TECHNOLOGICAL PROGRESS IN THE TEA MANUFACTURING INDUSTRY IN JAPAN*

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Abstract

The purpose of this paper is to analyze the factors of the process in which the tea manufacturing technology was developed from the hand-rubbing method to the mechanical method via the semi-mechanical method during the period from the late Meiji Era to the early Shōwa Era.

First, it is confirmed with the statistical data that tea manufacturing output increased and tea manufacturing methods by mechanization were changed where the real price of tea declined and wage rate rose.

Second, the following hypothesis is tested and verified. To the decline of product price and the changes of input factor prices, tea production farms responded rationally and they changed the tea manufacturing technique from the hand-rubbing method to the mechanical method. The mechanization of tea manufacture was accompanied by the induced technological innovation and required expansion of production scale.

I. Introduction

The objective of this paper is to analyze the factors that underlie the mechanization process in the green tea production during the period from the late Meiji Era to the early Shōwa Era.

Along with raw silk, tea was one of the important exported agricultural products in the Meiji and the Taishō Eras. Tea output increased from 5.04 million kan in 1880 to 12.54 million kan in 1935 at an annual average compound rate of 1.7 percent. Over this period, the tea price index relative to the price index of farm products decreased, whereas the real wage rate rose. If the technological innovation that induced the substitution of machines for manual labor had not caused the decline in tea production cost, the expansion of tea output could not have occurred in condition, when tea prices declined and the wage rate rapidly rose. Tea production includes the cultivation of the tea plant and manufacturing tea. Technological progress in the cultivation and manufacture of tea was historically made by the substitution of machines for manual labor.

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1 Kan is a weight unit in Japan and 1 kan is equivalent to 3.75 kg.
An analysis of the process in which an industry adopts new technology when product and input factor prices fluctuate is an interesting study field for students investigating the economic development or diffusion of new technology. The tea manufacturing industry was a sector of Japanese agriculture. Although it is widely held that the tea sector was the first mechanized sector in Japanese agriculture and played an important role in the process of Japanese modernization, few authors have analyzed it from the above-mentioned standpoint. Therefore, the purpose of this paper is to analyze processes in which the tea manufacturing techniques changed from te-momi-seihō (method of production by hand-rubbing or hand-rubbing method), to han-kikai-seihō (method of production partially using machines or semi-mechanical method) and finally to kikai-seihō (method of production by machines or mechanical method).

This paper is organized as follows: in Section II, the statistical data on development and mechanization in the tea manufacturing industry are reviewed. The hypothesis that tea manufacture was mechanized through induced technological innovation is presented in Section III. And Section IV empirically tests the hypothesis.

II. Development of Tea Production and Technology

Development of Tea Production

Tea output grew from 5.04 million kan in 1880 to 8.24 million kan in 1895. After having decreased to 6.97 million kan in 1905, it increased to 12.54 million kan in 1935 at an annual growth rate of 2.0 percent. The greater part of tea output was exported to the United States in the early Meiji Era. But the type of tea consumed by the American people changed from green tea to black tea. Consequently, the exports of tea had declined from the peak of 5.76 million kan in 1890 to 4.88 million kan in 1910 and further to 2.96 million kan in 1935. The difference between the increase of tea output and the decrease of tea export was covered by the rise of domestic tea demand. Since the income elasticity of tea was 2.78 in those periods, the major part of this increased domestic tea demand was generated by national income increased through the modernization of the Japanese economy.2

The decrease of tea exports was followed by the fall of the real tea price from 4.69 yen per kan in 1880 to 2.64 yen per kan in 1930.3 On the other hand, the real wage rate rose from 0.26 yen per day in 1980 to 0.83 yen per day in 1930. The annual rate of increase in wage rate during the 1910–1920 period was particularly notable: it was as large as 4.5 percent.

Without the changes in tea manufacturing method, tea output could not have been expanded in a situation where wage rate rose and product price declined, since the labor cost was more than half of tea production cost.4 That is, production cost decreased as a

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2 The tea demand function in 1920–1937 is given by

\[ \ln Q = 1.75 - 0.35 \ln P + 2.78 \ln Y \]

\[ R^2 = 0.80 \]

\[ (-3.70) \quad (9.45) \]

where: \( Q \) denotes tea consumption expenditures per capita; \( P \) tea price index; \( Y \) total consumption expenditures per capita. All figures are in 1934–36 year price.

3 The figures are a five-year-average centering on the year shown. This applies to all the subsequent figures.

4 The ratio of labor cost to tea production cost was 54 percent using the 21 samples of seven tea production prefectures to the east of Kyōto Prefecture in 1902. See Nōshōmushō (1903).
TECHNOLOGICAL PROGRESS IN THE TEA MANUFACTURING INDUSTRY IN JAPAN

FIG. 1. DIFFUSION OF TEA MANUFACTURING MACHINES IN REPRESENTATIVE PREFECTURES

Sources: [Chagyō Kumi'ai Chūō Kaigisho (1936, pp. 910–1153); (1926, pp. 241–242); Kyōtofu Sangyōbu (1924, pp. 12–13); Mieken Naimubu (1915, pp. 89–90); Naraken (1925, p. 9)]
result of technological progress and as machines were substituted for manual labor.

Tea production consists of cultivating the tea plant and processing raw tea leaves. The yield of tea per unit area had increased as the area in which only tea was planted increased and as the cultivation management technique, such as the use of fertilizer, were developed and used. Although the area of land under tea decreased from the peak of 59,500 ha in 1895 to 39,500 ha in 1935, the tea output increased.

Fig. 1 shows the changes in the total amount of tea manufacturing machines in the representative tea producing prefectures. The total number of tea manufacturing machines in 1909 was only 10 in Mie Prefecture and 94 in Kyoto Prefecture, whereas it was as many as 5,498 in Shizuoka Prefecture. But the number of machines diffused in 1930 amounted to 33,686 in Shizuoka, 2,905 in Kyoto, 1,824 in Mie, 1,901 in Nara, 1,075 in Saitama and 770 in Kagoshima Prefectures. Such rapid diffusion of tea manufacturing machines seems to have resulted from the substitution of machine for manual labor where wage rate rose.

Tea Manufacturing Technology

The kind of tea that we investigate in this paper is green tea, that is, non-fermented tea in which the oxidizing enzyme of raw tea leaves has been killed. It differs from black tea made by fermentation and Oolong tea made by semi-fermentation. The method of killing an oxidizing enzyme of tea leaves is to parch, to boil or to steam. An oxidizing enzyme is killed by steaming in the case of such green tea as Gyokuro, Sencha and Bancha, which compose the greater part of the tea output in Japan. After killing an oxidizing enzyme of tea leaves, rubbing and drying follows and the manufacture of green tea is completed.

There were many te-momi-seihe (hand-rubbing methods) in the early Meiji Era. The National Tea Production Experiment Station standardized the method of hand-rubbing. The procedure was as follows: (1) musu (steaming), (2) hauchi (rubbing), (3) kaiten-momi (rubbing with rolling), (4) tama-toki (breaking the tea ball), (5) momi-kiri (cutting by rubbing), (6) denguri-momi (rubbing with rolling), (7) shiage-momi (final rubbing) and (8) hoshi (drying). The machine tea manufacturing method replaced each hand-rubbing process with a corresponding machine: tea steaming machine for (1), primary drying tea roller for (2), secondary drying tea roller for (3) and secondary rolling tea dryer for (5), final drying tea roller for (6) and (7), and dryer for (8). In the process of the change from the hand-rubbing method to a completely mechanical method, there was an intermediate method in which only the process of hauchi was replaced with a machine and the remaining process was done by hand. This tea manufacturing method was called han-kikai-seihe (method partially using the machine or semi-mechanical method).

Diffusion of Tea Manufacturing Machines

Fig. 1 shows the number of tea manufacturing machines diffused in representative prefectures. The figures in Fig. 1 are a total number and do not indicate the number of tea manufacturing machines classified by kind. So, we will closely examine the detailed statistics for Shizuoka Prefecture in which the largest tea output was manufactured in those periods and in which the largest number of tea manufacturing machines had been diffused. Table 1 shows the changes in tea prices and wages rate in Shizuoka Prefecture. The chash" in Table 1 is a veteran worker using the hand-rubbing method, and it took more than 10
TABLE 1. CHANGE OF TEA PRICE AND WAGE RATE IN SHIZUOKA PREFECTURE

<table>
<thead>
<tr>
<th>Year</th>
<th>Tea price Yen/kan</th>
<th>Wage rate Cha-shi Yen/day</th>
<th>Wage rate Women pickers Yen/day</th>
<th>Charcoal price Sen/kan</th>
<th>Index of real wage Cha-shi (2)/(1)</th>
<th>Index of real wage Women pickers (3)/(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1892</td>
<td>1.27</td>
<td>0.26</td>
<td>0.12</td>
<td>3.5</td>
<td>100</td>
<td>100</td>
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<tr>
<td>97</td>
<td>1.39</td>
<td>0.46</td>
<td>0.14</td>
<td>3.7</td>
<td>162</td>
<td>145</td>
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<tr>
<td>1902</td>
<td>1.55</td>
<td>0.48</td>
<td>0.22</td>
<td>6.3</td>
<td>152</td>
<td>150</td>
</tr>
<tr>
<td>7</td>
<td>1.94</td>
<td>0.62</td>
<td>0.25</td>
<td>5.6</td>
<td>156</td>
<td>136</td>
</tr>
<tr>
<td>12</td>
<td>2.05</td>
<td>0.80</td>
<td>0.35</td>
<td>8.3</td>
<td>201</td>
<td>191</td>
</tr>
<tr>
<td>15</td>
<td>2.17</td>
<td>0.85</td>
<td>0.37</td>
<td>9.3</td>
<td>191</td>
<td>180</td>
</tr>
<tr>
<td>20</td>
<td>3.69</td>
<td>1.93</td>
<td>0.82</td>
<td>38.5</td>
<td>255</td>
<td>235</td>
</tr>
<tr>
<td>25</td>
<td>3.26</td>
<td>2.19</td>
<td>1.02</td>
<td>37.6</td>
<td>328</td>
<td>331</td>
</tr>
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<td>30</td>
<td>2.10</td>
<td>1.84</td>
<td>0.85</td>
<td>23.0</td>
<td>429</td>
<td>429</td>
</tr>
</tbody>
</table>

Sources: [Shizuokaken Chagyō Kumiai Rengō kaigisho (1922) for 1892-1920; (1937, pp. 199-201; 237-238; 247-251) for 1925-1930]

Note: Cha-shi is a veteran worker skillful at hand-rubbing. One sen is equivalent to one-hundredth yen.

TABLE 2. CHANGE OF TEA MANUFACTURING OUTPUT RATIO CLASSIFIED BY TEA MANUFACTURING METHOD IN SHIZUOKA PREFECTURE

<table>
<thead>
<tr>
<th>Year</th>
<th>Hand-rubbing</th>
<th>Partially using machines</th>
<th>Using machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>94</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>51</td>
<td>48</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>19</td>
<td>48</td>
<td>33</td>
</tr>
<tr>
<td>20</td>
<td>13</td>
<td>22</td>
<td>65</td>
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<td>25</td>
<td>9</td>
<td>19</td>
<td>73</td>
</tr>
<tr>
<td>30</td>
<td>6</td>
<td>19</td>
<td>75</td>
</tr>
</tbody>
</table>

Sources: [Shizuokaken Chagyō Kumiai Rengō Kaigisho (1925, p. 186); (1937, p. 237; 240-241)]

Notes: Figures are five-year averages centering the year shown; figures for 1900-15 are estimates; see footnote (6) in the text for the estimation method.

years for cha-shi to become skillful at the hand-rubbing method. The wage rate of cha-shi and women who picked the raw tea leaves rose significantly, as shown in Table 1, whereas tea prices only increased gradually. For example, the tea price in 1920 was 2.9 times as high as that in 1892, the wage rate of women who picked the raw tea leaves 6.8 times as high, the wage rate of cha-shi 7.4 times as high, and the price of charcoal, indispensable as a heat source for the rubbing method, rose to the level 11.0 times as high as that in 1892.

Table 2 shows the 5-year average ratio of tea output classified by tea manufacturing methods in Shizuoka Prefecture. The output yielded by the hand-rubbing method had
been decreasing, occupying a share of 6 percent in 1930. On the other hand, the output by the mechanical method reached a share of 65 percent in 1920; then its share increased to as high as 75 percent in 1930. The output achieved by the semi-mechanical method had temporarily accounted for the majority of output in the 1910's. It was decreasing.

**FIG. 2. DIFFUSION OF TEA MANUFACTURING MACHINES IN MAIN TEA PRODUCTION ZONES OF SHIZUOKA PREFECTURE**

Sources: [Shizuokaken Chagyō Kumiai Rengō Kaigisho (1925, pp. 244-247); (1937, pp. 220-224); Shizuokaken Haibaragun Chagyō Kumiai (1919, p. 25)]

Note: p in parentheses represents primary drying tea roller; f in parentheses final drying tea roller.
and accounted for about 20 percent after 1920. These figures show the process in which the tea manufacturing method had been changed from the hand-rubbing method to the mechanical method with the semi-mechanical method being as an intermediate method.

It is supposed that the mechanization of tea manufacture has been completed when a final drying tea roller has been completed. So, if we could know the diffusion of primary drying tea roller and final drying tea rollers, we could quantitatively confirm the change in tea manufacturing method. Fig. 2 shows the number of primary and final drying tea roller diffused in Abe, Shida, Haibara and Ogasa Counties which were the main tea production zones in Shizuoka Prefecture. Since the remaining counties in Shizuoka Prefecture exhibited a diffusion pattern similar to that exhibited by these four counties in those periods while the number of diffused machines were small, let us examine four counties in Fig. 2. The increasing trend of primary drying tea rollers is less obvious after 1912 for which we have the data available. So, it is assumed that primary drying tea rollers were diffused toward the last step in diffusion in these four counties. What diffusion pattern was present before 1911?

The four samples from Haibara County are available for the period before 1911. If we add these four samples to those in Fig. 4, we could suppose that the primary drying tea rollers diffused rapidly just before 1912. We analogize that diffusion period by using the Rogers’ categorization of adoption person based on the adoption time of technological innovation. As the number of primary drying tea rollers diffused in 1918 reaches its maximum, this number is assumed to be the number for 100 percent diffusion. In that case, we can say that the inflection point between the late majority (relative late accepter) and laggards (delayed person) was about the 1911–1912 period. Again, we suppose that the adoption time of primary drying tea rollers follows the normal distribution as Rogers proposed. If the figures for the 1908–1913 period are plotted on the normal probability paper, the inflection point between the early adopters and the early majority (early follower) would be about 1907. Then it is presumed that the early adopters of primary drying tea rollers appeared about 1905 and 65 machines were diffused. We believe that these inferences apply equally to the remaining counties in Shizuoka Prefecture. These inferences are consistent with the tea output ratio manufactured by the semi-mechanical method in Table 2.

The number of final drying tea rollers diffused in 1912 was as small as 4 in Abe, 5 in Shida, 35 in Haibara and 18 in Ogasa Counties. According to Fig. 2, all three counties except Shida are found to have an inflection point of 1916. The increase in final drying tea rollers coincide well with the increase in ratio of tea output manufactured by machine after 1920, as is clear from in Table 2.

III. Hypothesis

What actions did rational tea production farms take under the condition of decreasing
product price and rising input factor prices? One of them was to cut back tea production cost. This reduction of production cost is achieved by substituting the relatively cheap input for expensive input. The substitution of input factors made where wage rate rises was that of machine for manual labor in the tea manufacturing process. The introduction of tea manufacturing machine was more labor-saving than the reduction of labor made along the isoquant. That is, the substitution of labor for tea manufacturing machines was accompanied by the technological innovation which saved the input that had become relatively expensive. Generally, mechanization requires economies of scale. This completes the description of our basic hypothesis on the mechanization of tea manufacture.

How the adopted tea manufacturing method are varied is exhibited in Fig. 3, in which, with the horizontal axis representing the labor input per output and the vertical axis the capital input per output, the unit-isoquants and unit-isocost curves are drawn. In the case where wage rate is not relatively high and the isocost curve is \( W_1 \), the tea manufacturing method shown by unit-isoquant \( I_1l_1 \) is adopted by the farm, and the combination of inputs shown by point \( A \) is the equilibrium point. The isocost curve \( W_1' \), that is tangent to unit-isoquant \( I_2l_2 \), has the same relative price as the isocost curve \( W_1 \). The tea manufacturing method shown by \( I_2l_2 \) is not adopted since the production cost shown by \( W_1' \) is higher than that shown by \( W_1 \).

When the wage rate rises and the isocost curve is \( W_2 \), the equilibrium point for the tea manufacturing method shown by unit-isoquant \( I_1l_1 \) shifts from point \( A \) to point \( B \). But it is rational for tea production farms to adopt the tea manufacturing method shown by unit-isoquant \( I_2l_2 \) because the production cost at point \( D \), where the isocost curve \( W_2' \) has the same relative price as the curve \( W_2 \) and is tangent to unit-isoquant \( I_2l_2 \), is smaller than at point \( B \). The capital-labor ratio \( K_2 \) at the equilibrium point \( D \) is greater than at point
B. There is a tea manufacturing method shown by unit-isoquant $I_3I_3$, whose capital-labor ratio is greater than $K_2$. But the production cost shown by the isocost curve $W_2''$ that has the same relative price as the curve $W_2'$ is higher than the cost associated with $W_2'$ that is tangent to unit-isoquant $I_2I_2$. Therefore, the tea manufacturing method shown by unit-isoquant $I_3I_3$ is not adopted.

Tea production farms would select more labor-saving techniques when the wage rate rose. Moreover, they would choose the production technique for which the unit-isoquant is near the origin. This conjecture is displayed graphically in Fig. 3 as the change from the equilibrium point $A$ to point $D$. These are causes of change from the hand-rubbing method to the semi-mechanical method and finally to the mechanical method, as described in Section II.

The development and adoption of new technology which facilitates the saving of relatively scarce input is called an induced innovation. This concept was introduced initially by Hicks and further developed by Fellner and many others. Following the theory of induced innovation, the changes in tea manufacturing methods employed by the farm may be described as the changes arising from rises in wage rate.

Using average cost curves $T_1$, $T_2$ and $T_3$, Fig. 4 shows the process in which the tea manufacturing method is changed as wage rate rises and tea price declines. The average cost curves $T_1$, $T_2$ and $T_3$ correspond to tea manufacturing methods of hand-rubbing, of partially using machine and of fully using machine, respectively. It is supposed that in order of increasing fixed cost are the hand-rubbing method, the semi-mechanical method and the mechanical method. Compared with the marginal costs of two other methods, that of the hand-rubbing method increases from the small output level because the production capacity is small. The average cost of the hand-rubbing method first decreases from the high level and then exhibits, an increase as shown in Fig. 4. It is assumed that the semi-mechanical method lies between the hand-rubbing and the mechanical methods.

Now suppose that the tea manufacturing method associated with the average cost curve $T_1$, that is, the hand-rubbing method, is adopted when the tea price is $P_1$. Even if the farm

\* See Hicks (1965) and Fellner (1961), (1966).
tried to use the semi-mechanical or the mechanical method when the price is $P_1$, these methods would not be adopted because the production costs incurred by using these methods is higher than those incurred by using the hand-rubbing method; a comparison of the equilibrium point C with point A in Fig. 3 demonstrates that this is clearly the case. When the wage rate rises and the tea price declines to $P_2$ relatively, the farm cannot continue to produce by hand-rubbing along the average cost curve $T_1$, so it must shift to the technique whose average cost is given by curve $T_2$. That is to say, the tea manufacturing method changes from the hand-rubbing method to the semi-mechanical method. When tea price declines to $P_3$ relatively, the tea manufacturing method is changed further from the semi-mechanical method to the mechanical method. As the tea manufacturing method changes from the hand-rubbing method to the semi-mechanical and mechanical methods, production scale needs to be expanded. Consequently, small-scale tea production farms must take one of the following forms: stopping tea manufacture, selling raw tea leaves, participating in the cooperative tea production or manufacturing by buying raw tea leaves.

The tea production farms have no resources for developing new tea manufacturing machines. Therefore tea production farms must be supplied with the new tea manufacturing machines to be able to select the new technique to adjust to product price and input price change. The tea production farm could not act rationally as stated in the earlier hypothesis, if they could not promptly get information about product markets and input markets. Therefore to empirically verify our hypothesis, these conditions, too, must be made clear.

There exists a distinct type of method that is not referred to in our hypothesis. By using the labor intensive manufacturing method regardless of a rise in wage rate, this method produces a small amount of high-quality tea and yields sales at a high price. This is one type of technological progress. But judging from the demand conditions, this method did not become a widely used tea manufacturing method.

IV. Empirical Testing of Hypothesis

Development of Tea Manufacture Machines

A prerequisite for adoption of tea manufacturing machines is a supply of them. The history of development of tea manufacturing machines is briefly described as follows:\textsuperscript{10} the primary drying tea roller, invented by Kenzō Takabayashi in 1898, was improved and completed in the first half of the 1910's. Hatsutarō Mochizuki invented the secondary drying tea roller, which was used in practice. The prototype of secondary drying tea roller used today had been completed by Shintarō Terada in 1912 after the improvement by Kiichirō Usui and Hikosaburō Sugiyama. The secondary rolling tea dryer seems to have been completed in the first half of the 1910's. The machine developed by Kiichirō Usui in 1899 was very similar to today's final drying tea roller, and the prototype of today's final drying tea roller had been completed by Usui after the improvement in 1903 and in 1912. The tea manufacturing machines were made purely based on Japanese ideas; each manual

TABLE 3. NUMBERS OF PATENTS ON AND OF UTILITY MODELS OF
TEA MANUFACTURING MACHINES

<table>
<thead>
<tr>
<th>Year</th>
<th>Patents</th>
<th>Utility models</th>
</tr>
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<tbody>
<tr>
<td>1885</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>95</td>
<td>11</td>
<td></td>
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<td>1900</td>
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<tr>
<td>10</td>
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<tr>
<td>15</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>17</td>
<td>37*</td>
</tr>
<tr>
<td>25</td>
<td>32</td>
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<td>24</td>
<td>163</td>
</tr>
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<td>35</td>
<td>28</td>
<td>115</td>
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</table>

Sources: [Shizuokaken Chagyō Kumiai Rengō Kaigisho (1925, pp. 261–270); (1937, pp. 348–369)].

Notes: Figures are for five years centering on the year shown; figures for 1935 are those for 1933–35; the figure with * is a figure for 1921–22.

operation in the hand-rubbing method was only replaced with machines. Therefore, it was indeed a hard task to develop tea manufacturing machines. We can see one of the difficulties in the development from the large number of patents and utility models of tea manufacturing machines, as shown in Table 3; the patent regulation was enacted in 1885, and the second, third and fourth patents were given to Takabayashi’s tea manufacturing machines.

The following figures enable us to analogize the scale of the makers of tea manufacturing machine. Thirty-eight model names of machines, such as Takabayashi-type and Mochizuki-model, existed in Shizuoka Prefecture in 1909. The number of makers of tea manufacturing machines in Shizuoka Prefecture was fifty-six in 1935. The manufacturers of tea manufacturing machines that were diffused in Kyōto Prefecture in 1929 were more than twenty-one. The existence of many manufacturers leads us to analogize the following point. Judging from the number of tea manufacturing machines diffused, the small factories in rural areas manufactured tea manufacturing machines and made a great effort toward improving the machines. Selecting models was a very hard problem for tea production farms, since many makers of tea manufacturing machine manufactured a variety of models. National and prefectural tea experiment stations were engaged in the comparative testing of the performance of tea manufacturing machines, and the tea cooperative association was effective in extending such technological information from the results of comparative tests done by the tea experiment stations.

Tea Cooperative Association

*Nihon Chagyō Kumiai Chūōkai* (Japan Central Union of Tea Cooperative Association), *Ken Chagyō Kumiai Rengō Kaigisho* (Prefectural Union of Tea Cooperative Association)

12 See Shizuoka Chagyō Kumiai Rengō Kaigisho (1925, pp. 204–05).
14 See Asada (1937).
in each tea production prefecture and Gun Chagyō Kumiai (County Tea Cooperative Association) under the Prefectural Union were organized under the Tea Cooperative Association Law which was enacted in 1887. These associations made great contributions to the quality control through inspecting the tea output, and improving and extending the tea production technology. They were the channel for promptly transmitting market information.

The book titled "History of Tea Manufacturing Industry in Shizuoka Prefecture" describes the activities of the Association as follows: the activities which the Shizuoka Prefectural Union of Tea Cooperative Association conducted include the quality control of tea manufacture, the improvement of tea production techniques and the expansion of tea market. Since the greater part of tea output was exported to the United States, the reduction in tea quality by mixing the bad-quality tea was a grave problem for the Japanese tea export, under such United States' regulations as the Regulation of Impure Tea Import Control in 1897 and the Regulation of Colored Tea Import Inhibition in 1910. Consequently, the Prefectural Union of Tea Cooperative Association and each county tea cooperative association played a key role in quality improvement and quality control of products when making the standard tea, inspecting the tea and issuing the inspection label. As part of tea production improvement activities, the Prefectural Union of Tea Cooperative Association frequently held many kinds of competitive exhibitions, tea production farm meetings, tea manufacture study meetings and tea manufacture competitions. For example, the management performances of 162 tea production farms were exhibited in the competitive exhibition of tea production management method in 1915 and the superior farm was commended based on the tea production technique employed and the management results.

The county tea cooperative associations conducted the same activities as the Prefectural Union of Tea Cooperative Association. But they were able to conduct excellent activities, for they contacted the farm directly. For example, the Haibara County Tea Cooperative Association had been engaged in improving tea production since 1907; the association selected a tea production model farm in each town and village for exhibiting the model management method of tea production, and announced the management results of model farm every year.

The activities of the tea cooperative association contributed a great deal to transmitting to the tea production farms information about production technology, tea market and input factor market. Therefore, we maintain that they explain the greater part of the facts that

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16 See Shizuoka Chagyō Kumiai Rengō Kaigisho (1925).
17 The expenditures for inspection, improvement of production and market expansion were about 9,600 yen, 6,500 yen and 9,800 yen, respectively.
18 The Prefectural Union used police power to control tea manufacture until about 1900.
18 See Rogers (1962, pp. 363-67).
the tea production farms reacted rationally to the changes in product and input factor prices and that they changed their tea manufacturing method.

**Manufacturing Method and Cost**

The data for tea production cost are available for three tea production farms owning tea plant fields and manufacturing tea themselves in Haibara County of Shizuoka Prefecture in the early Taishō Era.¹⁹ Farm K, using the hand-rubbing method, manufactured 196.3 kan of tea on 35 a of tea plant field in 1914. The depreciation cost of tea manufacturing equipment was 2.31 yen, the current input cost per kan of tea 0.24 yen, and the labor input per kan of tea 1.51 persons.²⁰ Farm S, using the semi-mechanical method, manufactured 334.2 kan of tea on 52 a of tea plant field in 1915. The depreciation cost was 55.40 yen, the current input cost per kan of tea 0.22 yen and the labor input per kan of tea 0.53 persons. Farm M, using the mechanical method, manufactured 1,002.2 kan on 175 a of tea plant field in 1914. The depreciation cost was 115.33 yen, the current input cost per kan of tea 0.16 yen and the labor input per kan of tea 0.38 persons.

The average production cost AC of these three tea farms are summarized by using wage rate W and output Q as follows:

- **hand-rubbing**
  \[ AC = 0.24 + 1.51W + \frac{2.31}{Q} \]

- **semi-mechanical**
  \[ AC = 0.22 + 0.53W + \frac{55.40}{Q} \]

- **mechanical**
  \[ AC = 0.16 + 0.38W + \frac{115.33}{Q} \]

The constant terms are current input cost per kan and we can see the decline of the constant term according to further mechanization. The coefficients of wage rate W represent the labor input per kan measured by the wage rate of a cha-shi who is the veteran worker of tea manufacture; they fall down naturally according to further mechanization. The coefficients of tea output Q indicate the depreciation cost and they increase as mechanization proceeds. But the depreciation cost per output of every manufacturing method decreases as tea output increases. The decrease of depreciation per output is greater than that of the coefficient of W. Consequently, we can see that the hand-rubbing method is profitable at the low level of wage rate, but the mechanical method becomes profitable when the wage rate rises. These findings support the hypothesis as given in Fig. 3 and 4.

Farm K, using the hand-rubbing method, manufactured about 200 kan of tea. At this output level, the semi-mechanical method is more profitable than the hand-rubbing method. But since farm K intended to manufacture high-quality tea by hand-rubbing, it could sell the product at a high price, earning a profit.

**Regression Analysis**

The hypothesis is empirically tested by estimating the regression equation that describes

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¹⁹ Since Haibara County was the main tea production county in Shizuoka Prefecture, three samples may be considered good enough for us to investigate the tea production in those days. The figures for farm K and farm M were publicly announced at the model tea production farm meeting, and the figures of farm S were announced at the competitive exhibition of tea production management method. See Shizuoka Cha-gyō Kumiai Rengō Kaigisho (1937, pp. 1093–1097) and Shizuokaken Chagyō Kumiai Rengō Kaigisho (1919, pp. 524–529).

²⁰ The labor input was estimated from the total wages divided by the wage rate of cha-shi which was 1 yen in those days. With this estimation, the remaining labor inputs except cha-shi were converted to cha-shi standardized labor input. The same applies to two other farms.
the difference in the number of tea manufacturing machines diffused among prefectures as shown in Fig. 1.

The dependent variable is the tea manufacturing machine per tea production farm in each prefecture. The first independent variable is the wage rate. Since the wage rates of tea manufacture in the prefectures were not available to us, we used the wage rate of rice production in place of tea manufacture. The second independent variable is the tea planting area per farm, which indicates the production scale. This variable was included in the model to express the fact that the mechanization requires at least a certain scale of production. The third independent variable represents the role of tea cooperative associations for extension, which may be called an extension system variable. As a proxy for this variable, we use the activity cost of each prefectural union of the tea cooperative association per tea production farm in each prefecture.

The regression model is fitted with the cross-sectional data in 1925. We selected this year because the diffusion speed of machines was sufficiently fast and there were a lot of available data. The sample consists of 14 prefectures including Saitama Prefecture.21

The estimated results by the ordinary least square method after the logarithmic transformation are as follows:22

\[
\ln(\text{number of diffused machines}) = -2.30 + 2.09 \ln(\text{wage rate}) + 0.65 \ln(\text{scale}) + 0.64 \ln(\text{extension})
\]

\[
(2.11) \quad (1.39) \quad (3.14)
\]

\[R^2 = 0.90\]

The three independent variables explain 90 percent of the variance of tea manufacturing machines per farm among prefectures. We observe that the difference in wage rate influences the number of tea manufacturing machines diffused, since the elasticity of the wage rate is as large as 2.09. The results suggest that the number of diffused machines increases when the wage rate rises, for the coefficient of wage rate has a plus sign. We also find from the regression result that the tea cooperative association played a role in diffusing the tea manufacturing machines. The result further indicates that the increase in tea planting area connects with the increase in the number of diffused machines. These results coincide well with our hypothesis.

Other factors in Mechanized Tea Manufacture

Table 4 shows the number of the prime movers of tea manufacturing machines that diffused in Shizuoka Prefecture. In 10 years, the number of prime movers doubled from 4,068 in 1923 to 8,560 in 1934 at an annual growth rate of 7.0 percent. The number of internal combustion engines increased from 2,231 in 1923 to 3,637 in 1934, but their share of the total number of prime mover decreased from 55 percent to 42 percent. The number of electric motors increased from 878 in 1923 to 3,948 in 1934, and their shares, too, increased from 22 percent to 46 percent.

21 Samples include the following 14 prefectures; Saitama, Gifu, Shizuoka, Mie, Shiga, Kyōto, Osaka, Hyōgo, Nara, Kōchi, Fukuoka, Kumamoto, Miyazaki and Kagoshima. The number of machine diffused and activity cost incurred by the prefectural union of tea cooperative association were obtained from Cha-gyō Kumi'ai Chūō Kaigisho (1936, pp. 910–1153 and 1926, pp. 198–201; 241–242); the tea planted areas and the number of tea production farms from Norinshō (1969); the wage rate from Nōgyō Tōkei Kenkyūkai (1974).

22 The figures in parentheses are T statistics.
Table 4. Diffusion of Prime Movers in Shizuoka Prefecture

<table>
<thead>
<tr>
<th>Prime movers</th>
<th>1923</th>
<th>1925</th>
<th>1930</th>
<th>1934</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric motors</td>
<td>4,068</td>
<td>4,930</td>
<td>7,274</td>
<td>8,560</td>
</tr>
<tr>
<td>Internal combustion engines</td>
<td>878</td>
<td>1,248</td>
<td>3,435</td>
<td>3,948</td>
</tr>
<tr>
<td>Steam power</td>
<td>2,231</td>
<td>2,762</td>
<td>2,924</td>
<td>3,637</td>
</tr>
<tr>
<td>Water wheels</td>
<td>27</td>
<td>24</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Primary drying tea rollers</td>
<td>932</td>
<td>896</td>
<td>898</td>
<td>965</td>
</tr>
<tr>
<td>Final drying tea rollers</td>
<td>15,082</td>
<td>15,877</td>
<td>17,270</td>
<td>19,000</td>
</tr>
</tbody>
</table>

Source: [Shizuokaken Chagyō Kumiai Rengō Kaigisho (1937, pp. 219-236)].

The ratio of the prime movers to final drying tea roller increased from 94 percent in 1923 to 125 percent in 1934. These figures suggest that the increase of prime movers corresponds with the increase of final drying tea rollers.

On the other hand, the price of internal combustion engines per horsepower for agriculture by domestic production fell from about 192 yen in 1922 to about 63 yen in 1936, with about 135 yen in 1925 and about 85 yen in 1930. These figures were calculated from Fig. 2 in Nōgyō Hattatsushi Chōsakai (1978, p. 210). The factory price of standard one-horsepower electric motors decreased from about 190 yen in 1920 to about 25 yen in 1935, with about 53 yen in 1925 and about 27 yen in 1930. These figures were calculated from Fig. 6-1 in Minami (1976, p. 217). The price index of petroleum fell from 100 in 1920 to 86 in 1925 and further to 66 in 1930; the index of electric power rate fell from 100 in 1920 to 66 in 1925, and to 57 in 1930 and 50 in 1935. With the prices of small-sized prime movers, fuels and electric power falling, the tea manufacturing machines were easier to operate. Therefore we can argue that this was one of the factors inducing diffusion of tea manufacturing machine.

The reasons why there were more internal combustion engines than electric motors in 1923 and why the electric motors had diffused very rapidly, as shown in Table 4, are as follows: the equipment cost of internal combustion engines was high but its running cost low. On the other hand, the equipment cost of electric motors was low but its running cost high because of the high electric power rate and the disadvantageous long-term power contract effective for six months. The electric company stopped the electric power supply periodically on the fixed dates, and there existed the non-electric power delivering areas in those days. The Shizuoka Prefectural Union of Tea Cooperative Association experimented with the operation of a primary drying tea roller connecting directly to a small-sized electric motor at the electric exhibition in 1927; this made possible the prompt diffusion of electric motors in the Shōwa Era. But the rapid diffusion of electric motors in the Shōwa Era had been made possible by the reduction of the electric power rate, the expansion of power distribution area, the abolition of periodical power supply cut in the tea production period, and the shortening of terms of the power contract.

We failed to take into account in our empirical test the development of the remaining industries, especially, the development of prime movers and the decline in the operating cost. But these issues will also support the hypothesis if one hypothesizes that the change
### Table 5. Change in Number of Tea Manufacture Farms in Shizuoka Prefecture

<table>
<thead>
<tr>
<th>Cooperative association</th>
<th>Tea manufacture farms</th>
<th>Raw leaf selling farms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1911</td>
<td>1922</td>
</tr>
<tr>
<td>Kamo</td>
<td>31</td>
<td>63</td>
</tr>
<tr>
<td>Tagata</td>
<td>151</td>
<td>376</td>
</tr>
<tr>
<td>Shuntō</td>
<td>1,150</td>
<td>349</td>
</tr>
<tr>
<td>Fuji</td>
<td>3,351</td>
<td>2,500</td>
</tr>
<tr>
<td>Anbará</td>
<td>5,891</td>
<td>700</td>
</tr>
<tr>
<td>Abe</td>
<td>9,583</td>
<td>6,711</td>
</tr>
<tr>
<td>Shizuoka</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Shida</td>
<td>12,834</td>
<td>10,502</td>
</tr>
<tr>
<td>Haibara</td>
<td>9,807</td>
<td>4,972</td>
</tr>
<tr>
<td>Ogasa</td>
<td>11,014</td>
<td>7,711</td>
</tr>
<tr>
<td>Iwata-Nanbu</td>
<td>3,781</td>
<td>2,686</td>
</tr>
<tr>
<td>Iwata-Hokubu</td>
<td>2,650</td>
<td>1,295</td>
</tr>
<tr>
<td>Shuchi</td>
<td>3,779</td>
<td>1,713</td>
</tr>
<tr>
<td>Hamana</td>
<td>855</td>
<td>205</td>
</tr>
<tr>
<td>Hikusa</td>
<td>386</td>
<td>179</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>65,313</td>
<td>40,017</td>
</tr>
</tbody>
</table>

*Sources: [Shizuokakenritsu Nōjī Shikenjyō Chagyōbu (1919, p. 8) for 1911; Shizuokaken Chagyō Kumiai Rengō Kaigisho (1925, p. 211; 256) for 1922-25].*

in input factor prices induced changes in the tea manufacture technology.

**Influence of Mechanization**

It was stated in the hypothesis that further mechanization required a certain scale of production, and the small-scale tea production farm had to take one of the following specialized forms: stopping tea manufacture, selling the raw tea leaves, participating in cooperative tea production, and manufacturing by buying raw tea leaves. Table 5 shows the changes in the number of tea manufacture farms and the number of farms selling raw tea leaves which belong to each county tea cooperative association in Shizuoka Prefecture. The tea manufacturing farms decreased in every county except in Komo and Tagata Counties. The farms selling raw tea leaves increased rapidly in the short 1922-1925 period. This was one of the reactions exhibited by the tea production farms as tea manufacture was further mechanized.

### V. Summary

We analyzed the factors of the process in which the tea manufacturing technology was developed from the hand-rubbing method to the mechanical method via the semi-mechanical method. We confirmed with statistical data that tea manufacturing output increased and that mechanized tea manufacturing methods were changed where the real price of tea declined and wage rates rose.

We presented the following hypothesis. Tea production farms responded rationally to the decline of product price and the changes of input factor prices by changing tea man-
manufacturing technique from the hand-rubbing method to the semi-mechanical method and finally to the mechanical method. The mechanization of tea manufacture was accompanied by induced technological innovation and required expansion of production scale.

The hypothesis was empirically tested and verified in the following manner: (1) we have confirmed the establishment of institutions that diffused information about market conditions and tea production techniques which had been already developed for tea production farms.

(2) The hypothesis was supported by the data of farms' tea production cost in Shizuoka Prefecture in the early Taishō Era.

(3) The estimation results of the regression equation showed that the difference in the number of tea manufacturing machines diffused among prefectures was explained by the differences in wage rate, scale of production and organization of extension; and thus the hypothesis is supported by the statistical data.

(4) The remaining industries had developed along with mechanization in tea manufacturing technology.

(5) Finally, we have confirmed the fact that some tea manufacturing farms had to stop manufacturing tea and start selling the raw tea leaves because the mechanization of tea manufacture required expanded scale of production.

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