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Complementarity between Mechanization and Human Capital: How Did Machines and Educated White-Collar Workers Enhance Labor Productivity in Prewar Japanese Coal Mines?

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Complementarity between mechanization and human capital: How did machines and educated white-collar workers enhance labor productivity in prewar Japanese coal mines ?

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Abstract

This paper investigates how mechanization, white-collar human capital, and the complementarity between them led to an improvement in the labor productivity of blue-collar workers. We estimated production functions that included interaction terms between variables representing the intensity of physical capital and white-collar human capital, using detailed mine-level panel data from the coal mining industry in prewar Japan. We found that mechanization and white-collar human capital were indeed complementary. That is, in the mines where mechanization proceeded, and only in those mines, the higher the education level of white-collar workers was, the larger was the impact on the labor productivity of blue-collar workers.

Key words: Human capital, Skill, Mechanization, Complementarity, Productivity, White-collar, Coal mining, Japan

JEL classification numbers: D22, D24, J24, L25, L72, N35, N55, O33

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1. Introduction

The relationship between technology and skills or human capital has attracted the interest of economists and economic historians since the days of classical economics (Smith 1776; Ricardo 1821; Marx 1867). Recently, progress in new technologies, such as information and communication technology and artificial intelligence, has aroused new interest in this topic.

In the context of economic history, Goldin and Katz (1998) examine the relationship between indices of technology (capital intensity and purchased electricity use) and proxies for worker skills (education levels, occupation mix, and wages) using industry-level data for manufacturing industries in the United States (US) during 1909–1940. They find that technological progress was positively associated with the education levels of blue-collar workers, the proportion of white-collar workers, and wage levels, and conclude that a technology–skill complementarity existed in the US in the early twentieth century. Using plant-level data on manufacturing industries, Atack et al. (2004) find that a positive association between capital intensity and wages already existed in the US in the late nineteenth century. The view that technological change increased the demand for skilled jobs in the US in the late nineteenth century is confirmed by Katz and Margo (2014). Turning to Europe, Van Lottum and Van Zanden (2014) find that the human capital levels of crews engaged in intra-European marine shipping had a positive effect on labor productivity. They argue that this positive effect arose because shipping was a high-tech industry. Furthermore, Feldman and Van der Beek (2016) show that inventions in the British industrial revolution increased the demand for apprenticeships.

In discussing the technologies that existed until the twentieth century, many recent studies criticize the conventional view that technological progress had a deskilling effect—that is, that it resulted in skilled workers being substituted with unskilled workers—and claim that there is complementarity between technology and human capital. As evidence of this complementarity, most recent studies present the wages of skilled workers and the proportion of skilled workers in relation to total workers. This paper takes a different, more direct approach. That is, we examine whether technology and human capital contributed to productivity in a complementary manner by estimating a production function using unique data from the coal mining industry in Japan before World War II.

Focusing on the Japanese coal mining industry in this period has a number of advantages in the context of this paper. First, as we will see below, this industry experienced a substantial technological change centered on mechanization and was faced, with a sharp rise in wages and subsequently with intensified international competition. Second, the production process as well as the product was simple, which enables us to precisely measure productivity. Third, detailed mine-level panel data on production, horsepower of engines, the number of blue-collar workers and the number of white-collar workers by education level are available. Using these data, we can estimate a production function that allows for possible complementarity between mechanization and the human capital of white-collar workers. Finally, we can utilize historical studies and detailed descriptive materials in interpreting the results.

The remainder of the paper is organized as follows. Section 2 describes the historical background of the Japanese coal mining industry. Section 3 presents the data and descriptive analyses. Section 4 presents the regression analyses. Section 5 discusses the interpretation of the results, and Section 6 concludes the paper.

2. Development of the coal mining industry in Japan

Today, Japan is known as a natural resource-scarce country, but it possessed large endowments of coal during the late nineteenth and early twentieth centuries. During this period, Japan was labor-rich and capital-scarce, which gave it a comparative advantage in the labor-intensive coal mining industry. Therefore, coal was one of the major export goods from Japan, in addition to raw silk and fabrics. As steam power diffused into the manufacturing industries and thermal power generation developed, the domestic demand for coal rapidly increased. Japan's coal production increased to the extent that it was able not only to satisfy domestic demand, but also to export a substantial volume of coal (Figure 1).

Figure 1

World War I was a turning point for the Japanese coal mining industry, as well as for other labor-intensive industries. Under the stimulus the war provided to economic activity, nominal wages increased sharply. Indeed, the average wage of male coal mine workers in 1919 was 2.59 times higher than that in 1914, and the wage remained rigid against downward pressure after World War I. Although the Japanese economy faced a long depression and deflation from 1920, nominal wages remained stable and real wages increased substantially (Figure 2).

Figure 2

The coal mining industry experienced a decline in prices driven not only by deflation at the macro level but also by an increase in supply from China. During World War I, based on a large balance of payments surplus, Japan exported capital to China, especially Manchuria, the north east part of China, largely through the channel of the South Manchurian Railways Company (SMRC), a semi-public company (Kaneko 1985, pp. 352–355, 369–370). In this period, the SMRC expanded investment in coal mining (Fushun mine) and steel making (Anshan iron works) in Manchuria, in addition to investing in railways. Coal production at the Fushun mine, which was 1.47 million tons in 1912, had increased to 2.77 million tons by 1921 (SMRC 1937, pp. 368–369). Initially, the coal produced by the SMRC was used principally for its own railways or sold in local markets. However, as production at Fushun increased, a substantial volume of coal was exported to Japan, which is reflected in the increase in Japan's imports shown in Figure 1 (SMRC 1937, pp. 450–451).

A sharp increase in the nominal wage and the competition with imported coal from Manchuria pushed the Japanese coal mining firms to improve productivity. There was a particular focus on labor productivity and it is well documented that labor-saving technologies were introduced extensively by the coal mining firms after World War I. These labor-saving technologies included long-wall mining, coal blasting, and mechanization of underground haulage and mining (Kasuga 1980; Kozan Konwakai 1932; Makita 1932; Morimoto 2013; Nishinarita 1985; Ogino 1993; Oki 1960).

It is not easy to obtain nationwide quantitative data on the diffusion of these technologies for our study period. The Ministry of Commerce and Industry published data on the number of coal mining machines in its yearly issues of *Honpo Kogyo no Susei* (*Mining Yearbook of Japan*). However, these data are only available from 1932 onward. Hence, we estimate the number of machines before that based on the data for 1932 and the number of new installments in each year and the removal rate (the number of removals/the number of machines in the previous year). We can obtain the number of new installments for each year from *Honpo Kogyo no Susei* and Kozan Konwakai (1932). The removal rate was calculated from the number of machines in 1932 and 1933, and the number of new installments in 1933[1]. We focus on coal cutters and coal drills. A coal cutter is a machine to cut the bottom of a coal bed to collapse it, whereas a coal drill is a machine to make holes in a coal bed to insert explosives (Kasuga 1980).

Figure 3 shows the estimated numbers of coal cutters and coal drills divided by the number of workers. We find that the machine–labor ratio increased sharply in the

[1] The annual removal rates of coal cutters and coal drills used for estimation were 0.0791 and 0.1327, respectively.

1920s, especially for coal cutters. Labor productivity also increased sharply (Figure 4). The literature claims that the diffusion of new technologies contributed to the increase in labor productivity (Figure 3). In the next section, we investigate the impact of the technological change on labor productivity and the role of human capital in the technological change.

Figures 3 and 4

3. Data and descriptive analyses

To conduct our analyses, we use mine-level panel data from Fukuoka Prefecture, which is located in the southwest of Japan (Figure 5) and was the largest coal mining district in Japan in the prewar period. Figure 6 shows the coal production in Fukuoka Prefecture and its share in Japan's total production; it produced more than 50% of Japan's coal from the 1910s to the 1930s. Detailed and comprehensive mine-level data on inputs in coal mines are available for Fukuoka from 1917 to 1935 in various issues of *Fukuoka Ken Tokeisho* (*Statistical Yearbook of Fukuoka Prefecture*), edited by the prefecture office. The data include the name of the mine and the company, location, foundation year, horsepower of engines, number of workers by gender, yearly working days, daily working hours, and the number of white-collar workers by educational background. The data are unique in that they provide information on the quantity and quality of white-collar human capital by formal schooling qualifications at the mine level. Furthermore, the information on the working days and working hours enables us to precisely measure labor productivity.

Figures 5 and 6

One problem is that coal production data are not available in *Fukuoka Ken Tokeisho*. Hence, we obtain the mine-level coal production data from various issues of *Honpo Kogyo no Susei* (*Mining Yearbook of Japan*), edited by the Ministry of Commerce and Industry (known as the Ministry of Agriculture and Commerce before 1925). We match the data using the mine name and the location. As the 1922 issue of *Honpo Kogyo no Susei* was not published, our data set incudes 18 data points from 1917 to 1935, excluding 1922.

Panel A of Table 1 presents the basic statistics of the data. In total, we have 1,149 mine-year observations[2]. The variable WORKER is the number of blue-collar workers,

[2] We omitted one observation for the Hojuyama mine for 1935, as the engine horsepower

including male and female workers. The mean of the number of male workers is 805, whereas that of female workers is 284. ADWORKER is the sum of the number of male workers and the number of female workers converted to the equivalent number of male workers by the male–female wage ratio. The wages paid to male and female workers at coal mines are obtained from the Committee for Historical Materials on Labor Movement (1959) for 1926–1935, and we assume that the 1926 ratio applies to the years prior. WORKERHOURS represents the total hours worked by blue-collar workers. It is the product of ADWORKER, yearly working days and daily working hours. For the mines where daily working hours were 14 hours or longer, we divide the daily working hours by two, on the assumption that a two-shift system operated. HORSEPOWER is the total horsepower of engines. Using the ratio of HORSEPOWER to ADWORKER, we measure the capital intensity (CINTENSITY) of a mine. LP is PRODUCTION divided by WORKHOURS, which represents labor productivity.

Table 1

Fukuoka Ken Tokeisho classifies white-collar workers by their educational backgrounds. Up to 1925, the classifications divided workers into university graduates (with bachelor degrees), high school graduates, middle school graduates, and others. From 1926, the categories were university graduates, professional school graduates, middle school graduates, and others. In this period, the education system had three tiers (Ministry of Education 1972, Appendix). The primary tier consisted of elementary schools, which provided six years of schooling. The secondary tier consisted of middle schools, which provided five years of schooling, and vocational schools. The tertiary tier consisted of high schools, universities, and professional schools. Some middle school graduates entered high school for three years and then proceeded to university for another three years of schooling. Other middle school graduates entered professional schools, which also provided three years of schooling. The variables TERTIARYEDU, SECONDARYEDU, and PRIMARYEDU represent the number of white-collar workers with tertiary, secondary, and other educational backgrounds, respectively. Finally, TERTIARYRATIO, SECONDARYRATIO, and PRIMARYRATIO are the ratios of TERTIARYEDU, SECONDARYEDU, and PRIMARYEDU to ADWORKER, respectively.

To examine the intertemporal changes in these variables, Panel B and Panel C of Table 1 divide the basic statistics into two subperiods, i.e., 1917–1925 and 1926–1935.

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and the horsepower worker ratio were extraordinarily high compared with data for the same mine in the previous year and with data for other mines in the same year.

Although the mean labor input did not change substantially in terms of the number of workers, the mean coal production increased, indicating that labor productivity increased. At the same time, CINTENSITY became 2.27 times larger, which indicates progress in mechanization. Notably, human capital also substantially increased. The mean number of white-collar workers with tertiary and secondary educational qualifications increased 1.67 times (10.695/6.413) and 1.27 times (17.104/13.481), respectively. A similar change is observed for TERTIARYRATIO and SECONDARYRATIO. We can confirm that mechanization and human capital investment advanced simultaneously in the Japanese coal mining industry in the 1920s and 1930s.

4. Regression analyses

In this section, we present our regression analyses using the data described in the previous section to investigate the impact of mechanization and human capital on labor productivity. We assume the following production function:

$$Y/L = A(K/L)^{\alpha} (H_T/L)^{\beta_1} (H_S/L)^{\beta_2} (H_P/L)^{\beta_3},$$

where Y, K, L, and A represent output, physical capital, the labor of blue-collar workers, and total factor productivity, respectively, and H_T, H_S, and H_P are the human capital levels of white-collar workers who completed tertiary, secondary, and primary school educational qualifications, respectively. From this, we derive the following baseline empirical model:

$$\ln(LP_{it}) = \text{Constant} + \alpha\ln(\text{CINTENCITY}_{it} + 1) + \beta_1\ln(\text{TERTIARYRATIO}_{it} + 1) + \beta_2\ln(\text{SECONDARYRATIO}_{it} + 1) + \beta_3\ln(\text{PRIMARYRATIO}_{it} + 1) + \gamma_r + \delta_t + e_{it},$$

where γ and δ represent county and year fixed effects, respectively. We first estimate this equation using ordinary least squares (OLS). The estimation results are reported in Table 2. Column 1 shows the results when we use only physical capital intensity, i.e., the mechanization variable, on the right-hand side. Not surprisingly, the results indicate that mechanization had a significantly positive impact on labor productivity. In column 2, the human capital variables are added. We find that the mechanization variable and all the human capital variables have positive and significant coefficients. The coefficient on ln(CINTENSITY + 1), 0.181, indicates that a one standard error difference in capital intensity translates to a 0.227 standard error difference in ln(LP). Regarding the human capital variable, it is notable that the magnitude of the coefficients increases as the education level increases; i.e., the coefficient is highest for the tertiary education level, followed by the secondary, and then the primary education level, which suggests that the quantity and quality of human capital are associated with the education level.

Table 2

In column 3, we allow the impact of human capital to depend upon the extent of mechanization. That is, we divide the samples into the high and low capital intensity groups at the median value of CINTENSITY, and interact the human capital variables with dummy variables HCI and LCI, which represent the high and low capital intensity groups, respectively. We find that tertiary education had a positive impact on labor productivity but that it is significant only for the high capital intensity group. Furthermore, the magnitude of the positive impact was much larger for the high capital intensity group. Concerning secondary education, the coefficients on human capital are positive for both the high and low capital intensity groups, but they are insignificant or weakly significant. A difference is observed in the coefficients between the high and low capital intensity groups for secondary education, but the difference is substantially smaller than that for tertiary education. For primary education, the coefficients on human capital are significantly positive for both the high and low capital intensity groups. Notably, the magnitude of the coefficients is almost the same for the high and low capital intensity groups in this case. These results suggest that the value of higher education was enhanced by the mechanization process but that there was no association between mechanization and the value of primary education.

It is possible that the attributes of mines affected mechanization, human capital investment, and labor productivity, at the same time. To address this concern, we estimate a fixed effect model with mine fixed effects. The estimation results are presented in Table 3. The results in columns 1 and 2 are qualitatively the same as their counterparts in Table 2. Regarding the case in which we divided the sample into high and low capital intensity groups, the results from the fixed effects model are much clearer. For tertiary and secondary education, human capital has a positive and significant effect on labor productivity only for the high capital intensity group. For the low capital intensity group, the effect of human capital is positive but not significant, and the magnitude is substantially lower than that for the high capital intensity group. For primary education, human capital had a significantly positive effect on labor productivity for both the high and low capital intensity groups. Furthermore, the magnitude of the positive impact was the same for the high and low capital intensity groups. These results from the fixed effect estimation indicate that there was complementarity between mechanization and human capital, and that the complementarity was larger for higher levels of education.

Table 3

So far, in measuring labor productivity, we have assumed that the quality of coal was the same across mines. As a robustness check, we take coal quality differences into account by measuring labor productivity using the yen value of coal (VALUE). LPV is the value of coal divided by WORKERHOURS. We run the same OLS and fixed effect regressions using ln(LPV) as the dependent variable. The results of the OLS estimation, presented in Table 4, are similar to the results in Table 2, except that the impact on secondary education is weaker and the R-squared value is higher. For the fixed effect estimation (Table 5), the impact on secondary education is more significant and the R-squared value is higher. Generally, the results confirm that the main findings on the impact of mechanization, human capital, and their complementarity are robust regardless of the labor productivity measures used.

Tables 4 and 5

5. Discussion

What are the sources of the complementarity that we have found between mechanization and human capital? A straightforward explanation is that educated engineers were required to effectively operate the machines. Junjiro Nagazumi, a professor of engineering at Kyushu Imperial University, explained this as follows: “The only ways to save workers at coal mines are (1) mechanization of coal mining, (2) improvement of surface equipment, and (3) concentration of auxiliary equipment. For (1), they need to study many issues such as choosing machines, checking their applicability, and testing efficiency, for which engineers in place are responsible. Because (2) and (3) include design and planning of mechanization, the head of the engineering section should take charge” (Nagazumi 1931). Nagazumi’s article was published in the monthly bulletin of the mining association of Chikuho district, one of four districts of Fukuoka Prefecture and the one with the largest agglomeration of coal mines.

The case of the Tagawa coal mine, one of the largest coal mines in Chikuho district, illustrates the importance of engineers in ensuring the effective use of machines. The

Tagawa coal mine first introduced a coal cutter in 1915, but it did not work because it did not fit the features of the coal bed. The coal cutter was regarded as an obstacle until finally, in 1923, the introduction of an operational procedure enabled the cutter to fit the features of the coal bed and made cutters practical. Tagawa then began to train workers to specialize in machine operations, which would have been a role for engineers (Mitsui Mining Co. 1944, vol.3, p.26).

Mechanization also increased the role of white-collar workers (including engineers and administrative clerks) through another channel (Morimoto 2013). Before mechanization, coal mining depended heavily on the skills of individual workers, and mining works were decentralized to their discretions. Hence, a firm did not directly manage mining works and workers and it entrusted the management of workers to external intermediate managers[3]. However, mechanization enabled a firm to monitor workers and manage mining works. Consequently, coal mining firms introduced direct management of mining works and workers, eliminating the outside intermediate managers. Under the new system of direct management, the white-collar workers of the mining firms were the managers of mining works and workers. Thus, this was another source of the complementarity between mechanization and human capital.

6. Concluding remarks

Facing a rise in wages and intensified international competition in the product market, Japanese coal mining firms increased mechanization of mines in earnest after World War I. Machines such as coal cutters and coal drills were installed, and long-wall mining and coal blasting were adopted. At the same time, coal mining firms hired more white-collar workers with formal educational qualifications. In this paper, we investigated how mechanization, white-collar human capital, and the complementarity between them led to an improvement in the labor productivity of blue-collar workers. Specifically, we estimated production functions that included interaction terms between variables representing the intensity of physical capital and white-collar human capital, using detailed mine-level panel data from the coal mining industry in prewar Japan. We found that mechanization and white-collar human capital were indeed complementary. That is, in the mines where mechanization proceeded, and only in those mines, the higher the education level of white-collar workers was, the larger was the impact on the labor productivity of blue-collar workers.

[3] These managers were referred to as *naya-gashira* and *sewa-gata,* which, translated literally, mean the boss of a miners' shack and a person taking care of miners, respectively.

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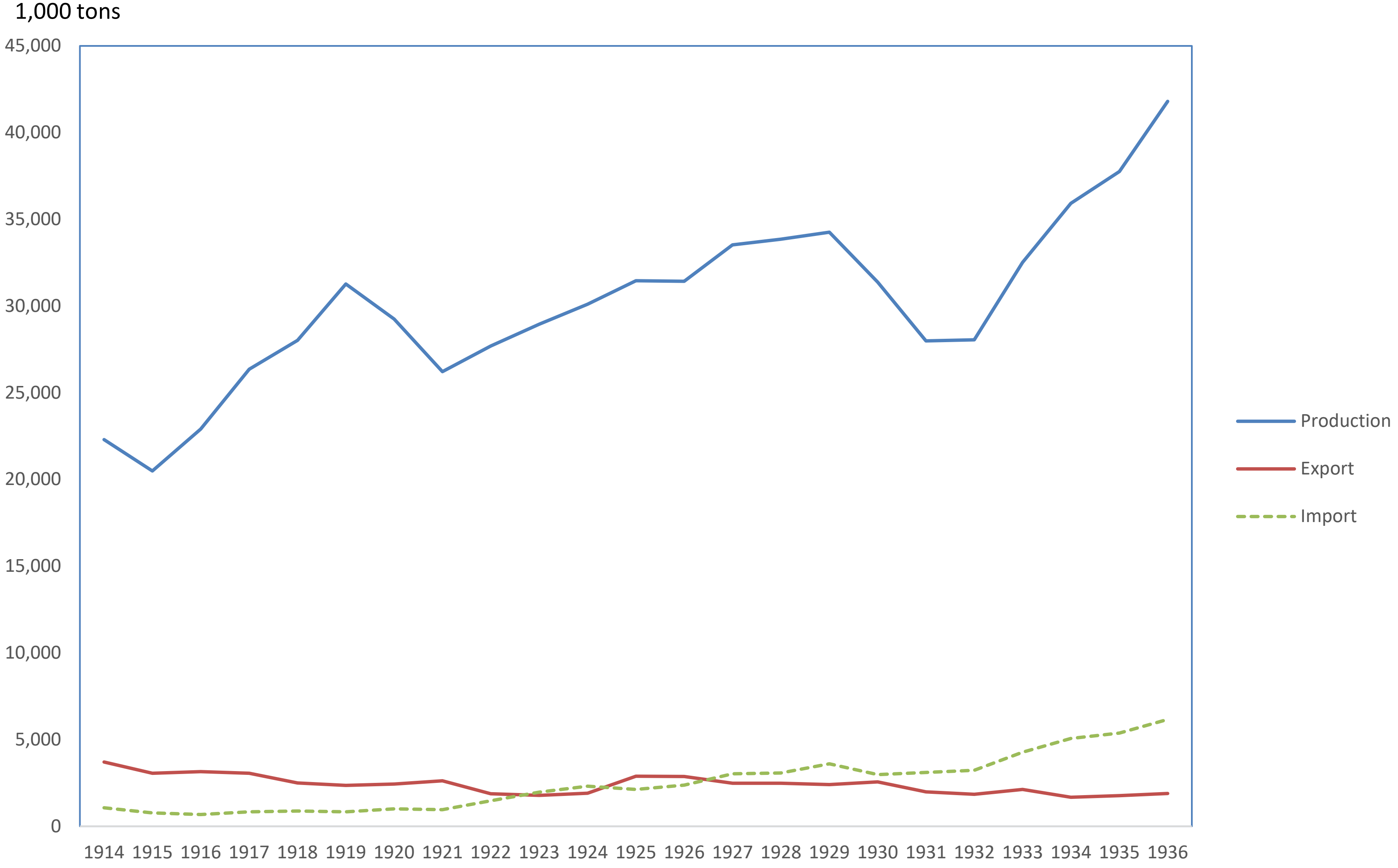
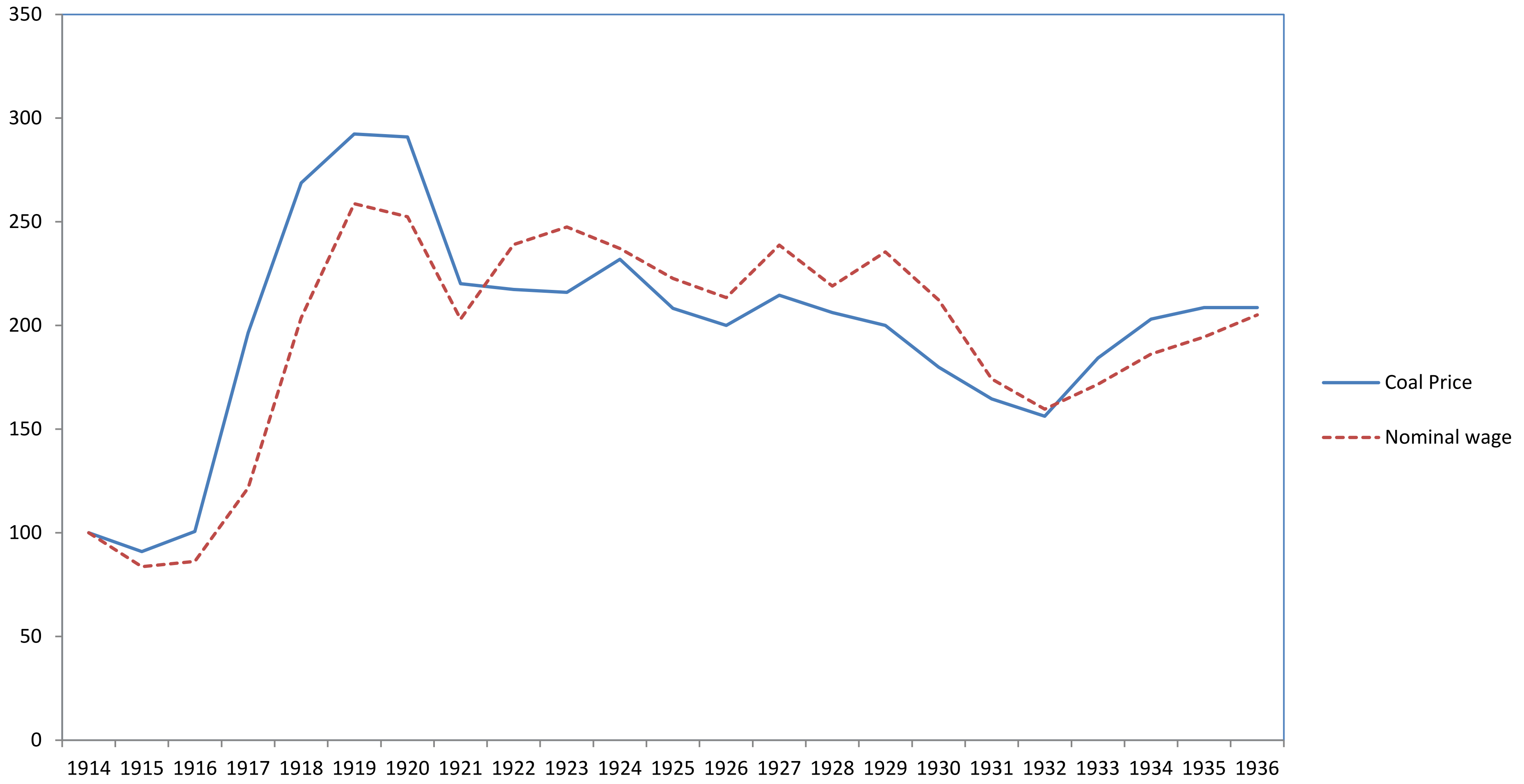
Figure 1 Development of the coal mining industry in Japan



Source: Ministry of International Trade and Industry (1959); Shimano (1980), p.54.

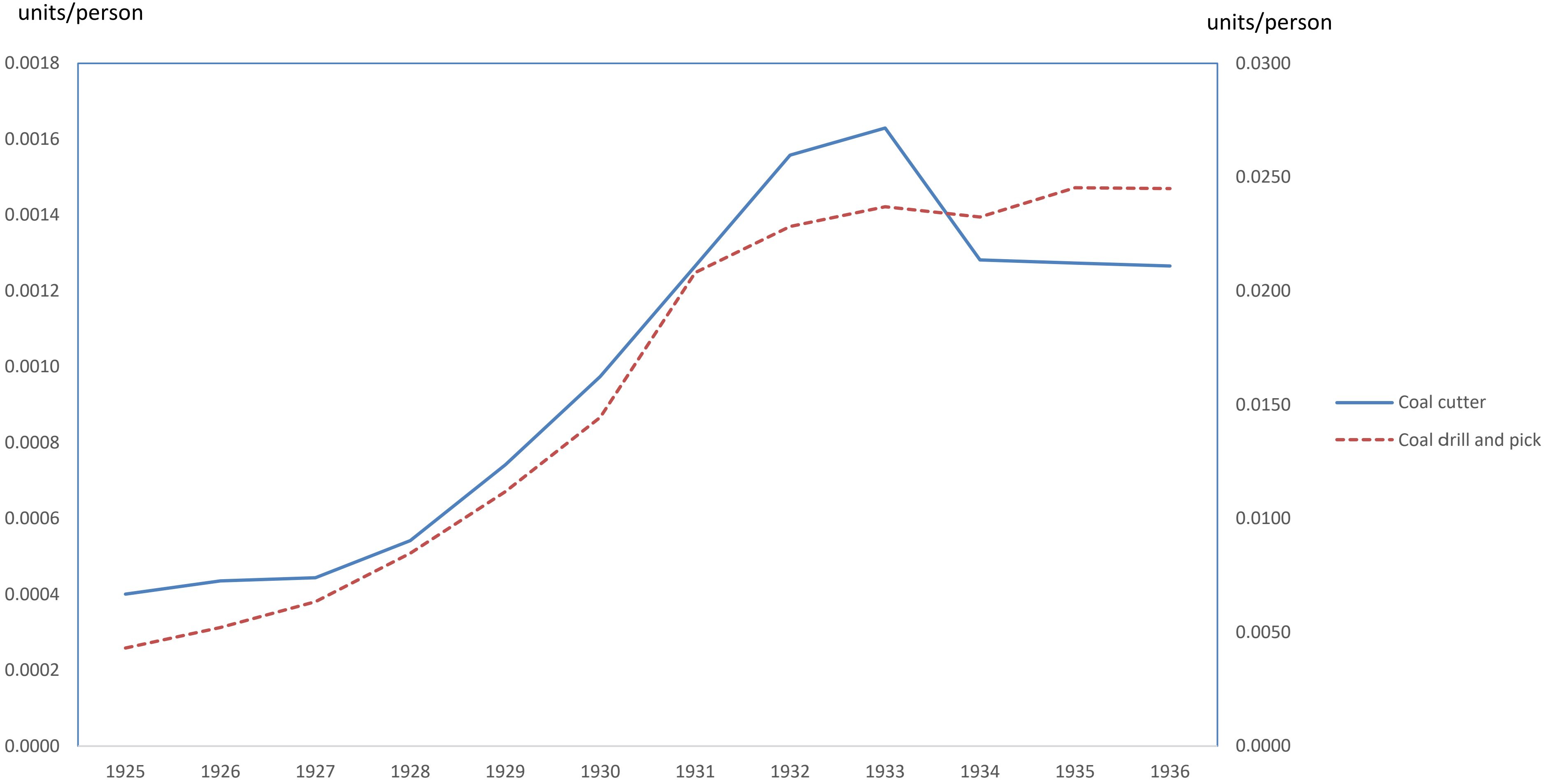
Figure 2 Coal price and wage of coal mining workers (1914=100)



Source: Committee for Historical Materials on Labor Movement ed. (1959), p.348; Ogino (1993), p.161, 305; Bank of Japan (1964), p.123, p.171.

Note: Because the national average of coal mining wages is available from 1926, we linked it with the series of the average wage at Sugamuta Mine and Onoura Mine before that.

Figure 3 Mechanization of coal mining



Source: Trend of the Japanese Mining Industry, various issues; Makita (1932), pp.1561-1563.
Note: The numbers of machine units at the end of the year are taken from Trend of the Japanese Mining Industry for 1932-1936. The data before that are calclated from the data for 1932, increases in each year, and sacapping in each year. Scrapping rates of coal cutter (0.0791) and coal drill (0.1327) are calclated from the data for 1932 and 1933.

Figure 4 Increase in labor productivity

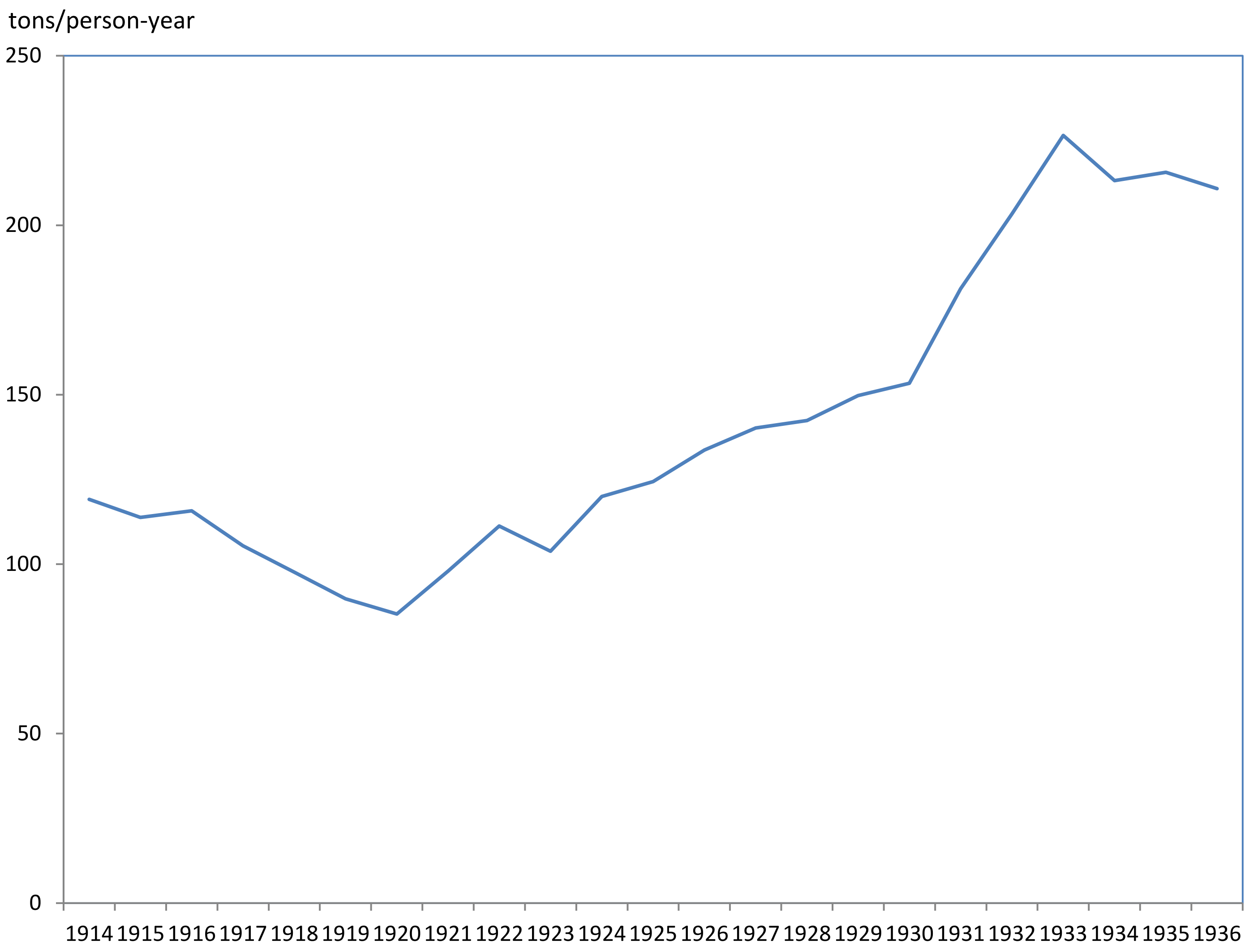
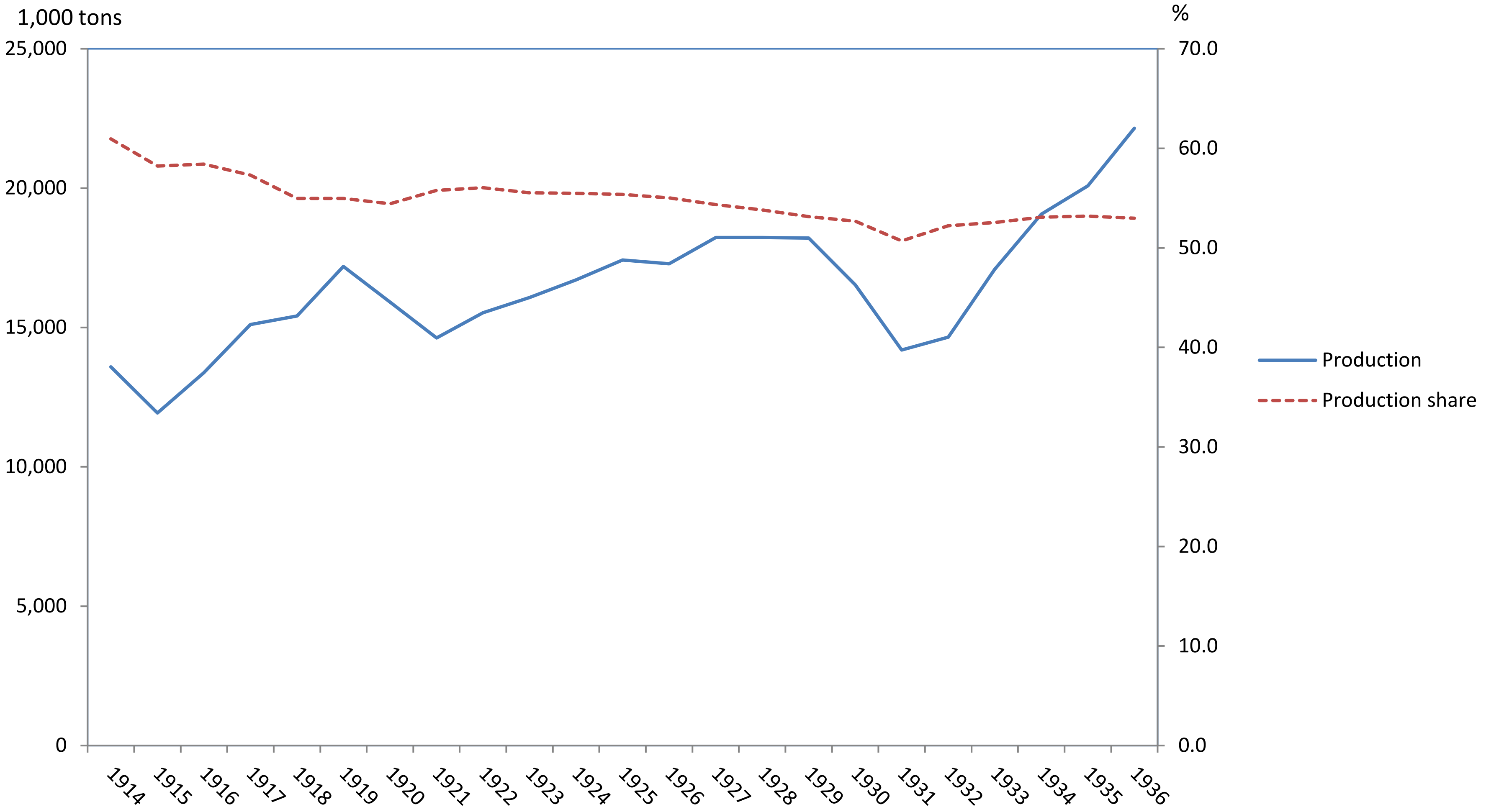


Figure 5 Map of Japan

Figure 6 Coal production and production share of Fukuoka Prefecture



Source: Society of Mining ed. (1932) pp.175-177; Various issues of *Honpo Kogyo no Susei*.

Table 1 Basic statistics

A. 1917–1935

Variable	unit	Obs	Mean	Std. Dev.	Min.	Max.
PRODUCTION	tons	1,149	228,583	326,951	10,124	2,810,529
VALUE	yen	1,149	1,866,078	3,167,163	36,490	35,306,376
WORKER	persons	1,149	1,089	1,129	9	8,481
ADWORKER	persons	1,149	978	1,028	7	8,442
WORK|HOURS	manhour	1,149	3,120,868	3,451,407	16,700	36,100,000
WORKHOURS	hoursepower	1,149	4,091	8,360	0	87,585
CINTENSITY	horsepower/person	1,149	3.596	5.891	0.000	113.305
ln(CINTENSITY+1)		1,149	1.206	0.723	0.000	4.739
LP	tons/manhour	1,149	0.077	0.095	0.005	1.798
ln(LP)		1,149	−2.776	0.576	−5.210	0.586
LPV		1,149	0.571	0.701	0.367	12.139
ln(LPV)		1,149	−0.839	0.682	−3.305	2.496
TERTIARYEDU	persons	1,149	8.735	15.790	0.000	106.000
SECONDARYEDU	persons	1,149	15.446	22.102	0.000	196.000
PRIMARYEDU	persons	1,149	69.347	80.753	0.000	537.000
TERTIARYRATIO		1,149	0.007	0.010	0.000	0.153
SECONDARYRATIO		1,149	0.016	0.017	0.000	0.193
PRIMARRATIO		1,149	0.078	0.044	0.000	0.547
ln(TERTIARYRATIO+1)		1,149	0.007	0.010	0.000	0.143
ln(SECONDARYRATIO+1)		1,149	0.015	0.016	0.000	0.177
ln(PRIMARYRATIO+1)		1,149	0.075	0.040	0.000	0.437

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WORK|HOURS	manhour	1,149	3,120,868	3,451,407	16,700	36,100,000
WORKHOURS	hoursepower	1,149	4,091	8,360	0	87,585
CINTENSITY	horsepower/person	1,149	3.596	5.891	0.000	113.305
ln(CINTENSITY+1)		1,149	1.206	0.723	0.000	4.739
LP	tons/manhour	1,149	0.077	0.095	0.005	1.798
ln(LP)		1,149	−2.776	0.576	−5.210	0.586
LPV		1,149	0.571	0.701	0.367	12.139
ln(LPV)		1,149	−0.839	0.682	−3.305	2.496
TERTIARYEDU	persons	1,149	8.735	15.790	0.000	106.000
SECONDARYEDU	persons	1,149	15.446	22.102	0.000	196.000
PRIMARYEDU	persons	1,149	69.347	80.753	0.000	537.000
TERTIARYRATIO		1,149	0.007	0.010	0.000	0.153
SECONDARYRATIO		1,149	0.016	0.017	0.000	0.193
PRIMARRATIO		1,149	0.078	0.044	0.000	0.547
ln(TERTIARYRATIO+1)		1,149	0.007	0.010	0.000	0.143
ln(SECONDARYRATIO+1)		1,149	0.015	0.016	0.000	0.177
ln(PRIMARYRATIO+1)		1,149	0.075	0.040	0.000	0.437

B.1917–1925

Variable	unit	Obs	Mean	Std. Dev.	Min	Max
PRODUCTION	tons	526	194,031	275,065	10,159	1,970,266
VALUE	yen	526	1,941,608	3,339,930	36,563	35,306,376
WORKER	persons	526	1,089	1,153	32	6,606
ADWORKER	persons	526	953	1,014	26	5,768
WORK|HOURS	manhour	526	3,080,247	3,308,327	63,346	19,000,000
WORKHOURS	hoursepower	526	2,582	6,000	0	82,876
CINTENSITY	horsepower/person	526	2.133	2.965	0.000	39.886
ln(CINTENSITY+1)		526	0.930	0.589	0.000	3.711
LP	tons/manhour	526	0.066	0.053	0.007	0.452
ln(LP)		526	−2.899	0.559	−4.915	−0.794
LPV		526	0.603	0.543	0.0409	5.1512
ln(LPV)		526	−0.750	0.678	−3.198	1.639
TERTIARYEDU	persons	526	6.413	12.559	0.000	92.000
SECONDARYEDU	persons	526	13.481	19.337	0.000	130.000
PRIMARYEDU	persons	526	74.865	85.905	0.000	537.000
TERTIARYRATIO		526	0.005	0.008	0.000	0.109
SECONDARYRATIO		526	0.015	0.019	0.000	0.193
PRIMARYRATIO		526	0.088	0.044	0.000	0.410
ln(TERTIARYRATIO+1)		526	0.005	0.008	0.000	0.103
ln(SECONDARYRATIO+1)		526	0.014	0.018	0.000	0.177
ln(PRIMARYRATIO+1)		526	0.083	0.039	0.000	0.343

C.1926–1935

Variable	unit	Obs	Mean	Std. Dev.	Min	Max
PRODUCTION	tons	623	257,754	362,728	10,124	2,810,529
VALUE	yen	623	1,802,308	3,014,839	36,490	25,731,438
WORKER	persons	623	1,089	1,108	9	8,481
ADWORKER	persons	623	1,000	1,040	7	8,442
WORK|HOURS	manhour	623	3,155,164	3,570,034	16,700	36,100,000
WORKHOURS	hoursepower	623	5,365	9,750	0	87,585
CINTENSITY	horsepower/person	623	4.832	7.300	0.000	113.305
ln(CINTENSITY+1)		623	1.439	0.744	0.000	4.739
LP	tons/manhour	623	0.087	0.118	0.005	1.798
ln(LP)		623	−2.672	0.570	−5.210	0.586
LPV		623	0.545	0.810	0.037	12.139
ln(LPV)		623	−0.915	0.677	−3.305	2.496
TERTIARYEDU	persons	623	10.695	17.849	0.000	106.000
SECONDARYEDU	persons	623	17.104	24.082	0.000	196.000
PRIMARYEDU	persons	623	64.689	75.890	0.000	456.000
TERTIARYRATIO		623	0.009	0.012	0.000	0.153
SECONDARYRATIO		623	0.016	0.015	0.000	0.153
PRIMARRATIO		623	0.071	0.043	0.000	0.547
ln(TERTIARYRATIO+1)		623	0.009	0.011	0.000	0.143
ln(SECONDARYRATIO+1)		623	0.016	0.014	0.000	0.143
ln(PRIMARYRATIO+1)		623	0.068	0.038	0.000	0.437

Table 2 Estination results of production function (quantity, OLS)

Dependent variable: ln(LP)						
	(1)		(2)		(3)	
ln(CINTENSITY+1)	0.251	(0.028) ***	0.181	(0.027) ***	0.145	(0.037) ***
TERTIARYRATIO			8.121	(2.077) ***		
SECONDARYRATIO			3.413	(1.561) **		
PRIMARYRATIO			3.264	(0.569) ***		
HCI × TERTIARYRATIO					9.879	(2.789) ***
LCI × TERTIARYRATIO					3.841	(3.315)
HCI × SECONDARYRATIO					4.474	(3.488)
LCI × SECONDARYRATIO					2.750	(1.483) *
HCI × PRIMARYRATIO					3.134	(0.604) ***
LCI × PRIMARYRATIO					3.194	(0.671) ***
cons.	−1.591	(0.083) ***	−1.886	(0.138) ***	−1.853	(0.148) ***
Year FE	Yes		Yes		Yes	
CountyFE	Yes		Yes		Yes	
# of obs.	1,149		1,149		1,149	
R^2	0.345		0.441		0.440	

Table 3 Estination results of production function (quantity, Fixed effect model)

Dependent variable: ln(LP)								
	(1)			(2)			(3)		
ln(CINTENSITY+1)	0.172	(0.027)	***	0.076	(0.027)	***	0.041	(0.032)	
TERTIARYRATIO				6.774	(1.601)	***			
SECONDARYRATIO				5.235	(0.909)	***			
PRIMARYRATIO				3.483	(0.373)	***			
HCI × TERTIARYRATIO							8.474	(2.084)	***
LCI × TERTIARYRATIO							2.900	(2.484)	
HCI × SECONDARYRATIO							6.697	(1.591)	***
LCI × SECONDARYRATIO							4.336	(1.069)	***
HCI × PRIMARYRATIO							3.314	(0.456)	***
LCI × PRIMARYRATIO							3.394	(0.440)	***
cons.	−0.300	(0.058)	***	−3.295	(0.059)	***	−3.248	(0.064)	***
Year FE	Yes			Yes			Yes		
# of obs.	1,149			1,149			1,149		
# of groups	150			150			150		
R^2 within	0.125			0.268			0.273		
between	0.217			0.181			0.172		
overall	0.198			0.256			0.263		

Table 4 Estination results of production function (value, OLS)

Dependent variable: ln(LPV)	(1)			(2)			(3)		
ln(CINTENSITY+1)	0.339	(0.028)	***	0.259	(0.029)	***	0.204	(0.040)	***
TERTIARYRATIO				10.711	(2.531)	***			
SECONDARYRATIO				2.670	(1.660)				
PRIMARYRATIO				2.965	(0.528)	***			
HCI×TERTIARYRATIO							12.733	(3.523)	***
LCI×TERTIARYRATIO							5.024	(3.872)	
HCI×SECONDARYRATIO							4.805	(3.913)	
LCI×SECONDARYRATIO							1.464	(1.400)	
HCI×PRIMARYRATIO							2.741	(0.620)	***
LCI×PRIMARYRATIO							2.866	(0.592)	***
cons.	0.116	(0.158)		−0.150		***	−0.103	(0..158)	
Year FE	Yes			Yes			Yes		
CountyFE	Yes			Yes			Yes		
# of obs.	1,149			1,149			1,149		
R^2	0.469			0.474			0.472		

Table 5 Estination results of production function (value, Fixed effect model)

Dependent variable: ln(LPV)	(1)			(2)			(3)		
ln(CINTENSITY+1)	0.173	(0.029)	***	0.079	(0.028)	***	0.042	(0.033)	
TERTIARYRATIO				6.601	(1.665)	***			
SECONDARYRATIO				5.035	(0.945)	***			
PRIMARYRATIO				3.499	(0.387)	***			
HCI × TERTIARYRATIO							9.106	(2.164)	***
LCI × TERTIARYRATIO							1.673	(2.580)	
HCI × SECONDARYRATIO							6.196	(1.652)	***
LCI × SECONDARYRATIO							4.203	(1.111)	***
HCI × PRIMARYRATIO							3.291	(0.473)	***
LCI × PRIMARYRATIO							3.439	(0.457)	***
cons.	−1.497	(0.062)	***	−1.788	(0.061)	***	−1.740	(0.066)	***
Year FE	Yes			Yes			Yes		
# of obs.	1,149			1,149			1,149		
# of groups	150			150			150		
R^2 within	0.300			0.405			0.410		
between	0.314			0.246			0.244		
overall	0.276			0.315			0.325		