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The Impact of Technological Change on Labor: The Japanese Silk Weaving Industry during the Industrial Revolution

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Abstract

The impact of the Industrial Revolution on labor has long attracted the interest of economists as well as economic historians, and recent technological changes and changes in the labor market have newly raised interest in this issue. The accepted view is that technological change in the Industrial Revolution was deskilling and lowered the wage of workers. This paper reexamines this view, by investigating the silk weaving industry in early twentieth-century Japan, which experienced the Industrial Revolution. Power looms, a major technological innovation in the Industrial Revolution, substituted for routine tasks of handloom weavers, and thereby made weavers concentrate on nonroutine tasks, such as stopping looms and supplying warp or weft when it ran out and connecting threads when they broke. Using the model of Autor et al. (2003) and newly constructed plant-level panel data, this paper studies the implications of this change in labor for wages. We find that adoption of power looms was associated with significant increases in the wage of both female and male adult workers, playing a central role in weaving, which suggests the need for revision of the view that technological change in the Industrial Revolution was deskilling.

Key words: Technological change, Industrial Revolution, Skill, Wage, Economic history

JEL classification numbers: J24, J31, L67, N35, N65, O33

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1. Introduction

The impact of technological change on labor has been one of the central issues in the literature on the Industrial Revolution. In this literature, it is widely accepted that technological change in the Industrial Revolution was deskilling, and hence had a large negative impact on skilled artisans. Luddite riots in the early nineteenth century, where handloom workers in Lancashire destroyed mechanized weaving mills, are often cited as a symbolic story (Goldin and Sokoloff 1982; Mathias 1983; Hounshell 1984; Sokoloff 1984; Mokyr 1990; Goldin and Katz 1998; Acemoglu 2002). However, as Acemoglu (2002) and Atack et al. (2004) pointed out, systematic quantitative analyses of the deskilling hypothesis prior to the twentieth century are scarce. Motivated by this understanding, Atack et al. (2004) examined the correlation between monthly wage, plant scale, capital intensity, and the use of steam at the plant level, using the United States Census data for 1850 and 1880. Regression analyses revealed that the wage was negatively associated with establishment size, while capital-intensive establishments and those with steam power had higher wages. Based on the findings, they concluded that "although the diffusion of the factory reduced skill intensity through its positive association with establishment size, these negative effects were offset to some degree by growth in capital per worker and greater reliance on inanimate power sources, which tended to raise skill intensity" (p. 174).

Although Atack et al. (2004) shed new light on the issue of skill intensity in the early stage of industrialization, there is room for further exploration. First, in interpreting the empirical results, Atack et al. (2004) directly applied the model of Goldin and Katz (1998). Their model divides the process of manufacturing into two distinct segments, "machine maintenance" and "production," and assumes that all workers in the machine maintenance segment are skilled, whereas all workers in the production segment are unskilled. The model further assumes that for all types or stages of technologies—the artisan shop, the factory, the factory with assembly line, and the factory with continuous process—the inputs to the machine maintenance segment are "raw capital" and skilled labor, while the inputs to the production segment are "workable machines," which are prepared in the machine maintenance segment, and unskilled labor. Thus, the ratio of skilled labor to unskilled labor in total is determined by the skilled labor intensity in the machine maintenance segment and workable capital intensity in the production segment. From this model, Atack et al. (2004) derived the implication that the ratio of skilled to unskilled labor for the factory is lower than that for the artisan shop because compared with the factory, the artisan shop has a higher skilled labor intensity in the machine maintenance segment and higher workable capital intensity in the production segment, and that this relationship is mitigated to the extent that the factory has high workable capital intensity in the production segment[1].

However, this theoretical framework is not appropriate for interpretation of the central part

[1] See Figure 1 in Goldin and Katz (1998).

of technological change in the early stage of industrialization, or the Industrial Revolution. The major technological change in the Industrial Revolution took place in the spinning and weaving processes of the textile industry, which is well known by the names of the famous inventors James Hargreaves, Samuel Crompton, Richard Arkwright, and Edmund Cartwright (Landes 1969, Mathias 1983; Mokyr 1990). Concerning the textile industry, it is important to note that workers before the Industrial Revolution were not as skilled as those in the artisan shop described in the model of Goldin and Katz (1998). On handloom weavers in the cotton weaving industry in late eighteenth-century Britain, Bythell (1969) wrote:

> From the outset, it is important to avoid the fallacy that cotton weaving was a skilled trade, or that the handloom weavers as a whole can be regarded as an 'aristocracy of labour' simply because, in the early years of expansion when weavers were in short supply, good wages were paid. Except in the fancy branches, the qualifications required for weaving were not excessive. Plain weaving was easily learnt; three weeks were reckoned 'a sufficient length of time to teach a mare labourer, when committed for any offence to the New Bayley prison, to weave calico' (pp. 42–43).

The technological change in the Industrial Revolution in the weaving industry, namely adoption of power looms, was substituting machine for many of the tasks of unskilled handloom weavers, as I describe more in detail later. According to the terminology of Goldin and Katz (1998), the role of handloom weavers in the machine maintenance segment was small, and the major change occurred in the production segment.

Second, concerning empirics, there is a concern about endogeneity in the regression analyses. Although Attack rt al. (2004) controlled for region and industry fixed effects in their analyses, we suspect that establishment size, capital intensity, and the use of steam correlate with error terms. For example, an establishment in the within-region areas where the market wage was higher, would adopt capital-intensive and/or steam-powered technology.

This paper attempts to address these two problems by reevaluating the impact of technological change in the Industrial Revolution on labor. First, we use the the model of Autor et al. (2003), which is designed to analyze the implications of computerization on skills in the present world. This model assumes a production function with three inputs, namely routine labor, nonroutine labor, and computer capital, where routine labor and computer capital are perfect substitutes, and these two inputs and nonroutine labor are relative complements. By replacing computer capital with the power loom, we can apply this model to examine the implications of technological change in the Industrial revolution.

Second, we use data from the Japanese silk weaving industry in the early twentieth century. As a backward country, Japan experienced the Industrial Revolution from the late nineteenth century to the early twentieth century. In this period, various industries adopted the factory system, and many factories installed machines, both imported and domestic, driven by inanimate power, such as water, steam, and electricity. As in Britain, a major technological change occurred in the textile industry. Modern machine technologies swiftly diffused and changed the structure of the textile industry, including cotton spinning, cotton weaving, silk reeling, and silk weaving (Kajinishi ed. 1964; Takamura 1971; Ishii 1972; Saxonhouse 1974; Otsuka et al. 1988; Tanimoto 1998; Nakabayashi 2003; Hashino 2007; Hashino and Otsuka 2013, 2020; Braguinsky and Hounshell 2015; Baguinsky et al. 2015; Okazaki 2021).

Among those subcategories of the textile industry, this paper focuses on the silk weaving industry. One reason is that silk weaving was a major textile industry, and it experienced a distinct technological change, that is, transition from handlooms to power looms, from the early 1900s. In addition, detailed plant-level data are available for the 1900s and 1910s for this industry. Unfortunately, the data only cover Fukui Prefecture, but this prefecture was one of the major centers of silk fabric production in Japan, especially a plain silk fabric called *habutae*. However, a focus on plain silk fabrics is appropriate in the context of this paper because “fancy branches” such as those varieties produced in Nishijin, Kyoto were woven by highly skilled artisans, as noted above in the quotation from Bythell (1969).

In summary, we explore the implications of technological change for labor in the Industrial Revolution, combining the model that distinguishes between routine labor and nonroutine labor, which are substitutes for and complements to machines, respectively, with the data from the Japanese silk weaving industry. The remainder of the paper is organized as follows. Section 2 provides an overview of the Industrial Revolution in Japan. Section 3 explains the technological change in silk weaving and the model to analyze its implications. Section 4 presents the data and regression analyses. Section 5 discusses the consistency of the estimation results with narrative evidence. Section 6 concludes.

2. The Industrial Revolution in Japan: An overview

Japan, which had been under a feudal regime and a seclusion policy for more than 250 years, started its modern economic growth in the latter half of the nineteenth century. The turning point was the opening of the country in 1859 and political regime change, the Meiji Restoration, in 1868. From then onward, the Japanese government and private sector extensively adopted modern institutions and technologies from Western countries, which provided the basis for economic development.

While the average annual growth rate of real GDP per capita was just 0.19% from 1820 to 1870, it increased to 1.68% from 1870 to 1920[2]. The structure of the economy changed substantially

[2] Calculated from the Maddison Historical Statistics (https://www.rug.nl/ggdc/historicaldevelopment/maddison/).

during this process. The ratio of manufacturing production to manufacturing plus agricultural production was 34.6% in 1875, but it had increased to 68.9% by 1920 (Figure 1). Thus, industrialization was an engine of modern economic growth in Japan.

Figure 1

It is notable that the organization of industry changed at the same time. The first manufacturing census for 1909 indicates that there were 32,124 factories with five or more workers, with a total production of 796,429 thousand yen, accounting for 41.8% of total manufacturing production. We can say that factories already held a substantial portion of the manufacturing sector. Furthermore, 28.2% of all such factories used inanimate power (Table 1). Based on these observations, most of the literature on Japanese economic history has judged that Japan experienced the Industrial Revolution in a similar manner to the British Industrial Revolution, in the early twentieth century (Oishi ed. 1975; Nishikawa and Abe eds., 1990; Okazaki 1997; Gordon 2002; Flath 2014; Fukao, Nakamura and Nakabayashi eds., 2017).

Table 1

The industry that led the Japanese Industrial Revolution was the textile industry, as in the British Industrial Revolution. Figure 1 shows that the percentage of textile production in total manufacturing production increased sharply until the middle of the 1890s; although it declined after that, it continued higher than 30% until the early 1930s, except for 1907. The decline in production from the late 1890s reflects the development of various new industries, including metals and machinery, that were triggered by government policy for promoting new industries after the First Sino-Japanese War (Okazaki 1997).

The textile industry was composed of two large subsectors, namely that producing fabric and that producing thread. The former comprises the weaving industry, and the latter includes the silk reeling industry producing raw silk and the cotton spinning industry producing cotton yarns. It is well documented that the silk reeling and cotton spinning industries played an important role in the Japanese Industrial Revolution (Takamura 1971; Ishii 1972; Nakabayashi 2003; Braguinsky et al. 2015). The role of the weaving industry was also substantial, with percentages in the textile and manufacturing industries of 39% and 12% in 1909, and 42% and 13% in 1914, respectively. In turn, the weaving industry included cotton weaving, silk weaving, hemp weaving, and wool weaving, but the first two were the major components (Panel A of Table 2).

Table 2

The weaving industry experienced organizational and technological changes from the 1900s. Factories, that is, plants with 10 workers or more, diffused[3]. While the percentage of weaving workers employed at factories was 12.3% in 1905, it increased to 26.7% in 1914 (Okazaki 2021). At the same time, the ratio of power looms to total looms (power looms + handlooms) increased from 2.6% to 20.5% in the same period, and the ratio was higher for factories (Figure 2).

Figure 2

Diffusion of power looms in the Japanese weaving industry has been extensively studied in the context of technology history and the history of the textile industry. Those studies pointed out that diffusion of power looms, especially in local weaving districts, was caused by such factors as the development of lower priced domestic power looms, the availability of electricity, and the rise in wages. It was also shown that power looms diffused more swiftly for weaving plain cotton and silk fabrics, which were easily woven by power looms (Kandachi 1974; Minami et al. 1982; Minami and Makino 1983; Makino 1984; Saito and Abe 1987; Kiyokawa 1995; Hashino 2012; Hashino and Otsuka 2013; Okazaki 2021).

As noted, we use the data on *habutae*, a plain silk fabric, from Fukui Prefecture, which is located near the Japan Sea, and adjacent to Kyoto Prefecture (Figure 3). Panel B of Table 2 indicates the composition of production in Fukui Prefecture. Compared with Panel A, we find that in terms of the ratio of manufacturing to agricultural production, in the early twentieth century, Fukui Prefecture was slightly more industrialized than Japan overall. Moreover, Fukui Prefecture had a distinctive characteristic in the composition of its manufacturing. Of manufacturing production, 82%–83% was textiles, and most of the textile production was silk fabric, especially *habutae*. Indeed, the ratio of *habutae* to total manufacturing production was 71%–74%. Comparing the data in Panels A and B, we find that the share of Fukui Prefecture in *habutae* production in Japan was as high as 53%–60%.

Figure 3

Habutae producers in Fukui Prefecture, especially *habutae* factories, adopted power looms very swiftly. As shown in Panel A of Figure 2, of *habutae* factories, the ratio of power to total looms, which was around 0 in 1905, increased to more than than 80% by 1914. Panel B of Figure 2 also indicates that the number of handlooms sharply declined in *habutae* factories from 1910. The factors that stimulated adoption of power looms—the development of domestic power looms at low price, the availability of electricity, and the rise in wages—apply to the *habutae* industry in Fukui (Sugiura

[3] Note that the definition of factory here (based on the number of workers) differs from that in Table 1.

1997; Hashino 2012)[4]. Domestic power looms were first produced by Sakichi Toyoda, the father of Kichiro Toyoda, the founder of Toyota Motors Co., in 1897; several other inventors followed with their own power looms. While these power looms were for cotton weaving, in 1898, Toichi Saito invented a power loom for *habutae*. The price of a domestic power loom was 30–60 yen in the 1900s, that is, one-seventh to one-twelfth the cost of an imported power loom (Kiyokawa 1995, p. 174), meaning that the development of domestic power looms drastically lowered the price of power looms.

3. Technological change in the silk weaving industry and the theoretical framework to analyze its implications

The impact of power looms on labor productivity was indeed substantial. Using plant-level data for the *habutae* industry in Fukui Prefecture, Okazaki (2021) reported that in 1913–1914, labor productivity was on average 2.62 times higher for powered plants than for nonpowered plants, after controlling for plant scale and working hours. This difference in labor productivity is consistent with narrative information on power looms for this period. Sanbe (1961, p. 366) noted that from the late 1890s to the early 1900s, a foot-operated handloom could produce 1.5 *tan* of silk fabric per day, while a power loom could produce 2 *tan* of silk fabric per day[5]. Thus, the difference in machine productivity was just 1.33 times between a foot-operated handloom and a power loom. However, Sanbe (1961, pp. 365–366) also noted that a worker could operate two to three power looms, whereas she could operate only one foot-operated handloom. For a worker operating two power looms, the difference in labor productivity would be 2.67, almost the same as the estimation of Okazaki (2021).

The fact that adoption of power looms enabled a worker to operate multiple looms is related to the operation of weaving in general and the innovation of the power loom. The operation of weaving consists of three basic tasks (Bythell 1969, p. 66)[6]: (a) sending the shuttle that contains the weft threads from one side of the loom to the other side through the threads of the warp; (b) raising and lowering with healds the alternate warp threads between each passage of the shuttle to create the “shed” through which the shuttle moves; and (c) beating together the weft threads with the lathe (reed). With a handloom, a worker does these three tasks in turn with her hands and legs, and is therefore constrained to operating only one loom at the same time. The power loom mechanized these three basic tasks, and thereby removed the physical constraint. The remaining task for a worker is to stop the power loom and supply warp or weft when it runs out, and threads require reconnecting when they break (Uchida 1960, pp. 190–191; Sanbe 1961, p. 394; Tsunoyama 1983, p. 301; Hunter

[4] In addition, Kandachi (1974) pointed out that in Fukui, many small- and medium-sized land owners founded *habutae* plants and the land rent revenue enabled them to finance investment in power looms.
[5] A *tan* is a unit of fabric, in particular the length of fabric with a regular width, widely used in prewar Japan. Usually one *tan* is equal to 11.3–12.5 m. (https://www.pref.yamanashi.jp/kaiki/kaiki_museum/kaiki-museum/kaiki-yougo.htm).
[6] Sanbe (1961, pp. 74–75) provides the same description of operation of a handloom in the Japanese context.

2008, p. 127). In other words, a power loom mechanized the routine tasks, leaving only nonroutine tasks for the worker.

This is what the technological change in the Industrial Revolution brought about for labor in the weaving industry. This appears to differ from what Goldin and Katz (1998) described as a shift from the artisan shop to the factory. It is notable that mechanization of the weaving process was at the core of the British Industrial Revolution, as well as the Japanese Industrial Revolution. Of course, operating the three tasks efficiently in a harmonized manner needed some skill, but unlike the skills of artisans, it was not very difficult to obtain (Bythell 1969).

Hence, to analyze the implications of mechanization of weaving on labor, we need an alternative theoretical framework. In analyzing the implications of computers on labor demand in the present world, Autor et al. (2003) focused on the fact that "because present computer technology is more substitutable for workers in carrying out routine tasks than non-routine tasks, it is a relative complement to workers in carrying out non-routine tasks" (p. 1285). In the case of computer technology, routine tasks that it substituted include "calculating, coordinating, and communicating functions of bookkeepers, cashiers, telephone operators, and other handlers of repetitive information processing tasks," while nonroutine tasks included those "demanding flexibility, creativity, generalized problem-solving, and complex communications" (Bresnahan 1999, cited by Autor et al. 2003, p. 1284). Although the contents of routine and nonroutine tasks naturally differ between computers and power looms, there is an essential commonality in that machines (computers or power looms) substitute for routine tasks, while they are relative complements to nonroutine tasks. Thus, we apply the model of Autor et al. (2003) to investigate the implications of power looms. For the convenience of readers, we reproduce the model, slightly customizing it for the case of the power loom. In the model, the production function is defined as:

$$Q=(L_R+P)^{1-\beta}L_N^{\beta}, \quad (1)$$

where L_R and L_N are routine and nonroutine labor inputs, respectively, and P is input of the power loom. All these inputs are measured in efficiency units. It is assumed that routine labor and the power loom are perfect substitutes, and that these two factors, routine task input and nonroutine labor, constitute a constant-returns Cobb–Douglas production function. Power looms are supplied perfectly elastically at price ρ. While exogenous decline in computer prices is the causal force in Autor et al. (2003), here the exogenous decline in power loom price ρ is the causal force, which reflects the fact that the development of domestic power loom production increased the supply of power looms and lowered their price. As an implication of the production function (equation (1)), the marginal productivity of nonroutine tasks rises with the quantity of routine task and power loom inputs. It is assumed that there are a large number of workers, each of whom inelastically supplies one unit of labor. Worker i has heterogeneous productivity endowments in both routine and nonroutine tasks, r_i and n_i ($0<r_i, n_i \leqq 1$), and she can choose to supply any convex combination of routine and nonroutine

task inputs, based on the relative wage of routine to nonroutine tasks. Thus, the labor supply of worker i is

$$L_i=[\lambda_i r_i, (1-\lambda_i)n_i] \ (0<\lambda_i \leqq 1). \quad (2)$$

An important feature of the model of Autor et al. (2003) in the context of this paper is that we can derive an implication on the relative wage of routine to nonroutine labor. From the assumption of perfect substitution between routine labor and power loom, we can directly derive:

$$W_R=\rho, \quad (3)$$

where W_R refers to the wage of routine labor. The relative efficiency of worker i at nonroutine to routine tasks is defined as $\eta_i=n_i/r_i$. At the labor market equilibrium, for the marginal worker,

$$\eta^*=W_R/W_N. \quad (4)$$

Worker i supplies routine labor (λ_i=1) if $\eta_i<\eta^*$, and supplies nonroutine labor, (λ_i=0), otherwise. The supplies of routine labor, $g(\eta)$, and nonroutine labor, $h(\eta)$, are

$$g(\eta)=\Sigma_i r_i \text{ for i satisfying } \eta_i<\eta^*, \text{ and } h(\eta)=\Sigma_i r_i \text{ for i satisfying } \eta_i \geqq \eta^*. \quad (5)$$

The first-order condition of profit maximization of weaving firms is

$$w_R = \frac{\partial Q}{\partial L_R} = (1-\beta)\theta^{-\beta}, \text{ and } w_N = \frac{\partial Q}{\partial L_N} = \beta\theta^{1-\beta}, \quad (6)$$

where θ is the ratio of the routine task input to nonroutine task input, that is,

$$\theta = [P+ g(\eta^*)] / h(\eta^*). \quad (7)$$

From equations (2) and (6), we have

$$\frac{\partial ln\theta}{\partial ln\rho} = -\frac{1}{\beta}. \quad (8)$$

That is, when the power loom price declines, the demand for routine task input, that is, power loom and/or routine labor, increases. Increased demand for routine task input is met by an increase in the input of power loom, because routine and nonroutine tasks are complements and hence the relative wage for nonroutine labor rises as ρ declines:

$$\frac{\partial \ln (W_N/W_R)}{\partial \ln \rho} = -\frac{1}{\beta} \text{ and } \frac{\partial \ln \eta^*}{\partial \ln \rho} = \frac{1}{\beta}. \quad (9)$$

Thus, when the power loom price declines and routine labor is substituted for by power loom, the relative wage of nonroutine labor, which is not substituted for power loom, increases. I hypothesize that this actually occurred in the Japanese silk weaving industry during the Industrial Revolution, and test this hypothesis using a set of micro data.

4. Data and regression analyses

We now focus on the silk weaving industry in Fukui Prefecture, for which detailed plant-level data are available. As noted, Fukui Prefecture was one of the major centers of the silk weaving industry. The *Statistical Yearbook of Fukui Prefecture*, published annually by the Fukui Prefectural Government, provides plant-level data on factories with 10 workers or more for the period 1904–1917. The plant-level data cover not only the silk weaving industry but also the other industries. The data include such information as the industry, plant name, location (city, town, or village), owner name, foundation year, major product, power source, total horsepower used, daily working hours, number of workers by gender and age category, and wage per day by gender and age category. One of the reasons we do not use the data from 1915 is that the age category was revised in 1915. Until 1914, the age categories were 14 years old or older (adult), and younger than 14 years old (child); from 1915, this changed to 15 years old or older, and younger than 15 years old. Another reason is that we want to exclude the impact of the boom and inflation during World War I.

We use all the data on plants for which their products are recorded as silk fabric or *habutae*. Because the data cover all industries, the data specific to the weaving industry, such as the number of looms, are not available. However, we can identify the plants with power looms using the information on the power source. That is, we regard those plants using inanimate power, water, steam, gas, or electricity, as power loom plants, and the other plants as handloom plants. The change over time in the numbers of powered and nonpowered plants in our samples is illustrated in Figure 4. Powered plants began to increase in 1908, while nonpowered plants declined from 1910. These observations are consistent with the change in the number of power looms and handlooms in Panel B of Figure 2.

Figure 4

From the data, we constructed our plant-level panel data. To do this, we linked individual plants in different years, using the information of (a) plant name, (b) plant owner's name, (c) plant address (city, town, or village), and (d) foundation year. Given that the data were created more than 100 years ago, we regard plants in different years as identical if the plant addresses are the same, and at least two of the other three pieces of information (a), (b), and (d) match. Thus, we identified 1,361 plants and 4,449 plant-year observations. Because there were many entries and exits, the panel data are unbalanced.

The basic statistics are reported in Table 3. "Power" is a dummy variable, which equals 1 if that plant used inanimate power and 0 otherwise. We regard the plant as using power looms as described above. Among the total of 4,449 plant-year observations, 21.3% are powered. "Worker" is the number of workers employed in a plant. The average number of employed workers in a plant is 24.523, but this varies substantially; the largest plant employed 698 workers. Although the data are principally for factories with 10 workers or more, a few smaller plants are included. "Hours" is the average daily hours worked at a plant. Most plants operated for 11–12 hours per day. "Female adult wage", "Male adult wage", "Female child wage", "Male child wage" are the log of the average daily wage of each worker category at a plant. The mean of "Female adult wage" is 3.023, so the average female adult wage was 20.55 sen, or 0.2055 yen. Comparing the four categories of workers, the category whose mean wage was highest was, unsurprisingly, male adult, followed by male child, female adult, and female child. Note that only a limited number of plants employed male children.

Table 3

To see the impact of the adoption of power looms on wages, we estimate the following equation:

$$W_{it}=\alpha+\beta Power_{it}+\gamma_i+\lambda_t+\delta_i*\lambda_t+\varepsilon_{it} \quad (10)$$

where W_{it} is the log of the average daily wage of a certain category of workers, that is, female adult, female child, male adult, or male child, at plant i in year t. γ_i is the plant fixed effect, and λ_t is the year fixed effect. δ_i indicates the area where plant i is located, and thus the interaction term, $\delta_i*\lambda_t$ represents the area and year fixed effect, and ε_{it} is the error term.

The estimation results are reported in Table 4. For each worker category, the baseline result and the result of the specification adding ln(Hour) and ln(Worker) to the independent variables are given, to control for the hours worked and the plant scale. The coefficient on Power is positive and statistically significant except for the case of male child, because the samples are small. Magnitude of the coefficient on Power is largest for female adult, followed by male adult and female child. In other words, the impact of the power loom on wages was largest for the largest category of workers, female adult workers, which accounted for 76.1% of workers (Table 3).

Table 4

The coefficient 0.108 of equation (2) indicates that the wage of female adult workers was 11.4% (=exp (0.108)) higher when a plant operated power looms, after controlling for the area and year fixed effect, as well as the year fixed effect. These two sets of control variables are especially important in the following sense. The extant studies on the adoption of power looms in Japan assume that plants adopted power looms in response to the increase in wages in the labor market (Minami, Ishii and Makino 1982; Saito and Abe 1987). However, the results in Table 4 indicate that a plant paid higher wage to workers, especially female adult workers, when it used power looms, even after controlling for area and year fixed effect, which includes the labor market condition in each area in each year. This result suggests that the quality of labor differed between powered plants and nonpowered plants, which is consistent with the feature of technology and work described in section 3, namely that a handloom worker engaged in the three routine tasks and nonroutine tasks with a single loom, as against a power loom worker who concentrated on nonroutine tasks and thereby could operate multiple looms.

We can confirm this interpretation by estimating the following equation, which focuses on overtime change in the impact of power loom adoption on wages:

$$W_{it}=\alpha+\sum_{j=-3}^{3} Change_{it+j}\ (j \neq -1) + \ln(Hour_{it}) + \ln(Worker_{it}) + \gamma_i + \lambda_t + \delta_i{*}\lambda_t + \varepsilon_{it}, \qquad (11)$$

where $Change_{it}$ is a dummy variable indicating that a plant adopted power looms for the first time in year t, and $Change_{it+j}$ is a dummy variable indicating that a plant adopted power looms for the first time j years before t (in case j is negative, j years after t). In estimating equation (11), we limit the samples to those that had power looms in at least one year from 1904 to 1914, but did not have a power loom when the plant first appeared in the data. In other words, we focus on the plants that shifted from nonpowered plants to powered plants during the observation period, and examine how the wage behaved before and after the adoption of power looms.

Table 5 reports the estimation results. The reference year is one year before the adoption of power looms, t-1. As for the female adult wage and the male adult wage, the impact of power loom adoption is clear. Before adoption, the wage had no trend, and was not significantly different from the wage in the reference year (t-1). However, once power looms were adopted, the wage significantly increased and the positive effect continued for at least three years. For the female child and the male child, the patterns of wage change are unclear and statistical significance is weak. Panels A–D of Figure 5 visually show the estimation results. The positive impact on wages after the event of power loom adoption is observed only for female adult workers and male adult workers. This result shows that adult workers, especially female adult workers, mainly operated handlooms and power looms, and hence their labor was most affected by the adoption of power looms.

Table 5, Figure 5

5. Discussion

The regression analyses in the previous section consistently indicate that adoption of power looms by a plant was associated with increase in the daily wage of female and male adult workers at the plant. Here, we discuss how this wage increase occurred based on narrative evidence.

A report of the Fukushima Prefectural Government (Fukushima Prefectural Government 1910, pp. 320–321) states that the piece-rate system was applied in the silk weaving industry in Fukui Prefecture, and that a worker produces six units of fabric in one month with a handloom, whereas she produces 15 units of fabric with two power looms. The piece wage per unit of fabric was 1.1 yen with a handloom, and 0.6 yen with power looms. This implies that the monthly earning of a worker was 6.6 yen with a handloom, and 9.0 yen with power looms. Although a firm reduced the piece rate for power looms, a worker could still earn a higher monthly wage thanks to much higher productivity with power looms. Reporting on the silk weaving industry in Fukui, Ishikawa, and Toyama Prefectures, Inoue (1913, p. 82) noted that a worker could produce 3–4 units of fabric per month with a handloom, in contrast to 16 units of fabric per month with two power looms. The piece wage per unit of fabric was 1.0 yen with a handloom, and 0.5 yen with power looms, indicating that a worker earned more than twice as much with power looms.

These documents confirm that power loom workers indeed earned higher monthly wages than handloom workers, and that this occurred through the relationship between labor productivity and the piece rate. If the quality of labor was the same between handloom workers and power loom workers, the monthly wage would converge to the same level through arbitrage in the labor market; however, in reality, there remained a substantial wage gap. This observation is consistent with the fact that a power loom worker concentrated on nonroutine tasks, whereas a handloom worker engaged in routine as well as nonroutine tasks.

6. Conclusion

The impact of the Industrial Revolution on labor has long attracted the interest of economists as well as economic historians, and recent technological change and changes in the labor market have newly raised interest in this issue. To my knowledge, however, the change in the labor market during the Industrial Revolution has not been well explored. As we briefly surveyed in the introduction, most of the economic history literature claims that the Industrial Revolution was deskilling, and this view is accepted in recent influential works such as Goldin and Katz (1998) and Acemoglu (2002). Yet, this view does not hold for the textile industry, whose technological changes were the core of the Industrial Revolution. As Bythell (1969) describes in detail, handloom workers before the Industrial Revolution did not have high skills, and most of their work comprised routine tasks. Invention and adoption of power looms substituted for these routine tasks, and as a result, they were left with only nonroutine tasks: stopping power looms, supplying warp or weft when it ran out, and connecting threads when they broke. Thus, power looms allowed weaving workers to concentrate on these nonroutine tasks.

Applying the model of Autor et al. (2003) and using newly constructed plant-level panel data, we examined the implications of this change in labor for wages. We find that adoption of power looms was associated with a significant increase in the wage of female and male adult workers, thereby playing a central role in weaving, which suggests the need for revision of the view that technological change in the Industrial Revolution was deskilling.

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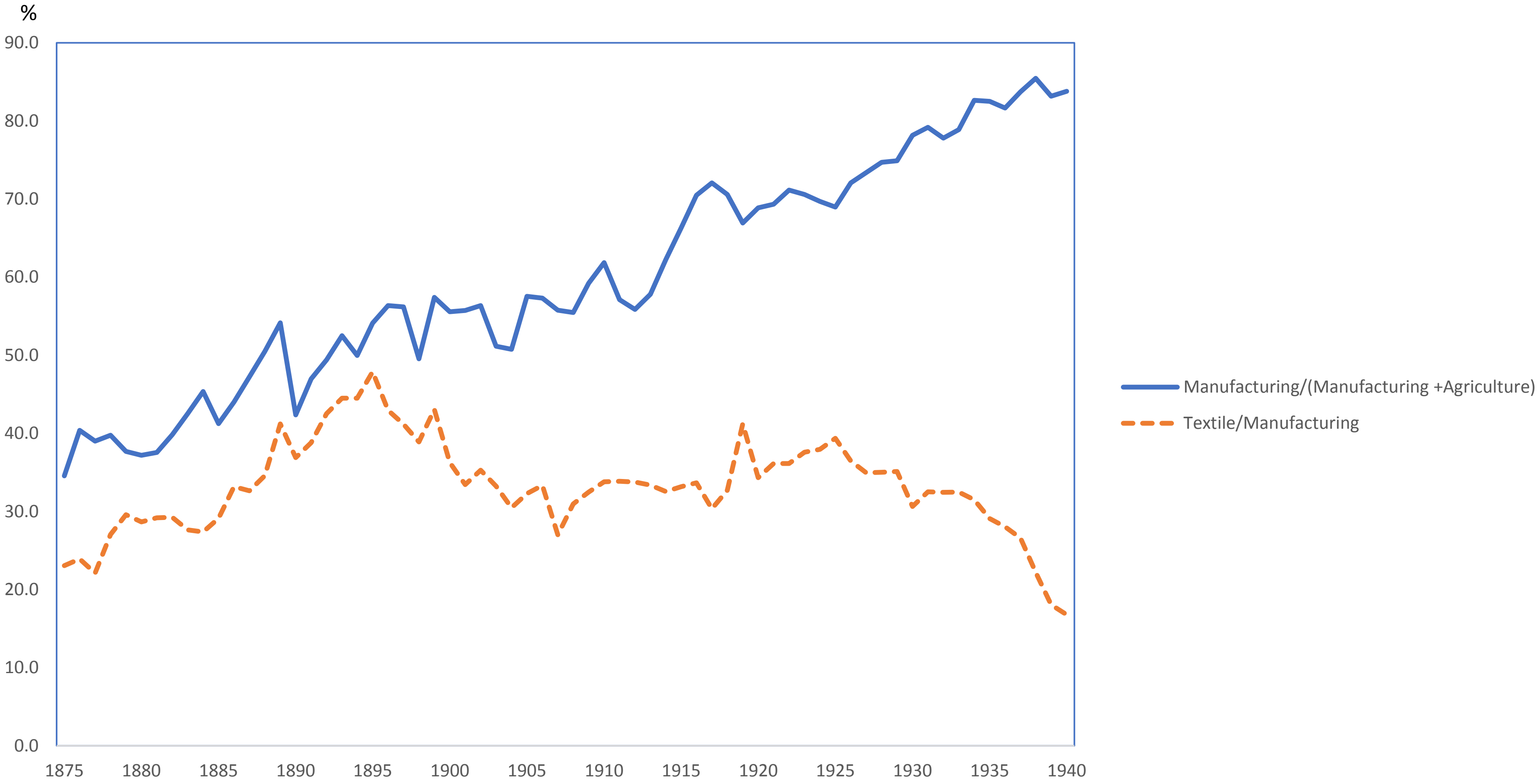
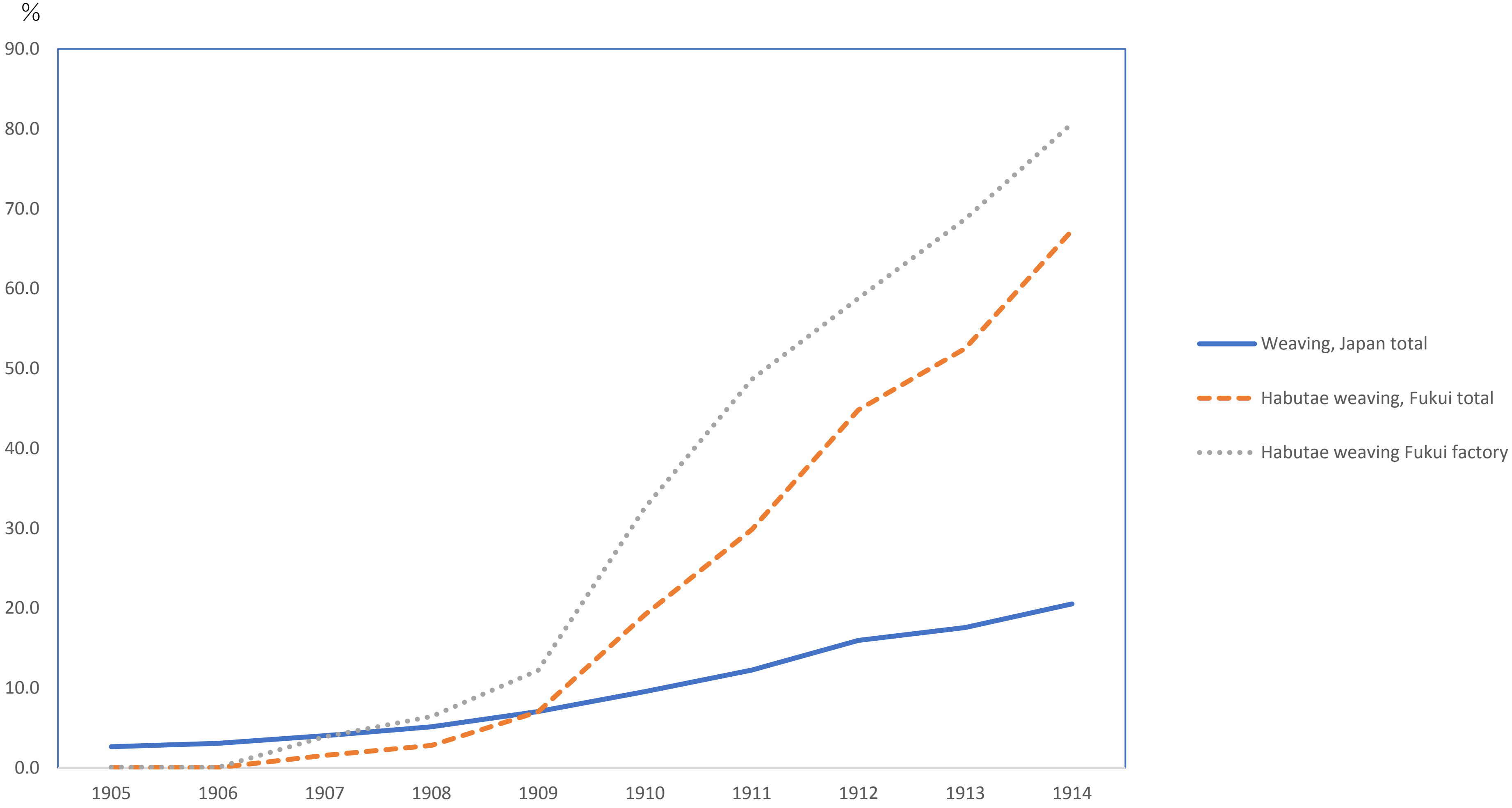
Figure 1 Industrialization in prewar Japan: Composition of production



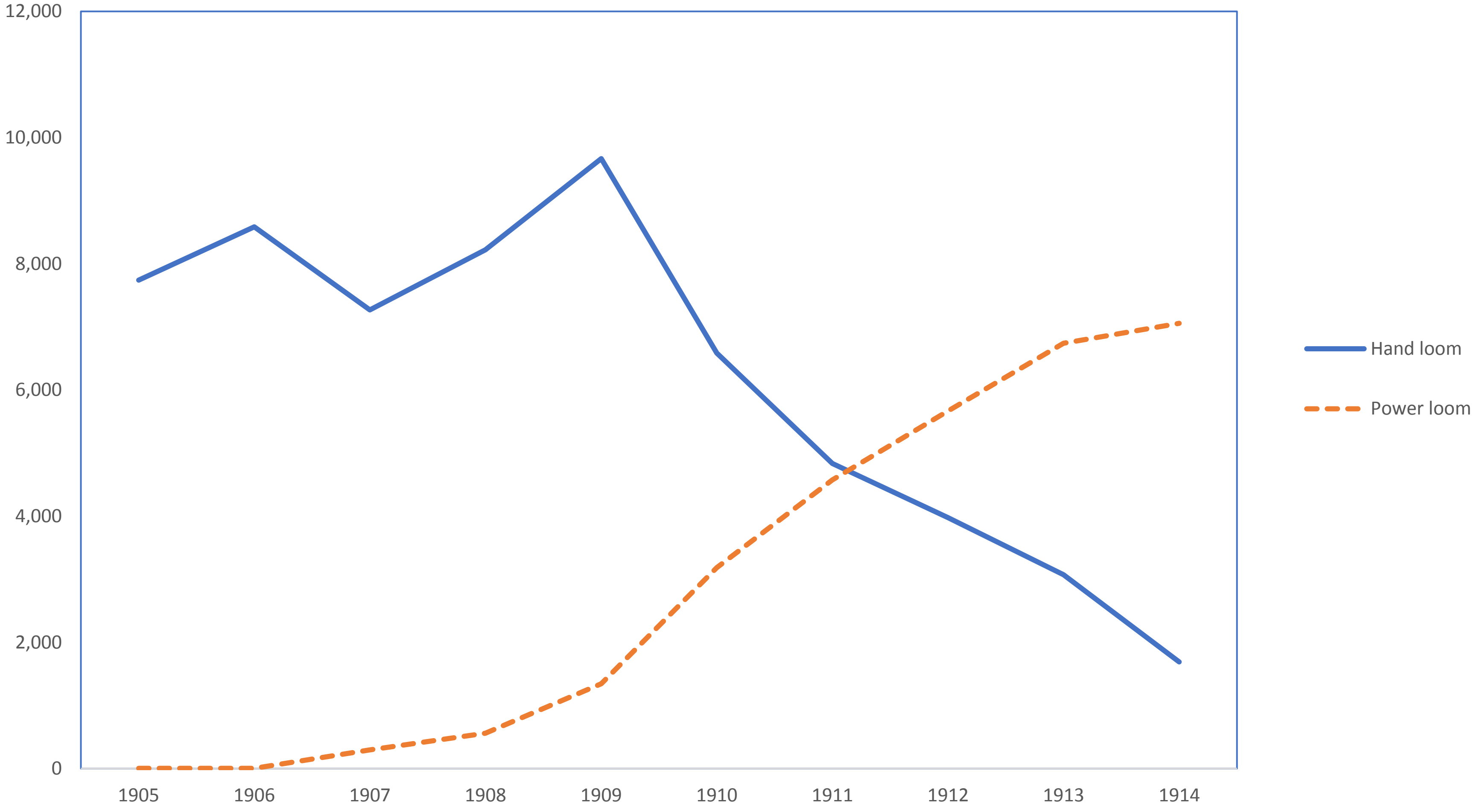
Source: Umemura et.al.(1966), p.146; Shinohara(1972), pp.140-143.

Figure 2 Diffusion of power loom

A. Ratio of the number of power looms to the number of total looms



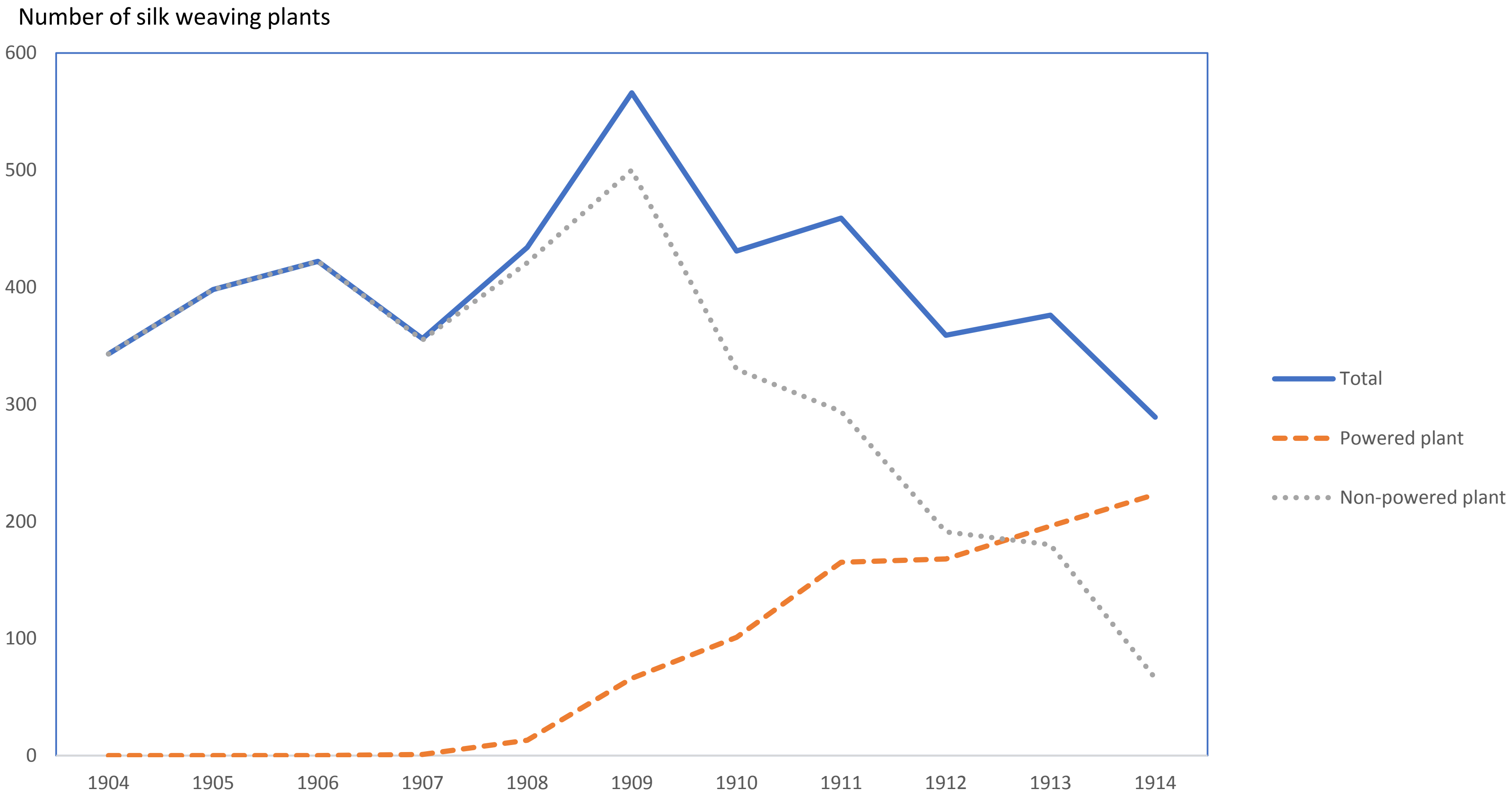
B. Number of hand looms and power looms at habutae factories in Fukui Prefecture



Source: *Statistical Yearbook of Fukui Prefecture*, various issues.

Figure 3 Map of Japan

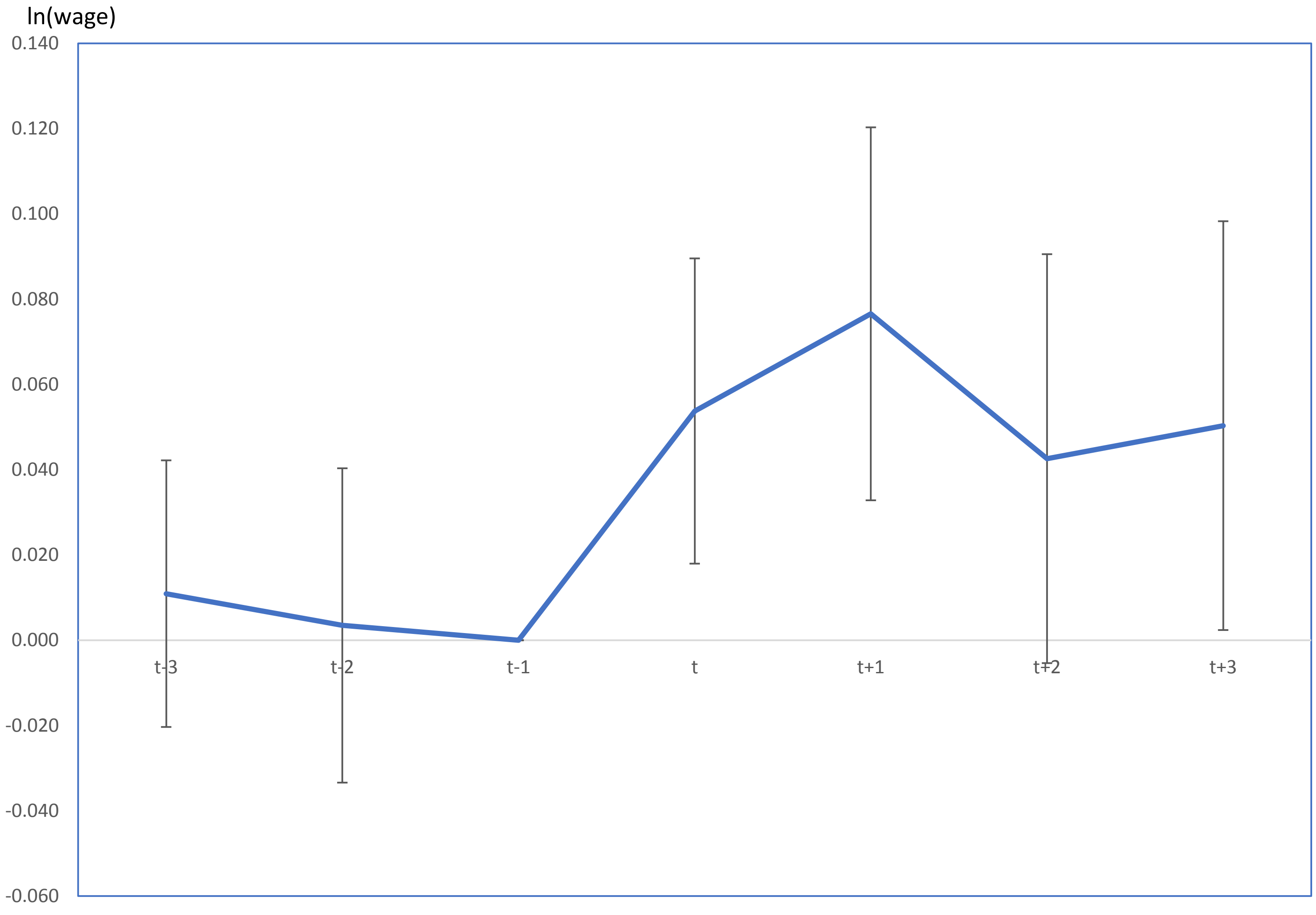
Figure 4 Number of silk weaving plants in Fukui Prefecture

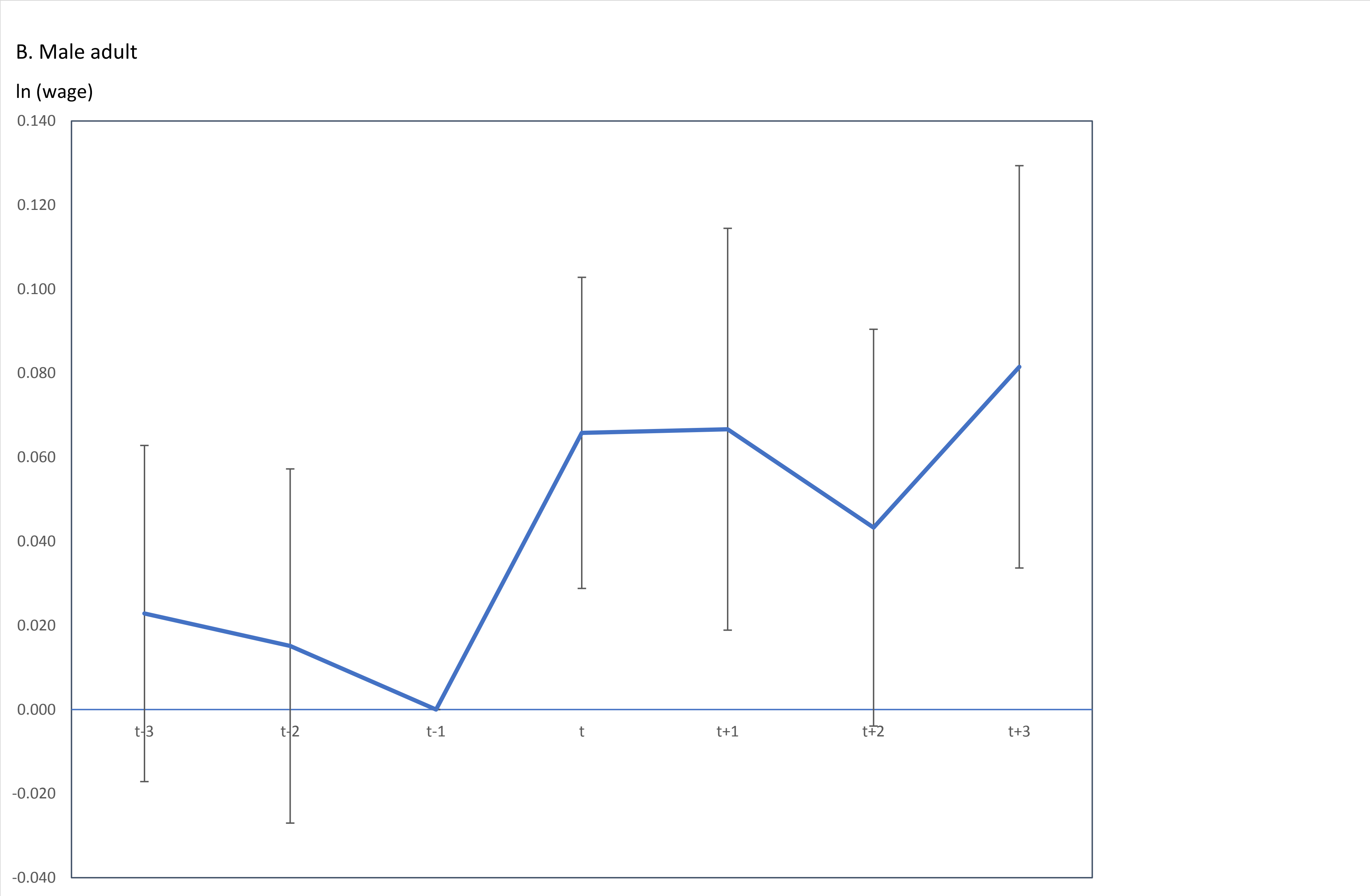


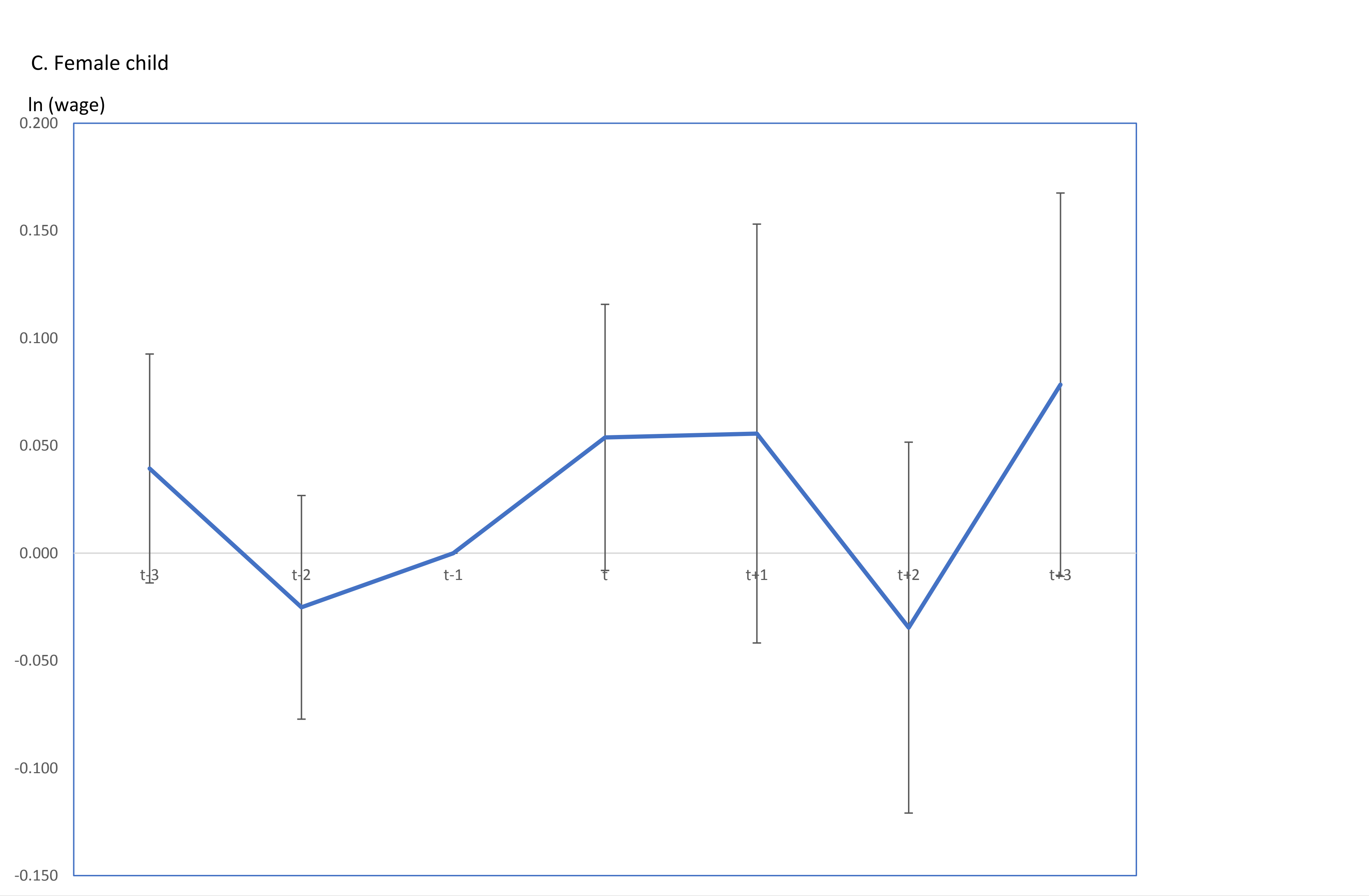
Source: *Statistical Yearbokk of Fukui Prefecture*, various issues.

Figure 5 Event study graph of the impact of adoption of power looms on wage

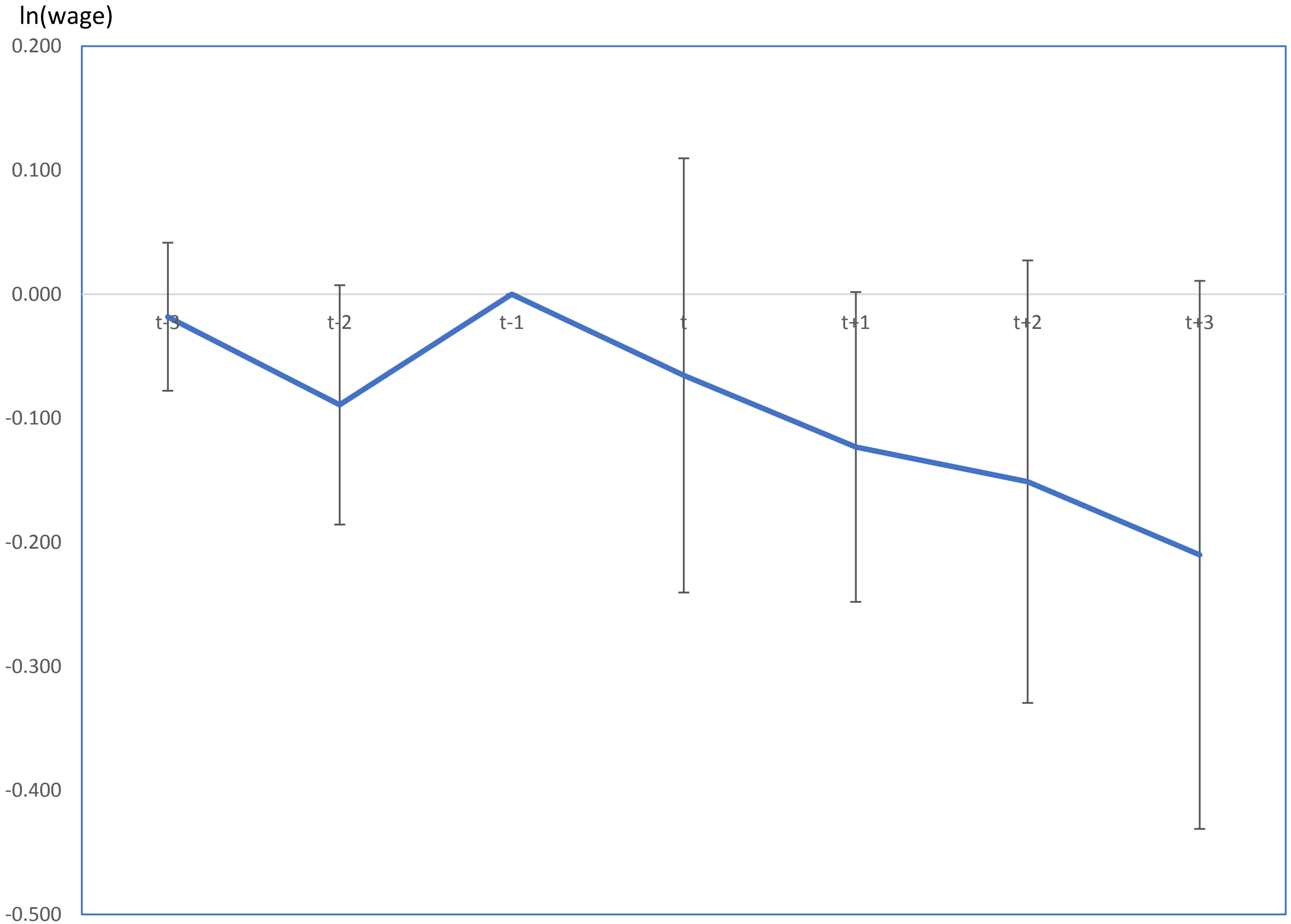
A. Female adult




B. Male adult
ln (wage)
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
-0.040
t-3
t-2
t-1
t
t+1
t+2
t+3


C. Female child
ln (wage)
0.200
0.150
0.100
0.050
0.000
-0.050
-0.100
-0.150
t-3
t-2
t-1
t
t+1
t+2
t+3

D. Male child



Note: Error bar indicates the 95% confidence interval.

Table 1 Diffusion of factory and inanimate power in manufacturing industries in Japan

		1909	1914
Manufacturing total	A. Total production (1,000 yen)	1,907,203	2,552,845
	B. Production of private factories with five workers or more (1,000 yen)	796,429	1,372,429
	B/A (%)	41.8	53.8
	C. Number of private factories with five workers or more	32,124	31,466
	D. Number of private factories with five workers or more, with inanimate power	9,060	14,343
	C/D (%)	28.2	45.6
Textile	A. Total production (1,000 yen)	619,617	830,482
	B. Production of private factories with five workers or more (1,000 yen)	403,452	660,175
	B/A (%)	65.1	79.5
	C. Number of private factories with five workers or more	14,753	13,249
	D. Number of private factories with five workers or more, with inanimate power	4,692	6,882
	C/D(%)	31.8	51.9

Source: Shinohara (1972), pp.140-141; Minami (1976), p.222; Ministry of International Trade and Industry 1961, pp.4-7.

Table 2 Composition of production

A. Japan total 1,000 yen

	1909	1914
Agriculture	1,314,000	1,549,000
Manufacturing total	1,970,203	2,552,945
Textile	619,617	830,482
Weaving	265,331	326,467
Silk	100,234	102,482
Habutae	38,599	39,636
Mixture of silk and cotton	26,233	25,543
Cotton	116,412	150,386
Hemp	3,834	4,705
Wool	15,730	40,527
Others	2,886	2,822

B. Fukui Prefecture

	1909	1914
Agriculture	13,543	15,672
Manufacturing total	28,800	32,181
Textile	23,976	26,514
Weaving	22,399	26,514
Silk	21,116	24,821
Habutae	20,412	23,777
Mixture of silk and cotton	317	547
Cotton	303	333
Hemp	247	473
Wool	413	337
Others	2	1

Source: The data on Japan total are from Umemura et al. (1966), and Shinohara (1972), pp.142-143. The data on Fukui Prefecture are from *Statistical Yearbook of Fukui Prefecture*, 1909 and 1914 issues.

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Table 3 Basic statistics

	Obs.	Mean	Stdev.	Min	Max
Power	4,449	0.213	0.409	0.000	1.000
Worker	4,449	24.523	23.334	4.000	698.000
ln(Worker)	4,449	3.000	0.565	1.386	6.548
Hour	4,447	11.450	1.349	5.000	19.000
ln(Hour)	4,447	2.431	0.118	1.609	2.944
Female adult wage	4,430	3.023	0.260	1.609	3.807
Male adult wage	3,086	3.262	0.297	0.639	4.382
Female child wage	2,662	2.445	0.290	0.693	3.970
Male child wage	1,074	2.550	0.275	0.693	3.611
Female adult ratio	4,449	0.761	0.176	0.000	1.000
Male adult ratio	4,449	0.091	0.103	0.000	1.000
Female child ratio	4,449	0.128	0.153	0.000	1.000
Male child ratio	4,449	0.021	0.045	0.000	0.813
Child ratio	4,449	0.149	0.173	0.000	1.000

Table 4 Impact of power loom on wage

	(1)			(2)			(3)			(4)		
DV	Female adult wage			Female adult wage			Male adult wage			Male adult wage		
Power	0.109	(8.37)	***	0.108	(8.29)	***	0.087	(5.71)	***	0.086	(5.66)	***
ln(Hours)				0.121	(2.80)	***				0.114	(1.82)	*
ln(Worker)				0.159	(1.64)					0.029	(2.50)	**
Const.	2.71	(86.43)	***	2.357	(19.53)	***	2.865	(33.48)	***	2.494	(13.61)	***
Plant FE	Yes			Yes			Yes			Yes		
Year FE	Yes			Yes			Yes			Yes		
Area and year FE	Yes			Yes			Yes			Yes		
Number of obs.	4,451			4,449			3,102			3,100		
Number of groups	1,357			1,357			1,080			1,080		
R^2 within	0.54			0.542			0.618			0.620		
between	0.344			0.341			0.462			0.463		
overall	0.407			0.404			0.516			0.521		

	(5)			(6)			(7)			(8)		
DV	Female child wage			Female child wage			Male child wage			Male child wage		
Power	0.055	(2.04)	**	0.054	(2.03)	**	0.107	(1.68)	*	0.083	(1.27)	
ln(hour)				0.378	(3.45)	***				0.393	(1.51)	
ln(worker)				-0.004	(-0.18)					0.028	(0.90)	
Const.	2.504	(35.39)	***	1.563	(5.18)	***	2.440	(50.85)	***	1.338	(2.02)	**
Plant FE	Yes			Yes			Yes			Yes		
Year FE	Yes			Yes			Yes			Yes		
Area and year FE	Yes			Yes			Yes			Yes		
Number of obs.	2,674			2,673			1,077			1,077		
Number of groups	1,000			1,000			501			501		
R^2 within	0.333			0.343			0.413			0.421		
between	0.068			0.071			0.011			0.025		
overall	0.114			0.118			0.064			0.091		

Note: *** Statistically significant at 1% lebvel.
** Statistically significanr at 5% level.
* Statistically significant at 1% level.
Standard errors are clustered at the plant level.

Table 5 Overtime change in the Impact of power loom on wage within firms that adopted power looms

	(1)			(2)			(3)			(4)		
DV	Female adult wage			Male adult wage			Female child wage			Male child wage		
t-3	0.011	(0.69)		0.023	(1.13)		0.039	(1.46)		-0.018	(-0.60)	
t-2	0.003	(0.19)		0.015	(0.71)		-0.025	(-0.96)		-0.089	(-0.84)	
t	0.054	(2.97)	***	0.065	(3.52)	***	0.054	(1.72)	*	-0.065	(-0.74)	
t+1	0.076	(3.46)	***	0.067	(2.76)	***	0.056	(1.13)		-0.123	(-1.96)	*
t+2	0.043	(1.76)	*	0.043	(1.81)	*	-0.035	(-0.79)		-0.151	(-1.68)	*
t+3	0.050	(2.08)	**	0.082	(3.37)	***	0.078	(1.74)	*	-0.210	(-1.89)	*
ln(Hours)	0.099	(1.03)		0.11	(0.88)		0.636	(2.65)	***	0.570	(1.67)	*
ln(Worker)	0.008	(0.62)		0.013	(0.94)		-0.033	(-1.01)		0.073	(1.79)	*
Const.	2.571	(9.77)	***	2.631	(7.93)	***	0.981	(1.57)		0.651	(0.72)	
Plant FE	Yes			Yes			Yes			Yes		
Year FE	Yes			Yes			Yes			Yes		
Area and year FE	Yes			Yes			Yes			Yes		
Number of obs.	991			777			602			238		
Number of groups	139			130			131			91		
R^2 within	0.700			0.777			0.587			0.761		
between	0.017			0.209			0.022			0.078		
overall	0.380			0.563			0.197			0.240		

Note: *** Statistically significant at 1% lebvel.

** Statistically significanr at 5% level.

* Statistically significant at 1% level.

Standard errors are clustered at the plant level.