ECONOMIC GROWTH CENTER

YALE UNIVERSITY

Box 1987, Yale Station
New Haven, Connecticut

CENTER DISCUSSION PAPER NO. 215

September 1974

THE INTRODUCTION OF ELECTRIC POWER AND ITS IMPACT ON THE MANUFACTURING INDUSTRIES: WITH SPECIAL REFERENCE TO SMALLER SCALE PLANTS

Ryoshin Minami

The Introduction of Electric Power and its Impact on the Manufacturing Industries: With Special Reference to Smaller Scale Plants

by

Ryoshin Minami

Introduction

The history of energy utilization constitutes an important part of the history of economy, society and culture. One of its most important aspects is the transformation of motive power, which is closely associated with improvements in production machinery, and has contributed to the rapid development of manufacturing industries. This was the case in the so-called industrial revolution which began with improvements in spinning machinery during the 1960s in England.[2] Waterframe spinning machinery invented by Richard Arkwright (1766) led to substitution of water power for human power. The further development of spinning machinery demanded new engines, powerful and independent of water streams. This demand was met by the appearance of the steam engine.

Improvements by James Watt during the 1770s and following decade permitted steam engines to be used for the first time for industrial purposes. Because of subsequent increases in speed and decreases in price, steam engines began to be employed to a greater extent in industry, notably in spinning factories equipped with waterframes and mules. Steam engines were continuously improved in response to various demands: large capacity, low fuel consumption, high speed, small size and light weight, etc. During the late nineteenth century, however, these technical improvements reached a plateau. Steam engines were gradually replaced by steam turbines having large capacity and high speeds, and internal combustion engines, small in size and light in weight. Furthermore, electric motors began to be used in a wide range of factories after the invention of the alternating current motor (1885-90) and eventually displaced the steam engine. This transformation from steam engines to electric motors—electrification—was really the most sweeping and complex technological change in manufacturing industries.

This paper aims at a quantitative study of electrification and its impact on smaller scale manufacturers in Japan. Emphasis is placed on the smaller plants because of the economic significance of electrification to them. By way of introduction, however, we will discuss the whole motive power transformation process including electrification in larger manufacturing plants. In the first section the process of transformation will be surveyed for the manufacturing sector as a whole and then by the scale of plants in this sector. In the last part of the section factors responsible for electrification will be reviewed. A section is devoted to an examination of the impact of electrification on smaller plants. The hypothesis that persistent growth of these plants was dependent largely on the introduction of motive power through electrification will be tested. That is, the relationship between electrification and the introduction of motive power is examined and the effects of motive power on productivity increases will be clarified for two industries, match making and weaving, as examples typical of smaller scale factories. Finally, conclusions from the first two sections will be summarized and their implications discussed. Further, another form of electrification, the use of electric lighting, and its significance will be taken up.

I The how and why of electrification in manufacturing industries

A Electrification in manufacturing industries

Prior to the age of electric motors, water wheels and steam engines were used by Japanese manufacturers. Water wheels were dominant from the end of the Tokugawa era until about 1890 in industries such as silk reeling and cotton spinning (Kanbayashi 1948, p. 63). Yamaguchi's compilation (1956, p. 96) from the Prefectural Statistical Tables (Fuken Tōkei-hyō) shows that around 1884, 47.3 percent of factories were equipped with water wheels whereas only 3.6 percent had steam engines, 44.2 percent had no motive power, and 4.9% were unaccounted for.

The introduction of steam engines dates from the 1860s (Kanbayashi 1948, pp. 75-76). In 1861 the Nagasaki Iron Mill began to use steam power. Shimazu Hisamitsu of the Satsuma clan, who imported cotton spinning machinery from England in 1866, completed a spinning plant equipped with a steam engine the next year. In 1871, the Tomioka Silk Reeling Plant, a government enterprise, began to operate steam powered machinery imported from France. The Takashima Colliery Company ran shaft transporters powered by a steam engine. Thereafter steam engines diffused rapidly, especially in the 1890s. Yamaguchi's statistics (1956, p. 111) show factories equipped with water wheels decreased to 19.9 percent around 1892, whereas factories using steam power increased to 25.3 percent. A rapid rise in steam power since 1884 can be seen in Figure 1, which shows horsepower of prime movers by type. Horsepower supplied by steam engines (including steam turbines), shown in Figure 2, already exceeded 85 percent in 1889. In contrast, water wheels (hydro turbines, Pelton, and Japanese-type) continuously decreased, amounting to less than 10 percent at the turn of the century.

During the phase of steam power diffusion, introduction of techniques for generating, transmitting and using electric light and power was already in progress.[3] The first actual use of electric light in Japan was at the Sangenya Plant of the Osaka Spinning Company in 1886, from electricity generated within the plant. The supply of electric lighting for public use was begun by the Tokyo Electric Light Company in 1887. In both cases power was obtained by thermal generation. Hydro generation dates from 1890. In this year two companies, the Shimotsuke Jute Yarn Spinning and the Ashio Copper Mine, commenced hydroelectric generation for their own use. In 1892 Kyoto City set up a water plant, the Keage Power Plant, and began to supply electricity for public use. Thereafter, numerous hydro plants were established in various regions and a remarkable rise in generating capacity occurred.

Statistics for generating capacity are available from 1903, and for electricity generated and consumed, from 1907. They are given in Table 1, columns (2), (3) and (4), respectively, for every fifth year. The number of electric bulbs installed, shown in column (1), suggests use spread rapidly after 1890.

During the late 19th century and the beginning of this century, electric power generation by firms for their own use was much greater than that by electric utilities. Statistics for 1907 show the latter was only 39 percent of total power generated. However, owing to a rapid increase in output by utilities. This increased to over 50 percent in 1913. The predominance of the utilities was made possible by their rapid progress in transmission techniques. A representative example is the completion of a power transmission line by the Tokyo Electric Light Company in 1914, which enabled the long distance (228 kilometers, third longest line in the world at that time) and high voltage (115,000 volt)transmission of 37,500 kilowatts from the Inawashiro Hydro Plant to the Tokyo district.

In the course of the development of electric generation, electric motors came to be widely used. Figure 1 shows horsepower of electric motors increased remarkably after 1899.[4] In 1905 it exceeded the horsepower of water wheels and in 1917 it exceeded that of steam engines. Figure 2 shows a rapid decrease in the percentage of steam power, which signifies a sweeping substitution of electric power for steam. The relative decrease in steam power and the increase in electric power, however, stopped around 1930, implying electrification in factories was actually completed around that time.

In summary, the substitution of steam engines for water wheels took place in 1890-1905. The substitution of electric motors for steam engines, beginning in the 1890s, occurred from 1905 to 1930. It appears that these two substitutions occurred in a much shorter time than was the case in the other industrialized countries.

B Examination by scale of factory

Power statistics by scale of factory are available from the Kōjō Tōkei-hyō beginning with 1909, though on an annual basis only from 1930. From these data, percentages of various prime movers in terms of horse are calculated and shown by scale of factory for six years from 1909 to 1940 in Table 2. In 1909 steam engines constituted about half of available horsepower in even the smallest plants, increasing to four-fifths for those with more than 500 production workers. The share of water wheels was somewhat greater for smaller firms. However the data for water wheel usage by large firms are so erratic for 1909-19 that problems of sampling and reporting may be significant. Plants with over 1000 workers relied relatively somewhat more on electric motors, but up to that level there was no significant scale pattern.

By 1930 composition of prime movers by type and by scale of establishment had changed substantially. The percentages of water wheels and of steam engines decreased sharply from 1909 to 1930. By 1930 the share of water wheels was almost zero in all scales except the smallest. Steam engines amounted to only 4-14 percent in the under 999 group and 19 percent for plants over 100 persons. The percentage of electric motors (β) increased rapidly in all scales, reaching 80 to 95 percent in 1930. That is, the completion of electrification at all scales had occurred by around 1930. Another index of electrification, γ, the percentage of electric motors to total prime movers, is calculated in Table 3 by scale of plant for the same six years.[5] Electric motors were only one-fifth of total prime movers on average in 1909, less for smaller plants and substantially greater for large factories; by 1930 electric motors were the predominant prime mover in all factories. With this index the more rapid electrification in the smaller plants and the completion of electrification around 1930 in all scales can be observed again.[6] And, as is discussed later (see Table 8) the percentage of factories with prime movers, always high for the largest scale factories, increased from low to high rates for small factories as well.

C Reasons for Electrification

The major factors responsible for the rapid substitution of electric power for steam power were the advantages electric motors have over steam engines and developments in the electric utilities and electric machine industry.

Merits of Electric Motors. Electric motors differ from steam engines in ease of operation and efficiency of small units of operation. Table 4, Panels A and B show average capacity (horsepower) of prime movers by type: i.e., electric motors, steam engines, steam turbines, gas engines, petrol engines and water wheels. Panel A gives figures for all scales of factories by year, and shows all other engines with the exception of petrol engines had greater average capacity than electric motors. The average capacity of steam turbines increased remarkably, to 3900 horsepower in 1940. Panel B gives figures by scale of factory for 1940, and indicates little difference in the average capacity among scales in the case of electric motors, whereas in the other engines, for example steam engines and turbines, an increasing trend can be seen in the average capacity as scale increases.

The significance of introducing small capacity electric motors into smaller factories and into larger ones will be considered separately. Because small plants could not be equipped with large capacity steam engines, tools and machinery continued to be operated by human power for a long time. The appearance of electric power had a revolutionary effect on these plants by enabling the replacement of human power, in many cases merely by extending a electric wire to an ordinary house and installing one small electric motor within the house (Hoshino 1956, p. 181). On the other hand, in larger plants, a comparison of economic efficiency between steam engines and electric motors was crucial.

The use of steam power necessitated group drive arrangements, where power of one or more steam engines was transmitted to machinery by means of big shafts and long belts. The introduction of electric motors gave rise to unit drive arrangements, where electric motors directly operated each tool and machine. This new system has many merits. One was greater flexibility of factory layout and design because the limitations entailed by big shafts were eliminated. Capital cost was reduced through reductions in floor space and in building construction; heavy, multistoried structures with reinforced floors capable of supporting reciprocating steam engines were not needed. Loss of energy was reduced because individual parts of the production process could be stopped independently.[7] This system was widely introduced in various industries during World War I and after, when small induction motors began to be produced in Japan. In the spinning industry, for example, the unit drive system was employed extensively from about 1932.[8] In two plants constructed in that year, the Inami Plant of the Kureha Spinning Company and the Sasazu Plant of the Tenman Weaving Company, all processes through spinning utilized unit drive arrangements. In the Sekigahara Plant of the Dai Nippon Spinning Company, completed in 1934, the new arrangements were introduced in all processes (Moriya 1948, p. 181).

Development of electric utilities and the electric machine industry. Without cheap electric motors, rapid introduction of electric power would not necessarily have been the case, even though electric motors were advantageous compared with other prime movers. Electrification was also dependent upon development of both electric utilities and the electric machine industry.

Electric utilities. Prior to 1932 electric light and power rates were not under government control but were determined by generating costs and supply-demand conditions. Table 5, columns (1) and (2) show the average rates of electric light and power, respectively.[9] During 1907-15 the average rate for electric light (used mainly for household consumption) showed a decrease, whereas that for power (used mainly for industrial purposes) showed an increase. The increase in power rates is a superficial trend resulting from statistical and methodological problems in estimation. In reality, the rate for electric power also seems to have declined during this period.[10] This was the result of a decrease in generating costs coming from the introduction of hydro generation and, after the Russo-Japanese War, the success of high voltage transmission. In 1908 the Tokyo Electric Light Company cut light and power rates by 12 percent and 22 percent, respectively, because of a sharp drop in generating costs due to the completion of the Komabashi Power Plant in 1907 (Nitta 1936, pp. 99-100). Aggressive competition among utilities accelerated this declining trend. In Tokyo, for instance, overlapping supply of light and power began around 1907 among three sources: the Tokyo Electric Light Company, Tokyo City government, and the Tokyo Electric Railway Company (Arisawa 1960, 3:114).

The Tokyo Electric Light Company reduced rates when the Yatsuzawa Power Plant started to operate in 1912 (Nitta 1936, p. 107). After a trough in 1915 (at which time the average electric power rate was 30 yen per 1000 KWH), rates began to rise because of a big increase in demand caused by the economic boom during and after World War I. The upward trend during these inflation years (1915-19) was much larger for the power rate than for the lighting rate. Because of this, as shown in Table 6, the ratio of the electric power rate to the manufacturing output price index (column (2)) was almost constant, whereas the ratio of the lighting rate to the consumer price index (column (1)) decreased for 1915-20.

During the recession years after the war boom the lighting and power rates showed different patterns of change. The lighting rate continued to rise during this period. It was 72 yen in 1920 and 99 yen in 1930 per 1000 KWH. Consequently the ratio of this rate to the consumer price index increased. On the other hand the power rate began to decline from a peak in 1923 (69 yen per 1000 KWH) and returned to the 1916 level in 1932. This decline was caused by aggressive price cutting among electric utilities resulting from excess supply.[11]

There were two reasons for this over-supply. The first is a technical one: hydro plants at that time did not have dams and thus could not control seasonal variations in water flows. Consequently, the need to have sufficient generation capacity to meet peak loads in periods of water shortage necessarily gave rise to over-supply under normal conditions. The second reason is a decrease in the growth of the demand for industrial use during the depression of the 1920s and early 30s. The low prices resulting from over-supply of electric power, however, created new sources of demand: smaller factories in manufacturing and electro-chemical industries such as ammonium sulphate and electrolysis.[12] The appearance of these new users lessened the financial difficulties of the electric utilities (Fujino 1965, pp. 444-449; Kurihara 1964, pp. 256-261).

Differences in changes between the lighting rate and the power rate are explained by differences in their price elasticities of demand. Electric lighting consumption, with a much lower elasticity, does not decrease much in response to a rise in its rate. This is not the case for the more elastic electric power consumption. Therefore the utilities intended to stimulate demand for electric power by reducing its price while increasing the lighting rate to compensate for the lower profits from power rates. In this way a large difference between the two rates appeared in this particular period.[13]

Since 1932, the year the electric power cartel was established, rates have been under government control. Owing to this control, rates for electric light and power could not increase rapidly compared with other price indexes: The ratio in column (1) of Table 6 decreased from 1935 to 1938 and the ratio in column (2) declined from 1930 to 1940.

As for substitution of electric power for steam, changes in the price of coal must also be considered.[14] The coal price index in Table 5, column

(3) shows a sharp increase after 1915. Consequently, the ratio of the electric power rate to the coal price, shown in Table 7, column (1) began to decline remarkably in the early 1920s. One of the basic causes of this decline seems to be that technological progress was much faster in the electric utilities than in coal mining: relative labor productivity calculated in Table 7, column (2) shows an increasing trend for the entire period. In short, the difference in the rate of technological progress between electric utilities and coal mining accelerated the substitution of electric power for steam power.[15]

Electric Machine Industry. A wide range of electric machinery and appliances was imported, mainly from the United States, in the Meiji era. The Miyoshi Electric Plant, the first manufacturer of electric machinery, began to operate in 1884. In the 1890s the Ishikawajima Shipbuilding Yard, the Tokyo Shibaura Electric Company and others appeared. Production techniques in these plants were, however, poor, and products were merely an imitation of the imports (Arisawa 1960, 6:17). Furthermore, technological progress was too slow to keep pace with the rapid development in the electric utilities. They produced mainly small capacity, low voltage machinery. With an increase in demand for electric machinery, the number of manufacturers increased from the late Meiji period. Because of progress in production techniques and the interruption of imports during World War I, production of previously imported large capacity, high voltage machinery began in the mid-Taishō period. By the early 1930s, demand was almost entirely met domestically (Hitachi 1949, vol. 1 and 1960, ch. 1). In this process borrowed technology was predominant. This is easily understood since almost all the major electric manufacturers had technological tie-ups with foreign manufacturers.[16]

This was the case for production of electric motors. The first domestically produced motor was a 25 horsepower two-phase induction motor manufactured by Tokyo Shibaura in 1895 (Meiji 1928, p. 401). Thereafter production was carried on by several manufacturers mainly for small capacity motors. Mass production of standard type small capacity motors began in 1918 when Hitachi began to produce this type of motor at its Kameido Plant. A history of this company tells us this caused the price to go down and quality to improve.[17] Figure 3 shows a sharp decline in the price of electric motors of one horsepower after 1920. This decline seems to have made electric power more accessible to smaller plants (see Chūshō 1960, p. 21).

II Impact on smaller scale plants of introducing electric power

A Electrification and introduction of motive power

The impact of the introduction of electric power on the growth of smaller enterprises deserves special attention, because the introduction of motive power occurred directly with electric motors. This change seems to have contributed to a rise in labor productivity.

According to a series based on the Nōshōmu Tōkei-hyō for establishments with ten or more production workers, only about 30 percent of factories were equipped with prime movers at the end of the nineteenth century. This increased steadily thereafter and reached 70 percent in 1918. Table 8 shows the ratio (α) of factories equipped with prime movers to total factories for all scales of manufacturing factories as a whole, based on data from Kōjō Tōkei-hyō for establishments with five or more persons. This ratio rose from 28 percent in 1909 to 93 percent in 1930. That is to say, the introduction of power was almost completed by the latter year. In comparison with Table 2 and Figure 2, one may see the introduction of power during the end of the nineteenth century and the beginning of the twentieth was accomplished mainly by the installation of steam power, whereas the introduction of power thereafter came from the utilization of electric motors.

Let us now elaborate upon the relationship between power introduction and the electrification by scale of factory. The percentage by scale of powered factories α appear in Table 8 and of electric motors β (in horse-power) and γ (in numbers) in Tables 2 and 3 respectively.[18] Figure 4 depicts changes over time in the percentages α, β and γ for factories employing 5-9 persons and for 1000 persons or more. For the very small plants α, β and γ show conspicuously increasing trends for 1909-30. However, α was already 100 for the largest factories in 1909 and thereafter did not show any relationship with electrification. The contrast between these two factory sizes is much clearer in Figure 5, which shows the relationship of α to β and γ. High correlations are found for the small plants while no correlations are found for the large ones. In other words, small firms relied much more than large upon electrification for the introduction of power, with electricity supplied by public utilities. Large firms were able to introduce other power sources directly and hence earlier, and could also generate their own electricity.

B Introduction of motive power and technological progress.

The impact of motive power on technological progress in smaller factories will be demonstrated for two industries: match making and weaving. This selection is for two reasons: the production processes are relatively easier to be understood and these industries are characterized by small factories.

Match making industry. Production of matches consists of producing matchsticks and boxes, spreading chemicals on the sticks, and putting the sticks into boxes.[19] With the exception of large manufacturers who carried out all of these processes within their plants, firms purchased matchsticks and boxes from special producers. Therefore, match making in Japan usually signified only the second and the third steps, with the arraying of matchsticks for spreading chemicals the most important process. This production requirement regulated the introduction of machinery and motive power.

There were three stages in the development of this procedure.

1. In the beginning boys and girls arrayed matchsticks by hand. This system was employed from about 1880 until 1905.

2. Treadle machines were introduced after 1895, operated by female adult workers.

3. Finally, the German-type machinery, made of iron and run mostly by electric motors, was used. This machinery, called doitsu (the Japanese word for German), was already known in early Meiji and came into wide use in late Meiji when Japanese matches began to be exported. Usually male adult workers operated this machinery. The productivity of labor was several times greater than using treadle machines.

The shift from treadle to German-type machinery was uniquely dependent upon the introduction of prime movers. In 1906 the total capacity of prime movers used in the industry was 80 horsepower. More than half of this was produced by steam engines; gas and petrol engines were used to a lesser extent. By 1914 the total capacity had risen to 335 horsepower, with 116 from steam engines. Thereafter, as shown in Table 9, β, 76 percent, and γ, 35 percent, in 1914, increased to 90 and 67 percent, respectively, in 1919 and to 97 and 81 percent in 1930. Owing to this rapid introduction of electric motors, the percentage of powered factories α, only 26 in 1914, increased to 49 in 1919 and to 86 in 1930.

Let us examine the same thing by scale of factory. In 1914 all the largest factories (500-999 persons) were equipped with prime movers. On the other hand, none of the smallest factories (5-9 persons) had prime movers, and only 6 percent of the second smallest (10-29 persons) were so equipped. In these small factories the level increased to about 80 percent in 1930 through the introduction of electric motors. If these factories had run one or two German-type machines (about 2 horsepower) with steam engines, they probably could not have survived the heavy burden of capital and operating costs. The Sweden Match Trust, established in 1921, drove Japanese matches out of foreign markets. Moreover, it intended to dominate the market in Japan by founding two companies, Daido Match and Asahi Match. This plan was not completely successful, in part because of the existence of a number of small scale factories (Komiyama 1941, p. 198), whose survival was supported by a decline in nominal wages during the depression years of the 1920s (Minami 1973, ch. 7), and by the mechanization of production processes during and after World War I.

Weaving industry. Japanese weavers were classified into two groups. The first group consisted of companies which produced foreign (double) width cotton cloth, i.e., the weaving section of cotton spinning companies and a small number of companies belonging to the All Japan Cotton Spinner's Association. The second group consisted of small-scale factories which produced domestic (single) width cloth and silk fabrics. Between these two groups there was a difference of timing in the introduction of power looms: whereas they were already in use by 1887 in the first group, in the second group they were employed only experimentally after 1897 and only after World War I were they used extensively (Sanpei 1961, p. 391). The diffusion of power looms was made possible by electrification. As seen in Table 10, the percentage of powered factories α, jumped from 38 percent in 1914 to 90 percent in 1930, and the use of electric motors increased similarly. Examination by scale of factory shows the diffusion of motive power based on electrification went on at a higher speed in the smaller scale factories belonging to the second group.

The electrification of smaller-scale weavers was possible because of the commencement of service by electric utilities. Three examples of the relationship between the start of electric utilities and the introduction of power looms in these factories are given from Sanpei (1961, p. 408).

1. In the case of the weaving industry of Tokamachi, Niigata prefecture, electric motors and power looms were introduced in 1924. This is attributable to the foundation of the Uonuma Electric Company in 1911.

2. The introduction of power looms in the Kiryu and Ashikaga districts was dependent upon the supply of electric power by the Watarase Electric Company established in 1908.[20]

3. Weavers in Ichinomiya, Aichi Prefecture, introduced power looms relying on cheap electric power purchased from the Ichinomiya Electric Company founded in 1923.

The transition from hand and treadle looms to power looms seems to have stimulated labor productivity. Quantitative evidence for this relation is found in the Niigata-ken Minami Kanbara Gunze (Economic Survey of Minami Kanbara District, Niigata Prefecture) in 1920. This survey shows that around 1916 daily production of striped cotton cloth per worker amounted to only one tan (about twelve yards) for hand looms and three tan for treadle looms, whereas it was nine tan in the case of power looms (Sanpei 1961, p. 407). Another survey (Tōyō 1950, 2:225) shows while one worker operated only one hand loom or treadle loom, he could run four to twelve power looms or forty to sixty automatic looms, clearly displaying the increase in labor productivity from the transformation of looms.

A time-series test for the relationship between the introduction of power looms and technical progress is made for the cotton weaving industry. Data is available from the Shōkōshō Tōkei-hyō (Statistical Tables of Commerce and Industry) for 1922-38. Denoting the volume of production in physical terms (in foreign width cloth equivalent) per production worker, the number of looms per worker and the percentage of power looms by p, k and α, respectively, the following model is set forth:

$$\ln p_t = a_o + a_1\alpha_t + a_2 \ln k_t + u_t \qquad a_1 > 0 \qquad a_2 > 0,$$

where ln signifies the natural log of a variable.

In the case where the number of looms was a good index of capital stock and the ratio of value added to gross output was constant, parameter a_2 can be taken as the output (value added) elasticity of capital. Special attention must be paid to the second term, $a_1\alpha_t$, which corresponds to an increase in labor productivity stemming from technological progress (defined as a shift in the production function). This formulation comes from our basic hypothesis that technological progress in this industry was dependent largely upon the diffusion of power looms.

The results of estimation of this equation are given in the upper part of Table 11. Data for 1938 were omitted because p showed an unreasonable drop, due perhaps to the dislocation of wartime industrial adjustment. The high determination coefficient suggests the model is appropriate for this industry, though there is some serial correlation. Parameter a_1, significant at the conventional significance level, shows high sensitivity of labor productivity to the diffusion of power looms. Parameter a_2 suggests the output elasticity of capital was on the order of 0.4-0.5.[21] In the lower part of the table, one may see that, of the 10.50 percent annual rate of increase in labor output, 9.8 percentage points was attributable to technological progress based on the introduction of power looms, and only 1.31 percentage points to the increase in the number of looms per worker.

III Electric lighting

Another aspect of electrification, the diffusion of electric lighting, has not been discussed in this paper. In factories, as has already been mentioned, electric lighting was introduced much more rapidly than electric power. This introduction contributed to the reduction of production costs by promoting nightshifts. Before the introduction of electric light, petrol lamps were used. Because of the danger of fire from using these lamps, however, there was a movement for the abolition of nightshifts (Arisawa 1959, 1:67). Electrification eliminated this and permitted the widespread use of the system. (This gave rise to the widely known tragedy of young female workers detailed in Jokō Aishi (Miserable History of Female Workers).)

The rapid diffusion of electric lighting for home use is indicated by the number of electric bulbs installed shown in Table 1, column (1). During Meiji, traditional lamps such as tōmyō (tapers), andon (paper-covered lamps) and Japanese candles were gradually being replaced by modern lamps using petrol, gas and so forth. Gas lamps were dominant until the late Meiji era, but then, owing to a decline in electric lighting rates and the appearance of tungsten bulbs, the use of electric lights increased remarkably (Kurihara 1964, pp. 63-64). Consequently, the number of gas lamps began to decrease after a peak in 1917 (Fujino 1965, p. 444). The substitution of modern lamps for traditional lamps and the transition among modern lamps (from petrol to gas to electric bulbs) may be explained by differences in economic efficiency. Table 12 gives mean candle power, cost per hour and hourly cost per candle power, respectively, in columns (1), (2) and (3), for various lamps. Mean candle power is very small in the traditional lamps: only 0.25 for tōmyō, 0.2 for andon and 0.5 for a Japanese candle. It is large in the modern lamps: 3.2 for petrol, 20.0 for gas and 18.0-30.0 for electric bulbs.

Hourly cost per candle power is larger in the traditional, and smaller in the modern lamps. Among modern lamps, hourly cost per candle power is lowest in electric bulbs (0.021-0.025) and highest in petrol bulbs (0.12). Thus, diffusion of electric lighting seems to have had a significant influence on the daily life of the people.

IV Conclusions and some implications

There are five main conclusions from our analysis.

1. A distinctive characteristic of the revolution in motive power in Japan lay in its high speed compared with countries which had developed earlier.[22] During the late 1880s when horsepower of water wheels increased rapidly, horsepower of steam engines also showed a big increase. Furthermore, even during the golden age of steam engines, up until the beginning of the twentieth century, the introduction of electric motors made rapid progress. Consequently, the capacity of electric motors surpassed steam engines in 1917 and electrification was eventually completed around 1930. In the case of smaller factories, the introduction of electric motors proceeded during and after World War I and was almost completed by 1930.

2. One of the factors responsible for electrification is this form of motive power's divisibility into small units. It was due to this characteristic that unit drive arrangements replaced group drive arrangements in large scale factories, saving production costs. In smaller factories the initial introduction of motive power consisted of installing small capacity electric motors. Another factor in electrification was the externalities from developments in electric utilities and in the electrical machine industry.

3. The introduction of motive power through the electrification of smaller factories enabled labor productivity to increase and gave rise to a persistent growth in these factories. As an example, in the match-making industry, where smaller factories were dominant, the substitution of the German-type machinery for treadle machines was facilitated by the introduction of electric motors. This substitution, which raised labor productivity, was considered to be one of the main reasons why the smaller plants did not disappear in the wake of the Japanese market by the Sweden Match Trust. A second example is the weaving industry. A shift from hand and treadle looms to power looms relied upon electrification and, again, increased labor productivity.

4. The more rapid displacement of steam power by electric power than in the case of countries which had developed earlier was largely due to the rapid progress of electric utilities. For example, the first supply of electricity for public use by the Tokyo Electric Light Company in 1887 lagged by only five years the establishment of a distribution station in New York by the Edison Electric Company. At the beginning of hydro generation, a ten year lag existed between the United States and Japan: i.e., 1882 for the hydro plant in Appleton, Wisconsin, and 1892 for the Keage Hydro Plant in Kyoto.

The rapid progress of electric utilities in Japan was entirely dependent on borrowed technology. Generation and transmission techniques were introduced from abroad, and tools and machinery were all imported. Let us take two plants of the Tokyo Electric Light as examples. For the

Komabashi Power Plant completed in 1907, water wheels, generators, and transformers and distributing boards were imported from Switzerland, Germany and the United States, respectively (Arisawa 1960, 6:24-25). Even the Inawashiro Hydro Plant in 1914 was equipped almost entirely with imports: water wheels from Germany, generators from England, and transformers, transmission towers and insulators from the United States. Electric wires were the only exception (Hoshino 1964, p. 99). Thus development of electric utilities was independent of a domestic electric machine industry for a long time. The history of electrification in Japan provides a good example of a characteristic inherent in the concept of borrowed technology: various kinds of techniques tend to be introduced into less developed countries with shorter intervals between techniques relative to the countries developing these techniques.

5. Without the introduction of motive power, many of the smaller plants would have disappeared during the 1920s, which were depression years in Japan. Large factories made some attempts to prevent declining profits by introducing new technologies, discharging unskilled workers and so forth. On the other hand smaller plants could introduce motive power and raise profitability because of the diffusion of cheap electric motors and the big decline in the costs of electric power. Smaller enterprises, like agriculture, have been taken as a pool of disguised unemployment. Large number of workers discharged from large enterprises during the 1920s were absorbed in these enterprises. It appears this absorption would not have been possible without an improvement in technology in the smaller enterprises.

These suppositions lead to another hypothesis: if the era of steam engines had continued for as long as in the earlier developed countries, smaller establishments would have been swept away by larger enterprises equipped with steam engines.[23] That is, the survival of smaller establishments in Japan seems to have been in some part due to the earlier start of the age of electric power. The existence of surplus labor has usually been pointed out as a basic reason for the dual structure of the economy or the coexistence of small scale and large scale enterprises. As an additional factor, in the writer's opinion, the very rapid transformation of motive power in Japan has to be taken into due consideration.

Acknowledgement

The writer is very much indebted to Ohkawa, Kazushi, Professor Emeritus of Hitotsubashi University for his encouragement in this study. Great thanks are also due to Umemura, Mataji also of Hitotsubashi. Richard F. Kosobud of the University of Illinois, and to Hugh T. Patrick of Yale University for their help in finding relevant literature. Grateful acknowledgement is also made to Kiyokawa, Yukihiko, of Hitotsubashi, for his many comments and to Suzuki, Susumu of the Hitachi Company Ltd. for guidance to a history of electric machinery industry. Finally, thanks are due to Paul Zimmer for an initial English editing.

Footnotes

1 "Motive power" stands for the work done by prime movers which convert the energy of nature directly into the energy of motion. Strictly speaking electric motors are not prime movers in that they consume electricity generated by other prime movers. In this study, however, they are included as prime movers, because, from the standpoint of the user, that is what they are (see Fènichel 1966, p. 443).

2 Regarding the transformation of motive power during and after the industrial revolution in western countries, see Landes (1966). For a history of the introduction of steam engines and electric motors, see Temin (1966) and DuBoff (1967).

3 For a history of electric generation in Japan see Kurihara (1964) and Arisawa (1960, vol. 3).

4 Continuous statistics for horsepower of electric motors are not available prior to 1898. Kanbayashi (1943, p. 300) states the introduction of electric motors began in the mid-1880s.

5 The differential in the level of γ among factories by size in 1909 is large compared with the differential in β. This is because the average horsepower of an electric motor is much smaller than that of a steam engine. (Refer to Table 4).

6 An examination of electrification by industry-group appears worthy of further study. A brief reference to this is found in Minami (1965, pp. 74-76).

7 The impact of introducing electric motors in large manufacturing plants was different between the two periods. In the first phase, when electric power was mostly supplied by the manufacturing factories themselves, a substitution of electric motors for steam engines did not necessarily mean a saving in capital costs, because these factories needed large plants for electric power generation. Savings occurred only in fuel consumption because of the greater efficiency of electric motors compared to steam engines. According to DuBoff, citing estimates by engineers for 1895-97 in the United States, loss of power was cut by 20 to 70 percent in various circumstances. In the second phase, cheap electric power was available from electric utilities. Elimination of the need for generation plants in large factories saved capital costs to a great extent. An estimate by another engineer shows that by dismantling steam engines and purchasing electric power a firm might cut power costs by 70 to 83 percent, taking into accounts expenses for fuel, labor, and above all, capital (DuBoff 1967, pp. 510-512).

8 Merits of the unit drive arrangements in the spinning industry have been mentioned by many authors, e.g., Arisawa (1960, 7:59), Mariya (1948, pp. 80-81, Iijima (1949, pp. 201-202), Nippon Sen-i 1958, p. 788).

9 Indexes of electric light and power estimated from electric rates tables of individual electric utilities are conceptually superior to these average rates estimates. However, the reason for not using the former is that in the period of over-supply after World War I, electric power was sold at much lower rates than those indicated in the rate tables, so indexes based on them would probably substantially over-estimate the actual rates during this period.

Household and industrial use are fairly clearly seperated. Different wires were used to deliver electric light and electric power, so even small-scale factories were using service provided under the electric power rate schedules.

10 The index for electric power rates estimated by Fujino Shozaburo (1956, pp. 66-67 and 1965, Statistical Note IV) did show a decline during this period.

11 Severe competition among electric suppliers was also found in Nagoya. Thus, electric rates were much cheaper in Tokyo and Nagoya than other areas. This fact may explain a predominance of small-scale enterprises in these cities, as pointed out by Watanabe Tsunehiko at the conference, and leads to a hypothesis that geographical differences in the price of electricity were related to the geographical distribution of small firms. This hypothesis merits empirical testing.

12 Of these two over-supply factors, the first seemed to have been much more influential. Electric light and power generated, shown in Table 1, column (3), continued to increase during the years after the war boom. On the other hand, electric generating capacity, shown in column (2), increased even faster. Consequently, column (5), the ratio of column (2) to column (3) and hence a proxy for the capital-output ratio in the electric utilities, increased from 1920 to 1930. This ratio changed with changes in economic activity. A study on the capital-output ratio in the electric utilities has been made in LTES, 12: 81-82.

13 It should be emphasized that this difference continues even to the present day. There are several factors for this. The first is a difference in transmission cost coming from a difference in voltage. (Large users take high voltages and are often closer to the thermal power stations.) The second is that large companies often consume most of their electricity late at night. The third, and most important, lies in the intention of the government to stimulate industrial development. Such an energy policy is possible basically because of the difference in the price elasticity between the electric light and power (see Hoshino et al. 1964, pp. 338-339).

14 For an estimate of the substitution of electric power for coal, see Fujino (1956).

15 The substitution of electric power for steam power does not necessarily mean a substitution for coal, if thermal generation depending on coal was dominant. Such a transformation in energy sources is worth further study.

16 The first cooperation began in 1909 between the Tokyo Shibaura Electric and General Electric of the United States, it continues to the present.

17 (Hitachi 1949, 2:118). The Tokyo Shibaura Electric Company, as well, began to produce standard electric motors in 1919 (Tōkyō 1963, p. 651).

18 Data for firms with fewer than five production workers are not provided in the Kōjō Tōkei-hyō. A survey in Tokyo City in 1934, however, gives some information for this scale. In Table F-1, column (1) the percentage of powered factories is tabulated by scale in terms of capital. The figures for the average number of employes for respective scales in column (2) indicate most of the factories not covered in the Kōjō Tōkei-hyō were not equipped with any prime movers. Table F-2, calculated from the same survey, shows for small factories with fewer than five employes having prime movers, the percentages of electric motors β and γ were near 100 percent.

19 For information on the match making industry this study relies heavily on Komiyama (1941).

20 In the Ashikaga district electric power was introduced during and after World War I into small scale home plants. These plants were called thereafter dōryoku-ya, which signified weaving plants with power looms run by electric motors (Sanpei 1961, p. 426).

21 Kiyokawa Yukihiko (1973) estimates the output elasticity of capital as 0.391 in the weaving sector of the cotton spinning companies for 1919-24. Our result is close to his estimation.

22 This is stressed by Kanbayashi (1943, p. 300). For instance a peak in the percentage of steam engines in the total horsepower in manufacturing was reached during almost the same period in both Japan and the United States. In Japan, it was in 1890-1905 (Figure 2) and in the United States, at the turn of the century (Fenichel 1966, p. 425).

23 The impact of electrification on Japan's persistent growth has not been properly appreciated, as can be seen from the small amount of literature on it. (See Suzuki ; Kōgyō 1936, p. 92).

The fact that the introduction of electric motors increased labor productivity can be seen in other countries. According to DuBoff (1967, p. 516) for instance, printing and publishing, one of the first major industries to be electrified in the United States, was also a leader in productivity increases.

Table F-1: Percentage of powered factories (α) and number of employes by scale of establishment: Tokyo City, 1934

Factory size by amount of capital	α (1)	Average number of employes (2)
(yen)	(percent)	(persons)
Total	35.8	5.4
- 99	1.6	1.6
100- 499	8.4	2.1
500- 999	22.7	2.7
1000- 1999	39.0	3.2
2000- 4999	54.9	4.4
5000- 9999	65.4	6.7
10000- 49000	75.8	13.2
50000- 99000	86.2	27.5
100000- 499000	91.3	69.1
500000-	96.1	290.7

Source: Tōkyō City 1934. Col. (1): p. 86; Col. (2): pp. 87-88.

Table F-2: Percentages of electric motors to total prime movers (β,γ) by scale of establishment: Tokyo City, 1934.

Number of Employes	β (1)	γ (2)
(persons)	(percent)	
Total	89.9	99.2
1	99.4	99.8
2 - 4	99.6	99.7
5 - 10	98.4	99.6
11 - 15	94.5	98.5
16 - 30	92.5	98.6
31 - 50	97.1	98.9
51 - 100	93.6	98.7
101 - 200	95.4	98.8
201 - 500	92.4	97.2
501 - 1000	94.7	99.7
1001 -	73.9	99.8

Note: For those factories with any prime movers.

Source: Tokyo City 1934, pp. 94-95.

Table 1

Number of electric bulbs installed, electric generating capacity, electricity generated and consumed

	Number of electric bulbs installed (1)	Electric generating capacity (2)	Electricity Generated (3)		Electricity Consumed (4)		Capacity-output ratio (5)
	(1000)	(1000 KW)	(million KWH)		(million KWH)		(1/1000 hours)
1890	21						
1895	89						
1900	217						
1905	464	39					
1910	1949	161	427	(621)	329	(523)	377
1915	7538	569	1811	(2217)	1396	(1802)	314
1920	16138	951	2815	(4669)	2941	(3795)	249
1925	27321	2167	7735	(9093)	5964	(7322)	280
1930	36840	3961	14034	(15773)	10878	(12618)	282
1935	43231	5137	22155	(24698)	17389	(19932)	232
1940	54083	7881	30603	(34566)	24614	(28576)	258

Remarks : [a]Smaller figures are for electric utilities only. Figures including industrial plants are shown in parentheses.

[b]Col. 5 = [Col. 2] ÷ [Col. 3].

Source:

LTES, vol. 8. Col. (1) from p. 69; col. (2), p. 206; col. (3), p. 196; col. (4), p. 198.

Table 2

Composition of prime movers by type and by scale of factory in terms of horsepower (in percents)

Factory size (persons)	Electric motors (β)	Steam engines	Gas engines	Petrol engines	Water wheels
1909					
Total	13.0	70.0	3.7	2.5	10.7
5 - 9	10.6	49.6	6.7	12.5	20.6
10 - 29	9.8	59.7	7.8	9.6	13.2
30 - 49	7.0	63.4	6.0	5.4	18.2
50 - 99	9.8	76.0	4.2	3.1	6.9
100 - 499	13.2	64.5	4.0	0.7	17.7
500 - 999	9.7	83.7	1.5	0.0	5.0
1000 -	18.3	78.2	1.4	0.0	2.2
1914					
Total	30.1	46.8	6.0	1.0	16.0
5 - 9	27.4	41.8	10.6	6.9	13.2
10 - 29	26.1	46.3	15.4	4.9	7.2
30 - 49	20.5	47.2	11.8	1.2	19.3
50 - 99	23.7	40.0	8.1	1.0	27.2
100 - 499	26.1	47.2	7.7	0.2	18.8
500 - 999	33.7	32.8	0.6	0.1	32.9
1000 -	36.7	60.1	2.9	0.0	0.2
1919					
Total	58.5	28.0	4.3	0.5	8.6
5 - 9	56.9	19.7	6.4	4.4	12.6
10 - 29	58.7	24.3	9.1	2.6	5.3
30 - 49	55.1	34.0	7.3	0.7	3.0
50 - 99	59.8	30.7	5.2	0.6	3.8
100 - 499	59.3	27.9	3.4	0.1	9.2
500 - 999	69.1	29.3	0.8	0.1	0.8
1000 -	55.7	28.0	4.0	0.1	12.1

Table 2: continued

1930					
Total	86.7	11.4	0.6	0.6	0.7
5 - 9	84.4	6.4	2.1	3.3	3.8
10 - 29	86.3	9.3	0.8	1.7	2.0
30 - 49	82.9	13.8	0.7	2.2	0.4
50 - 99	88.0	9.8	0.4	1.0	0.8
100 - 499	87.2	11.2	1.0	0.2	0.4
500 - 999	95.8	3.9	0.0	0.1	0.2
1000 -	80.4	18.5	0.1	0.3	0.7
1935					
Total	82.2	15.3	0.7	1.2	0.5
5 - 9	85.5	4.2	2.5	5.0	2.8
10 - 29	87.8	6.3	1.3	3.5	1.0
30 - 49	87.8	6.9	0.9	3.9	0.6
50 - 99	90.9	5.6	0.2	3.1	0.3
100 - 499	80.4	18.1	0.0	0.9	0.6
500 - 999	90.3	8.5	0.0	1.1	0.1
1000 -	78.6	19.7	1.2	0.2	0.4
1940					
Total	81.5	16.4	0.5	0.7	0.9
5 - 9	89.3	1.0	2.1	4.8	2.8
10 - 29	92.4	2.7	1.1	2.8	1.0
30 - 49	93.5	3.3	0.6	2.3	0.3
50 - 99	94.9	3.3	0.2	1.4	0.2
100 - 499	84.8	14.0	0.1	0.7	0.3
500 - 999	86.2	12.1	0.1	0.2	1.4
1000 -	74.8	23.6	0.6	0.1	0.9

Remarks: Excluding gas and electric utilities. Steam engines in this table include steam turbines. Water wheels are composed of hydro turbines, Pelton water wheels and Japanese-type water wheels. Factory (establishment) size is measured in number of production workers.

Source: LTES, 12: 232-245.

Table 3: Percentage of electric motors (γ) by scale of establishment

(in percents)

Factory Size	1909	1914	1919	1930	1935	1940
Total	19.7	50.8	74.7	94.1	97.8	98.9
5 - 9	17.2	52.1	71.7	91.5	93.8	95.2
10 - 29	15.2	44.8	69.9	92.4	95.2	97.2
30 - 49	10.7	33.3	63.3	91.6	95.7	98.0
50 - 99	13.4	34.8	61.8	90.6	95.9	98.5
100 - 499	26.2	49.5	73.5	94.6	97.4	98.9
500 - 999	42.3	70.3	87.7	97.0	98.7	99.6
1000 -	63.6	89.3	94.5	98.6	99.7	99.8

Remarks: γ = (number of electric motors/total number of prime movers) x 100.

Source : Kōjō Tōkei-hyō.

Table 4: Horsepower per prime mover

	Electric motors	Steam engines	Steam turbines	Gas engines	Petrol engines	Water wheels
Panel A:						
Average of Establishments						
1909	15	35	46	13	5	12
1914	14	41	84	19	5	35
1919	19	42	134	28	6	36
1930	22	44	844	38	14	15
1935	9	41	1965	76	21	16
1940	8	64	3888	70	14	41
Panel B:						
By scale of establishments (1940)						
Number of persons						
5 - 9	4	17	9	21	8	7
10 - 29	5	30	5	27	11	11
30 - 49	7	35	150	42	17	16
50 - 99	8	26	313	39	20	21
100 - 499	11	31	2435	60	36	165
500 - 999	10	34	2949	94	35	3700
1000 -	7	297	5456	1777	66	2512

Source : Kōjō Tōkei-hyō.

Table 5: Average electric light and power rates and coal price index

	Average rate of Electric Light (1)	Electric Power (2)	Wholesale price index of coal (3)
	(yen/1000 KWH)		(1934-36 = 1)
1900			0.34
1905	85.1[a]	20.2[a]	0.42
1910	69.4	30.0	0.42
1915	50.5	30.0	0.44
1920	72.4	66.3	1.40
1925	88.9	55.6	1.00
1930	98.8	38.0	0.86
1935	105.9	29.4	1.00
1940	112.4	37.6	1.48

Remarks: a: data for 1907.

Sources: Columns (1) and (2) from LTES, 12: 222.

Column (3) from Arisawa 1960, 3: Appendix Tables pp. 10-11.

Table 6: Ratios of electric lighting rate to consumer price index and of electric power rate to manufacturing output price index

	Ratio of electric lighting rate (1)[a]	Ratio of electric power rate (2)[b]
1907	1.30	0.83
1910	1.14	1.33
1915	0.82	1.23
1920	0.47	1.13
1925	0.64	1.27
1930	0.90	1.30
1935	1.00	1.00
1940	0.83[c]	0.77

Remarks:

[a]Average electric lighting rate/consumer price index.

[b]Average electric power rate/manufacturing output price index.

[c]1938 data.

Sources:

Electricity rates: Table 5.

Consumer price index: LTES, 8: 135-136.

Manufacturing output price index: LTES, 8: 192-193.

Table 7: Price ratio of electric power to coal and labor, and the productivity ratio of electric utilities to coal mining

	Price Ratio (1)[a]	Productivity Ratio (2)[b]
	(1934-36 = 1)	
1907	1.56	
1910	2.43	0.22
1915	2.32	0.40
1920	1.61	0.71
1925	1.89	0.76
1930	1.50	0.96
1935	1.00	1.00
1940	0.86	1.33

Remarks:

a: Average electric power rate/wholesale price index of coal.

b: Electric power generated per employe/ coal produced per employe .

Sources:

Electric power rate: Table 5.

Electric power generated per employe : LTES, 12: 207.

Number of employes in coal mining and coal output:

Arisawa, 1960, 3: Appendix Tables pp. 10-11.

Table 8: Percentage of Powered Factories (α) by Scale of Establishment

Number of Production Workers (persons)	1909	1914	1919	1930	1935	1940
Total	28.2	45.6	61.1	82.5	86.0	84.1
5 - 9	14.4	28.5	46.0	76.6	80.4	78.5
10 - 29	30.1	48.8	65.0	87.2	90.5	88.4
30 - 49	63.7	75.9	85.7	93.8	95.5	95.8
50 - 99	78.0	87.7	92.8	97.3	98.0	98.2
100 - 499	87.1	92.8	97.2	99.1	99.7	99.6
500 - 999	95.1	96.8	100.0	100.0	99.7	100.0
1000 -	100.0	97.6	99.4	100.0	100.0	100.0

Remarks: α = (number of factories with prime movers/total number of factories) x 100.

Source: LTES, 12: 228-231 and Kōjō Tōkei-hyō.

Table 9: Percentage of Powered Factories (α) and Percentages of Electric Motors Among All Prime Movers (ρ,γ) in the Match Making Industry by Scale of Establishment

(%)

Number of Production Workers (persons)	1914			1919			1930		
	α	β	γ	α	β	γ	α	β	γ
Total	26.2	76.1	34.6	49.1	90.2	67.3	86.1	97.2	81.1
5 - 9	0	-	-	0	-	-	80.0	88.2	70.7
10 - 29	5.5	50.0	16.6	23.0	88.8	57.1	78.8	96.0	81.2
30 - 49	17.2	100.0	100.0	30.4	100.0	100.0	100.0	95.2	95.8
50 - 99	19.4	80.0	69.2	48.5	100.0	100.0	100.0	96.8	63.7
100 - 499	50.8	70.0	25.8	83.3	88.3	67.7	100.0	99.3	98.5
500 - 999	100.0	83.3	62.5	100.0	86.6	47.7	100.0	100.0	100.0

Source: Kōjō Tōkei-hyō.

Table 10: Percentage of Powered Factories (α) and Percentages of Electric Motors Among Prime Movers (β,γ) in the Weaving Industry by Scale of Establishment

Number of Production Workers (persons)	1914			1919			1930		
	α	β	γ	α	β	γ	α	β	γ
Total	37.5	54.6	29.9	53.2	77.9	64.9	90.4	96.4	81.9
5 - 9	17.2	69.9	52.2	33.4	81.8	64.7	87.1	96.0	93.5
10 - 29	43.1	49.1	27.6	58.5	73.1	51.9	93.1	95.0	94.5
30 - 49	71.9	42.2	24.9	85.7	70.2	57.0	95.7	96.9	93.5
50 - 99	81.8	50.8	30.2	92.6	66.4	54.6	98.8	96.4	94.8
100 - 499	90.8	53.5	27.9	87.8	69.0	51.3	99.5	94.3	82.2
500 - 999	100.0	56.7	32.4	100.0	97.0	66.0	100.0	98.3	91.9
1000 -	100.0	83.3	31.3	100.0	97.7	78.6	100.0	99.2	66.0

Sources: Kōjō Tōkei-hyō.

Table 11: Estimates of production function and annual rate of growth of productivity by components in cotton weaving industry: 1922-37

(1) Estimates of production function[a]

Parameters				
a_o	a_1	a_2	R^2	d
-1.274	0.046	0.457	0.990	0.82
(5.4)	(10.5)	(1.6)		

(2) Annual rate of growth of output and its components (in percents)

G(p)	$a_1 \Delta\alpha$	$a_2 G(k)$	Error
10.50	9.81	1.31	-0.62
(100)	(93)	(13)	(-6)

Remarks: a: The model for estimation is $\ln p_t = a_o + a_1 \alpha_t + a_2 \ln k_t + u_t$. R^2 and d stand for the determination coefficient and Durbin-Watson statistic respectively. Statistics in parenthesis under parameters signify student t-value of the respective parameters.

b: G( ) stands for the exponential rate of growth of the variable in parenthesis.

Sources: Data underlying Figure 6.

Table 12: Mean candle power, cost per hour and hourly cost per candle power of various lamps

	Mean Candle Power (1)	Hourly Cost (2)	Hourly Cost Per Candle Power (3)=(2)/(1)
		(sen)	(sen)
Traditional			
<u>tōmyō</u>	0.25	0.5	2.0
<u>andon</u>	0.2	0.5	2.5
Japanese candle	0.5	2.5	3.1
Modern			
Western candle	0.9	0.9	1.0
lantern (with Western candle)	0.6	0.9	1.5
petrol lamp (15mm wick)	3.2	0.38	0.12
acetylene lamp	16.0	1.5	0.093
gas lamp (rated 20 candle power)	20.0	0.6	0.03
carbon electric bulb (rated 10 candle power)	8.5	0.57	0.067
tungsten electric bulb (rated 24 candle power)	18.0	0.45	0.025
gas filled electric bulb (40W)	30.0	0.65	0.021

<u>Remarks:</u> Figures in 1926 prices.

<u>Sources:</u> Estimates by Seki Shigehiro, in Kurihara, 1964, p. 65.

Minami figures: Titles and text

Figure 1: Horsepower of prime movers by type in manufacturing industries

Remarks: Excludes gas and electric utilities. Figures for 1884-1918 are for establishments with ten or more production workers, figures for 1919-40 are for establishments with five or more production workers.

Source: LTES, 12: 223.

Figure 2: Composition of prime movers in terms of horsepower

Source: Same as Figure 1.

Figure 3: Price of one horsepower electric motors

Source: Hitachi 1949, 2:118.

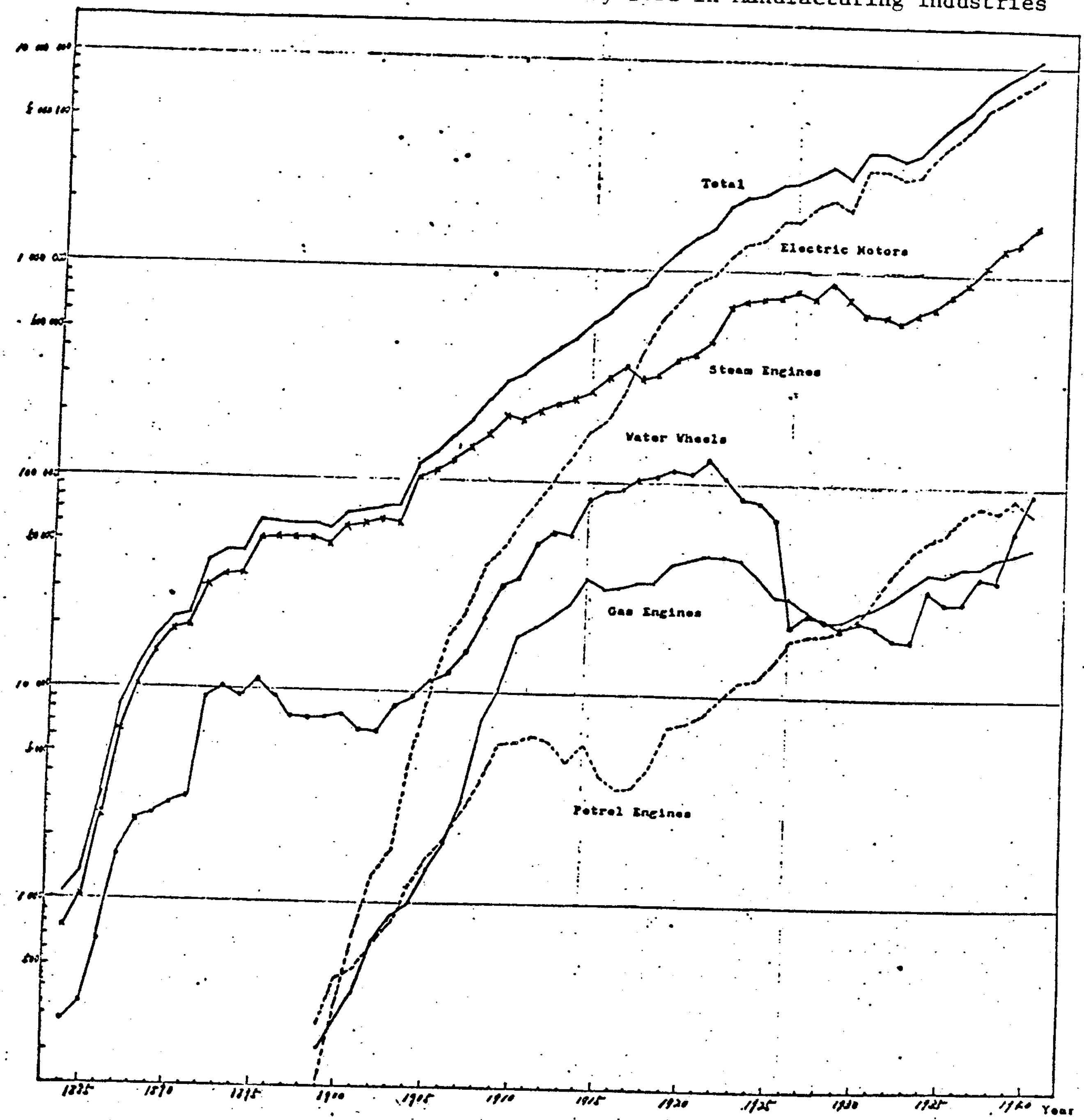
Figure 4: Percentage of powered factories (α) and percentages of electric motors (β,γ) for the two extreme scales

Source: Tables 2, 3, 8.

Figure 5: Relationship between percentage of powered factories (α) and percentages of electric motors (β,γ) for two representative scales

Source: Tables 2, 3, 8.

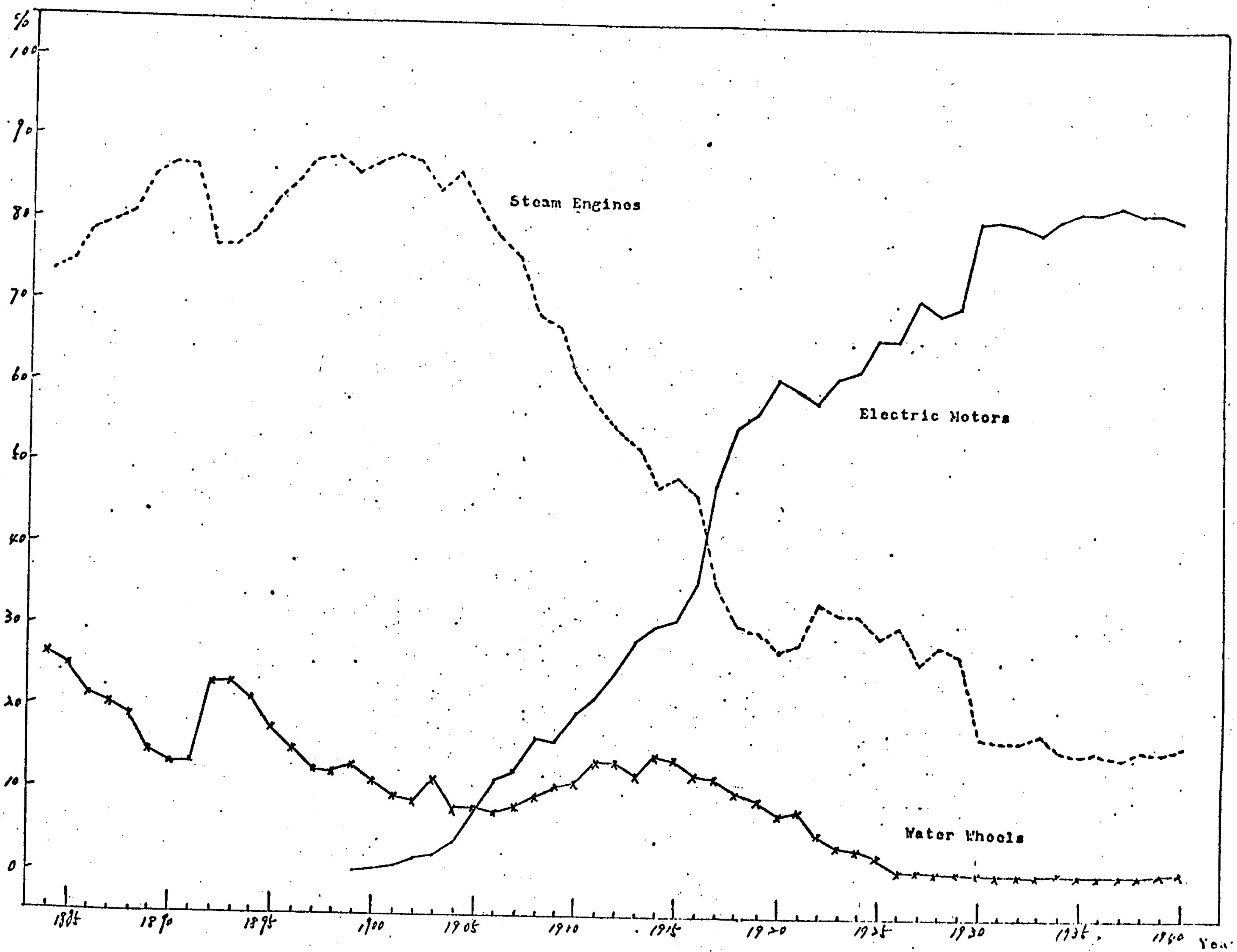
Figure 1: Horse Power of Prime Movers by Type in Manufacturing Industries



Remarks: Excludes gas and electric utilities. Figures for 1884-1918 are for establishments with ten or more production workers, figures for 1919-40 are for establishments with five or more production workers.

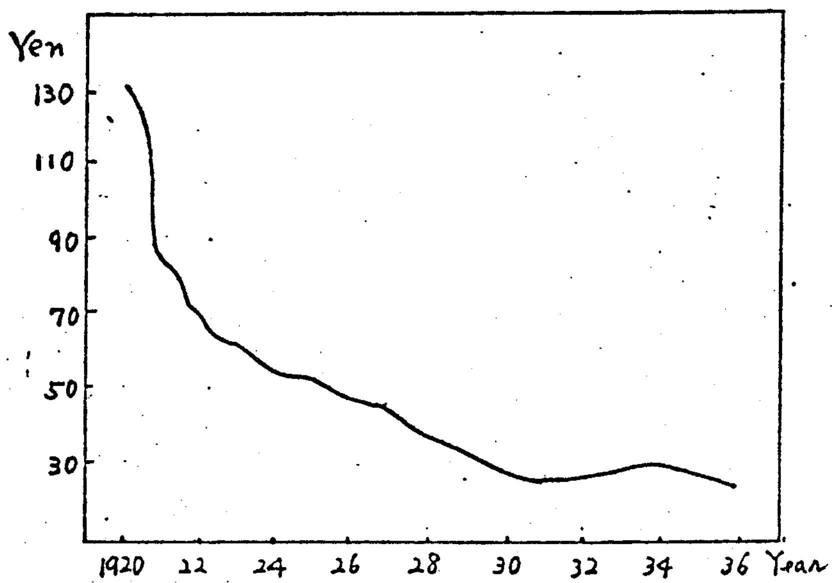
Source : Minami 1965, p. 223.

Figure 2: Composition of Prime Movers in Terms of Horse Power



Sources: Same as Figure 1.

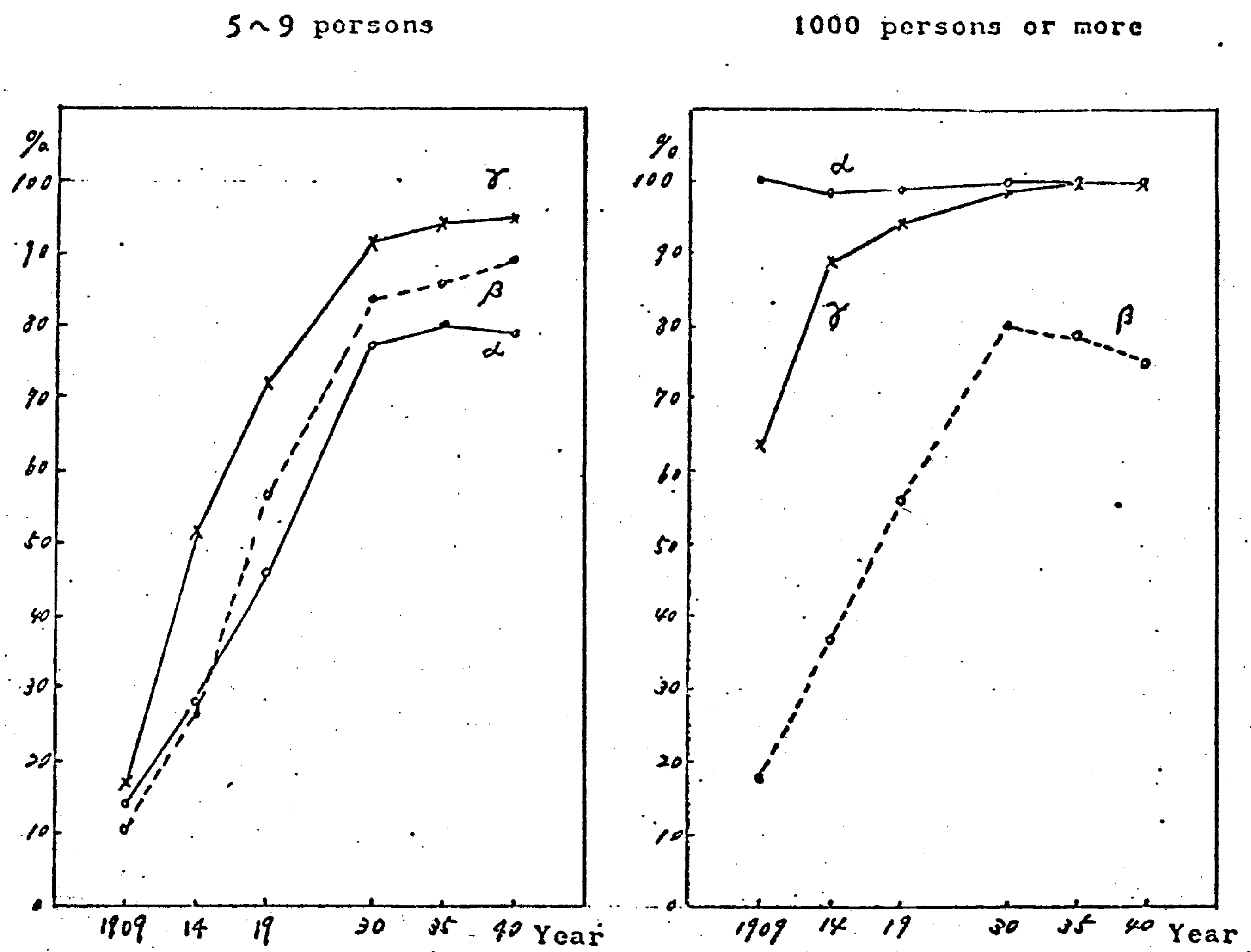
Figure 3: Price of One Horse Power Electric Motors



Source:

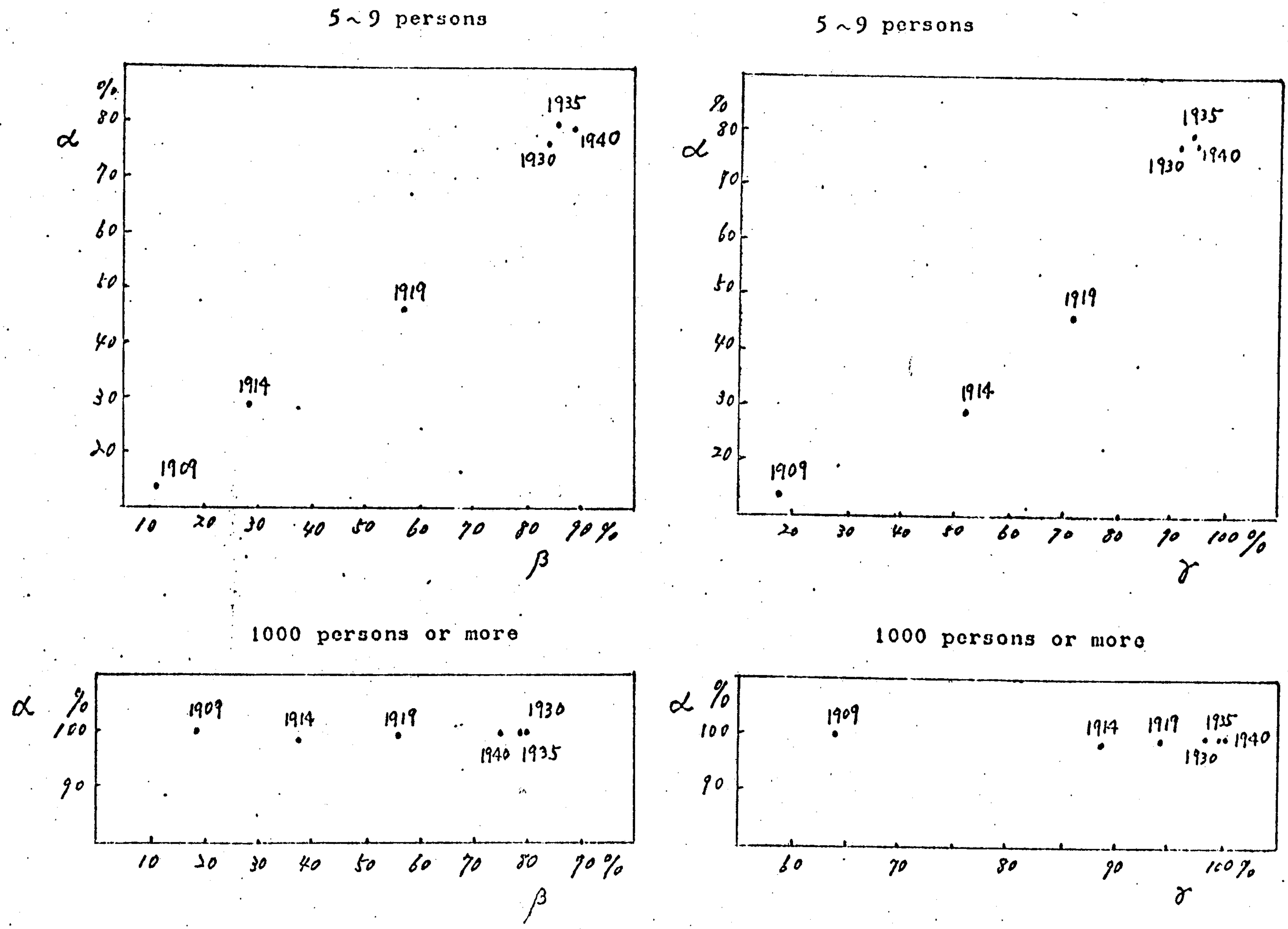
Hitachi Co, Ltd., Hitachi Seisaku-jo Shi (History of Hitachi), Vol. 2, p. 118.

Figure 4: Percentage of Powered Factories (α) and Percentages of Electric Motors (β,γ) for the Two Extreme Scales



Source: Tables 2, 3, 8.

Figure 5: Relationship between Percentage of Powered Factories (α) and Percentages of Electric Motors (β, γ) for Two Representative Scales



Source: Tables 2, 3, 8.