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Abstract

The Japanese aircraft industry, which was of very small scale before World War II, became Japan's largest manufacturing industry by the end of the war. In this paper, we explore the basis for the growth of the aircraft industry during this time by focusing on the No. 5 Works of Mitsubishi Heavy Industries Co. It was revealed that during the war, the supply of basic inputs increased substantially: the labor force and "machinery parts" were in sufficient supply and neither was a binding constraint on production. The binding constraint existed in the supply of "special parts." Put differently, aircraft production expanded as the supply of special parts increased. This increase in the supply of special parts and still faster growth in the supply of machinery parts came about through the expansion of the supplier network in terms of both the number of suppliers and the geographical area in which they were located.

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1. Introduction

The Japanese aircraft industry, which was of a very small scale before World War II, became a huge industry employing 1.5 million workers by the end of the war. Such rapid growth has attracted interest since at least just after the war, and many important studies have been undertaken. Among others, the “Final Reports of the United States Strategic Bombing Survey (USSBS)” (hereafter, “Final Reports”) and *Japan’s Economy in War and Reconstruction* by Jerome B. Cohen (a member of the USSBS) discussed the structure of the Japanese war economy in detail, drawing on thorough investigations obtained through the authority of the postwar occupation forces. Both studies are still worth referring to as providing the basic literature on the Japanese war economy, including the aircraft industry.

One of the most important contributions of the former is that it initially presented the view that aircraft production in Japan depended on parts supply from numerous small-sized suppliers. For instance, the report states that, “...a considerable percentage of airframe and engine subassembly manufacturing was let out to subcontractors, a high percentage of parts came from a large network of sub-subcontractors,” and “shops scattered throughout the industrial areas supplied the thousands of bits and pieces that made up the finished aircraft.”¹ Many subsequent studies on the Japanese war economy have accepted and extended this viewpoint. For example, in an article focusing on the policy of the Japanese government and the military authorities, Shiro Yamazaki detailed the percentage of parts let out to the outside suppliers and discussed the problems in managing these suppliers, using documents from the Administration Inspection Mission, which inspected Nakajima Aircraft in September and October 1943.²

Hirofumi Ueda analyzed the lists of “cooperative factories,” and concluded that, despite government policy to strengthen and put in order the relationships between assemblers and suppliers, the relationships were discontinuous and in a mess.³ Further, as the wartime aircraft industry was pioneering the mass production system in Japan, there are many other studies on the aircraft industry from the standpoint of production management. This literature, including research by Yasutaka Takahashi, Kazuo Wada, Satoshi Sasaki, Yuko Maeda, and Masanao Kasai,⁴ has also focused on parts suppliers as the basis of the mass production system. The key implication is that wartime production in Japan comprised an extensive division of work between firms and outsourcing. This is important because recent work revealed that this feature was not unique to Japan. For example, a recent work by Lutz Budrass and coauthors found that labor productivity increased substantially during World War II and that it was mainly because of outsourcing combined with learning-by-doing⁵.

However, in the context of Japan, much still remains unexplored. One interesting area is the function of the supplier networks. A shortcoming of the existing literature is that it heavily relies on documents associated with the Administration Inspection Mission in September and October 1943. Hence, the information concentrates on what the members of the mission observed during these particular months. It is then desirable to examine the function of supplier networks

¹ USSBS, “Final Reports,” Aircraft Division, p. 23. Similar findings are found in Cohen’s study (p. 221). Toyo Keizai Shinposha eds., *Showa Sangyoshi* also writes, “As the aircraft industry was a highly synthetic industry and it was requested a sharp production increase in a short period, each aircraft firm rapidly increased to the extent let out to the outside suppliers, while expanding its own equipment” (p. 620).

² Yamazaki, “Taiheiyo Senso Kohanki.”

³ Ueda, *Senjiki*.

⁴ Takahashi, *Nakajima Hikoki*; Wada, “Nihon”; Sasaki, *Kagakuteki Kanri*; Maeda, *Senjiki*; Kasai, “Senjika”

⁵ Budrass et al., “Fixed Price.”

from a longer term as well as a quantitative perspective. Fortunately, the archives of the Nagoya Aircraft Works of Mitsubishi Heavy Industry Co. hold documents that were prepared for the USSBS immediately after the war. These documents provide rich information on aircraft production and the parts supply of Nagoya Aircraft Works from 1939 to 1945, information not fully utilized by the “Final Reports” of the USSBS. In this paper, we examine the expansion of the supplier network, the parts supply from the network, and the relationship between the parts supply and aircraft production in wartime Japan by focusing on the Nagoya Aircraft Works of Mitsubishi Heavy Industries.

The paper is organized as follows. Section 2 provides an overview of aircraft production and the relevant policies of the Japanese government and the military authorities during the war. Section 3 describes the expansion of Nagoya Works and its supplier network. In Section 4, we analyze the relationship between the parts supply and aircraft production. Section 5 concludes the paper.

2. Expansion of the aircraft industry

As shown in Figure 1, one of the remarkable features of the Japanese economy during World War II is the rapid growth of the machinery industry. As the Census of Manufactures is not available after 1943, we estimated the number of employees in the machinery industry and in the manufacturing industry as a whole for 1943 and 1944 using the manufacturing production index compiled by the Ministry of International Trade and Industry (MITI) after the war. According to our estimates, employment in the manufacturing industry in 1944 was about 2.5 million, five times larger than in 1936 when the war with China began. Consequently, the machinery industry came to be the largest sector of all manufacturing industries. Indeed, as shown in Figure 1, its share of manufacturing industry employment rose from 18.0% in 1936 to 54.1% in 1944.

Figure 1 here

This rapid growth of the machinery industry mainly reflects the expansion of the aircraft industry. Table 1 provides the estimated production share of the aircraft industry. We estimated the production of the aircraft industry using the data on airframe and engine production in the “Final Reports” of the USSBS and unit price data from Mitsubishi Heavy Industries Co. We extrapolated the production of the machinery industry in 1943 and 1944 using the MITI manufacturing production index and the Bank of Japan’s wholesale price index. According to Table 1, the share of manufacturing industry production held by the aircraft industry increased from 8.2% in 1941 to 33.9% in 1944. It is also notable that the production share of the aircraft industry increased sharply in an industry that, at the time, was also exhibiting rapid growth.

Table 1 here

Until the early 1930s, the Japanese aircraft industry was very small, annually producing only 100–200 planes. However, in 1944, the year before the end of the war, it was producing some 24,000 aircraft. Figure 2 shows the monthly time series of Japanese airframe production. We can discern several phases in this time series. First, while the increase in production was very slow until the early 1930s, it accelerated starting in 1937. Second, following the slowdown of the increase in production from 1939 to 1941, production growth again accelerated, and we can identify two further accelerations in about September 1942 and September 1943. Third, from April 1944, the increase in production again slowed, and finally from October 1944, a declining production phase began. These phases in airframe production reflect the conduct of the war and the policies of the Japanese government

and the military authorities.⁶ For the remainder of this section, we overview these production phases by focusing on these policies.

Figure 2 here

When the Sino–Japanese War broke out, the Army put into action the First and Second Munitions Mobilizations in 1937 and 1938, respectively. In these action plans, the respective targets for annual aircraft production were set at 1,533 and 2,652, while actual aircraft production in 1936 was only 305. To achieve the rapid production increase required, the Army made “The First and Second Requests for Production Capacity Expansion,” whose targets were 3,960 airframes by March 1939 and 5,460 airframes by September 1939.⁷ Then in December 1939, the Army requested aircraft producers to again expand the production capacity of airframes to 6,816 by September 1941.⁸ Meanwhile, in November 1938, the Navy requested producers to expand the production capacity of airframes to 3,024 by March 1940.⁹ The sharp increase in airframe production from 1937 shown in Figure 2 reflects these measures taken by the Japanese Army and Navy.

The year 1941 was one of the major turning points of the Japanese war economy. The outbreak of war between Germany and the Soviet Union in June 1941 substantially changed the strategic prospects for the Japanese Army. Given the weakening of the military threat from the Soviet Union to the north, the Army decided to invade the southern part of Indochina to cut off the aid route from the U.S. and the U.K. to the Chinese government. This invasion invoked a strong reaction by the U.S. and the U.K., and culminated in the freezing of Japanese oversea assets. In a situation where the probability of war with the U.S. and the U.K. was increasing, the Japanese military authorities accelerated their policy for expanding the munitions industries, particularly the aircraft industry. In September 1941, the Army determined the “Outline of the Revised Munitions Mobilization Plan,” where the target for airframe production in 1941 was set at 4,809.¹⁰ The Navy also issued instructions for the “Second Production Capacity Expansion Plan” to aircraft producers in April 1941, which aimed at expanding the production capacity of airframes to 5,412 by the end of 1942.¹¹ As shown in Figure 2, the acceleration of airframe production in 1941 reflects the broader events of that year.

The outbreak of war between Japan and the U.S. and the U.K. in December 1941 announced a new epoch in the Japanese war economy. The “Final Reports” of the USSBS states, “...the real expansion, the ‘all-out’ national effort, came during the war years, 1942 to 1944,” after highlighting the increase in aircraft production from 1936 to 1941.¹² In early 1942, the Army instructed Japanese aircraft producers to produce 6,300 aircraft in 1942, and at the conference on the munitions mobilization of the Army, the Minister of the Army, Hideki Tojo, announced that priority should be given to aircraft in the mobilization.¹³ The Navy also stressed the policy of giving

⁶ The constitution of prewar Japan included a clause stating that the Emperor directly controlled the Army and Navy. Especially after the 1930s, this clause was widely interpreted to mean that the Army and Navy were independent of the civilian government.

⁷ National Institutes for Defense Studies, *Rikugun Koku Heiki*, pp. 200–202.

⁸ *Ibid.*, p. 254.

⁹ Editorial Committee of the History of the Japan Navy Air Force ed., *Nihon Kaigun*, p. 328. The deadline was later postponed until March 1941.

¹⁰ National Institutes for Defense Studies, *Rikugun Koku Heiki*, pp. 263–265.

¹¹ Editorial Committee of the History of the Japan Navy Air Force ed., *Nihon Kaigun*, pp. 335–336.

¹² USSBS, “Final Reports,” p. 1.

¹³ National Institutes for Defense Studies, *Rikugun Koku Heiki*, p. 326.

priority to aircraft production as a result of the performance of the air force in the early stages of the war with the U.S. and the U.K., notwithstanding making up for the losses of aircraft from the Battles of the Coral Sea and Midway. In August 1942, the Navy announced the Third Production Capacity Expansion Plan to aircraft producers, which aimed at expanding the production capacity of airframes to 11,610 by March 1946.¹⁴ Meanwhile, the government determined a policy to concentrate resources on the “Five Priority Industries”: namely, iron and steel, aluminum, coal, ships and aircraft.¹⁵

However, it was not until September 1943 that an “all-out national effort” in its narrowest sense was made for aircraft production. To cope with the deteriorating war situation, the Japanese military authorities and the government placed their last hopes on the increase in aircraft production. In September 1943, the Conference in the Presence of the Emperor by the Army and Navy and the government determined “The Outline of the Future War Management,” which promoted the strategy of rapidly expanding the air force while defending the “Absolute Defense Sphere,” namely, the area inside the Chishima Islands, Ogasawara Islands, New Guinea, Java, Sumatra, and Burma. Based on this strategy, the Conference set the target for aircraft production in 1944 for the Army and Navy to be 40,000, more than double the aircraft production of 1943. To achieve this target, the government and the Army and Navy went to great efforts, including the reform of government organization.

To begin with, in September and October 1943, the Cabinet dispatched the Administration Inspection Mission headed by Ginjiro Fujiwara, the Consultant of the Cabinet and a powerful man in the business society, to major aircraft factories. This is significant in the sense that the government now started to concentrate the authorities relating to aircraft production hitherto dispersed across many ministries. The mission concluded that it was indeed possible to produce the 40,000 aircraft required, and that with appropriate measures, the production of up to 50,000 aircraft was feasible. The mission also argued that it was essential to reform the administrative system of aircraft production to remove the harmful effects of the conflict between the Army and the Navy.¹⁶

The administrative reforms advised by the Fujiwara Mission took form with the foundation of the Ministry of Munitions in November 1943. The Ministry of Munitions integrated the administrative functions for aircraft production in the Army Air Headquarters and the Naval Air Headquarters, all functions of the Planning Board, and the functions on munitions production in the Ministry of Commerce and Industry. In this sense, the Ministry of Munitions became the ministry in charge of all issues concerning munitions production and distribution. The aircraft production plan for 1944, the first plan drawn up by the Ministry of Munitions, set the aircraft production target to be 52,500, of which 27,120 aircraft were for the Army and 25,380 aircraft for the Navy.¹⁷

However, the environment of the Japanese war economy continued to deteriorate after the foundation of the Ministry of Munitions. From February 1944 to April 1944, the Army and Navy requisitioned additional ships every month, a process that damaged the production of aluminum. In June 1944, U.S. forces landed on Saipan, signifying the breaking of “The Absolute Defense Sphere.” After that, Japan continued to lose ships and abandon ship routes because of attacks by U.S. forces. From November 1944, B-29s based at Saipan conducted the strategic bombing of

¹⁴ National Institutes for Defense Studies, *Kaigun Koku*, pp. 281–282; Editorial Committee of the History of the Japan Navy Air Force ed., *Nihon Kaigun*, p. 339.

¹⁵ Hara, “Senji Tosei”; Hara “Taiheiyo Senso”; Yamazaki, “Taiheiyo Senso Ki”; Okazaki, “Nihon.”

¹⁶ Hara, “Senji Tosei”; Yamazaki, “Taiheiyo Senso”; Yamzaki, “Taiheiyo Senso Kohanki.”

¹⁷ Yamazaki, “Taiheiyo Senso Kohanki.”

Japan,¹⁸ the main targets being the aircraft industry. The strategic bombing and the associated factory evacuations provided the final assault on Japanese aircraft production, which as shown in Figure 2 had already started to decline from October 1944.¹⁹

3. Production capacity expansion of Mitsubishi Heavy Industries Co. and its supplier network

Mitsubishi Heavy Industries Co. (MHI) was one of the largest aircraft producers in wartime Japan. Mitsubishi Zaibatsu entered the aircraft industry when it founded Mitsubishi Internal Combustion Engine Co. (MICE) in Nagoya in 1920. Mitsubishi originally intended to produce aircraft and automobiles at MICE, but gradually MICE began to focus on aircraft, and in 1928 was renamed Mitsubishi Aircraft Co. In 1934, Mitsubishi Aircraft Co. and Mitsubishi Shipbuilding Co. merged to become Mitsubishi Heavy Industries Co., with Nagoya Aircraft Works (NAW) becoming the center for aircraft production.²⁰

The expansion of the aircraft industry described in the previous section greatly influenced the NAW, as both the Army and the Navy expected it to bear a substantial portion of the expansion plan and correspondingly ordered many aircraft. With respect to The First and Second Production Capacity Expansion Requests of the Army in 1938, the expectation was that MHI would produce 480 and 660 airframes of the total 3,960 and 5,460 airframes, respectively. With respect to The Third Production Capacity Expansion Request of the Army in 1939, it was expected MHI would produce 1,296 of the total 6,816 airframes. Meanwhile, with respect to The First Production Capacity Expansion Plan the Navy in 1938, MHI was to produce 900 of the 3,024 total airframes.²¹

Table 2 shows the number of airframe orders for and the production of MHI. Table 2 clearly indicates that orders from the Army and the Navy increased sharply in 1937 and again in 1938. On August 1 1937, just after the breakout of the Sino-Japanese War, the Navy instructed MHI to increase production sharply, and held a conference attended by all major aircraft producers at the NAW calling for an increase in production. The “Summary History of Nagoya Works” observes that, in response to this conference, the works began to rapidly expand production as an emergency measure.”²²

Table 2 here

The number of workers at the NAW reflected the increase in production from 1937, and equipment began to increase in 1938 when MHI received instruction from the Army and Navy to expand its production capacity (Table 3). In 1938, MHI moved the engine plant of the NAW and made it an independent establishment, Nagoya Engine Works, while the NAW became specialized in airframe production. At the same time, the airframe plant was reorganized. All of the existing airframe plants were then assigned to naval airframes, and a new plant for army airframes was constructed.²³

¹⁸ Hara, “Senji Tosei.”

¹⁹ The USSBS evaluation stated: “During the dismantling of plants and the moving and reestablishment of production lines, the loss in production was greater than that because of direct air attacks” (“Final Reports,” p. 3).

²⁰ MHI, “Mitsubishi Jukogyo,” p. 294; Maeda, “Senjiki,” pp. 50–53.

²¹ National Institutes for Defense Studies, *Rikugun Koku Heiki*, p. 202, p. 254; Editorial Committee of the History of the Japan Navy Air Force ed., *Nihon Kaigun*, pp. 335–336.

²² The page on August 1, 1937 of “Mitsubishi Kokuki Seisakujo Gaishi” (held at the

²³ MHI, *Mitsubishi Jukogyo*, p. 297.

As stated in the previous section, the Army and the Navy instructed the major aircraft producers to expand their production capacity in September 1941 and April 1941, respectively. Upon receiving these instructions, MHI newly established the Kumamoto Works for Army airframes and the Okayama Works for Naval airframes, both away from the Nagoya area.²⁴ Meanwhile, the NAW continued to expand.²⁵ By comparing the scale of the NAW at the end of 1936 and the end of 1943, we can see that it was 7.0, 11.8 and 15.9 times larger in terms of floor space, the number of employees, and the number of machine tools, respectively (Table 3).

Table 3

In December 1944, the NAW suffered from two seriously damaging incidents: a major earthquake and U.S. bombing. Given the scale of the damage, the NAW evacuated its plants to avoid any future bombing. The NAW plants were evacuated to many geographic areas, including Nagano, Toyama, Shizuoka, Shiga, Mie, and Fukui. To manage these dispersed plants, the NAW was then divided into four separate establishments, namely No. 1, No. 2, No. 5, and No. 11 Works.²⁶

An increase of parts supply should accompany the expansion of airframe production capacity. While the Nagoya Engine Works inside MHI supplied the engines, the most important part of an aircraft so to speak, the NAW relied on a number of outside suppliers for the various other aircraft parts.²⁷ For instance, the “Final Reports” on the USSBS details that MHI let out 32% of its work on aircraft production to subcontractors.²⁸ The NAW undertook some efforts to find and manage its subcontractors when the expansion of production capacity began. For example, the “Chronological Table of the Factory” prepared by the NAW²⁹ details “As the need to utilize subcontractors became more and more immediate, we set up a branch office with stationed staff in Osaka, in order to find subcontractors and then supervise their work. Afterwards, we also stationed staff in Tokyo.”³⁰ Because the document was written in April 1940, we can say that by this time the NAW had stationed staff to find and manage subcontractors in both Tokyo and Osaka.

In terms of the NAW department responsible for the Army airframes, detailed data on parts suppliers are available. In December 1944, the Army airframe department was reorganized into No. 5 Works, and this subsequently produced a document titled “Factory Survey” in October 1945 to file with the USSBS.³¹ This document contains rich data on the Army airframe section of the NAW from 1939. Concerning the period before December 1944, the data are for the No. 2 Processing Department of the NAW, but in the subsequent part of the paper, we refer to No. 2 Processing Department as No. 5 Works for simplicity. The “Factory Survey” contains a list of suppliers and their locations by parts categories, namely “special parts,” “machinery parts,” “castings and forgings,” “metal sheet processing,” “material,”

²⁴ NAW, “Genkyo Shinkokusho,” Match 1943 (held at the NAW archives).

²⁵ *Ibid.*

²⁶ MHI, *Mitsubishi Jukogyo*, p. 298, pp. 350–351.

²⁷ Of the 13 aircraft producers in Japan, six major producers produced engines as well as airframes, including Mitsubishi and Nakajima (Toyo Keizai Shinposha, *Showa*, p. 606. Concerning, Nagoya Engine Works of Mitsubishi Heavy Industries Co., see Maeda, *Senjiki*.

²⁸ USSBS, “Final Reports,” p. 28. For other aircraft producers, the ratios were 43% for Nakajima Aircraft Co. and 31% for Aichi Aircraft Co. See also Toyo Keizai Shinposha, *Showa*, p. 621.

²⁹ Held at the NAW archives.

³⁰ NAW, “Kojo Genkyo Hokoku, Kojo Enkaku Nenpyo,” April 1940 (held at the NAW archives), p. 10.

³¹ Held at the NAW archives.

“material processing,” and “lumber.” The numbers of suppliers in the list are, by parts category, 83, 115, 30, 24, 73, 10, and 13, respectively. Furthermore, with respect to “special parts,” “machinery parts,” and “castings and forgings,” data on the year when each supplier started to supply parts to No. 5 Works and the year when it ceased supply are also available.

In terms of the categories of parts, special parts include bearings, electric parts, and springs, and many large firms, including Fujikoshi Steel Co. (bearings), NSK Co. (bearings), Mitsubishi Electric Co. (electric parts), Tokyo Shibaura Electric Co. (electric parts) and Chuo Spring Co. (springs) are included in the list as suppliers for the No. 5 Works. However, machinery parts generally comprise miscellaneous items such as “small parts,” “large parts,” and “kind of stopcocks,” and few large firms are included in the list. Further, we consider that the special parts and machinery parts in this document correspond to the official categories of parts, namely “special technical parts” and “general parts.” Special technical parts are then further classified into “controlled parts,” “government-coordinated parts,” and “government-supplied parts.” While controlled parts were produced under government supervision, orders and distribution were directly between assemblers and suppliers. With government-coordinated parts, the government gave orders to suppliers, which then delivered the ordered parts to the assemblers. Finally, with respect to government-supplied parts, the government purchased these to deliver to the assemblers itself.³² In sum, the government was directly involved in the production and/or distribution of special technical parts in at least some way.

Using the “Factory Survey,” Masanao Kasai pointed out that the years when suppliers started to supply parts were concentrated in 1938–1939 for special parts and 1941–1944 for machinery parts, and the increase in suppliers corresponds to the introduction of the tact system at the NAW.³³ However, Kasai focused on the starting years of parts supply. By using information on the end years along with the start years, we can discern the list of suppliers for each year.

Table 4 provides the number of suppliers for No. 5 Works by parts category. As shown, the number of suppliers increased sharply in 1939 and again in 1943–1944. Importantly, the suppliers of special and machinery parts increased sharply in 1939. In 1943–44, suppliers of castings and forgings increased sharply alongside special and machinery parts. These changes in the number of suppliers are approximately associated with the orders and production of Army airframes in Table 2. Indeed, the sharpest increase in orders took place in 1938 and 1943.³⁴ For instance, the “Factory Survey” concludes, “(From late 1942 to 1943) we began an epoch-making expansion. This is a period of finding and fostering cooperative factories³⁵ entering the aircraft parts industry from other industries. During this period, production capacity substantially increased.” Together, this suggests that No. 5 Works strategically found and fostered suppliers as a part of its expansion in production capacity.

Table 4 here

Using the supplier list, we can observe the stability of the transaction relationships between No. 5 Works and its suppliers. For example, of the 83 suppliers of special parts on the list, only 13 disappeared before 1945, while of the 115

³² Final Reports of the USSBS, p. 13.

³³ Kasai, “Senjika,” p. 104. Concerning the tact system at Mitsubishi Engine Works, see Maeda, *Senjiki*.

³⁴ The time lag for the first sharp increase in suppliers may reflect the fact, as stated earlier, that the NAW prepared its internal organization for finding and managing suppliers in 1938.

³⁵ During the war, subcontractors were referred to as “cooperative factories” (kyoryoku kojo).

suppliers of machinery parts in the list, only 15 disappeared before 1945. Moreover, of the 30 suppliers of castings and forgings, only one supplier disappeared before 1945. As discussed in Section 1, Hirofumi Ueda previously stressed the instability of the wartime transaction relationship between assemblers and suppliers.³⁶ This does not appear to be the case for the No. 5 Works of MHI.

Finally, we can view the geographical distribution of suppliers (Table 5, 6). First, the distribution of the suppliers was substantially different between special parts and machinery parts. Whereas most machinery parts suppliers were located in Aichi prefecture, the largest portion of the special parts suppliers were in Tokyo, and only 20–30% were located in the Aichi prefecture. One reason may be that the government was more intensively involved in the production and distribution of special parts. Further, it is also possible that only a limited number of firms with relatively high technological capabilities could produce special parts.

Second, over time the regional distribution of suppliers of machinery parts and castings and forgings changed, while the distribution of the suppliers of special parts was more stable. In terms of machinery parts, the most remarkable changes are the declining percentages in 1944. Meanwhile, the percentage of suppliers in Osaka, the prefecture in which the second-largest group of machinery parts suppliers was located, also declined from 1942.

As substitutes for Aichi and Osaka, the percentage share of suppliers in Gifu, Shizuoka, and Tokyo increased. Overall, the suppliers of machinery parts dispersed geographically from 1942. The geographical dispersion of suppliers is even clearer for castings and forgings. For example, suppliers in the Aichi prefecture supplied all castings and forgings until 1940. Afterwards, the percentage of suppliers in the Aichi prefecture declined substantially, while the percentages of suppliers in Tokyo, Osaka, Kanagawa, and Shizuoka increased. By 1943, most suppliers of castings and forgings were located in prefectures other than Aichi. In sum, with the expansion process of No. 5 Works, the parts supply base also expanded, in terms of both the number of suppliers and their geographic distribution.

Table 5 here

Table 6 here

4. Parts supply and aircraft production

In this section, we examine how the expansion of the supplier networks contributed to airframe production at No. 5 Works. The “Factory Survey” included sections that explained the reasons why production had fallen short. With respect to the labor force, “our labor force expansion plan will not finally be satisfied until the end of the war.” Further, “however the fact that the requested labor force was not satisfied did not provide actual damage to production.” This was because, “as the expansion of our equipment and the production expansion of outside part suppliers did not keep pace with the increase in labor force, the labor force was relatively in excess.” It also points out that special parts were particularly in short supply among those parts supplied by outside suppliers. In sum, the “Factory Survey” recognized that the binding constraints of airframe production were equipment and parts supply, particularly the supply of special parts.

We can also examine this observation quantitatively. To start with, the “Factory Survey” includes monthly data for No. 5 Works for airframe production, the supply of special parts, the supply of machinery parts, and the total hours worked from 1939.³⁷ Airframe production is shown in Figure 3-A. The decline at the end of 1940 is a result of a condition peculiar to No. 5 Works entailing a change in the major type of

³⁶ Ueda, *Senjiki*, Chapter 6.

³⁷ Only a diagram concerning the supply of special parts is available. We obtained the requisite data from this diagram.

airframe manufactured.³⁸ The production of No. 5 Works then increased sharply from 1941 to 1943, with further accelerations in late 1942 and late 1943. Both these accelerations reflect policy measures taken to increase the national level of production. Production at No. 5 Works then began to decline in early 1944, some months earlier than the decline in the national level of production. Furthermore, production declined sharply in December 1944 when Nagoya suffered from bombing and a major earthquake. From February 1945, production recovered. In May and June 1945, the recovery accelerated but in July 1945, it again declined.

Figures 3-A, 3-B, and 3-C here

Figure 3-B shows the supply of parts. While the supply of both special parts and machinery parts increased up until 1943, the supply of machinery parts grew relatively faster. In addition, whereas the supply of special parts began to decline after April 1944, the supply of machinery parts continued to increase until September 1944. However, the supply of machinery parts declined very sharply from October 1944, and consequently the index of machinery parts supply fell relative to the supply of special parts.

The fact that the increase in special parts supply was lower than that of machinery parts is consistent with the recognition that special parts were the binding constraint of production. The timing of the decline in production and the special parts supply supports this view. Meanwhile, in early 1944, machinery parts supply was still increasing. Furthermore, the total hours worked also continued to increase until the end of 1944 (Figure 3-C). In sum, the mobilization of the labor force and the expansion of the supplier network raised the upper limit of airframe production at No. 5 Works, and within the upper limit the supply of special parts, whose increase was relatively slow, provided the binding constraint.

However, the situation changed after the end of 1944. When production declined sharply in December 1944, the decline in the supply of special parts was moderate. In addition, when production recovered from February 1945, the supply of special parts did not increase. In contrast, the supply of machinery parts declined sharply in December 1944 and temporarily recovered from February 1945. Using these observations, we can declare that the binding constraint of production was special parts. From the end of 1944 onwards, the supply of machinery parts also became a binding constraint.

We can test this hypothesis using regression analysis. For this purpose, we use monthly data on airframe production, special parts supply, machinery parts supply, and the total hours worked at No. 5 Works from January 1939 to July 1945. As our focus is the change in binding constraints, we use a switching regression technique³⁹. Assuming a Cobb–Douglas production function, we estimate the following equation system.

$$\begin{aligned}
 LN(Y_{t1}) &= \beta_{01} + \beta_{11}LN(SP_t) + \beta_{21}LN(MP_t) + \beta_{31}(L_t) + e_{t1} \\
 LN(Y_{t2}) &= \beta_{02} + \beta_{12}LN(SP_t) + \beta_{22}LN(MP_t) + \beta_{32}(L_t) + e_{t2} \\
 REGIME_t &= \beta_{03} + \beta_{13}(SP_t/L_t) + \beta_{23}(MP_t/L_t) + e_{t3} \\
 \left\{ \begin{array}{l} Y_t = Y_{t1} \quad \text{if } REGIME_t < 0 \\ Y_t = Y_{t2} \quad \text{if } REGIME_t \geq 0 \end{array} \right.
 \end{aligned}$$

where Y_t is airframe production in month t , SP_t is the special part supply in month t , MP_t is the machinery parts supply in month t , L_t is the total hours worked in month t , $Regime_t$ is a latent variable determining which regression regime the dependent

³⁸ “Factory Survey.”

³⁹ Concerning a switching regression model, see Zimmerman, “Switching Regressions.”

variable is from, and e_{it} is a normally distributed error term.

Table 7 provides the estimation results. Column (1) provides the simple OLS estimation results. The coefficient for special parts supply is positive, large, and statistically significant, while the coefficient for machinery parts supply is negative and statistically insignificant. However, the coefficient for total hours worked is positive and statistically significant. Column (2)-1, 2, 3 provide the estimates using the switching regression model. As shown, in Regime 1, the coefficient of special parts supply is positive and statistically significant, while the coefficients of machinery parts supply and total hours worked have the wrong sign. In contrast, in Regime 2, the coefficient of machinery parts supply is positive and statistically significant, while the coefficients of the other two variables are statistically insignificant. Given these features of the two regimes, the timing of the regime switch is especially of interest. Figure 4 shows the estimated probability that Y_t was in Regime 2, where $(1 - \text{the probability of Regime 2})$ equals to the probability of Regime 1. As shown, for most of the period of the war, Y_t is inferred to be in Regime 1, but by the end of 1944, Y_t has shifted to Regime 2.

Table 7 here
Figure 4 here

These estimation results are consistent with our observation from Figures 3-A, 3-B, and 3-C. That is, the special parts supply was the binding constraint for airframe production for most of the period before the final phase of the war, while in the final phase of the war, machinery parts supply came to be the binding constraint. Meanwhile, as the “Factory Survey” suggests, labor supply was not binding throughout the war period. Put differently, until the end of 1944, airframe production at the NAW increased as the upper limit bounded by the special parts supply increased, and from the end of 1944 (when strategic bombing and an earthquake destroyed the networks for machinery parts supply), airframe production at the NAW collapsed.

5. Concluding remarks

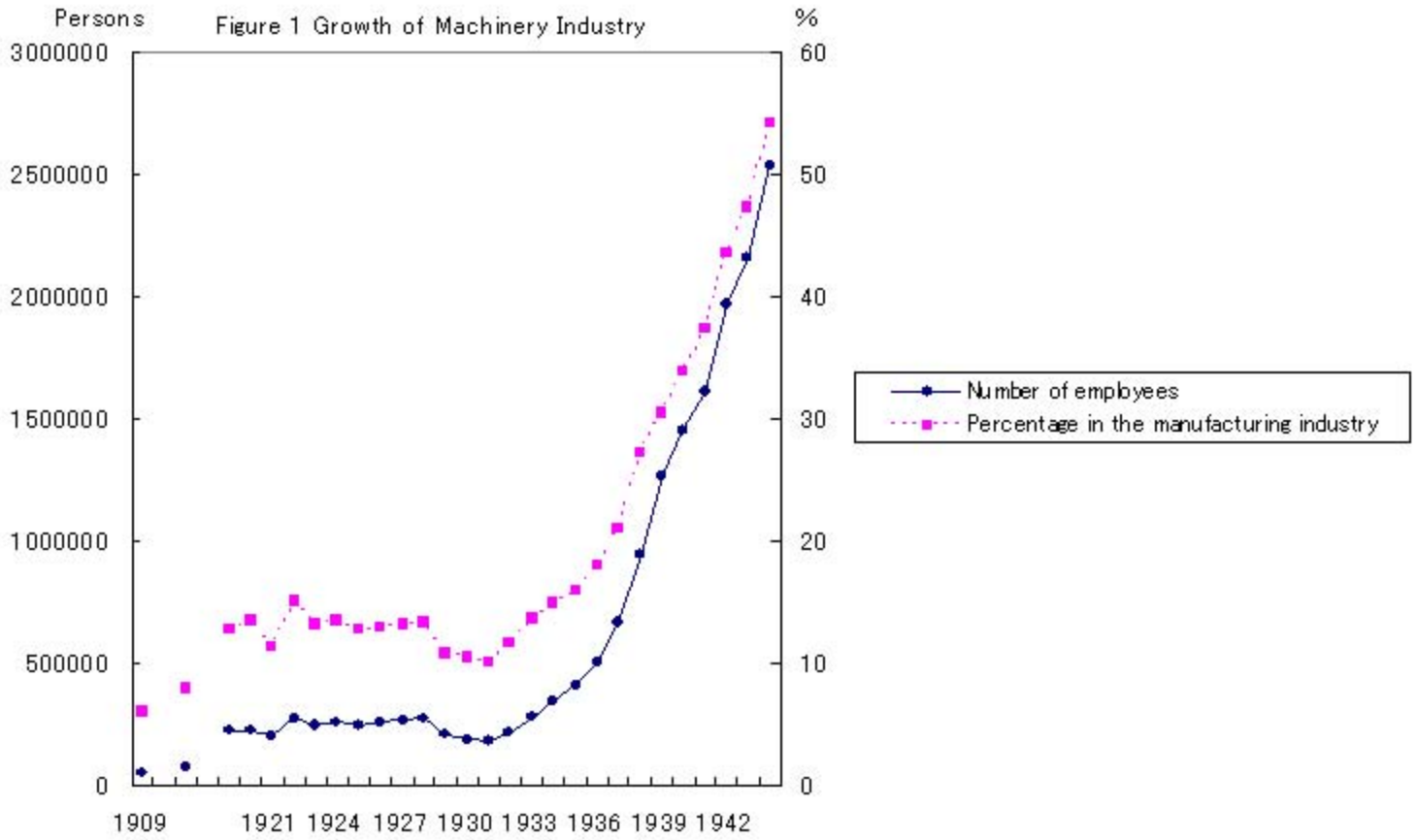
The rapid growth of the Japanese aircraft industry during World War II has attracted the interest of many researchers since immediately after the end of the war. In this paper, we explored the basis for this growth by focusing on the No. 5 Works of Mitsubishi Heavy Industries Co. Our findings indicate that the supply of basic inputs increased sharply and that the labor force, once effectively mobilized, was not a binding constraint on production. The supply of machinery parts from medium and small-sized suppliers was also not a binding constraint, at least until the final phase of the war. In fact, the binding constraint on aircraft production was the supply of special parts from large firms. Put differently, the expansion of production at No. 5 Works took place with increase in the supply of special parts. In turn, the increase in the supply of special parts and the more rapid increase in the supply of machinery parts supply were achieved thorough the expansion of the supplier network, in terms of both the number of suppliers and the geographical area where they were located. In this sense, extensive division of works between firms was a basis for rapid expansion of the Japanese aircraft industry during the World War II. However, from early 1944, the decline in the supply of parts caused a decline in aircraft production. That is, airframe production began to fall because of the decline in special parts supply from early 1944, finally destroyed by a sharp decline in the supply of machinery parts beginning at the end of 1944.

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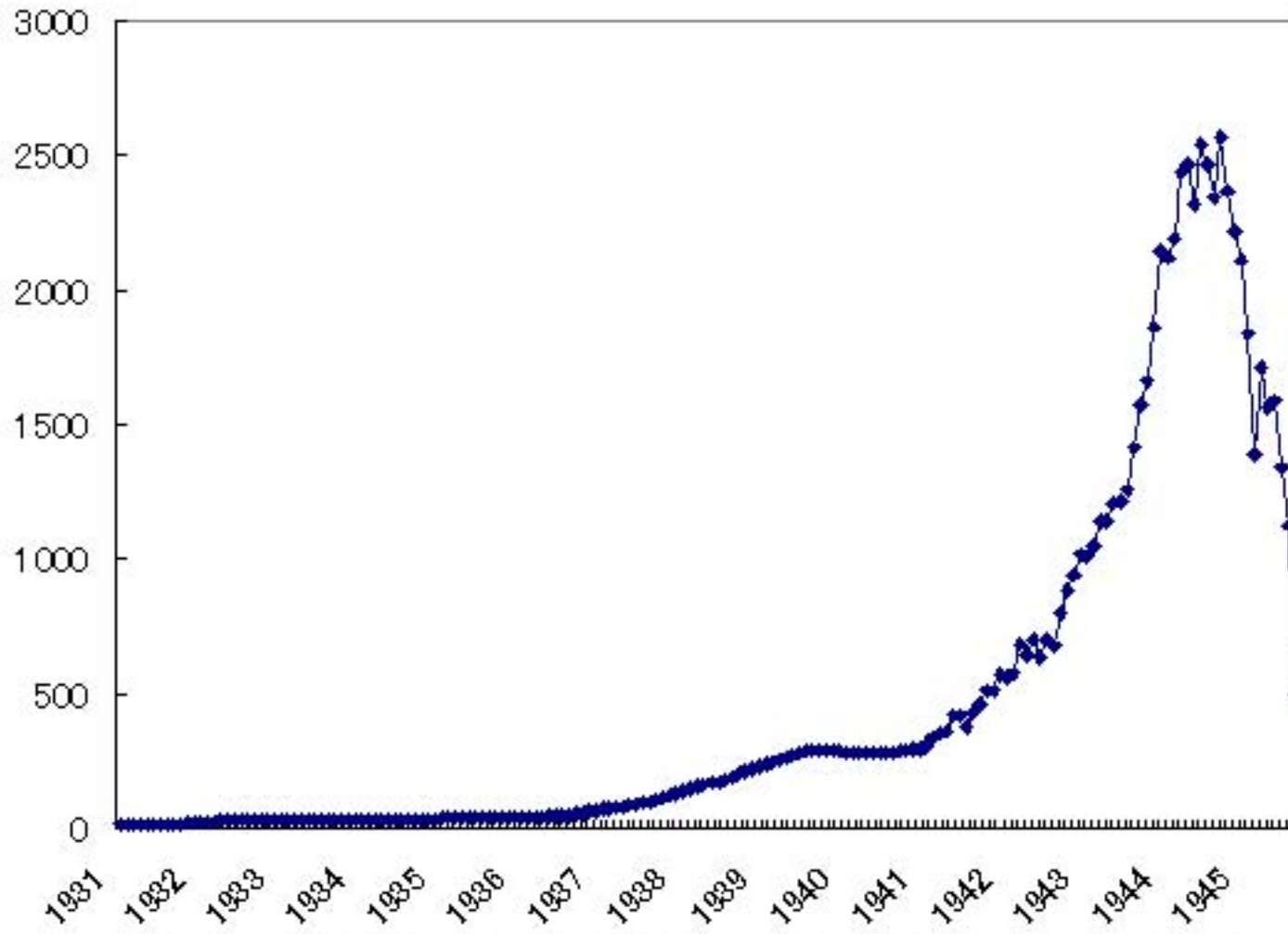
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Figure 1 Growth of Machinery Industry



Note: See the text

Figure 2 Monthly Airframe Production

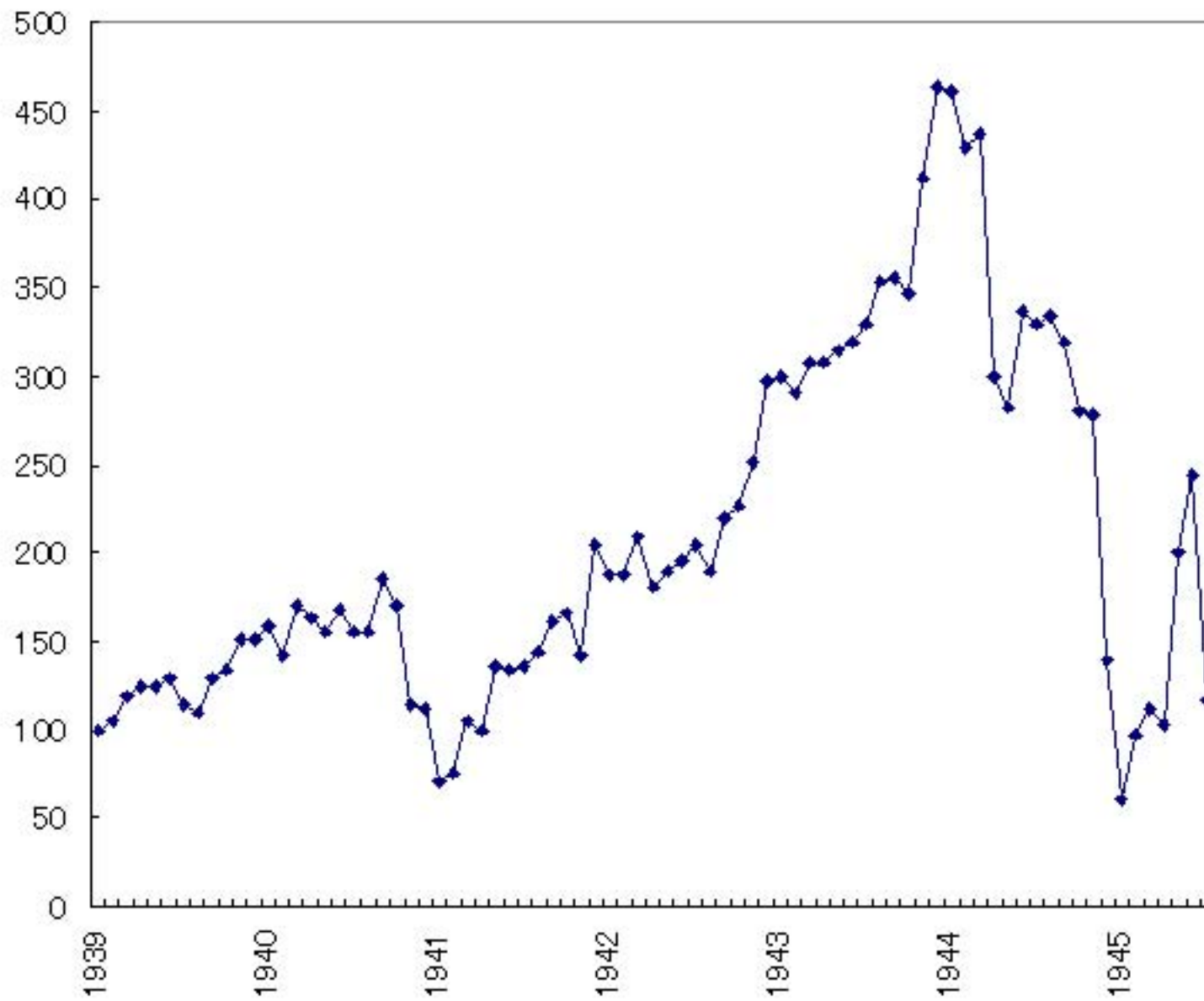


Source: USSBS, "Final Reports," p161; Toyo Keizai Shinposha, *Shawa*, p608.

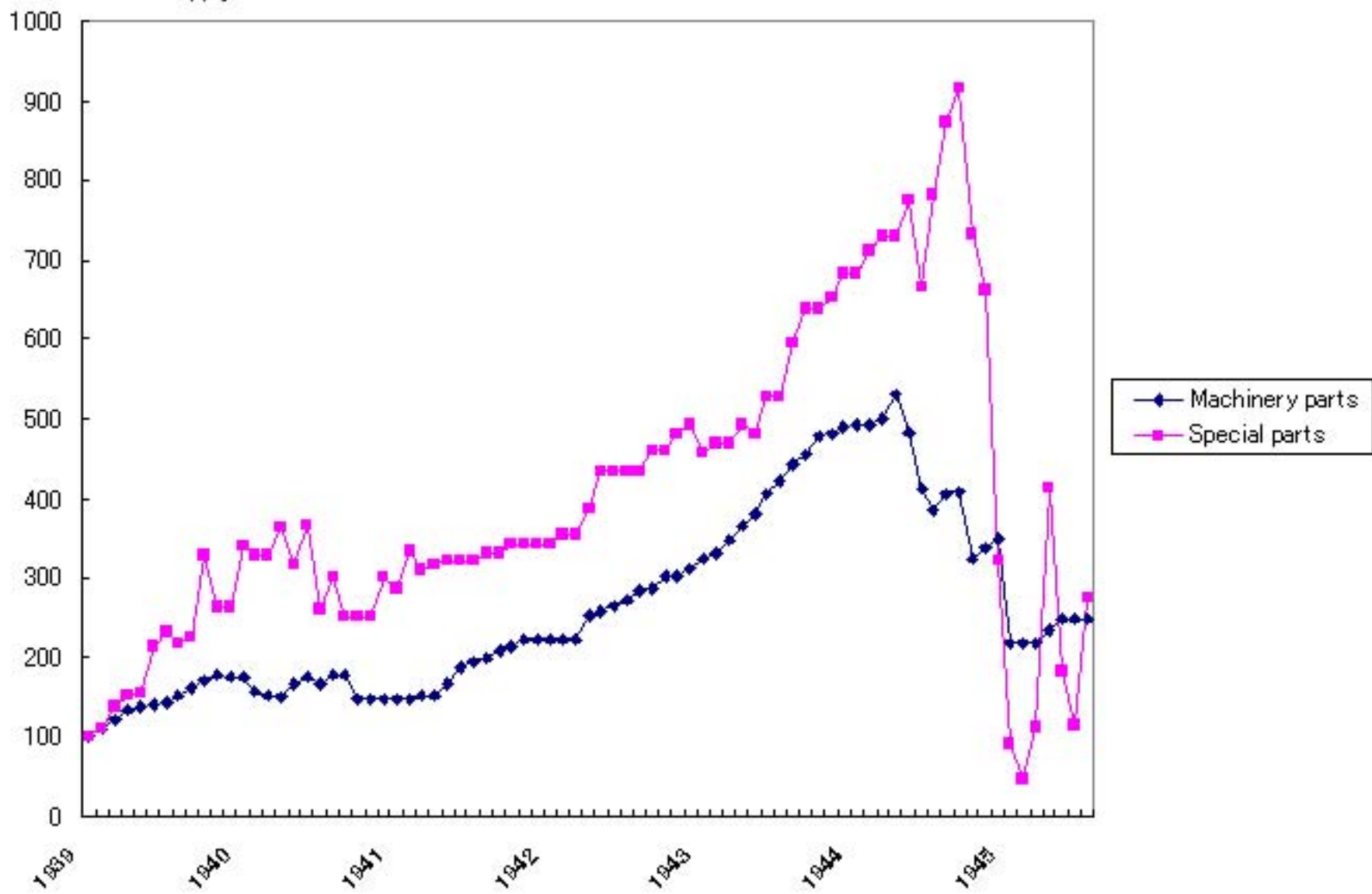
Note: The monthly production before 1940 was estimated by interpolation, assuming that average monthly production was achieved in July of each year.

Figure 3 Airframe Production and Supply of Inputs at No.5 Wwrks of NAW
(1939.1=100)

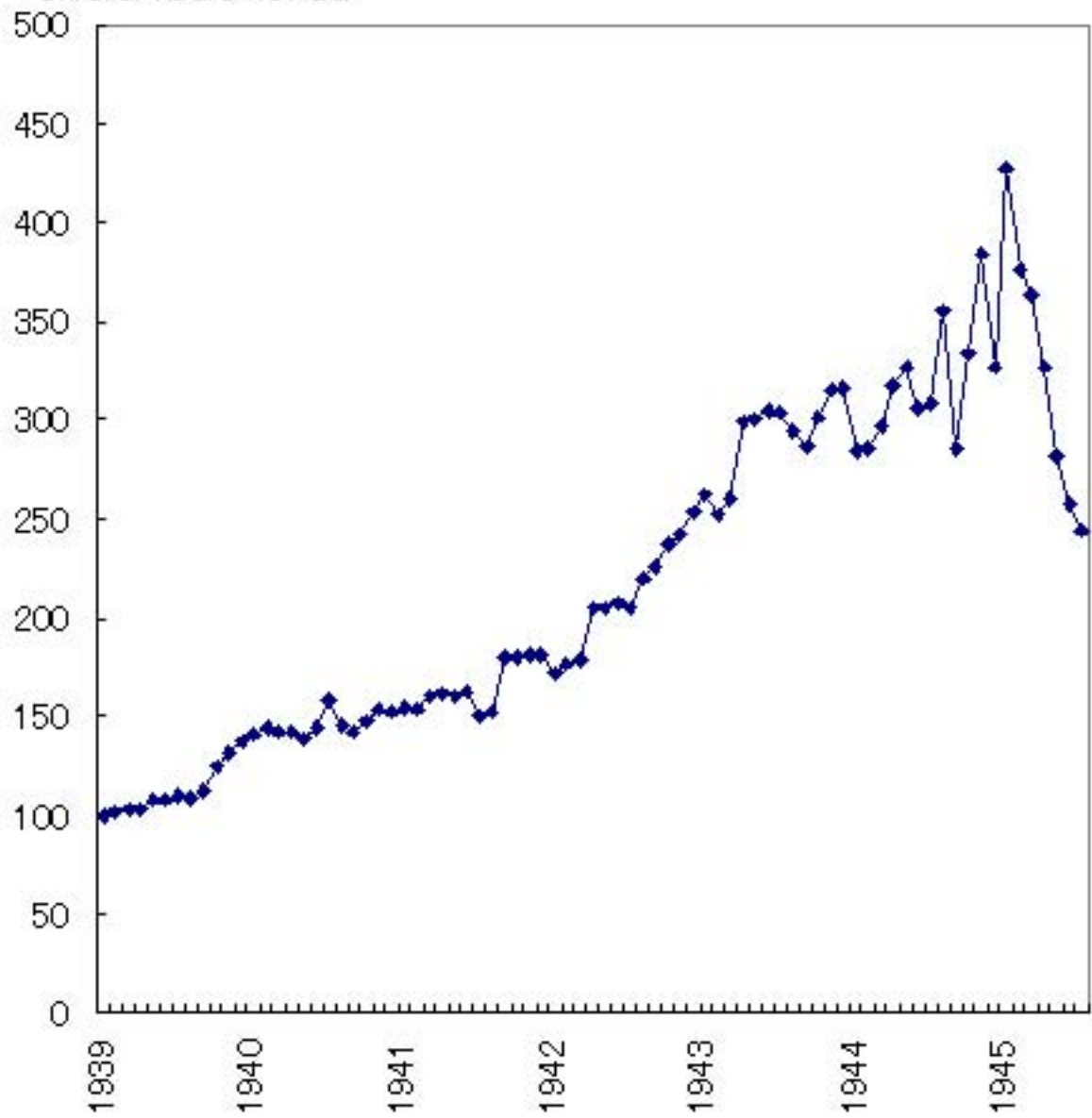
A.Production



B. Parts supply



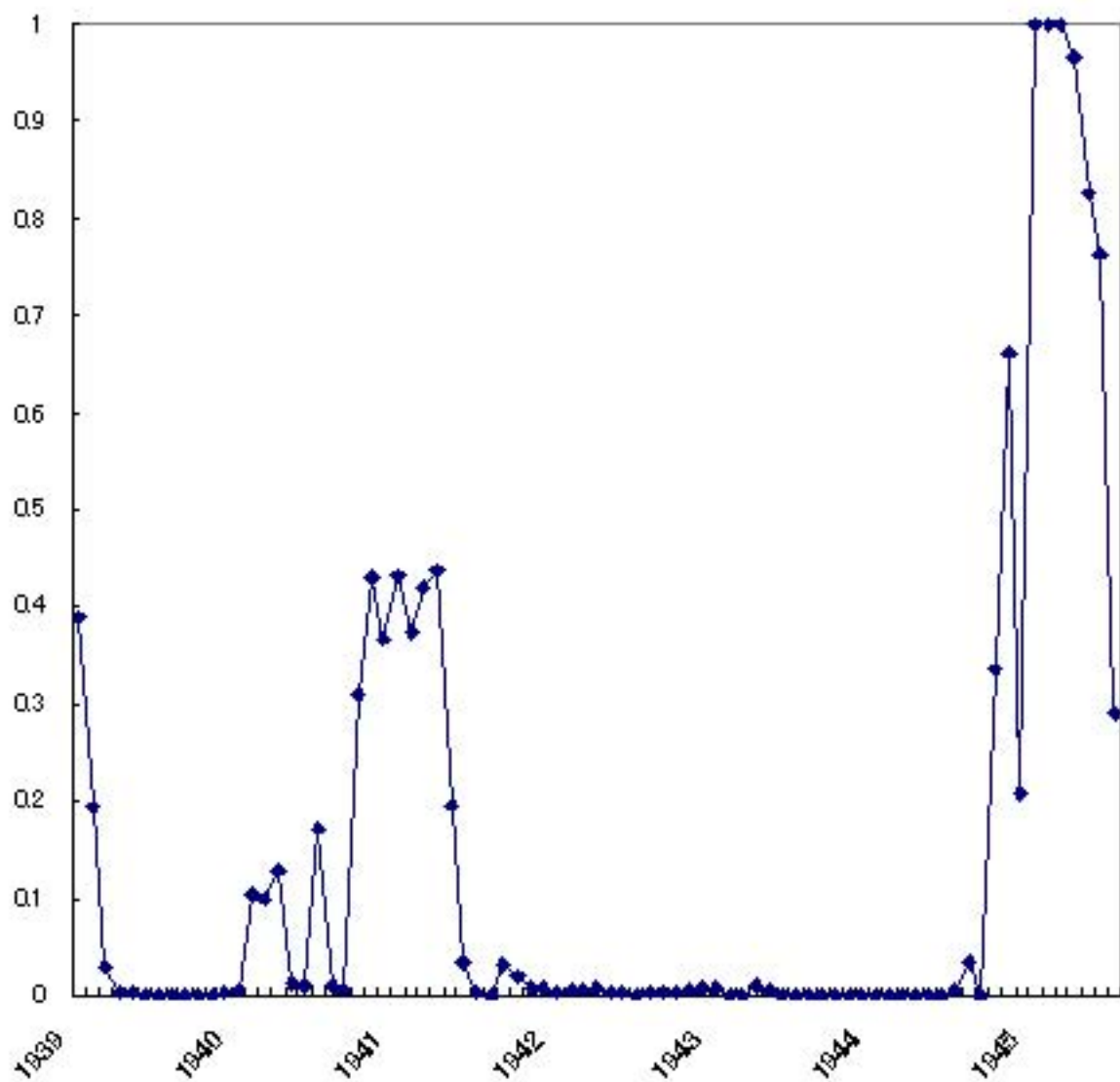
C. Total hours worked



Source: "Factory Survey"

Note: See the text.

Figure4 Estimated Probability of Regime 2



Note: See the text.

Table 1 Estimated Share of the Aircraft industry in the Machinery Industry in Terms of Production Amount

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Airframe production		Engine production		Airframe +engine	Machinery production	(5)/(6)
	Number of aircraft	1,000 yen	Number of engines	1,000 yen	1,000 yen	1,000 yen	%
1927					3,556	567,739	0.6
1932					49,425	553,645	8.9
1941	5,088	512,517	12,151	371,369	883,887	10,793,565	8.2
1942	8,861	934,319	16,999	506,061	1,440,380	10,332,396	13.9
1943	16,693	2,433,735	28,541	787,809	3,221,544	11,354,661	28.4
1944	28,180	3,370,113	46,526	1,629,875	4,999,987	14,744,586	33.9

Note: (1): USSBS, "Final Reports," p.155.

(2): (1) times unit price of airframe calculated from "Materials for the Corporate History of Mitsubishi Heavy Industries Co." (held at the Headquarters of Mitsubishi Heavy Industries Co.)

(3): USSBS, "Final Reports," p.155.

(4): (3) times unit price of engine calculated from "Materials for the Corporate History of Mitsubishi Heavy Industries."

(5): The data on 1927 and 1932 are taken from MITI, *Kogyo Tokei*, and the data from 1941 to 1944 are calculated by (2)+(4).

(6): The data from 1927 to 1942 are taken from MITI *Kogyo Tokei*. The data on 1943 and 1944 are estimated by the data on 1942, production index of machinery industry and price index of metal and machinery industry. Production index and price index are taken from Toyo Keizai Shinposha, *Kanketsu*.

Table 2 Orders and Production of Airframe at NAW

	(1)Orders			(2)Production			(1)/(2) (%)		
	Total	Army	Navy	Total	Army	Navy	Average	Army	Navy
1922	122	30	92	122	30	92	100.0	100.0	100.0
1923	98	32	66	98	32	66	100.0	100.0	100.0
1924	97	40	57	97	40	57	100.0	100.0	100.0
1925	97	36	61	97	36	61	100.0	100.0	100.0
1926	116	51	65	116	51	65	100.0	100.0	100.0
1927	101	36	65	90	27	63	89.1	75.0	96.9
1928	74	25	49	74	25	49	100.0	100.0	100.0
1929	82	9	73	82	9	73	100.0	100.0	100.0
1930	67	5	62	67	5	62	100.0	100.0	100.0
1931	67	7	60	67	7	60	100.0	100.0	100.0
1932	181	80	101	181	80	101	100.0	100.0	100.0
1933	191	95	96	191	95	96	100.0	100.0	100.0
1934	221	76	145	221	76	145	100.0	100.0	100.0
1935	199	75	124	191	72	119	96.0	96.0	96.0
1936	111	46	65	104	43	61	93.7	93.5	93.8
1937	418	163	255	322	74	248	77.0	45.4	97.3
1938	1,125	561	564	914	350	564	81.2	62.4	100.0
1939	1,096	601	495	1,194	663	531	108.9	110.3	107.3
1940	1,741	982	759	1,147	627	520	65.9	63.8	68.5
1941	2,038	1,135	903	1,697	800	897	83.3	70.5	99.3
1942	3,287	1,337	1,950	2,514	1,170	1,344	76.5	87.5	68.9
1943	3,656	1,736	1,920	3,864	1,860	2,004	105.7	107.1	104.4
1944	10,259	4,309	5,950	3,628	1,210	2,418	35.4	28.1	40.6
1945	1,450	569	881	563	282	281	38.8	49.6	31.9

Source: "Mitsubishi Kokuki Ryakushi," pp.23483-23485、 pp.23492-23493、 pp.23502-23503 (held at the Headquarters of Mitsubishi Heavy Industries).

Table 3 Expansion of Production Capacity of NAW

	Floor space (tsubo)	White collar workers	Blue collar workers	Conscripted workers as of blue collar workers	Machine tools
1920	3,464	43	61	0	n.a.
1921	4,884	117	921	0	n.a.
1922	5,577	137	1,491	0	n.a.
1923	7,014	145	1,250	0	n.a.
1924	7,401	150	1,285	0	n.a.
1925	8,229	164	1,411	0	n.a.
1926	8,584	175	1,515	0	n.a.
1927	8,919	197	1,583	0	n.a.
1928	9,497	214	1,766	0	n.a.
1929	11,236	211	1,726	0	n.a.
1930	11,312	218	2,337	0	n.a.
1931	12,367	258	2,505	0	n.a.
1932	15,932	296	4,936	0	n.a.
1933	21,799	360	5,994	0	n.a.
1934	23,926	411	6,134	0	n.a.
1935	26,068	444	6,177	0	n.a.
1936	29,684	504	7,155	0	202
1937	33,471	736	12,695	0	n.a.
1938	63,100	810	17,314	0	572
1939	96,415	1,254	21,276	0	1,221
1940	115,500	1,664	25,985	0	1,644
1941	136,387	2,485	34,415	700	1,771
1942	166,400	3,835	57,592	8,845	2,600
1943	207,880	4,779	84,731	22,870	3,208
1944	200,000	7,172	92,244	23,368	3,800

Source:(1) "Nagoya Kokuki Seisakujo Gaishi"; (2)"Kojo Genkyo Hokoku," November 1938; (3)"Genkyo Hokoku" April 1941, December 1941, December 1942, March 1943, April 1944; (4)"Kojo genkyo Hokoku Hojo Enkaku Nenpyo," April 1940; (5)"Genkyo Shinkokusho, March 1943; (6)MHI, *Mitsubishi*, p.298. (1) is held at the headquarters of MHI, and (2)-(5) are held at the Archives of NAW.

Note: 1 tsubo equals to 3.3 m².

Table 4 Increase of Suppliers for No5 Works of NAW

	Number of suppliers		
	Special parts	Machinery parts	Forgings and castings
1937	0	2	2
1938	0	4	4
1939	38	42	6
1940	49	44	6
1941	52	42	7
1942	55	50	10
1943	64	74	24
1944	74	101	29
1945	70	101	29

Source: "Factory Survey."

Table 5 Geographical Distribution of Suppliers for No5. Works of NAW

		1937	1938	1939	1940	1941	1942	1943	1944	1945
Special Parts	Aichi	0	0	10	14	16	17	19	20	20
	Nagoya	0	0	10	14	16	17	19	20	20
	Gofu	0	0	0	0	0	0	1	1	1
	Shizuoka	0	0	0	0	0	0	0	0	1
	Mie	0	0	1	1	1	1	1	1	3
	Tokyo	0	0	19	24	24	25	28	32	26
	Kanagawa	0	0	3	3	5	5	6	7	6
	Saitama	0	0	0	1	1	1	1	1	1
	Osaka	0	0	3	3	2	2	3	5	5
	Hyogo	0	0	2	2	2	3	4	5	5
	Fukuoka	0	0	0	1	1	1	1	1	1
	Unknown	0	0	0	0	0	0	0	1	1
Machinery parts	Aichi	1	3	22	23	25	30	45	51	55
	Nagoya	0	2	8	9	10	14	22	24	25
	The others	1	1	14	14	15	16	23	27	30
	Gifu	0	0	1	1	1	1	6	8	9
	Shizuoka	0	0	1	1	1	3	6	9	9
	Mie	0	0	0	0	0	0	0	4	4
	Tokyo	0	0	1	1	1	1	1	5	4
	Kanagawa	0	0	2	2	2	2	2	3	3
	Saitama	0	0	0	0	0	1	1	1	1
	Osaka	1	1	7	7	7	7	7	11	11
	Hyogo	0	0	2	3	2	2	2	2	2
	Kyoto	0	0	0	0	0	0	1	1	1
	Nara	0	0	0	0	0	0	0	1	1
	Fukuoka	0	0	1	1	1	1	1	1	0
	Ishikawa	0	0	1	1	1	1	1	2	0
Nagano	0	0	1	1	1	1	1	1	0	
Unknown	0	0	3	3	0	0	0	1	1	
Forgings and castings	Aichi	2	4	6	6	6	7	12	13	13
	Nagoya	2	3	5	5	5	5	8	9	9
	The others	0	1	1	1	1	2	4	4	4
	Shizuoka	0	0	0	0	0	0	1	1	1
	Tokyo	0	0	0	0	1	2	3	3	3
	Kanagawa	0	0	0	0	0	0	2	3	3
	Chiba	0	0	0	0	0	0	0	1	1
	Osaka	0	0	0	0	0	0	4	5	5
	Nagano	0	0	0	0	0	0	1	1	1
	Yamagushi	0	0	0	0	0	0	0	1	1
	Fukuoka	0	0	0	0	0	1	1	1	1

Source: "Factory Survey."

Table 6 Geographical Distribution of Suppliers for No5. Works of NAW (Percentage)

	1939	1940	1941	1942	1943	1944	1945
Special Pa							
Aichi	26.3	28.6	30.8	30.9	29.7	27.0	28.6
Nagoya	26.3	28.6	30.8	30.9	29.7	27.0	28.6
Gofu	0.0	0.0	0.0	0.0	1.6	1.4	1.4
Shizuoka	0.0	0.0	0.0	0.0	0.0	0.0	1.4
Mie	2.6	2.0	1.9	1.8	1.6	1.4	4.3
Tokyo	50.0	49.0	46.2	45.5	43.8	43.2	37.1
Kanagawa	7.9	6.1	9.6	9.1	9.4	9.5	8.6
Saitama	0.0	2.0	1.9	1.8	1.6	1.4	1.4
Osaka	7.9	6.1	3.8	3.6	4.7	6.8	7.1
Hyogo	5.3	4.1	3.8	5.5	6.3	6.8	7.1
Fukuoka	0.0	2.0	1.9	1.8	1.6	1.4	1.4
Unknown	0.0	0.0	0.0	0.0	0.0	1.4	1.4
Machinery							
Aichi	52.4	52.3	59.5	60.0	60.8	50.5	54.5
Nagoya	19.0	20.5	23.8	28.0	29.7	23.8	24.8
The others	33.3	31.8	35.7	32.0	31.1	26.7	29.7
Gifu	2.4	2.3	2.4	2.0	8.1	7.9	8.9
Shizuoka	2.4	2.3	2.4	6.0	8.1	8.9	8.9
Mie	0.0	0.0	0.0	0.0	0.0	4.0	4.0
Tokyo	2.4	2.3	2.4	2.0	1.4	5.0	4.0
Kanagawa	4.8	4.5	4.8	4.0	2.7	3.0	3.0
Saitama	0.0	0.0	0.0	2.0	1.4	1.0	1.0
Osaka	16.7	15.9	16.7	14.0	9.5	10.9	10.9
Hyogo	4.8	6.8	4.8	4.0	2.7	2.0	2.0
Kyoto	0.0	0.0	0.0	0.0	1.4	1.0	1.0
Nara	0.0	0.0	0.0	0.0	0.0	1.0	1.0
Fukuoka	2.4	2.3	2.4	2.0	1.4	1.0	0.0
Ishikawa	2.4	2.3	2.4	2.0	1.4	2.0	0.0
Nagano	2.4	2.3	2.4	2.0	1.4	1.0	0.0
Unknown	7.1	6.8	0.0	0.0	0.0	1.0	1.0
Forgings a							
Aichi	100.0	100.0	85.7	70.0	50.0	44.8	44.8
Nagoya	83.3	83.3	71.4	50.0	33.3	31.0	31.0
The others	16.7	16.7	14.3	20.0	16.7	13.8	13.8
Shizuoka	0.0	0.0	0.0	0.0	4.2	3.4	3.4
Tokyo	0.0	0.0	14.3	20.0	12.5	10.3	10.3
Kanagawa	0.0	0.0	0.0	0.0	8.3	10.3	10.3
Chiba	0.0	0.0	0.0	0.0	0.0	3.4	3.4
Osaka	0.0	0.0	0.0	0.0	16.7	17.2	17.2
Nagano	0.0	0.0	0.0	0.0	4.2	3.4	3.4
Yamagushi	0.0	0.0	0.0	0.0	0.0	3.4	3.4
Fukuoka	0.0	0.0	0.0	10.0	4.2	3.4	3.4

Source: "Factory Survey."

Table 7 Determinants of Airframe Production

Dependent variable: LN(Y _t)	(1)	(2)-1	(2)-2	(2)-3
	OLS	Switching regression		
		Regime 1	Regime 2	Classification equation
LN(SP _t)	0.841 *** (5.42)	1.799 *** (14.70)	-0.039 (-0.35)	2.569 *** (6.46)
LN(MP _t)	-0.047 (-0.68)	-0.153 (-1.92) *	0.776 *** (18.35)	-1.139 *** (-6.48)
LN(L _t)	0.463 *** (3.53)	-0.829 (-7.28)	0.005 (0.05)	-1.956 *** (-5.83)
Const.	-1.304 *** (-3.93)	0.663 *** (2.99)	0.754 *** (3.05)	3.588 (4.22)
Number of obs.	79			
Ad-R ²	0.865			
Log-likelihood				28.269

Note: t-values in parentheses.

***: Statistically significant at 1% level.

** : Statistically significant at 5% level.

* : Statistically significant at 10% level.