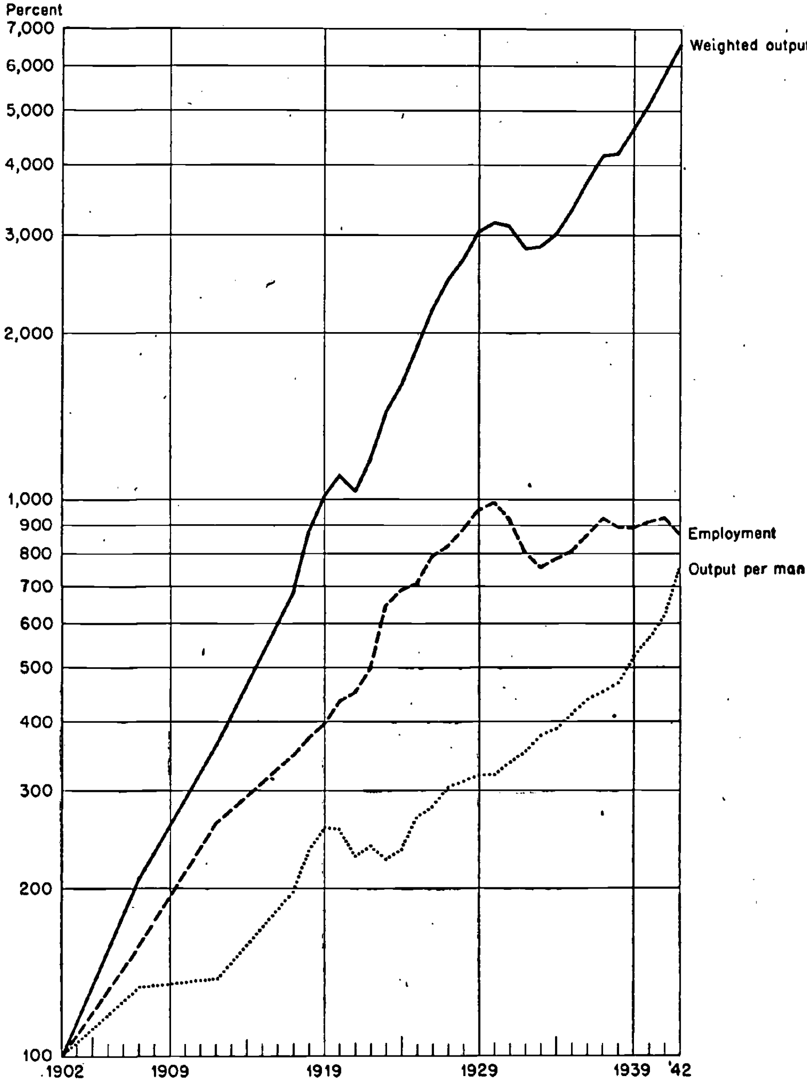
(3) National Bureau estimates of employment, excluding municipal and other public companies, based on employment indexes of New York, Ohio, Pennyslvania, Wisconsin, and Illinois (Simon Kuznets, *National Income and Its Composition, 1919–1938*, National Bureau of Economic Research, 1941, II, 676, 710).

(7) Data for 1932–40, from Hours and Earnings in the United States, 1932–40 (Bureau of Labor Statistics, *Bulletin 697*, Washington, D. C., 1942, p. 126), are 12-month averages; the figures for 1941 and 1942 are averages of monthly data, for private companies only published in successive issues of the *Monthly Labor Review*. The figures for 1932–37 are described as not strictly comparable with those for later years because the latter exclude corporation officers, executives, and other employees whose duties are mainly supervisory. The figures for 1917–31 were derived by extending the BLS series by means of estimates of "average actual hours per week" made by the National Industrial Conference Board (*Economic Almanac for 1942–43*, p. 356, and M. A. Beney, *Wages, Hours and Employment in the United States, 1914–1936;* National Industrial Conference Board, 1936; p. 162).

(10) The weighted output index was constructed in precisely the same manner as that shown in Table 13, but is comparable to the employment index in that electricity sold by electric railway companies is excluded.

CHART 9

Electric Light and Power, 1902–1942
Indexes of Weighted Output, Employment, and Weighted Output per Man
(1902:100)



Based on Table 21.

Ratio scale

far below those in the 'twenties,[11] and the absence of any increase

[11] The average annual expenditure was $728.1 million in 1921–30; $433.2 million in 1931–42 (*Statistical Bulletin 10*, p. 34).

in electric light and power employment since 1930 may be correlated with the falling off in new construction work. Even if the Census injunction against the inclusion of new construction employment was heeded, the figures reported to the Census may have been considerably influenced by employment on the extension of *existing* facilities; i.e., the distinction between extension and construction may not always be clearcut. In any case, to the degree that our employment series does *not* include construction employment, it is evident that we are omitting from present consideration a considerable portion of the employment associated with the rise of the electric light and power industry.

Total employment rose about 770 percent, 1902–42, or at an average annual rate of 5.6 percent. Most of the gain was achieved before 1929; the average annual increase in 1902–29 was 8.8 percent. These advances, while striking in themselves, are somewhat smaller than those characterizing the growth of capital assets in the industry. Deflated capital assets per worker rose, 1902–37, a bare 10 percent, according to our calculations, although our measures of capital are not nearly as accurate as our employment data.

The output index with which we compare employment in Table 21 is the *weighted* rather than the *unweighted*, not so much because we believe there is a direct relation between shifts in the production of high- and low-valued current and changes in employment but for more general considerations. In this Chapter we have indicated how the concept of productivity may be enlarged to include the input of all production factors. Nevertheless, in the absence of a summary measure of total input, productivity measures are usually confined to comparing output and labor input. In most industries, of course, labor is the only component of input for which we have data. In addition, labor, being a human resource, is the most important single component of total input.[12] During long periods, for instance, a productivity measure comparing the movement of the nation's net output with changes in the nation's labor force may be regarded as an index of the rise in the national standard of living. It is within this broad frame of reference then that we single out an index of *weighted* output per unit of labor in the electric light and power industry. Increases in it will reflect the total contribution of

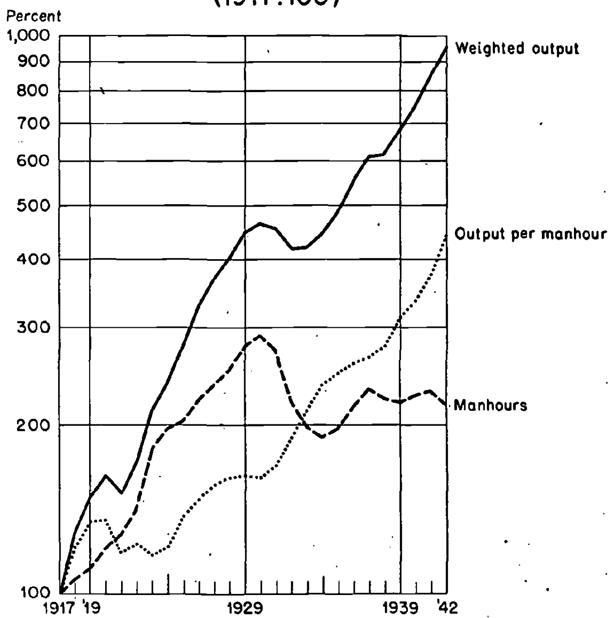
[12] However, in the electric light and power industry the wage bill constitutes a smaller than average proportion of total income originating in the industry; see the Introduction.

the industry to the nation's output in relation to its immediate consumption of human services rendered.

The weighted output per man index (Table 21) rises vigorously throughout the forty years under review. In 1942 it is 650 percent

CHART 10

Electric Light and Power, 1917–1942
Indexes of Weighted Output, Manhours, and Weighted Output per Manhour
(1917:100)



Based on Table 21.

higher than in 1902, which is equivalent to an average annual rate of growth of 5.2 percent. The regularity of the upward movement is broken only once, in 1920–23 (that is, after 1917, for we have no annual information before). In the recession year 1921, as already noted in Chapter 1, the index of output declined slightly, though employment did not; as a result, the output per man index declined. The year to year movements of output per manhour are similar to those of the output per man index, but rise more because of a 13 percent decline in the average working week between 1917 and 1942 (Table 21). The average annual rate of increase associated with the 341.0 percent gain in output per manhour 1917–42 was 6.1 percent; the average annual growth rate for the output per man index was 5.5 percent (Chart 10).

The labor productivity indexes and the other output-input ratios considered here all rise markedly and indicate little retardation in the rate of growth. These increases provide a background against which one may judge the industry's ability to lower the total cost and price of service rendered. In Chapter 5 we discuss in greater detail the significance of these advances in output-input ratios, which are far greater than those in other industries.