CIGS The Canon Institute for Global Studies

CIGS Working Paper Series No. 23-009E

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2023.5

General Incorporated Foundation
The Canon Institute for Global Studies
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Planning mass production of merchant ships in Japan during the Pacific War*

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Abstract

Building merchant ships was one of Japan's top priorities during the Pacific War because marine shipping capacity was a decisive factor in the outcome of the war. The Planned Shipbuilding scheme carried out by the Technical Department of the Navy was a scheme to achieve a drastic increase in merchant shipbuilding. The Technical Department of the Navy designed the Wartime Standard Vessels and assigned one or two types of such vessels to each private shipyard, and managed the progress of each ship using the Bar Chart system. Under this scheme, merchant shipbuilding did indeed soar, and the productivity of shipbuilding substantially increased. In this article, I showed that Nagasaki Shipyard of Mitsubishi Heavy Industries Co., which specialized in building Wartime Standard tankers along with naval ships, achieved a sharp increase in labor productivity from FY 1942, even under conditions of a declining capital–labor ratio and declining labor quality. At the same time, the shipbuilding period was reduced to less than half what it had previously been. This increase in productivity and the reduction of the building period reflected various ingenuities introduced at the shop-floor level in customizing the design of the Wartime Standard Vessels, improving operations, and introducing two basic technological innovations, block building and electric welding.

Key words: War economy, economic planning, shipbuilding, mass production, productivity, Japan

JEL classification numbers: L52, L62, N15, N45, N65

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1. Introduction

It is well documented that the Japanese economy and its war potential hinged on its marine shipping capacity during the Pacific War (Nakamura 1989; Hara 1998). Japan acquired territory in East Asia through military power in the 1930s and expanded its territory to South East Asia in the early 1940s. To utilize the natural resource endowments of these acquired territories for the war, it was necessary to transport their resources to the mainland of Japan by ship. Recognizing that, the United States strategically attacked Japanese merchant ships using submarines, and huge numbers of ships were sunk, especially from mid-1942. Hence, it became urgent for the Japanese government and the military to maintain Japan's shipping capacity by increasing shipbuilding. For this purpose, they launched a new scheme for administrating shipbuilding, i.e., the "Planned Shipbuilding" scheme in May 1942, which aimed at mass production of "Wartime Standard Vessels."

Ichiro Onozuka, who was in charge of the Planned Shipbuilding scheme as an officer of the Technical Department of the Navy during the war, published what has become a classic book (Onozuka 1962)[1] on the scheme. In addition, two volumes of the official history by the Agency of Defense provide an organized description of the scheme (War History Section, Institute for Defense Study, Agency of Defense, 1971, 1975). Furthermore, as the Planned Shipbuilding scheme was an important event in the history of the Japanese shipbuilding industry, it is described in detail in the shipbuilding industry literature (Toyo Keizai Shinpo-sha 1950; Kaneko 1964; Goto 1992). In particular, Goto (1992), focusing on the technological aspect of the Planned Shipbuilding and the Wartime Standard Vessels, stressed that two technological innovations, i.e., block building and electric welding, contributed to the mass production of merchant ships, and that these new technologies provided a basis for the development of the Japanese shipbuilding industry in the postwar period. In the context of planning and controlling materials, Yamazaki (2016) examined the relationship between the Material Mobilization Plan and the Planned Shipbuilding scheme. Finally, in the context of the history of the zaibatsu business group, Shiba (1987) described the management of shipbuilding at Mitsubishi Heavy Industry Co. during the war, and mentioned the Planned Shipbuilding scheme.

In this article, building on this literature, I aim to shed new light on the Planned Shipbuilding scheme, focusing on the Nagasaki Shipyard of Mitsubishi Heavy Industry Co., the largest private shipyard. First, I examine the productivity of merchant

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[1] Onozuka (1962) is a classic book cited by most of the literature on shipbuilding during the Pacific War. However, Ryoji Nishijima, who worked for the Technical Department of the Navy as a senior officer of Onozuka made the following critical comment on the book: "Mr. Onozuka's *Wartime History of Shipbuilding* was written from the standpoint of an engineer, and I do not think there is a point to be criticized on technological data etc., but the book contains many criticisms on the military policies and other issues … Of course, an opinion of an engineer itself is valuable … [but t]here are many misunderstandings and arbitrary claims" ("An opinion etc. on Mr. Onozuka's *Wartime History of Shipbuilding,"* held at the War History Section, Institute for Defense Study, Ministry of Defense). Thus, we need to use Onozuka (1962) carefully, especially on issues other than the engineering and technological data issues.

shipbuilding at this shipyard. It is well known that the building of simple, standard model ships, called the "Wartime Standard Vessels," was adopted under the Planned Shipbuilding scheme (Toyo Keizai Shinpo-sha 1950; Onozuka 1962; Kaneko 1964; Goto 1992). However, to my knowledge, no studies have yet systematically explored how the Planned Shipbuilding scheme and the Wartime Standard Vessels affected the productivity of merchant shipbuilding.

Second, I explore the change in the production process at the shop-floor level. As mentioned above, Goto (1992) stressed the contribution of block building and electric welding. He described the application of these new technologies in each shipyard based on the official histories of the shipbuilding companies and plants. In this article, I explore in detail how Nagasaki Shipyard customized the design of the Wartime Standard Vessels and introduced ingenuities into the production process in applying the new technologies. To do this, I exploit an unpublished document, titled "Nagasaki Zosenjo senji zosen-shi" (History of shipbuilding at the Nagasaki Shipyard during the war"), which was written just after the war. This document is described by Onozuka (1962) as follows: "this is written and filed by the Mitsubishi Nagasaki Shipyard just after the war as material for the government, by the request of the Bureau of Shipping, the Ministry of Transportation. It is rare material indicating the facts at the shipyard during the war, but is not open to the public" (author's translation). Although this document has not been utilized by any studies to date, including Onozuka (1962), I found that it was located at the Economics Library of the University of Tokyo, with a group of papers titled "Documents regarding WWII Wartime Marine Transportation." Using this hitherto unexamined document, I investigate how the engineers and workers achieved mass production of Wartime Standard Vessels under severe materials and workforce constraints.

The remainder of this article is organized as follows. Section 2 overviews the development of the Planned Shipbuilding, largely based on the literature. Section 3 quantitatively examines the production and productivity at the Nagasaki Shipyard of the Mitsubishi Heavy Industry Co. Section 4 describes the efforts and ingenuities at the shop-floor level. Finally, Section 5 concludes the paper.

2. Development of the Planned Shipbuilding Scheme

Merchant shipbuilding in Japan, which had been stagnant from the end of World War I, began to increase from 1933 owing to the recovery of the macroeconomy and a government policy that promoted scrapping old, low-quality ships and building new high-quality ships (Toyo Keizai Shinpo-sha 1950, p. 219) (Figure 1). As a result of the disposal of old ships, the stock of merchant ships continued to decline even after 1933, despite the increase in production; however, from 1937 the stock of ships began to increase (Toyo Keizai Shinpo-sha 1950, p. 239). At the end of June 1939, Japan had the third largest shipping capacity in the world, following the U.S. and Britain, holding 5,630,000 gross ton (GT) of merchant ships (Nihon Kaiji Shinko-kai, 1952, p. 661).

Figure 1

After 1937, the quantity of merchant shipbuilding began to decline again. It has been claimed that the reasons for the decline were the shortages and hence rising prices

of steel, competition with naval shipbuilding, and the dominant status of shipping companies in order building of ships. In response, the government legislated the Temporary Ship Control Law (October 1937), the Shipbuilding Industry Law (August 1939), and the Shipping Control Act (February 1940) to promote building new merchant ships (Toyo Keizai Shinpo-sha 1950, pp. 259–263; Onozuka 1962, pp. 6–8). Nevertheless, the decline in the quantity of merchant shipbuilding continued until 1941 (Figure 1).

The outbreak of the Pacific War in December 1941 made increasing merchant shipbuilding truly urgent for the Japanese government and the military. At the Imperial General Headquarters and Government Liaison Conference in October 1941, in which Japan decided to open the war with the U.S., the Minister of the Planning Board stated 3 million GT of merchant ships were required for civil use to maintain Japan's economic power, and that 400,000 GT and 600,000 GT of merchant ships should be built in 1942 and 1943, respectively. Meanwhile, the representative of the Technical Department of the Navy indicated that there was potential to produce 400,000, 600,000, and 80,000 GT of merchant ships in the first, second, and third years after the opening of the war, respectively. In addition, he pointed out that to realize this prospective production, several conditions must be satisfied, such as giving priority to shipbuilding concerning the supply of materials, shipping capacity, labor force, and expansion of production capacity, restricting the shipping capacity allocation to the Army to 900,000 GT, unifying the administration of shipping and shipbuilding, and mass production of standard vessels of 3,000 GT with a speed of 12 knots (General Staff Office of the Army 1967, pp. 355–357). Given that the peak of the merchant ship production in Japan was 428,000 GT in 1937, and that production in 1941 was 241,000 GT, powerful measures were indeed required to achieve the prospects put forward by the Navy.

The new scheme to expand shipbuilding was the Planned Shipbuilding scheme. In May 1942, the Cabinet decided "On Ensuring Implementation of the Planned Shipbuilding." Based on the recognition that "building the planned quantity of standard vessels with a certain planned period is an indispensable need to prosecute the war"(author's translation), the following measures were taken. First, it was required that orders of standard vessels to shipbuilding companies were placed by the Industrial Equipment Corporation, a public corporation, not by shipping companies. Second, the Industrial Equipment Corporation purchased the ships from the shipbuilding companies, and sold them to shipping companies at the prices determined by the government. In this way, the direct relationship of order building between shipbuilding and shipping companies was eliminated. Third, the Industrial Equipment Corporation owned the equipment to expand the building of standard ships. Fourth, the government compensated the Industrial Equipment Corporation for the risks that it assumed concerning standard vessel building, and the government totally supported the corporation's fundraising (Toyo Keizai Shinpo-sha 1950, pp. 285–286; Juyo Sangyo Kyogikai 1943, pp. 96–106).

In addition, the administration of shipbuilding for steel ships longer than 50 meters was transferred from the Ministry of Communications to the Ministry of the Navy in July 1942. The concentration of the administrative power for both naval and merchant ships in the hands of the Ministry of the Navy enabled it to coordinate the building of naval ships and merchant ships, which otherwise competed with each other for

production equipment and material. In preparation for this reform of the administration, the Merchant Ship Section was established in the Technical Department of the Navy in January 1942 (War History Section, Institute for Defense Study 1975, pp. 383–387; Toyo Keizai Shinpo-sha 1950, p. 264). The change in the administration was reflected in the Material Mobilization Plan, which was the plan for allocating strategic materials to several sectors and purposes, including the Army (A), the Navy (B), domestic civil use (C), exports to the yen bloc areas, and exports to the non-yen bloc areas, among others, which provided the basis for distribution controls. From the 1943 financial year (FY), the Material Mobilization Plan separated the steel shipbuilding sector from the civil sector, to the military sector named "Bx". This was indicative of the allocation of materials to the steel shipbuilding sector being administered by the Navy, which would ensure effectiveness of material distribution (Onozuka 1962, p. 769; Yamazaki 2016, p. 165).

The Technical Department of the Navy started to draw up plans for building standard vessels in December 1941 before the transfer of the administration. The plans were called the "Bar Charts" (Sen-pyo). They were literally a bar chart that indicated the planned progress of shipbuilding from the keel being laid to the completion of each ship at each shipyard[2]. Using this bar chart as a tool, the Technical Department intended to plan and control merchant shipbuilding at every private shipyard. The Technical Department had drawn up 12 Bar Charts by the end of the Pacific War, and each Bar Chart was numbered (first, second, etc.). The Fourth Bar Chart, decided in April 1942, was the first chart that was actually implemented (War History Section, Institute for Defense Study, the Ministry of Defense ed. 1975, pp. 393–394).

The aggregate targets for shipbuilding established by each Bar Chart are shown in Table 1. Each Bar Chart could be regarded as a medium-term plan, in that it covered two to three fiscal years. The aggregate characteristics of each Bar Chart can be observed by focusing on the total quantity of shipbuilding, the composition of ships by class (cargo ship, tanker, etc.), and the composition of ships by types (Wartime Standard Vessels, other ships, etc.). As stated above, the idea of Planned Shipbuilding predated the adoption of the Wartime Standard Vessels. The Technical Department intended for each shipyard to specialize in building one or two types of Wartime Standard Vessels to enhance productivity (Toyo Keizai Shinpo-sha 1950, pp. 289–290). The First Wartime Standard Vessels were determined at the end of 1941, based on the Peacetime Standard Vessels, which had been authorized by the Ministry of Communications in 1939. The First Wartime Standard Vessel included six types of cargo ships, three types of tankers, and one type of ore carrier. As shown in Table 2, the specifications of the First Wartime Standard Vessels were similar to those of the Peacetime Standard Vessels. This was because the First Wartime Standard Vessels gave priority to economic efficiency, taking into account competition in the international shipping market after the war (Toyo Keizai Shinpo-sha 1950, p. 266; Onozuka 1962, pp. 40–45).

Table 1, Table 2

[2] The Bar Charts of August 26, 1944, October 26, 1944, and February 3, 1945 are held at the War History Section, Institute for Defense Study, the Ministry of Defense.

As shown in Table 1, FY 1942 was covered by the Fourth Bar Chart (April 1941) and its revised version, the Fifth Bar Chart (December 1941). Although the total quantity in the Fourth Bar Chart exceeded the prospects presented by the Technical Department presented at the Imperial General Headquarters and Government Liaison Conference in October 1941, the Fifth Bar Chart was consistent with these prospects. Examining the composition of ships by type, it is evident that these two Bar Charts did not include the Wartime Standard Vessels. That is, the intention of the Technical Department to implement the Planned Shipbuilding scheme by making private shipyards concentrate on building the Wartime Standard Vessels was not realized at first. This was because private shipbuilding companies already had orders for 224 merchant ships of 710,000 GT at the end of 1941, and although part of these orders were canceled, some shipbuilding to fulfil them continued in 1942 (War History Section, Institute for Defense Study, Agency of Defense 1975, pp. 398–399).

For FY 1943, the Sixth and Seventh Bar Charts were newly drawn up. I note that they set substantially higher targets for total quantities of ships, of 1,220,000 and 1,120,000 GT, respectively. This reflected the assumption that most of the ships would be Wartime Standard Vessels (Table 1). In addition to the First Wartime Standard Vessels, Second Wartime Standard Vessels were included. The Technical Department designed the Second Wartime Vessels to cope with the increase in the loss of merchant ships after the Battle of Guadalcanal in October 1942. This loss, amounting to 231,000 GT, whose annual equivalent was 2,766,000 GT, would have caused a sharp decline in the stock of merchant ships unless shipbuilding could be extraordinarily accelerated (Onozuka 1962, pp. 130–131). Given this situation, the design of the Second Wartime Vessels, three types of cargo ships and two types of tankers, gave priority to rapid mass production and saving materials at the cost of cruising speed and durable years (Table 2). At the same time, in terms of the class of ships, the percentage of tankers to be built was raised in the Sixth and Seventh Bar Charts. This reflected the fact that crude oil production in the occupied areas of South East Asia was larger than expected, and the government and the military wanted to transport as much crude oil to Japan as possible (Toyo Keizai Shinpo-sha 1950, p. 266; Onozuka 1962, pp. 54–56, 130–131; War History Section, Institute for Defense Study, Agency of Defense 1975, pp. 400–407).

For FY 1944, four Bar Charts were newly drawn up, the Eighth, Ninth, Tenth, and Eleventh Bar Charts (Table 1). The repeated revisions of the Bar Charts were driven by the rapid and unexpected changes in the tide of the war during this year. The Eighth Bar Chart, determined in April 1944, set the target of total quantity of shipbuilding in FY 1944 at 2,550,000 GT, which was more than twice the target for FY 1943. Correspondingly, it was planned that more than 80% of the total quantity would be Second Wartime Standard Vessels. The percentage of tankers was almost as high as the plans for FY 1943. In the Ninth and Tenth Bar Charts, the target was reduced, but the percentage of tankers was raised substantially. Changing the composition of ships by class on the way would impede smooth shipbuilding together with delay in the supply of materials (Onozuka 1962, pp. 69–70). Concerning the composition of ships by type, the percentage of Second Wartime Standard Vessels remained as high as 70%–90% in these Bar Charts. At the end of 1943, the Third Wartime Standard Vessels were designed with slightly higher specifications than the Second Wartime Standard Vessels, to reduce the

loss of ships due to submarine attacks. They were included in the Bar Charts, but the quantity was small (Toyo Keizai Shinpo-sha 1950, p. 267).

3. Merchant shipbuilding at Mitsubishi Nagasaki Shipyard

Under the policies described in Section 2, the quantity of merchant shipbuilding increased sharply during the Pacific War (Figure 1). While quantity in the 1930s peaked at 428,000 GT, achieved in 1937, the quantity of merchant ships built in 1944 was more than four times as large, at 1,730,000 GT. Furthermore, in the same period, the quantity of naval shipbuilding at private shipyards increased from 37 displacement tons (DT) to 205 DT, noting that DT was the measure used for naval ships, whereas merchant ships used GT (the differences are discussed in more detail below in relation to Figure 3 and changes in productivity).

Table 3 indicates the position of the Mitsubishi Heavy Industries Co. and its Nagasaki Shipyard. The market share of Mitsubishi Heavy Industries Co. in merchant shipbuilding exceeded 10%, except in 1935. Meanwhile, Nagasaki Shipyard built more than 40%–50% of merchant ships in the Mitsubishi Heavy Industries Co., except for 1935. The quantity of merchant shipbuilding at Mitsubishi Heavy Industries Co. and Nagasaki Shipyard increased 5.8 times and 7.2 times, respectively, from 1942 to 1944.

Table 3

As stated above, under the Planned Shipbuilding scheme, each shipyard was expected to specialize in building one or two types of Wartime Standard Vessels. Nishi-Nihon Jukogyo Co. (1951) provides data on shipbuilding at Nagasaki Shipyard at the individual ship level. Table 4 aggregates the data by type of ships. 1TL and 1TM denote large and medium-sized tankers, respectively, of the First Wartime Standard Vessels, and 2TL denotes a large tanker of the Second Wartime Standard Vessels. It is evident that Nagasaki Shipyard specialized in building 1TL, 1TM, and 2TL ships. In other words, Nagasaki Shipyard took charge of building standard tankers, which were given increasing priority over time, as noted in the previous section.

Table 4

To increase shipbuilding, the factors of production, i.e., capital and labor, were mobilized to Nagasaki Shipyard. Concerning capital, the Nagasaki Shipyard invested a large amount of money in equipment from 1936, along with the revision of the Naval Armament Supplement Program. In addition, it undertook a further expansion of equipment according to the instructions of the Technical Department of the Navy after the onset of the Pacific War. The expanded equipment included not only that required for shipbuilding in a narrow sense, but also equipment for machine production and dormitories for drafted workers (Shiba 1987, pp. 31, 43, 50–53). Table 5 shows the amount of investment in equipment for the shipbuilding sector by Mitsubishi Heavy Industries Co. and Nagasaki Shipyard, which was approved by the directors meeting of Mitsubishi Heavy Industry Co. Figure 2 shows the area of buildings (factory, office, and warehouse) of Nagasaki Shipyard as a measure of its physical capital. The area began

to increase from 1935, and increased sharply in 1943 and 1944. By 1944, it was 1.9 times as large as in 1935.

Figure 2, Table 5

Nagasaki Shipyard's labor force, which consisted of both white- and blue-collar workers, increased even faster than the capital (Figure 2). The total number of employees in 1944 was 3.7 times the number in 1935. Meanwhile, the composition of blue-collar workers changed substantially. As ordinary workers were drafted to the Japanese Army and Navy, the numbers of nonordinary workers, including workers requisitioned according to the National Requisition Act, Women's Volunteer Corps, and prisoners, increased. At the end of 1944, the percentage of these nonordinary workers was as high as 48.4%, which implies that the quality of the labor force declined substantially during the Pacific War (Shiba 1987, pp. 51–53).

Next, I measure the change in productivity at Nagasaki Shipyard. Because Nagasaki Shipyard built naval as well as merchant ships, for which the units of quantity differed (DT for naval ships and GT for merchant ships), I need to convert the units to determine the total quantity of merchant and naval ships. In the literature on the Japanese shipbuilding industry, 1DT = 5GT is the conventional measure of conversion, but there is no solid ground for this (Koike 1973; Hashimoto 1974). Therefore, I estimate the conversion rate using the method explained in more detail in the footnote. Essentially, the idea is to choose the conversion rate so that the ratio of naval ships (the quantity of naval ships in DT/quantity of merchant ships in GT) does not affect the labor productivity of each shipyard[3]. Somewhat surprisingly, the conversion rate estimated is 1.0 DT = 1.0 GT.

Figure 3 shows the labor productivity of Nagasaki Shipyard, calculated using this conversion rate. While labor productivity declined from 1935 to 1941, it increased sharply afterward. Labor productivity in 1944 was higher than in 1935. Notably, the capital–labor ratio declined in this period, such that in 1944 it was only 39.3% of that in 1935. An increase in labor productivity when the capital–labor ratio was declining implies a substantial increase in the total factor productivity.

Figure 3

[3] I used data on the 14 shipyards for which data on the quantity of merchant ships and naval ships built during the period 1941–1944 are available in Toyo Keizai Shinpo-sha (1950), and for which the number of employees in 1941–1944 is available in the United States Strategic Bombing Survey (1946). Defining labor productivity as (quantity of merchant ships in GT + quantity of naval ships in DT × conversion rate)/ number of employees, I calculated labor productivity using various conversion rates (0.1, 0.2 … 1.0, 1.1, 1.2, etc.). Then, I regressed each of the calculated values for the labor productivity of each shipyard in each year on the ratio of naval ships (quantity of naval ships in DT × conversion rate/quantity of merchant ships in GT) for each shipyard in each year, incorporating shipyard and year fixed effects. Based on the estimation results, I chose the conversion rate that made the coefficient on the ratio of naval ships closest to zero.

A productivity increase corresponded with a reduction in the building period required to complete ships. Nishi-Nihon Jukogyo Co.(1951) lists the comprehensive data on each ship built at Nagasaki Shipyard, such as the GT for merchant ships, the DT for naval ships, and the dates that keels were laid, ships launched, and completion dates. Figure 4 shows the average building period and the total quantity (GT) of merchant ships for each fiscal year. While the average building period was around 250–300 days over the 1935–1942 FYs, it declined sharply from FY 1943 and was only 101 days in FY 1944. As Nagasaki Shipyard concentrated on the Wartime Standard Vessels from FY 1943, and especially in FY 1944, it was almost completely specialized in 2TL tankers (Table 4). This suggests that specialization in the Wartime Standard Vessels contributed to the sharp decline in building periods required to complete ships at Nagasaki Shipyard.

Figure 4

Using the ship-level data on shipbuilding at Nagasaki Shipyard from FY 1925 to FY 1944, I can decompose the building period into several factors, including types of ships, using a regression analysis. That is, I estimate the following equation:

$$DAYS_i = \beta_0 + \beta_1 \ln(GT_i) + \beta_2 CARGO_i + \beta_3 TANKERi + \beta_4 1TL_i + \beta_5 1TM_i + \beta_6 2TL_i + \beta_7 3TL_i + e_i, \quad (1)$$

where $DAYS_i$ is the production period (from keel laid to completion) of ship i, GT_i is the gross tons of ship i, and CARGO and TANKER are dummy variables indicating the class of a ship. The reference category for class is a cargo–passenger ship. 1TL, 1TM, 2TL, and 3TL are dummy variables indicating the type of Wartime Standard Vessels. The reference category for type is a ship not the Wartime Standard Ships.

The estimation results are reported in column (1) of Table 6. The coefficient on ln(GT), 58.69, means that a 1% increase in the gross tons of a ship was associated with an increase in the building period of 58.69 days. The coefficients of CARGO and TANKER, –51.57 and –105.44, indicate that the building periods for a cargo ship and tanker, respectively, were 51.57 days and 105.44 days shorter than the building period for a cargo–passenger ship. The coefficients of interest in the context of this article are those on the dummy variables indicating the types of Wartime Standard Vessels. All the coefficients are negative and statistically significant, and their magnitudes are large. In particular, the impact on the building periods for the Second and Third Vessels is outstanding. For example, the building period for a 2TL tanker was 154.86 days shorter than those of ships other than Wartime Standard Vessels, after controlling for GT and class of ships. Evaluating building periods at the average scale (8,013 GT), while the average building period for a tanker other than a Wartime Standard Vessel was 242.70 days, the average building period of a 2TL type tanker was 36.02% of this; that is, only 87.83 days.

Table 6

The same ship-level data are available for Kobe Shipyard of Mitsubishi Heavy Industries Co. (Shin-Mitsubishi Jukogyo Co. 1957). By combining the data from the two sources, not only can the number of observations be increased, but also the impact of the Wartime Standard Vessels on cargo shipbuilding becomes evident because Kobe Shipyard built 2A-type cargo ships, whereas Nagasaki Shipyard specialized in tankers in building the Wartime Standard Vessels. Hence, I combine the data from the two sources, and estimate equation (1), adding a dummy variable indicating 2A-type cargo ships. The estimation results are reported in column (2) of Table 6. The results are qualitatively the same as those in column (1), and the coefficient on the dummy variable indicating 2A-type cargo ship is –189.85, which implies that the 2A-type cargo ship had the largest impact in reducing the building periods of merchant ships.

4. Changes and ingenuities at the shop-floor level

In the previous section, I established that Nagasaki Shipyard achieved a substantial productivity increase and reduction in building periods for ships, and that these changes were associated with their concentration on building the Wartime Standard Vessels. Here, I describe the changes at the shop-floor level that underlay these achievements, using an unpublished document, "Nagasaki Zosenjo senji zosen-shi" (History of shipbuilding at the Nagasaki Shipyard during the war")In the introduction of this document, it is stated that:

> "The most important characteristic of the Planned Shipbuilding during the war was 'mass production' and all the merits and demerits of the wartime shipbuilding are related to it. The largest merit of the wartime shipbuilding was that mass production was achieved with great efforts, overcoming shortages of materials and labor. In transitioning from the system that gave priority to dexterity in the prewar period to the efficient mass production system, our shipyard took various effective measures in the aspects of design technology, engineering, and operation. In what follows, we describe the history of the measures we took during the war concerning (1) shipbuilding, (2) machine making, and (3) electricity. Here, we focus on the description on shipbuilding" (author's translation).

The part on shipbuilding is composed of subparts on design and operation. Concerning design, Nagasaki Shipyard aimed at (i) simplifying operation, (ii) increasing operations before the keel was laid, (iii) increasing operations before launch, (iv) processing in factories in advance, (v) smoothing the flow of processed materials, and (vi) dividing and standardizing operations. For these purposes, new blueprints for operation were drawn up to achieve the following.

(a) Decentralization of operations to concentrate on berth to preparatory operation, such as material processing and assembly on the ground.
(b) Controlling the flow and arrangement of materials for each unit of the building process.
(c) Clarifying the workload of each unit of the building process to optimize the allocation of workers and promote efficient operations.

For (a), the shipyard adopted a block building method, “drawing an operation blueprint for each unit of blocks to clarify operation workload, and thereby to calculate standard operation days and optimize allocation of workers” (author’s translation). In addition to operation blueprints, a “member material chart” was drawn up, which recorded the quantity of each material to coordinate marking operations at a molding loft and to confirm the arrival of materials at a process area and an assembly area.

The issues concerning operations on the shop floor were: (i) full utilization of berths, (ii) expansion of the assembly area on the ground, (iii) increasing berths, (iv) recruiting workers, (v) improving transporting equipment, (vi) securing motors and machines, (vii) complementing machine processing capacity by hand processing, (viii) strengthening the block building method, (ix) expanding the range of electric welding, (x) simplifying operations and saving materials, (xi) implementing countermeasures to address the decline in the quality of workers, and (xii) others.

Point (i) is illustrated by the following quotation from the unpublished document “Nagasaki Zosenjo senji zosen-shi”: “In order to increase the quantity of shipbuilding given the extant berths, we needed to reduce the period of operation on berths. For this purpose, we took such measures as increasing operation before the keel was laid, simplification of the structure of ships and operations, and increasing workers” (author’s translation).

The document expanded on the block building method noted in point (viii) concerning design, to point out the following effects on shop-floor operations.

(viii-1) By increasing operations on the ground, the operating period on berths was reduced.
(viii-2) By building a certain block using certain workers at a certain speed at a certain area, efficiency was enhanced.
(viii-3) By increasing operations on the ground, the safety, efficiency, and quality of operations were improved. This was essential because most workers were inexperienced during the war.
(viii-4) Cranes were utilized efficiently.
(viii-5) Scaffolding was made more efficient.

The block building method was adopted through trial and error. At first, a 2TL type tanker was built by dividing the ship into large blocks of 30–60 tons. However, it took a long time to make large blocks and it was hard to combine them to construct a ship. Hence, the shipyard began to divide a ship into smaller blocks of 10–25 tons.

Concerning point (ix) on electric welding, the data shown in Table 7 were reported in the document. By adopting electric welding, the number of rivets required per ship weight was 30%–40% smaller for the Second and Third Wartime Standard Vessels than for nonstandard ships.

Concerning countermeasures to address the decline in the quality of workers, its countermeasures, the “Nagasaki Zosenjo senji zosen-shi” document stated that, “The decline in the quality of workers became serious as the end of the war approached, and it is said that whether a shipyard could achieve the plans instructed by the bar chart

totally hinged on its management of inexperienced workers. Hence, we made every effort to train and ensure efficient operations by inexperienced workers" (author's translation). The countermeasures were described as follows.

(ix-1) We provided short-term quick training to inexperienced workers and made them work as practical training on the shop floor. We carefully inspected the results of their work.
(ix-2) We organized teams of inexperienced workers only, and allocated the teams like flying columns, when there were tasks appropriate for them.
(ix-3) We expanded the range of operations on the ground and fully exploited inexperienced workers for this work.
(ix-4) We simplified operations.
(ix-5) We selected excellent trainers.

Table 7

The descriptions in "Nagasaki Zosenjo senji zosen-shi" summarized above vividly illustrate how substantial changes occurred in the design and operations on the shop floor. Based on the design of the Wartime Standard Vessels and two technological innovations, the block building method and electric welding, the engineers of Nagasaki Shipyard customized the design and introduced various operational ingenuities through trial and error, and thereby increased the operations on the ground and effectively utilized inexperienced workers. This represented the technological and operational background for the mass production and productivity increase demonstrated in the previous section.

5. Concluding remarks

Building merchant ships was one of Japan's top priorities during the Pacific War because marine shipping capacity was a decisive factor in the outcome of the war. The Planned Shipbuilding scheme carried out by the Technical Department of the Navy was a scheme to achieve a drastic increase in merchant shipbuilding. The Technical Department of the Navy designed the Wartime Standard Vessels and assigned one or two types of such vessels to each private shipyard, and managed the progress of each ship using the Bar Chart system. Through the political power of the Navy, huge resources were concentrated in the Planned Shipbuilding scheme.

Under this scheme, merchant shipbuilding did indeed soar. It is notable that the increase in shipbuilding was larger than the increase in the inputs of production factors. In other words, the productivity of shipbuilding substantially increased. In this article, I showed that Nagasaki Shipyard of Mitsubishi Heavy Industries Co., which specialized in building Wartime Standard tankers along with naval ships, achieved a sharp increase in labor productivity from FY 1942, even under conditions of a declining capital–labor ratio and declining labor quality. At the same time, the shipbuilding period was reduced to less than half what it had previously been. This increase in productivity and the reduction of the building period reflected various ingenuities introduced at the shop-floor level in customizing the design of the Wartime Standard Vessels, improving operations,

and introducing two basic technological innovations, block building and electric welding.

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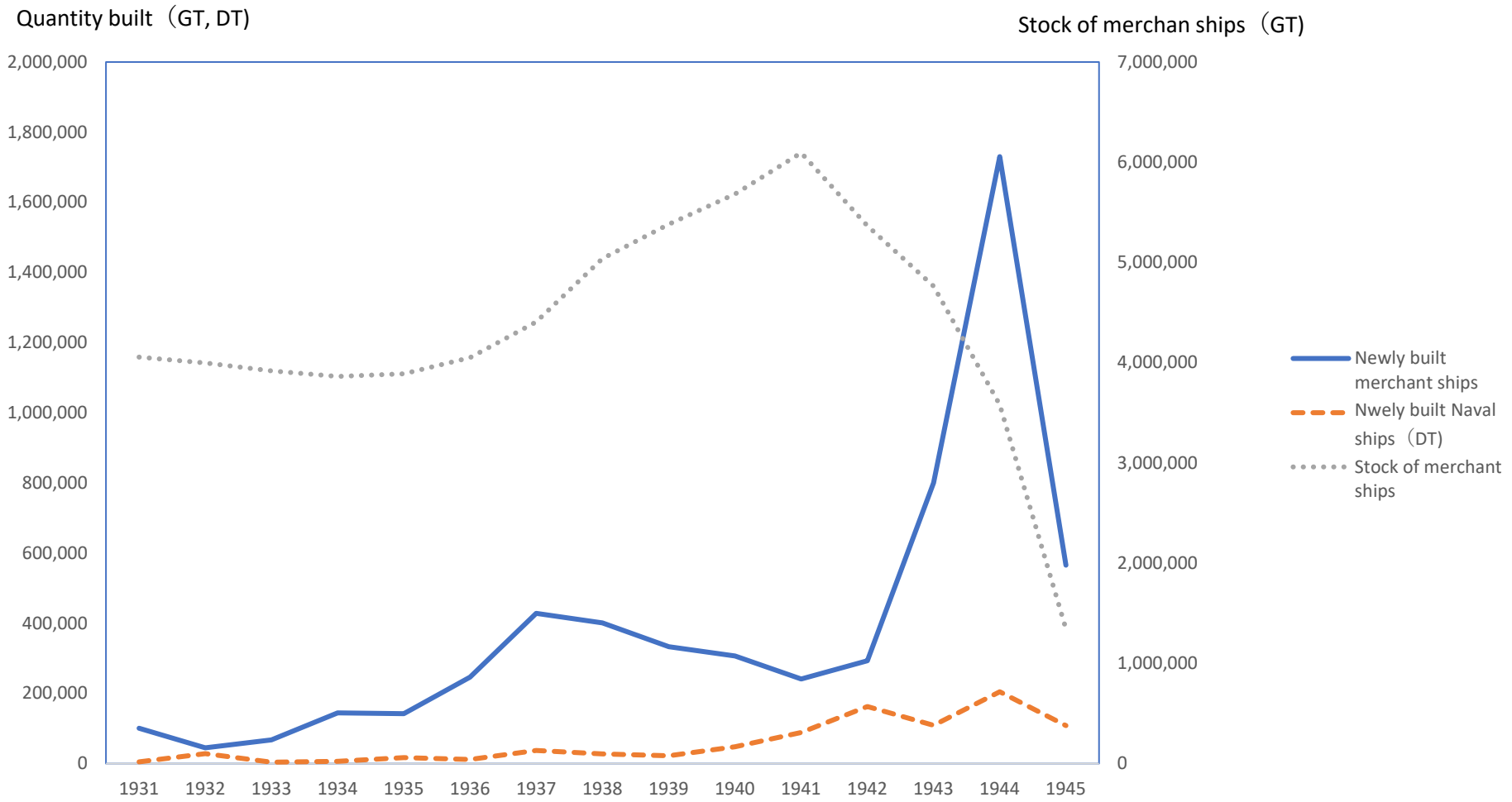
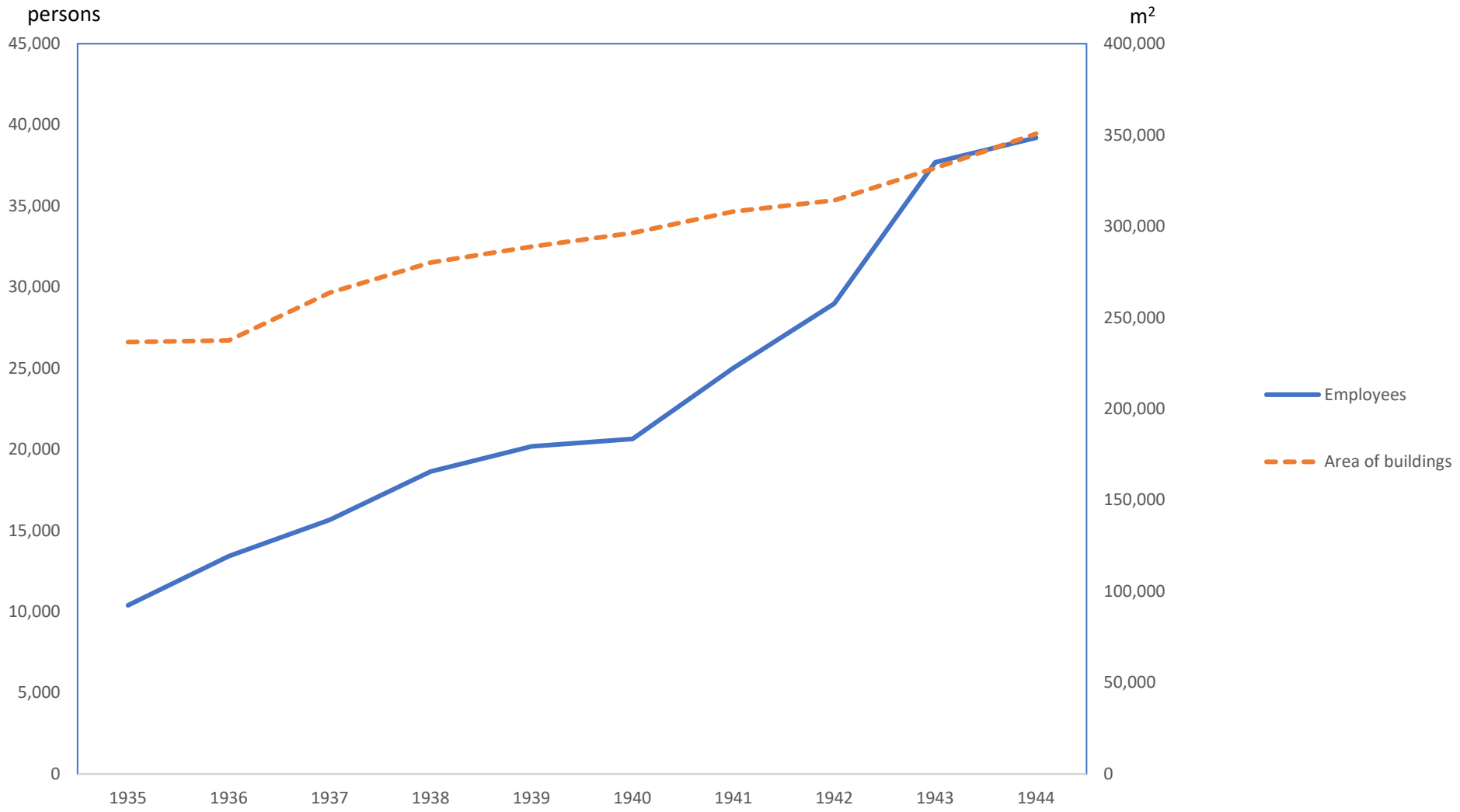
Figure 1 Quantity of merchant ships and Naval ships builf at



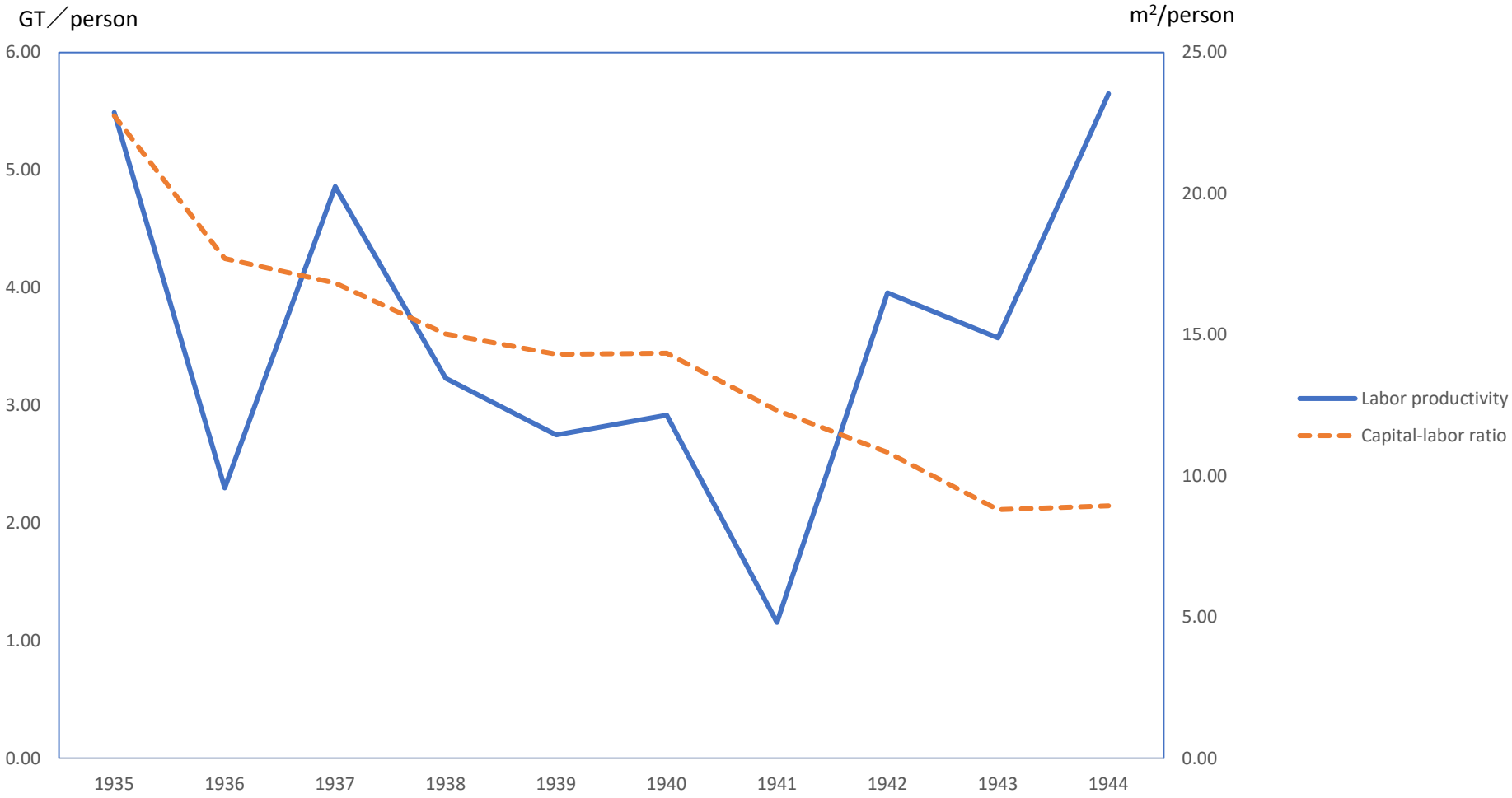
Source：Department of Marine Shipping Administration, Ministry of Transaportation (1953

Figure 2 Employees and area of buildings of Nagasaki Shipyaed,



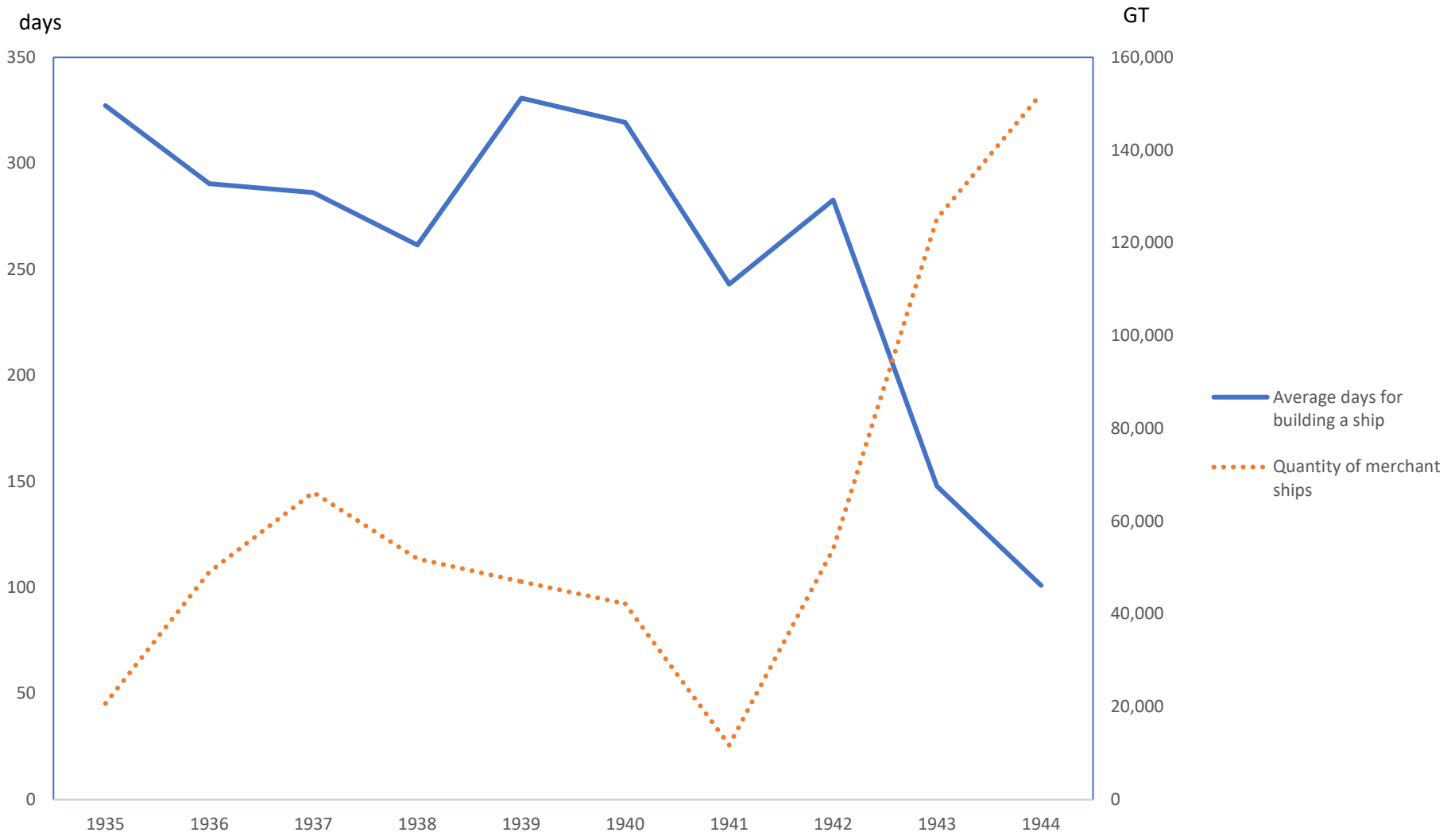
Source: Nishi-Nihon Jukogyo Co. (1951), p. 66, 69, 117.

Figure 3 Labor productivity and capital-labor ratio at Nagasaki Shipyard



Source: Toyo Keizai Shinpo-sha (1950), p.271; Nishi-Nihon Jukogyo Co. (1951), p. 69.
Note: Conversion rate between DT and GT here is 1.0. See the main text and footnote 3.

Figure 4 Average days for building a ship at Nagasaki Shipyard



Source: Nishi-Nihon Jukogyo Co. (1951).

Table 1 Plans for building merchant ships

Target year	Number of the Bar Chart	Month of decision	Planned and actual quantity of shipbuilding (1,000 GT)								
			Total	Class				Type			
				Cargo ship	Tanker	Percentage of tanker	Others	Wartime Standard Ship I	Wartime Standard Ship II	Wartime Standard Ship III	Others
FY 1942	Anticipation by the Navy	Dec-41	520	336	78	(14.9)	106	0	0	0	520
	Fourth	Apr-42	495	268	46	(9.3)	181	0	0	0	495
	Fifth	Dec-42	400	273	45	(11.3)	82	0	0	0	400
	Actual		424	277	44	(10.4)	104				
FY 1943	Anticipation by the Navy	Dec-41	670	436	112	(16.7)	110	0	0	0	670
	Fourth	Apr-42	690	382	135	(19.6)	173	166	0	0	524
	Fifth	Dec-42	750	371	247	(32.9)	132	570	0	0	180
	Sixth	Mar-43	1,220	750	310	(25.4)	160	626	389	0	205
	Seventh	Dec-43	1,120	758	323	(28.8)	39	626	389	0	205
	Actual		1,124	701	376	(33.5)	46				
FY 1944	Anticipation by the Navy	Dec-41	870	587	163	(18.8)	120	0	0	0	870
	Fourth	Apr-42	773	497	174	(22.5)	102	742	0	0	31
	Fifth	Dec-42	1,500	n.a.	n.a.		n.a.	76	1,390	0	34
	Sixth	Mar-43	1,500	n.a.	n.a.		n.a.	76	1,390	0	34
	Seventh	Dec-43	1,900	1,300	550	(28.9)	50	96	1,561	40	203
	Eightf	Apr-44	2,550	1,700	770	(30.2)	80	164	2,153	60	173
	Ninth	Sep-44	2,005	1,010	934	(46.6)	61	133	1,481	90	301
	Tenth	Nov-44	1,930	945	927	(48.0)	58	132	1,641	93	64
	Actual		1,582	829	718	(45.4)	35				

Source: Onozuka (1962); Defence Agency (1975), pp.392-393; Technical Department of the Navy, "Ko-zosen keikaku senpyo (kai 9)" (Bar Chart for building steel ships, #9) , "Ko-zosen keikaku senpyo kai 10)" (Bar Chart for building steel ships, #10), held at National Instutute for Defense Studies.

Table 2 Specifications of the standard vessels

	Class	Type	GT	Knot	Qumulative quantity built
Peacetime Standard Ships	Cargo	A	6,300	13.0	n.a
	Cargo	B	4,500	12.0	n.a
	Cargo	C	2,700	11.0	n.a
	Cargo	D	1,990	11.0	n.a
	Cargo	E	800	10.0	n.a
	Cargo	F	490	10.0	n.a
First Wartime Standard Vessels	Cargo	1A	6,400	12.0	57,600
	Cargo	1B	4,500	12.3	72,000
	Cargo	1C	2,700	11.0	91,800
	Cargo	1D	1,900	10.0	41,800
	Cargo	1E	830	10.0	10,760
	Cargo	1F	490	10.0	10,290
	Ore carrier	1K	5,300	10.5	106,000
	Tanker	ITL	10,000	15.0	190,000
	Tanker	1TM	5,200	12.5	135,200
	Tanker	1TS	1,010	10.0	5,050
	Total				720,500
Second Wartime Standard Vesse	Cargo	2A	6,600	10.0	798,600
	Cargo	2D	2,300	9.0	188,600
	Cargo	2E	870	7.5	364,530
	Tanker	2TL	10,000	13.0	280,000
	Tanker	2TM	2,850	9.5	96,900
	Tanker	2ET	870	7.0	117,450
	Total				1,846,080
Third Wartime Standard Vessels	Cargo	3A	7,200	12.0	0
	Cargo	3B	5,000	14.0	0
	Cargo	3D	4,700	12.0	3,000
	Cargo	3E	870	7.5	
	Tanker	3TL	10,000	16.0	30,000
	Tanker	3ET	870	9.5	
	Total				33,000

Source: Onozuka (1962), pp.116-117; Toyo Keizai Shinpo-sha (1950), p.268.

Note: Quantities of 3E and 3ET are included in 2E and 2ET, respectively.

Table 3　Quantity of building merchant ships and Naval ships by Mitsubishi Heavy Industry Co. and its Nakasaki Shipyard

	Merchant ships					Naval ships				
	Japan total	Mitsubishi Heavy Industries Co.				Japan total	Mitsubishi Heavy Industries Co.			
		Total	Share in Japan (%)	Nagasaki Shipyard	Share in Mitsubishi Heavy Industries Co.		Total	Share in Japan (%)	Nagasaki Shipyard	Share in Mitsubishi Heavy Industries Co.
1935	141,920	75,174	34.2	48,555	64.6	17,229	10,335	49.3	8,500	82.2
1936	246,735	64,691	12.5	30,838	47.7	11,655	2,430	0.0	0	0.0
1937	428,188	151,426	17.8	76,102	50.3	37,099	1,855	0.0	0	0.0
1938	401,090	124,124	12.9	51,713	41.7	27,741	12,134	30.6	8,500	70.1
1939	333,431	99,061	14.1	46,971	47.4	22,080	8,989	38.5	8,500	94.6
1940	307,161	96,314	16.2	49,848	51.8	47,618	25,590	21.8	10,360	40.5
1941	241,090	63,950	12.0	28,888	45.2	88,582	14,020	0.0	0	0.0
1942	293,059	80,429	8.5	24,777	30.8	164,935	100,539	54.5	89,940	89.5
1943	800,535	234,766	12.3	98,753	42.1	109,183	46,111	32.9	35,940	77.9
1944	1,730,388	467,464	10.4	179,506	38.4	204,759	63,401	20.5	41,970	66.2

Source: Toyo Keizai Shinpo-sha (1950), pp.270-271.

Table 4 Quantity of merchant ships built at Nagasaki Shipyard by type of ships

		Total	1TL	1TM	2TL	2TM	3TL	Others
GT	FY 1942	54,001	0	0	0	0	0	54,001
	FY 1943	125,270	62,805	26,167	30,723	0	0	5,575
	FY 1944	152,141	0	0	142,176	0	9,965	0
%	FY 1942	100.0	0.0	0.0	0.0	0.0	0.0	100.0
	FY 1943	100.0	50.1	20.9	24.5	0.0	0.0	4.5
	FY 1944	100.0	0.0	0.0	93.5	0.0	6.5	0.0

Source: Nishi-Nihon Jukogyo Co. (1951).

Table 5 Amount of investment in the shipbuilding sector approved by the director meeting of Mitsubishi Heavy Industries Co.

thousand yen, %

	Total	Nagasaki	Share of Nagasaki
1936 FY	12,241	10,156	83.0
1937	11,428	8,294	72.6
1938	18,902	2,739	14.5
1939	11,000	6,337	57.6
1940	5,016	1,204	24.0
1941	46,500	19,655	42.3
1942	40,010	7,634	19.1
1943	58,982	18,852	32.0
1944	82,798	55,701	67.3

Source: Shiba (1987), p.31, 51.

Table 5 Amount of investment in the shipbuilding sector approved by the director meeting of Mitsubishi Heavy Industries Co.

Table 6 Decomposition of days for building a ship

	(1)		(2)	
ln(GT)	58.686	(4.18)	58.351	(6.27)
1TL	-82.704	(-2.58)	-87.494	(-2.98)
1TM	-60.098	(-1.78)	-65.120	(-2.09)
2TL	154.865	(-6.28)	-160.184	(-7.02)
3TL	-145.492	(-2.23)	-153.943	(-4.08)
2A			-189.851	(-10.17)
Cargo	-51.569	(-3.57)	-35.460	(-3.13)
Tanker	-105.439	(-4.86)	-90.524	(-4.74)
Kobe			14.681	(1.12)
Cons.	-179.382	(-1.42)	-186.404	(-2.22)
Obs.	118		178	
AdR^2	0.654		0.670	

Note : t-values are in parentheses.

Table 7 Increase in the range of electric welding

Number of ship	889	911	917	938	942	945	975	980
Type of ships	Ordinary	1TL	1TM	2TL	2TL	2TL	2TL	3TL
Weight of ship ton	2,467	4,120	2,176	3,520	3,520	3,520	3,520	3,550
Lengh of welding／m/ton	8.3	6.6	8.6	7.4	7.7	8.0	8.6	11.1
Number of rivets／rivets/ton	211	158	175	143	139	130	122	115

South: Nagasaki Shipyard, “Nagasaki Zosenjo senji zosen-shi” (History of shipbuilding at the Nagasaki Shipyard during the war".