ELSEVIER

Japan and the World Economy 11 (1999) 1–27

Japan and the WORLD ECONOMY

Comparative productivity of Japanese and U.S. steel producers, 1958–1993

Marvin B. Lieberman[a,*], Douglas R. Johnson[b]

[a] *John E. Anderson Graduate School of Management, UCLA, Los Angeles CA 90024-1481, USA*
[b] *Department of Business Administration University of Illinois at Urbana-Champaign, Illinois, USA*

Manuscript received April 1996; Final version received April 1998

Abstract

Using historical, firm-level data, this study compares the productivity of Japanese and U.S. integrated steel producers. In recent decades Japanese producers have demonstrated higher labor productivity than their U.S. counterparts, due largely to higher investment. Calculations of multi-factor productivity suggest that the American firms, nevertheless, maintain a small advantage in overall efficiency. One implication is that steel producers in Japan may have invested too heavily in capital equipment, while American companies invested too little. In both countries, productivity differences among integrated steel producers appear small relative to those found among auto manufacturers. © 1999 Elsevier Science B.V.

JEL classification: D24; L61

Keywords: Productivity; Steel industry; Investment

1. Introduction and overview

In recent decades the steel industries of Japan and the United States have exhibited substantial differences in productivity, a fact widely recognized by prior researchers and the business press.[1] This article compares the historical productivity performance of the major U.S. and Japanese steel companies since the 1950s. It documents the dramatic rise of

* Corresponding author. Tel: +1-310-206-7665; fax: +1-310-206-3337; e-mail: marvin.lieberman@anderson.ucla.edu

[1](Barnett and Schorsch (1983), Chapter 5) give a detailed industry-level comparison of the productivity of U.S. and Japanese steel producers through the early 1980s. Baber et al. (1993) compare various productivity and financial ratios for the U.S. and Japanese steel industries in the 1970s and 1980s, as derived from company financial data. Yonekura (1994) gives an excellent historical account of the development of the Japanese steel industry.

PII: S0922-1425(98)00032-2

Japanese efficiency and recent improvements by U.S. producers. Distinct growth paths are found for the steel industries of the two countries, linked to differences in investment behavior. Boosted by new technology and large-scale plants, Japanese steelmakers have long surpassed the U.S. level of labor productivity. Nevertheless, our calculations of the multi-factor productivity, which control the heavy capital investment of Japanese producers, suggest that U.S. steelmakers may hold continued advantage in overall efficiency.

Numerous studies have drawn international productivity comparisons at the country or industry level.[2] Such comparisons mask the variations in productivity among firms within a given country, which are often substantial. This study goes beyond prior work by estimating productivity at the level of individual firms. The extent of productivity variation among steel companies is compared with similar variation among auto manufacturers in Japan and the United States.[3]

Our productivity measures are derived primarily from information in company annual financial reports. We demonstrate that meaningful inter-company productivity comparisons can be performed using these public data. Our sample covers the six Japanese integrated steelmakers,[4] six U.S. integrated producers, and one U.S. minimill firm.[5] Thus, we have good coverage of the integrated sector in both countries, but only a token coverage of minimill producers. For most companies, annual data were collected for the period from 1958 to 1993.[6]

1.1. Industry Background

Since the end of World War II, Japanese competitors have beleaguered the U.S. steel industry, once considered an example of American industrial strength. In 1960, American producers supplied more than one-fourth of the total world market for steel, but by the early 1980s the U.S. share had fallen to only one-tenth. As the American domination of the world steel market declined, the Japanese ascended. The 1959 steelworkers strike gave the Japanese a toehold in the important U.S. market, and exports steadily expanded. The Japanese share of the world steel market grew from approximately 6% in 1960 to 16% by 1983.

There are numerous explanations for the decline of the U.S. integrated steel industry.[7] The failure of American firms to adopt improvements in steelmaking technology has often

[2]For example, Jorgenson et al. (1987) make industry-level productivity comparisons for Japan and the U.S..

[3]A related study, Lieberman et al. (1990), assesses productivity differences among U.S. and Japanese auto producers.

[4]The six Japanese producers in the sample are Kawasaki, Kobe, Nippon, Nisshin, NKK, and Sumitomo. Nippon Steel was created in 1970 through the merger of Fuji Steel and Yawata Steel. We represent Nippon steel as a merged entity going back to 1957, the earliest year of our data. Nisshin has operated at a relatively small scale and is, therefore, often excluded from the listings of the major Japanese steel producers.

[5]The six U.S. integrated producers are Bethlehem, Inland, National, Republic, Wheeling-Pittsburgh and USX. The minimill producer is Nucor.

[6]Exceptions are Republic, which was purchased by LTV in 1982, and National. NKK purchased 50% of National in 1984, increasing its ownership to 70% in 1990. In addition, USX failed to report unconsolidated information on its steelmaking operations for several years following the merger of U.S. Steel and Marathon Oil in 1981.

[7]See, for example, Crandall (1981), Barnett and Schorsch (1983), Tiffany (1988) and Hoerr (1988).

been identified as one of the central causes of decline. U.S. firms were often the early adopters of technologies that currently dominate the production of steel in the world, but U.S. companies failed to thoroughly implement these technologies as quickly as the Japanese and other foreign competitors. Faced with growing pressure from imports and unionized labor in a commodity product industry with high fixed costs, U.S. integrated producers responded by cutting investment in new plants and equipment. According to O'Brien (1986, p. 63), "individually, each company could protect itself from potential losses by steadfastly avoiding increases in fixed costs, the precise opposite of the pattern in Japan."

Meanwhile, Japanese producers embraced and implemented the new technologies for steel production in facilities of ever-larger scale. Rapid growth of the domestic market allowed new plants to be built by competing firms without creating overcapacity. Through the 1950s and 1960s the Japanese steel industry grew in a cycle of "investment calling for investment" (Yonekura, 1994, p. 224) as firms aggressively substituted capital for labor. The race to ever-larger and more capital-intensive facilities was fueled in part by MITI, which believed that "the route to...securing world market share in steel was to invest continually in more efficient means of production." Moreover, MITI linked "the right to build new steel capacity explicitly to a firm's demonstrated efficiency," which was typically defined on the basis of labor and materials productivity (O'Brien, 1986, p. 42). The net result was a trajectory that emphasized labor-saving technology and was forward-looking, as compared with the relative stagnation of the U.S. steel industry. According to Yonekura (1995), in adopting new innovations American managers tried to make decisions "in a rational way, while their Japanese counterparts relied more on their intuition."

These patterns began to shift in the 1980s, as Japanese growth slowed and surviving U.S. integrated producers staged a partial comeback. The U.S. producers shut their older mills and invested in their remaining plants to bring them up to world technological standards. In the minimill sector, firms such as Nucor grew rapidly, and they now rank among the most efficient steelmakers in the world. Following the lead of these U.S. companies, minimills have been expanding in Japan.

In recent years, integrated producers in both Japan and the U.S. have faced a common problem: how to achieve productivity growth in an environment with stagnant or declining demand, where productivity gains imply further cuts in employment. Fig. 1(A) and (B) show the number of workers employed by Japanese and U.S. steel companies since the late 1950s. Japanese employment grew through the 1960s but has been falling since the early 1970s. For the American integrated producers, employment has declined over the entire period, with dramatic layoffs in the 1980s. In both countries there has been a tendency for the largest producers to cut back proportionately more than smaller firms.

1.2. Diversification and subcontracting

To offset the decline in steel demand, many of the integrated firms have sought diversification. Extensive diversification can make it difficult to interpret productivity figures derived from company financial data, which may cover a range of activities outside of steelmaking. But, fortunately, for purposes of this study, most of the integrated

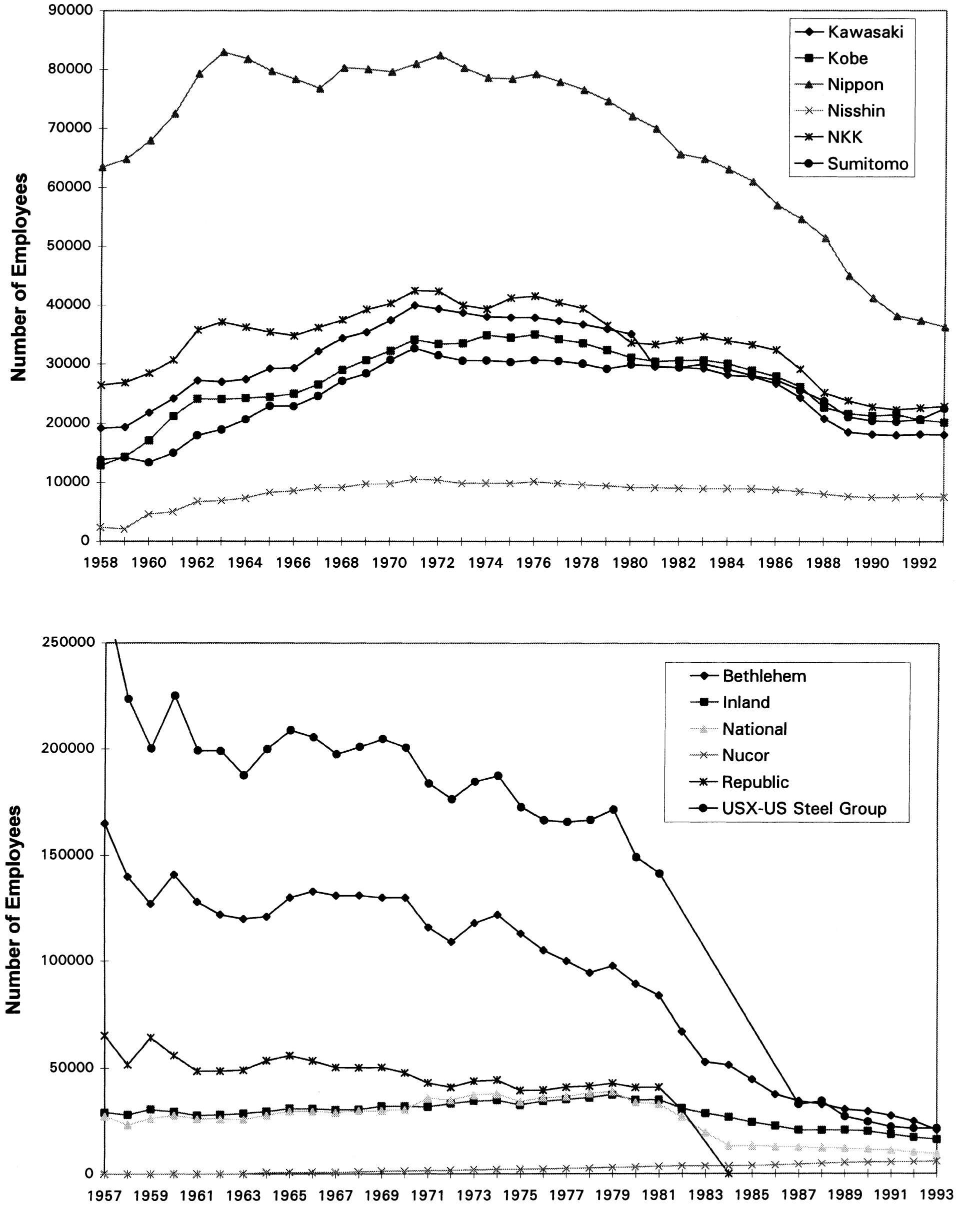


Fig. 1. (A) Steel company employment – Japan; (B) Steel company employment – U.S.

Table 1
Non-steel operations and 'dispatched' workers of Japanese steel companies[a]

Company	Basic steel as % of total sales		Major non-steel businesses (1991)	Employees 'dispatched' to unconsolidated subsidiaries	
	1981 (%)	1991 (%)		1981 (%)	1991 (%)
Kawasaki	89	77	Engineering (18%); Chemical products (5%)	14	37
Kobe	58	49	Aluminum (21%); Machinery (30%)	2	17
Nippon	87	86	Engineering (12%)	5	31
Nisshin	100	100	—	0	0
NKK	82	75	Engineering (25%)	3	19
Sumitomo	91	87	Engineering (10%); Electronics (3%)	4	32

[a] As reported in company unconsolidated financial statements (Yuka Shoken Hokokusho). The Japanese steel producers typically hold extensive investments in diversified subsidiaries, which are not included.

companies report financial information that is fairly specific to the steel sector.[8] Tables 1 and 2 show the breakdown of revenues and employment for Japanese and U.S. steel producers in 1981 and 1991, based on the data sources used in this study. For most firms, the vast majority of revenues have been derived from the sale of iron and steel products. The exceptions are Kobe Steel, whose non-steel revenues have historically accounted for about half of the company's total, and Inland Steel, whose steel distribution business has grown to represent nearly half of company revenues (one-fourth of total employment). But for all other firms in the sample, diversification is unlikely to induce serious distortion of the productivity estimates.

The last two columns of Table 1 give some additional pertinent information on the diversification and employment practices of Japanese steel companies. While U.S. steelmakers have been able to shed workers through layoffs, Japanese producers have been constrained by the custom of lifetime employment in Japan. To deal with this situation, in the 1980s the Japanese steelmakers began to embrace a practice of 'dispatching' excess workers to their subsidiaries. Table 1 reveals that by the 1990s, Kawasaki, Nippon and Sumitomo had 'dispatched' more than 30% of their labor forces in this way. These dispatched workers are not engaged in steelmaking, and they are excluded from the employment data shown in unconsolidated financial reports. Hence, we have omitted these workers from the productivity calculations in this study.[9] Nevertheless, the Japanese steel companies remain responsible for these workers, whose effective utilization remains a vexing problem.

A further issue affecting the measurement of productivity is the practice of subcontracting. This practice has been particularly prevalent in Japan, where more than half of the workforce in newer mills may be subcontracted (Hasegawa, 1996, pp. 90–97). Subcon-

[8] In the U.S., for example, USX now releases separate financial data for its Steel Group. The Japanese companies generally report two sets of financial data: consolidated and unconsolidated. The unconsolidated data, which are fairly specific to the steel business, are used in this study.

[9] During the 1980s the Japanese boosted labor productivity by significantly reducing their steelmaking employment. At Nippon Steel from 1980 to 1991 for example, total employment in the company's steelworks fell by more than one-third while steel production declined only 7%, implying a 41% gain in tonnage per worker. If dispatched workers are counted, however, this productivity gain largely disappears.

Table 2
Business mix of American steel companies

Company	1981		1991		
	Steel products as % of total sales	Non-steel businesses	Steel products as % of total sales	Steel products as % of total employment	Non-steel businesses
Bethlehem	90[a]		86	NA	Raw materials sales (<8%); Other steel-related (5%)
Inland	66	Steel service centers (34%)	56	71	Steel service centers (44%)
U.S. Steel/USX	63	Engineering & Fab. (12%); Chemicals (10%); Resource Development (5%)	78	79[c]	Raw materials sales (8%); Diversified businesses (14%)
Wheeling-Pittsburgh	94[b]		96[d]	NA	

[a] Includes fabricated products (14%).
[b] Includes fabricated products (12%).
[c] Includes ore operations (7%).
[d] Includes fabricated products (24%).
NA: Not available

tracting has also been increasing in the U.S.. The existence of subcontracting leads to an overstatement of labor productivity using measures of tonnage output, but less serious bias when output is measured in terms of 'value-added.'[10] Data on subcontracting rates by company are not available.

The remainder of this paper is organized as follows. Section 2 focuses on labor productivity. It presents historical data on 'man-hours per ton' as well as estimates based on the concept of 'value-added,' which is the preferred approach in this study. Section 3 considers the role of capital input. This section describes our methodology for estimating the capital stock of each company, which is used to assess the level of fixed investment per worker and capital productivity. We show that much of the labor productivity differential between Japan and the U.S. can be accounted for by differences in the level of capital investment per worker. Section 4 gives estimates of multi-factor productivity (MFP), based on labor and capital inputs combined. Section 5 assesses the extent of productivity differences among steel companies within each country, comparing these results with related data on the automotive industry. Section 6 summarizes the findings and concludes. An Appendix provides supplementary information, including a discussion of the methodology for computing MFP.

2. Labor productivity estimates

The concept of 'productivity' refers to the efficiency with which physical inputs are converted to useful outputs.[11] *Single-factor* productivity ratios give output per unit of input of a single type, such as labor or capital. *Multi-factor* productivity ratios are computed by dividing output by a weighted sum of input types. This study presents several measures of productivity, including labor productivity (man-hours per ton, or preferably, 'value-added' per worker-hour), capital productivity (value-added per unit of capital stock), and a weighted average, representing 'multi-factor' productivity.

In this section we give two alternative estimates of labor productivity. First, we report labor productivity measured in terms of 'worker-hours per ton produced.' This is the standard way of reporting productivity in the steel industry, but it has some serious shortcomings. The second measure of labor productivity is the firm's 'value added' per employee. This measure also has drawbacks, but these are less severe.

These two methods for assessing labor productivity differ in terms of the output measure used ('tonnage' versus 'value added'). However, both utilize the same measure of labor input. Labor input was taken as the total hours worked by the firm's employees during the year. To calculate this measure, the average number of persons employed by

---

[10]Subcontracting implies a shift in labor input from the firm's employees to outside workers. This typically leads to an overestimate of labor productivity when measured in 'tons per employee.' Productivity measures based on 'value-added' are less likely to be affected, given that the subcontracted work is excluded from both the numerator and the denominator of the productivity ratio. Some bias may occur, however, if low productivity tasks are shifted to subcontractors while high productivity jobs are retained by the firm's employees.

[11]Note that firms with superior productivity may not enjoy an advantage in cost. Relative costs are jointly determined by productivity, input prices and exchange rates.

each firm was multiplied by an estimate of the number of hours worked annually by each employee.[12]

2.1. Hours per ton produced

Fig. 2(A) gives historical estimates of labor productivity, in hours per metric ton produced, for each of the Japanese companies.[13] In the early 1960s, the Japanese firms required 15 to 30 worker-hours per ton of steel; but by the early 1970s this figure had fallen to about 5 h per ton. In more recent years Japanese productivity measured in hours per ton has shown only small incremental gains. One firm, Kobe Steel, appears to be a low-productivity outlier, but this is largely due to Kobe's extensive diversification into non-steel activities.

Fig. 2(B) gives annual estimates of labor productivity, in hours per metric ton produced, for the American companies. From 1958 to 1964 U.S. labor productivity rose significantly (from a range of 12 to 23 labor-hours per ton in 1958, to a range of 7 to 14 h per ton in 1964). Subsequently, however, productivity stagnated in the U.S. for nearly two decades. Then, with the restructuring activities of the 1980s, labor productivity began to improve again, ultimately falling below 5 h per ton for some producers. Nucor, the minimill firm, is shown to have the best productivity performance since the 1980s. At the other extreme, Inland Steel appears as an outlier with low labor productivity in recent years, although this is partly an artifact of Inland's increasing employment in downstream distribution activities.

Barnett and Schorsch (1983) performed a detailed historical analysis of man-hours per ton in the U.S. and Japanese steel industries. Table 3 compares our estimates, based on annual report data, with the Barnett and Schorsch calculations for cold- and hot-rolled sheet, two major product categories. For the Japanese, our estimates track the Barnett and Schorsch figures quite closely and generally lie between their estimates for cold- and hot-rolled sheet. For the American companies, our figures lie above the Barnett and Schorsch estimates and track more roughly. The discrepancy is due in part to the fact that the U.S. producers have maintained considerable upstream integration into mining and transport operations, which are included in our man-hour figures but not those of Barnett and Schorsch.[14]

While such comparisons are insightful, there are numerous problems with 'worker-hours per ton produced' as a measure of labor productivity. When computed from corporate data,

---

[12]The data on the average number of employees are from company annual reports. The working hours figures are country-level data pertaining to blue collar employees; we assumed that they apply to white collar workers as well. Information on monthly working hours in the Japanese steel industry was obtained from *Historical Statistics of Japan*. Data on weekly working hours in the U.S. steel industry was obtained from annual reports of the American Iron and Steel Institute.

[13]Strictly speaking, labor productivity is represented by 'tons per worker-hour,' the reciprocal of what is shown in Fig. 2A and Fig. 2B.

[14]U.S. producers have been shedding these upstream operations over time, but they remain substantial relative to the Japanese, whose raw materials are procured by contract. If upstream ore and coal operations could be removed from the data, our hours per ton estimates for 1993 (4.2 h/ton for the Japanese versus 4.9 h for the Americans) would probably swing in favor of the U.S. companies.

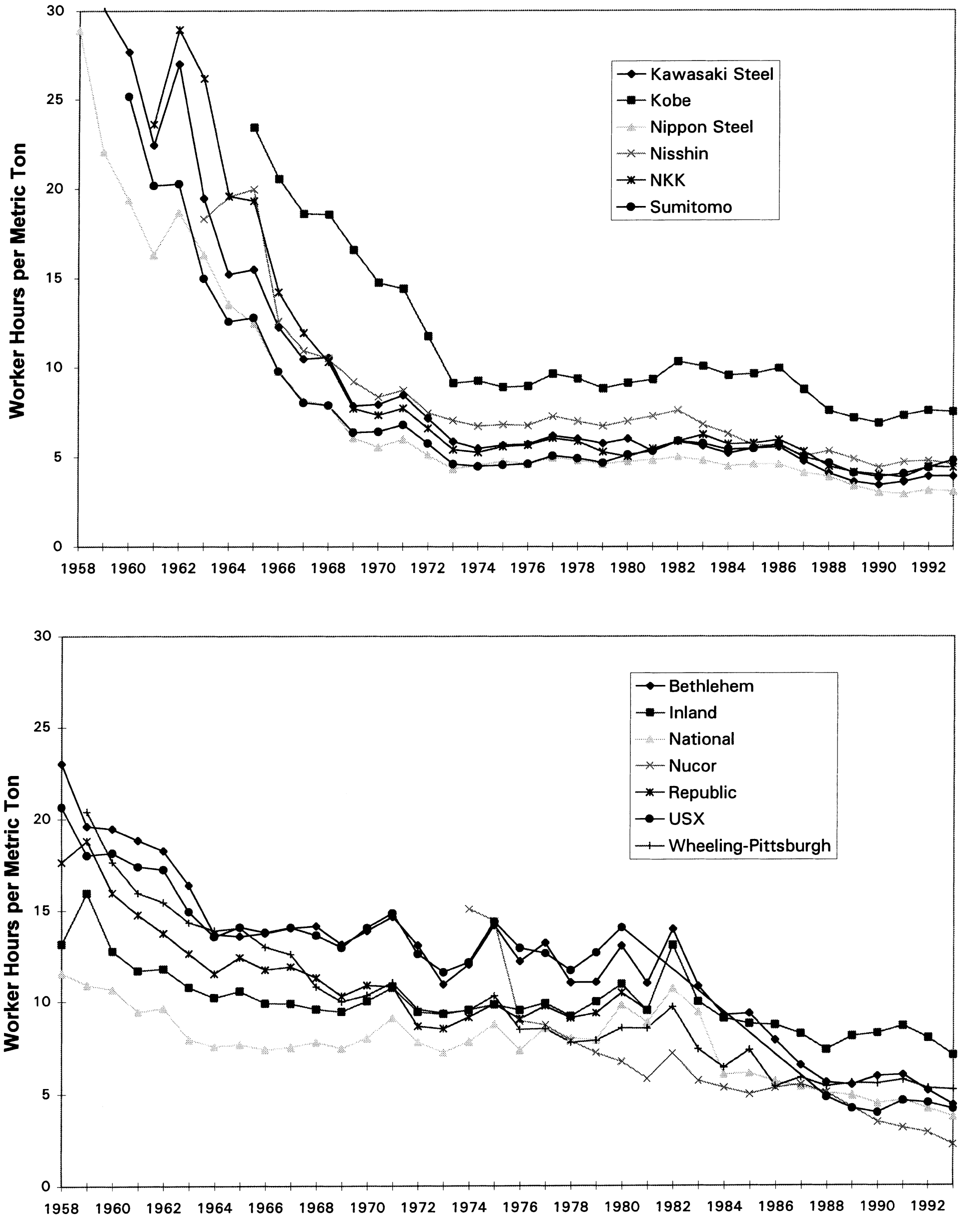


Fig. 2. (A) Worker-hours per ton produced – Japan; (B) worker-hours per ton produced – U.S.

the measure fails to account for differences in the extent of diversification and vertical integration. Even when firms are highly focused on steelmaking, tonnage-based measures make no adjustment for differences in steel 'quality' and the extent of finishing

Table 3
Comparison of hours per ton estimates: Barnett/Schorsch calculations vs. data from annual reports

	Annual report data		Barnett/Schorsch hours per ton estimates[a]	
			Cold-rolled sheet	Hot-rolled sheet
Japan	1958	37.6[c]	35.7	27.0
	1964	16.1[c]	19.1	14.4
	1972	6.4[c]	8.2	6.2
	1980	5.6[c]	5.8	4.4
	1993	4.2[c]	NA	NA
U.S.	1958	17.2[d]	11.6	9.2
	1964	11.7[e]	10.1	7.9
	1972	10.2[e]	8.1	6.2
	1980	11.2[e]	7.2	5.4
	1993	4.9[f]	NA	NA

[a] Barnett and Schorsch (1983), Table 5.5.
[b] Average of data in Figure 2A for Kawasaki and Nippon.
[c] Average of data in Figure 2A for Kawasaki, and Nippon, Nisshin, NKK and Sumitomo.
[d] Average of data in Figure 2B for Bethlehem, Inland, National, Republic and USX.
[e] Average of data in Figure 2B for Bethlehem, Inland, National, Republic, USX and Wheeling-Pittsburgh.
[f] Average of data in Figure 2B for Bethlehem, Inland, National, USX and Wheeling-Pittsburgh.
NA = Not Available.

operations.[15] Moreover, the recent reduction in hours per ton shown for U.S. producers is partly a reflection of the current trend towards outsourcing. Increased subcontracting will normally lead to a reduction in a company's worker-hours per ton, even though there may be no change in the firm's true productivity.

Given these biases, the 'worker-hours per ton' figures are likely to underestimate the recent growth in labor productivity in Japan and overestimate such growth in the U.S.. This is because 'value-added per ton' rose appreciably in Japan during the 1970s, whereas in the U.S., 'value-added per ton' has fallen due to outsourcing, particularly during the 1980s. Appendix 1A and Appendix 1B plot these changes in 'value-added per ton,' measured in constant, 1980 dollars, assuming a 'purchasing power parity' exchange rate. In Japan, value-added rose from an average of about \$150 per ton during the 1960s to about \$200 per ton during the 1980s, reflecting changes in product mix (increases in quality and extent of finishing operations). For the U.S. producers, value-added fell from an average of about \$200 per ton during the 1960s and 1970s to about \$150 per ton during the 1990s, as firms expanded their use of subcontracting. The decline is particularly striking for USX.[16]

[15]A related problem is that tons produced exceed tons shipped, so output is overstated. Advances such as continuous casting have reduced this differential over time, yielding productivity gains that are not reflected in the figures on 'worker-hours per ton produced.'

[16]USX made substantial reductions in vertical integration through the mid-1960s and again in the early 1980s. 'Value-added' fell from about 75% of the firm's revenues in the 1950s to about 25% in the 1990s.

2.2. Value-added per worker-hour

In this study, we emphasize the measurement of output in terms of the 'value-added' by the firm during each fiscal year. 'Value-added' is simply the difference between the firm's total sales and its purchases of raw materials and contracted services. In each year, the firm's nominal value-added was calculated as the sum of all employee compensation, depreciation, operating income, and (non-income) taxes.[17] These data were collected from the annual financial reports of both Japanese and U.S. firms. To arrive at real value-added, nominal value-added was divided by a steel price deflator.[18] Using these deflators, all U.S. values were converted to constant 1980 dollars, and all Japanese values were converted to constant 1980 yen. In addition, the Japanese figures were expressed in constant 1980 U.S. dollars, based on an assumed exchange rate of 200 yen per dollar in that year, as explained below.

Fig. 3(A) and (B) plot the labor productivity of Japanese and U.S. producers, respectively, based on our estimates of value-added per worker hour. The growth shown for the Japanese is dramatic: labor productivity increased roughly ten-fold over the sample period. By comparison, a slight growth with a long period of stagnation from the mid-1960s through the early 1980s is shown for the Americans. U.S. labor productivity began rising again in the 1980s and experienced a major boost in the final year of the sample. At the same time, Japanese productivity has been falling since 1990, reflecting the recession in Japan.

Fig. 3(A) and (B) show differences among producers within each country, as well as differences between the two countries.[19] In Japan, Kawasaki, NKK and Nisshin appear to have had the highest labor productivity in recent years. (These firms also have the highest capital investment per worker, as discussed in Section 3.) In the U.S., Nucor, the minimill producer, has been the productivity leader. Among the integrated firms, Bethlehem had the lowest labor productivity during the 1950s and early 1960s but appears to enjoy the highest labor productivity today.

The growth in labor productivity shown for the Japanese steelmakers during the most recent decade is in contrast with common perceptions of the industry, and one caveat is essential. As discussed in the previous section, our productivity ratios exclude workers who were 'dispatched' to unconsolidated subsidiaries, a practice that became increasingly frequent during the 1980s. This practice became particularly prevalent in the 1985-90 period and accounts for most of the concurrent gains in productivity shown in Fig. 3A. If 'dispatched' workers are added back into the steel company totals, the productivity gains of the 1980s largely disappear.

---

[17]Equivalently, value added can be computed by subtracting the costs of purchased materials, services and utilities from the firm's total revenue. However, complete information on these items is seldom provided in company financial reports, so the summation approach is preferable.

[18]For the U.S. firms, we used the steel price deflator reported in the *Economic Report of the President* (United States Government). For Japanese companies, we used the deflator for iron and steel published in *Historical Statistics of Japan* and *Economic Statistics Annual* (Bank of Japan, 1985).

[19]However, these differences among firms appear smaller than those documented for the U.S. and Japanese auto industries in Lieberman et al. (1990).

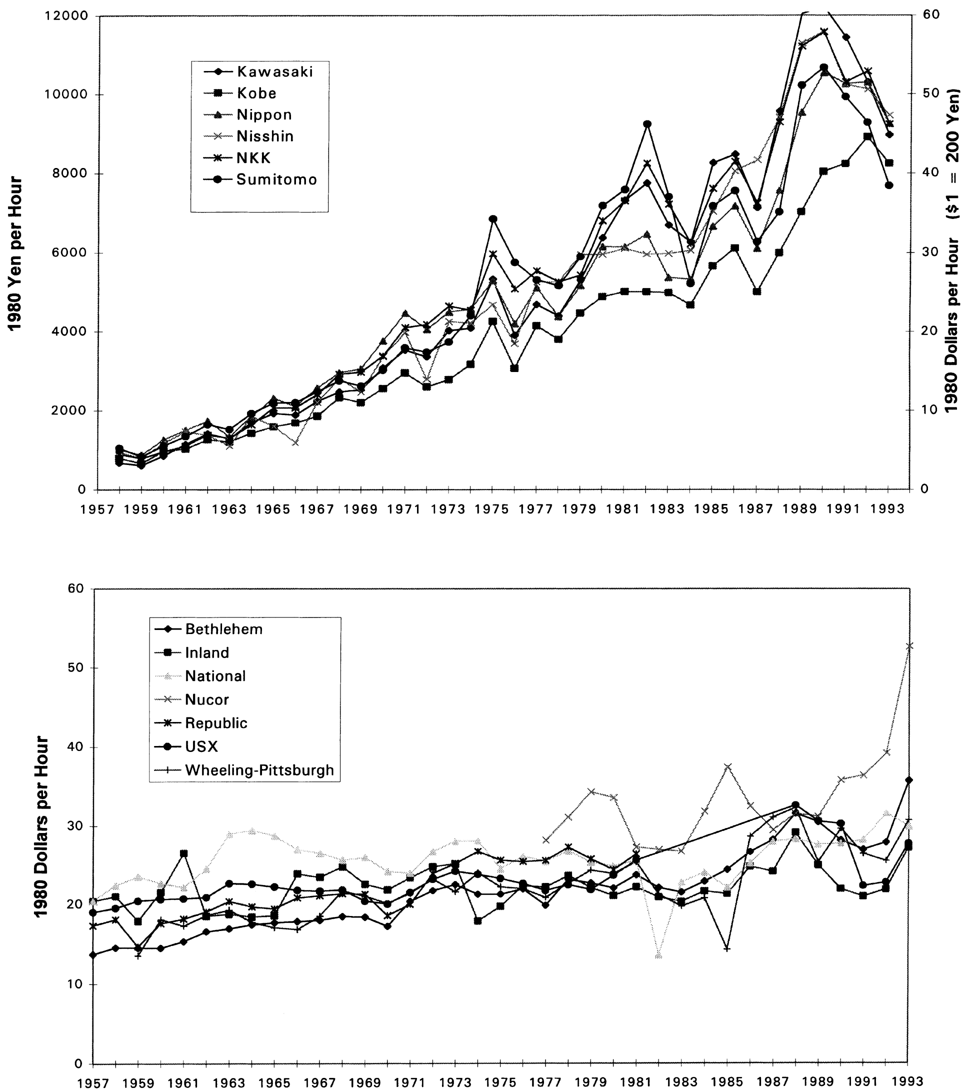


Fig. 3. (A) Value-added per worker-hour – Japan; (B) value-added per worker-hour – U.S.

2.3. *Conversion of Japanese values into constant U.S. dollars*

An objective of this study is to make absolute productivity comparisons between producers in the two countries, based on a common currency. To allow such comparisons, the vertical scale on the right-hand side of Fig. 3A converts the Japanese labor productivity

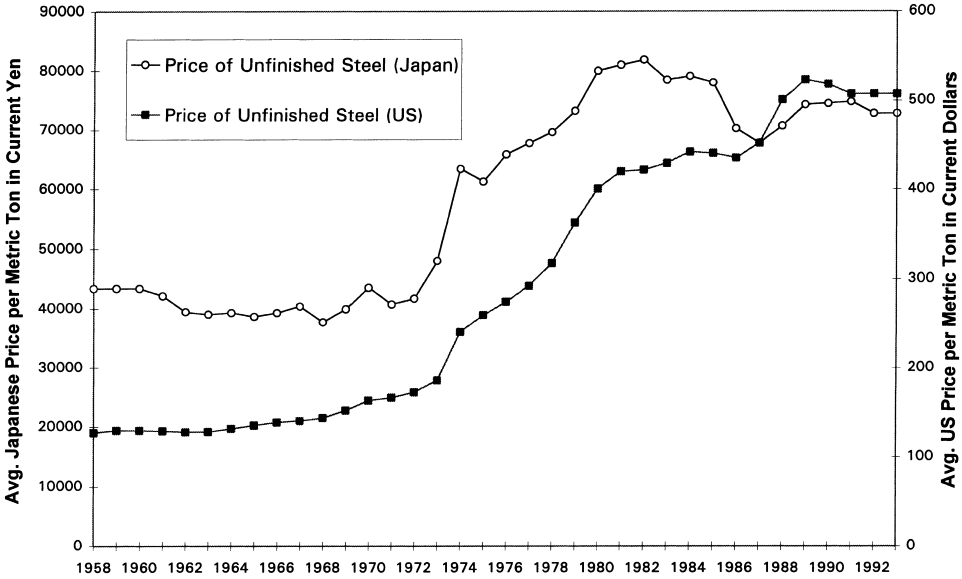


Fig. 4. Steel prices in Japan and the U.S.

values from constant yen to constant U.S. dollars. This conversion was made using a 'purchasing power parity' exchange rate, derived as follows.

Given that steel is a reasonably homogeneous commodity, it is possible to define a yen/dollar exchange rate that equates the price of steel in the two countries at any point in time. Such an exchange rate is known as a 'purchasing power parity' (PPP) rate (as distinguished from the actual exchange rate prevailing in the financial markets). In this study, we use a purchasing power parity rate to convert Japanese yen values into constant 1980 dollars. Figs. 4 and 5 illustrate the procedure for computing this rate. Fig. 4 plots the average wholesale price of unfinished steel in Japan and the U.S., measured in current yen and current dollars, respectively. Fig. 5 plots the PPP exchange rate derived from these two sets of price data. The PPP rate was obtained in each year by dividing the Japanese steel price (in current yen per metric ton) by the U.S. steel price (in current dollars per metric ton).[20] In 1980, the base year for the calculations, the market price of unfinished steel in the U.S. was \$400.63 per ton, while the price for similar steel in Japan was 80 000 yen per ton. Simple division gives an exchange rate of 200 yen per dollar in that year. This closely approximates the actual market exchange rate prevailing at the end of 1980, shown in Fig. 5.

Using these PPP conversions, it is possible to directly compare the labor productivity of Japanese and U.S. steelmakers. As reflected by the right-hand scale of Fig. 3(A), the Japanese value-added per worker-hour during the most recent five-year period ranged from approximately \$30 to \$60. Over the same period, the comparable figure for the U.S.

[20]The U.S. data are from the 'Annual Review of Prices' published in *Iron Age, 1980.* The data for Japan are derived from *Historical Statistics of Japan* and *Economic Statistics Annual.*

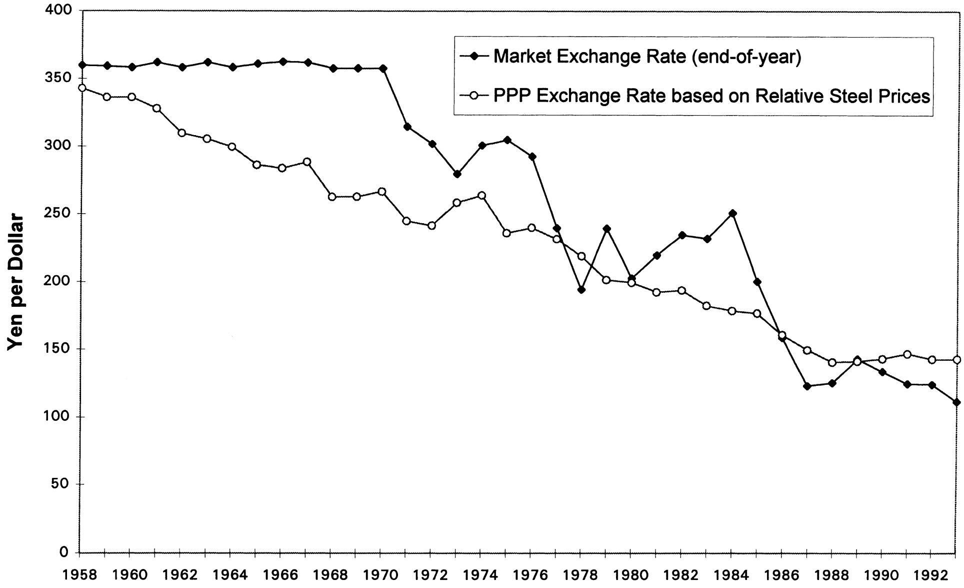


Fig. 5. Yen/Dollar exchange rates.

integrated producers ranged from about \$20 to \$35.[21] Thus, the Japanese labor productivity continues to be nearly twice as great as that observed for U.S. firms. A primary reason for this difference, discussed below, is the substantially higher level of capital investment per worker in Japan.

While Japanese steelworkers have much higher labor productivity than their U.S. counterparts, average hourly compensation is now similar for the two countries.[22] The observation that the Japan–U.S. differential in labor productivity fails to be reflected in a wage differential is consistent with the fact that Japan's labor productivity advantage is largely derived from high levels of investment per worker. We now turn to an assessment of relative capital investment and a comparison of capital productivity.

3. Investment per worker and capital productivity

High rates of investment in new plants and equipments are the major reason for Japan's rapid growth in labor productivity. In this section we examine capital investment per worker and capital productivity. Capital productivity is more difficult to compute and somewhat more arbitrarily measured than labor productivity, since it requires procedures for evaluating the magnitude of capital input.

[21]Both sets of figures are in 1980 dollars.

[22]Hourly compensation includes all benefits, pensions, and payroll taxes paid by the firm.

3.1. Measurement of capital input

One measure of a firm's capital stock is the value of its net property, plant and equipment, as reported in annual financial statements. However, this measure is subject to numerous accounting biases, which can vary among firms and countries. As an alternative, we estimated the firms' capital stocks using the perpetual inventory method, which is commonly used in econometric studies.

We constructed a real capital stock series for each firm using a perpetual inventory capital adjustment equation:

$$K_t = (1 - d)K_{t-1} + I_t \tag{1}$$

where K_t is the real capital stock in year t, d is the annual rate of economic depreciation,[23] and $I(t)$ is the firm's gross investment in year t, adjusted for inflation. Gross investment is defined as the change in the firm's undepreciated capital stock[24] since the preceding year. To deflate gross investment we used the gross domestic capital formation deflator (from *Economic Statistics Annual*) for Japan, and the implicit price deflator for total nonresidential gross private domestic investment (from 'The Economic Report of the President') for the United States. We assumed that r, the real depreciation rate, was equal to 10%. We judged this rate to be reasonable given the composition of the gross capital stock and the rates of economic depreciation estimated by Hulten and Wykoff (1981).

Eq. (1) recursively updates the capital stock based on new investment in each year. The initial capital stock values, K_0, for each Japanese and U.S. firm were established as the earliest available reported figures for net property, plant, and equipment. In most cases, the net property, plant, and equipment data for the firms extend back to well before 1957.[25]

The perpetual inventory method is typically used to estimate capital stocks in situations where gross investment is positive in each year. For many firms in the U.S. steel industry, however, there have been periods with negative gross investment, due to the sell-off or closure of a large proportion of the firm's steelmaking assets. In the years with negative gross investment, we assumed that the real capital stock, K_t, fell by the same proportion as the firm's gross capital stock (property, plant and equipment, plus accumulated depreciation).[26]

3.2. Capital stock per worker

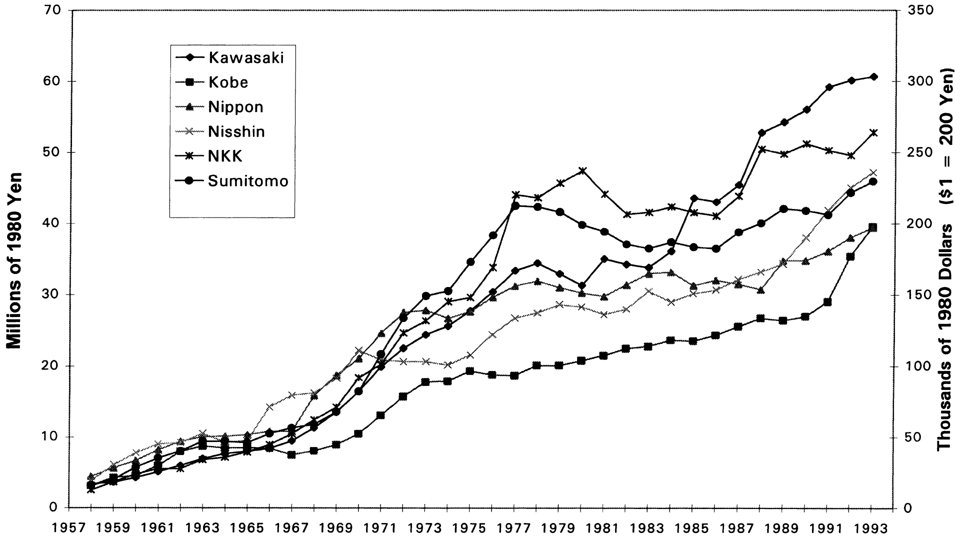
Fig. 6(A) and (B) plot the magnitude of fixed capital per employee (K_t divided by number of employees) in Japan and the U.S., respectively. Fig. 6(A) documents the huge

[23]The depreciation rate, d, is an assumed average rate that applies across all categories of the capital stock. The accounting depreciation shown in the firms' financial statements generally exceeds the true economic depreciation, given the tax incentives for accelerated write-off.

[24]As our measure of gross capital stock, we took the sum of net property plant and equipment, plus accumulated depreciation, as listed in the firm's annual financial reports.

[25]For example, the Bethlehem Steel series extends back to 1939; a capital stock series for Bethlehem was calculated for the period from 1939–1991.

[26]We used a slightly different approach in the case of USX, for which it was necessary to estimate the change in capital stock from 1981 to 1987. During this period many plants were closed by the company, but unconsolidated financial information was not reported.



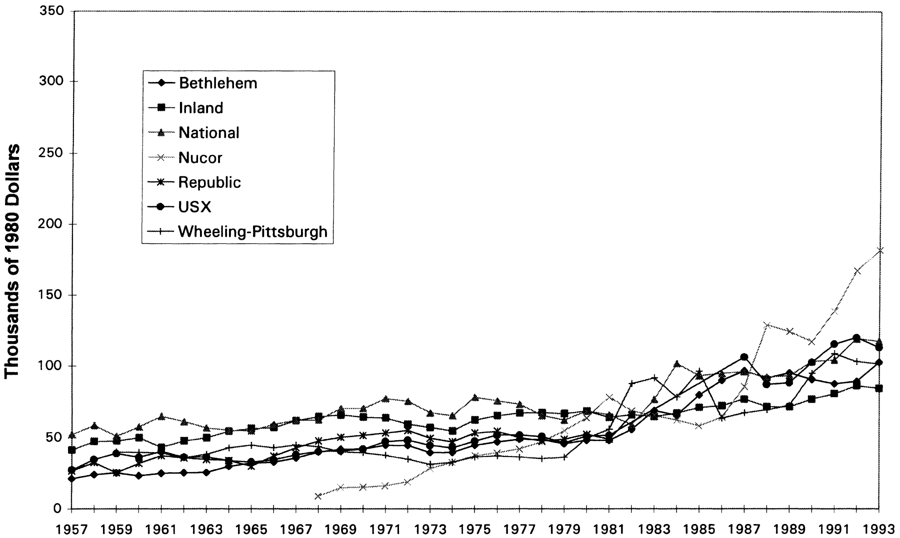


Fig. 6. (A) Fixed capital per employee – Japan; (B) Fixed capital per employee – U.S.

build-up of investment by Japanese steel companies from the 1950s through the late 1970s. By 1980, fixed capital per worker ranged from slightly more than \$100 000 at Kobe, to over \$200 000 at NKK (all figures in constant 1980 dollars). Since then, the capital/labor ratio has nearly doubled at Kawasaki and Kobe, risen more incrementally at Nisshin, and remained stable (or fallen slightly) at Nippon, Sumitomo, and NKK. A comparison of

Fig. 6(A) and Fig. 3(A) reveals that the companies with the greatest investment per worker have tended to enjoy the highest labor productivity.

Relative to the Japanese, fixed investment per worker in the U.S. steel industry has been puny. Comparison of Fig. 6(A) and (B) shows that Japanese capital intensity began to exceed U.S. levels beginning in the mid-1960s. At that time, U.S. fixed investment per worker ranged from about \$30 000 at Bethlehem to about \$60 000 at National and Inland. For the next fifteen years there was little growth in U.S. capital intensity. In 1980, for example, fixed investment per worker remained below \$70 000 at all of the U.S. integrated firms, as compared with \$100 000 to \$250 000 for steelmakers in Japan. But starting in the 1980s the U.S. capital/labor ratio began rising significantly, driven primarily by reductions in employment. By 1993 fixed investment per worker had risen above \$100 000 at all of the surviving firms except Inland.

Nucor, the minimill producer, stands out from the U.S. integrated firms. In the late 1960s and early 1970s Nucor's fixed investment per worker was minimal. By 1993, however, Nucor's capital/labor ratio had risen to nearly twice the level of most U.S. integrated firms and was approaching the levels shown for the Japanese.

3.3. Capital productivity

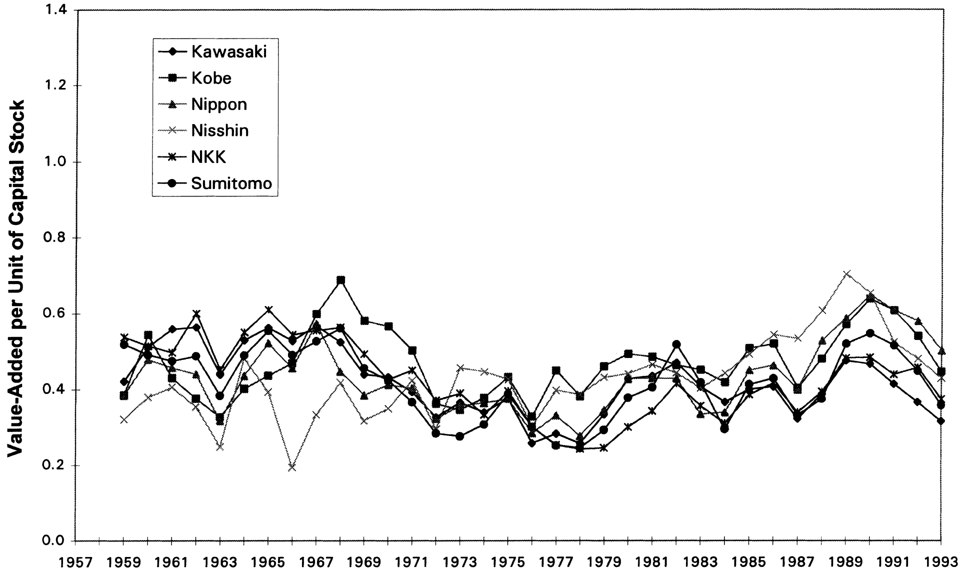
Fig. 7(A) and (B) report measured levels of capital productivity for the Japanese and U.S. firms. Capital productivity is defined as value-added per unit of capital stock.[27] These figures show that the capital productivity of Japanese steelmakers has been roughly half the level of the Americans. Considerable short-term fluctuation is apparent in both countries, stemming from cyclical factors and the 'lumpiness' of major new investments. Net of these fluctuations, capital productivity has remained fairly constant in both Japan and the U.S.. Nevertheless, capital productivity appears to have dipped temporarily in Japan during the 1970s, and it has fallen in the U.S. since about 1980.

With regard to individual firms, within each country there is a tendency for capital productivity to be inversely related to the magnitude of investment per worker. For example, in Japan in recent years, Kawasaki and NKK have had the highest fixed capital per employee and the lowest capital productivity. Among the Japanese firms, Nisshin stands out: its capital productivity was considerably below average during the 1950s and 1960s but rose to become the highest in the industry during the late 1980s.

4. Multi-factor productivity

Labor and capital productivity are only partial indexes and thus, can give misleading indications of changes in the efficiency of a firm. For example, labor productivity can usually be augmented by raising the level of capital input, i.e., at the expense of capital productivity. Labor productivity is the more important of these two measures from the

[27] For the Japanese firms, the vertical scale in Fig. 7A represents yen of value-added per yen of net capital stock. For the U.S. firms, the vertical scale in Fig. 7B represents dollars of value-added per dollar of capital stock.



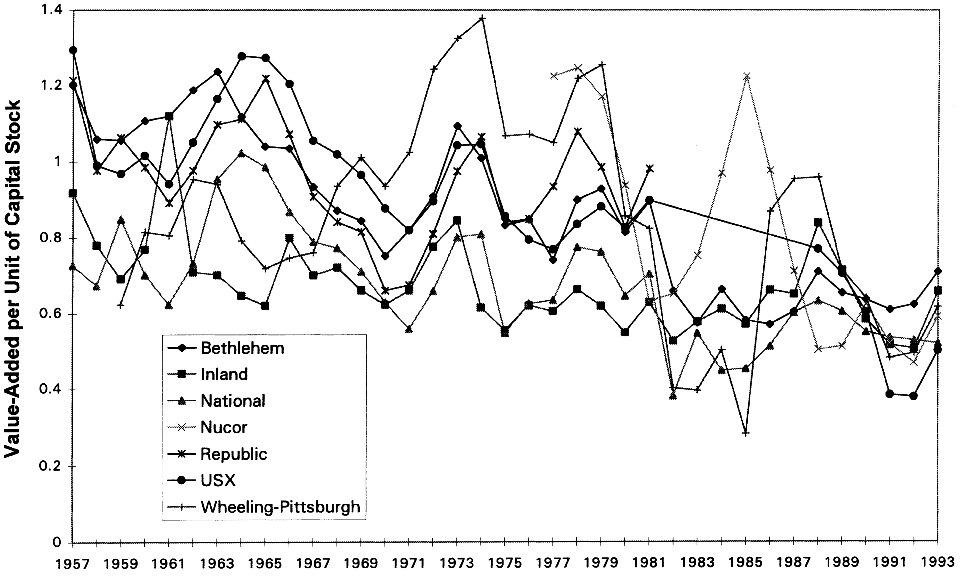


Fig. 7. (A) Capital productivity – Japan; (B) Capital productivity – U.S.

standpoint of a nation's economic welfare, since at the level of the economy as a whole, labor productivity corresponds closely with real income per capita. While not directly interpretable as an indicator of economic welfare, capital productivity does provide information on the efficiency of resource use.

Multi-factor productivity, which attempts to measure the change in output net of the changes in all inputs, is commonly regarded as a more appropriate measure of overall efficiency. As computed in this study, multi-factor productivity is a weighted average of labor and capital productivity, where the weights are determined by the relative amounts of labor and capital employed in the production process.[28] The methodology for estimating multi-factor productivity is described in the Appendix.

Fig. 8(A) and (B) plot our measures of multi-factor productivity for Japanese and U.S. producers, respectively. These figures were derived using Eq. (A.4) from the Appendix to compute the annual growth rates of MFP for each company. In addition, we set the MFP levels for each company relative to a base index of 100 for Nippon Steel in 1980. This was accomplished by applying Eq. (A.4) to estimate each company's MFP relative to Nippon Steel in 1980.[29]

As an example of this inter-company MFP comparison, consider Bethlehem Steel and Nippon Steel in 1980. In that year, Bethlehem Steel used 89 200 employees and a real capital stock of $4.3 billion to produce output (value-added) of $3.5 billion. Nippon Steel used 72 095 employees and a real capital stock of $10.9 billion to produce output (value-added) of $4.6 billion. Thus, Bethlehem produced about three-fourths of Nippon's output, using 27% more workers but only 40% as much capital. Using the MFP formula, a relative efficiency index can be computed.[30] Substituting values into Eq. (A.4) of the Appendix gives a MFP index of 94 for Bethlehem, versus 100 for Nippon Steel.

Comparison of Fig. 8(A) and (B) shows that MFP growth has been much more rapid in Japan than in the U.S.. From the late 1950s to the 1990s, MFP in Japan started from a low level and roughly tripled. Over the same period, MFP rose about 50% for U.S. integrated producers. Moreover, there have been some notable differences in MFP growth among firms within each country. Nisshin and Bethlehem stand out in that each had below-average MFP in early years but now rank among the most efficient producers in their respective countries.

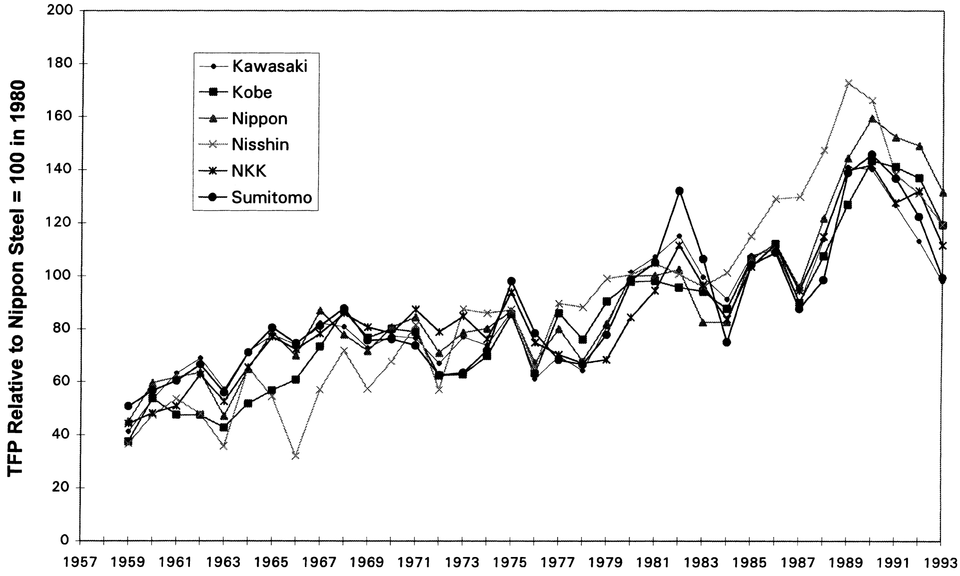
Fig. 8(A) and (B) also suggest that the current levels of MFP are roughly equivalent in the two countries. Indeed, given the recession in Japan, MFP now appears higher for most producers in the U.S.. This conclusion is subject to some qualification, as it is sensitive to the weights used in the MFP calculations.[31] The Japanese companies use much more capital than the Americans per unit of output, which may be appropriate if the cost of capital is much lower in Japan than in the U.S.. If these assumptions are strongly violated (for example, managers have been choosing to invest too much capital in Japan, or not

[28]Ideally, materials and energy inputs should be included in the MFP calculations as well, but the annual reports for the steel companies do not contain sufficient information. Thus, we are unable to assess materials or energy productivity.

[29]Instead of computing the change in MFP for a single company across two annual observations, we computed the difference in MFP across two companies in a single year. Values for the comparison firm were substituted for the t-subscripted variables, and values for Nippon Steel were substituted for the t-1 subscripted variables in Eq. (A.4) of the Appendix.

[30]In the MFP calculation, the weights given to capital and labor are based on an average of the companies' labor income shares. In 1980, 81% of Bethlehem's value-added was paid out to employees, whereas at Nippon the comparable figure was 43%.

[31]The weights are based on the assumption of efficient markets, where factors of production are paid their 'marginal product.'



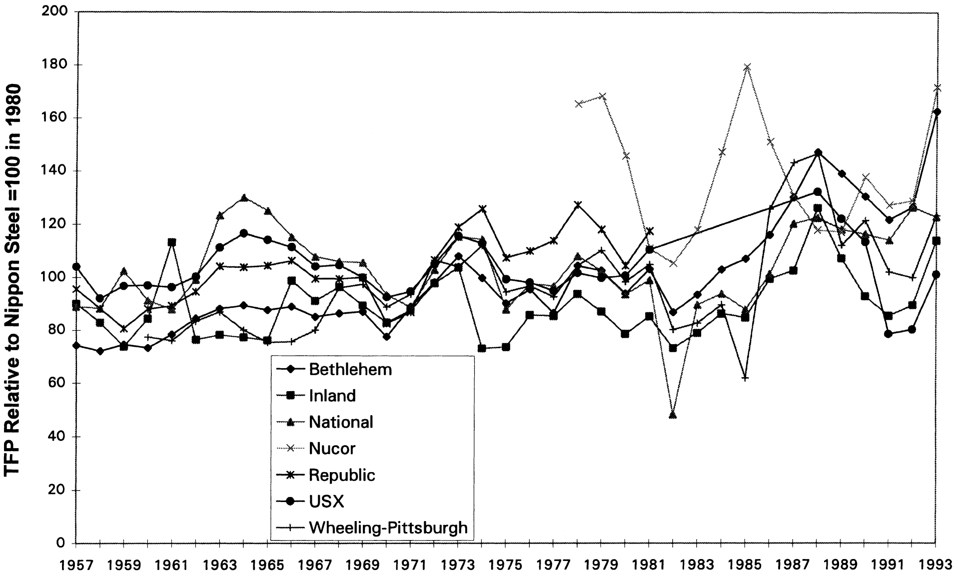


Fig. 8. (A) Total factor productivity – Japan; (B) Total factor productivity – U.S.

enough in the U.S.) then the weights used in the MFP calculations will be biased, which introduces some distortion. However, large changes in these weights would be necessary to modify the conclusions substantially.

Thus, one major finding of this study is that the Japanese and American companies have chosen dramatically different proportions of capital and labor input, but have ended up with comparable levels of overall efficiency, as reflected by MFP. This raises a number of questions about the incentives and choices of managers in the two countries. It also suggests considerable flexibility of steelmaking technology to changes in input mix.

We speculate that integrated producers in Japan invested too heavily in capital equipment, while American producers invested too little. As discussed earlier, Japanese producers followed a trajectory of aggressive technology adoption, while U.S. producers have endeavored to avoid increases in fixed costs. In Japan, plant-level information on tonnage output per worker was widely disseminated, and MITI led a campaign to boost these measures of labor productivity. Moreover, the Japanese main banks often encourage their keiretsu companies, such as the integrated steelmakers, to over-employ capital, in an effort to raise the total return to the main bank (Hoshi et al., 1991; Weinstein and Yafeh, 1995). Responding to these incentives, Japanese managers may have over-invested to stimulate growth in labor productivity. In the U.S., on the other hand, observers have suggested that investment in the integrated steel industry may have been constrained below efficient levels, due to troubled labor-management relations, myopic management and cash-flow limitations (Barnett and Schorsch, 1983; Baldwin, 1983; Baldwin et al., 1984). The costs of labor and capital are now roughly comparable in the two countries, yet a substantial difference in capital/labor ratio continues to persist. Conceivably, the technology of steelmaking may be sufficiently flexible to accommodate differences in input mix without much variation in overall efficiency.

5. Inter-firm productivity variation: comparison of steel and auto producers

Prior sections of this paper have emphasized international differences in steelmakers' productivity; this section considers the extent of productivity variation among producers within each country. In their investigation of U.S. and Japanese automobile producers, Lieberman et al. (1990) conclude that productivity "differences among firms within each country have become large relative to the gap between the U.S. and Japan." An interesting question is whether the pattern of productivity variation in the steel industry is similar to that observed in auto manufacturing and potentially other sectors.

One common approach for assessing variations in efficiency is via estimation of stochastic production frontiers. Prior studies have used this technique to compare technical efficiency across manufacturing sectors in the U.S. and Japan (e.g., Torii and Caves, 1992). Unfortunately, the small number of companies in our sample renders this method infeasible. We rely instead on simple comparisons of the coefficient of variation in labor productivity among firms within each country.[32] This approach risks confounding variations in input choices with true differences in efficiency. Nevertheless, the coefficient of variation can be easily computed from the productivity measures in Section 2, and it is relatively straightforward to interpret. Moreover, the coefficient of variation is likely to be more robust than estimates derived from stochastic production function models, which are often sensitive to specification error.

[32] The coefficient of variation equals the standard deviation divided by the mean.

Fig. 9 plots the coefficients of variation in labor productivity, computed annually across the integrated steel producers within each country.[33] To eliminate year-to-year fluctuations, a 5-year moving average is shown. Included for comparison are similar coefficients of variation computed across the major auto manufacturers in Japan and the U.S.[34]

The Japanese integrated steel companies are often considered to be a homogeneous group. Hence they might be expected to exhibit less productivity variation than their U.S. counterparts. Fig. 9 reveals, however, that the coefficient of variation among integrated steel producers has been remarkably similar in Japan and the U.S.. By comparison, the productivity variation among Japanese automakers has been nearly three times greater than that observed among the steelmakers.[35] In recent years the U.S. 'Big 3' automakers have shown less productivity variation than automakers in Japan, but more than that of the steel companies. These patterns have been fairly stable since about 1970.

Thus, the evidence suggests that inter-firm productivity variations are much smaller in the steel industry than in the auto industry, particularly in Japan. These findings have various possible explanations. Conceivably, the success and failure of new product designs in the auto industry give rise to greater dispersion of productivity than in the steel industry, where the product is homogeneous. Moreover, new steelmaking technology is often capital-embodied and hence may diffuse fairly rapidly. In the auto industry, proprietary technologies such as the venerated 'Toyota production system' cannot be easily codified and are therefore more difficult to imitate.

6. Summary and conclusions

This study has provided a comparative historical analysis of the productivity of integrated steel producers in the U.S. and Japan. It has long been recognized that Japanese labor productivity began to surpass U.S. levels in the early 1970s, largely as the result of higher capital investment in Japan. More recently, the massive restructuring of the American steel industry has led to a partial convergence between the two countries. U.S. producers have boosted their 'tonnage' labor productivity to nearly the level of the Japanese, although a larger gap remains when productivity is measured in terms of value-added.

Much of the Japanese advantage in labor productivity can be attributed to the high levels of investment per worker in Japan. When capital and labor are considered jointly as inputs, our 'multi-factor' productivity calculations suggest that U.S. producers may enjoy a small advantage in overall efficiency. The Japanese and American steelmakers have followed trajectories with radically different proportions of capital and labor input but have ended up with comparable levels of overall efficiency, as reflected by MFP.

The persistence of these differences in input choices raises an economic paradox and a managerial question. Currently, steelmakers in the U.S. and Japan face similar costs of

[33]Kobe Steel, which is substantially diversified, is omitted from the calculations for Japan.

[34]The Japanese automakers are Toyota, Nissan, Honda, Mazda, Daihatsu, Fuji Heavy Industries, Suzuki and Isuzu; the U.S. automakers are GM, Ford and Chrysler, based on data presented in Lieberman et al. (1990).

[35]Much of the variation among auto companies is due to the unusually high productivity of Toyota. Nonetheless, substantial differentials persist in the auto industry even if Toyota is excluded.

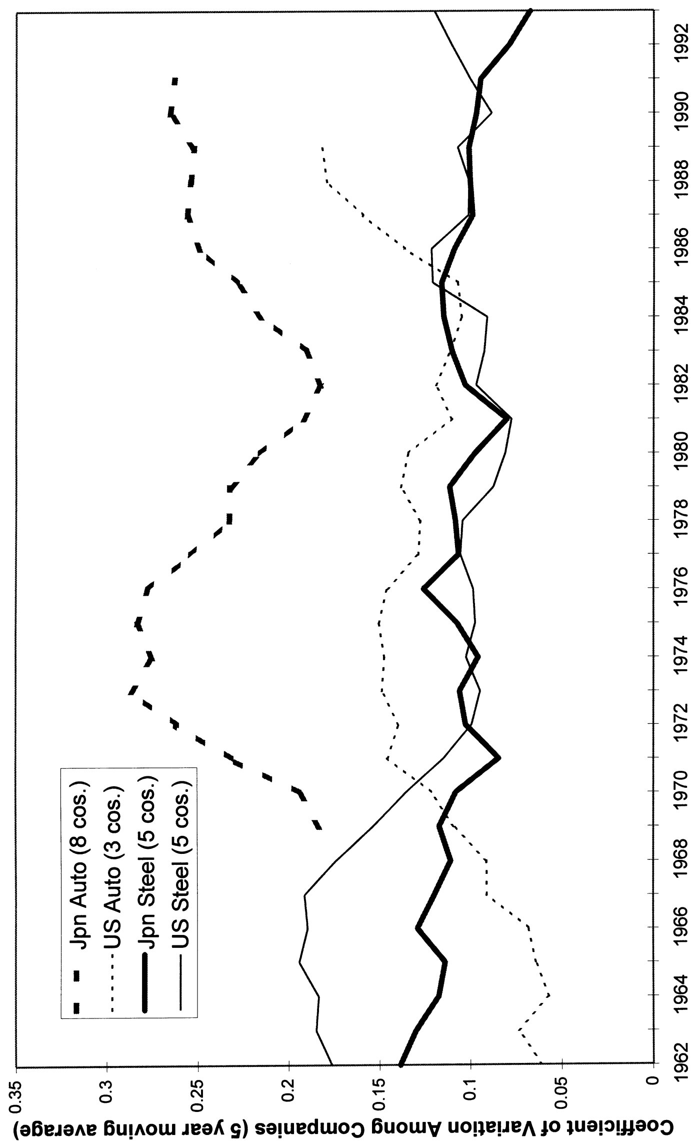


Fig. 9. Interfirm variation in labor productivity

labor and capital, yet the Japanese maintain more than twice as much fixed investment per worker. It seems unlikely that these differences can be explained entirely as rational responses to market forces. Have Japanese steelmakers invested too heavily in capital equipment, or have U.S. producers invested too little? The evidence suggests that non-market incentives and various types of distortions may have led managers in both countries to depart from an otherwise optimal input mix.

Our firm-level analysis also allows us to make productivity comparisons among producers within each country. In the steel industry, we find that the range of productivity variation among firms has been similar in Japan and the U.S. A further comparison shows that such inter-firm variation has been much smaller in the steel industry than in the auto industry, particularly in Japan. Additional work is needed to identify the reasons for these differences and generalize more broadly across other sectors.

Finally, we have shown that meaningful international and inter-company productivity comparisons can be made using public data from standard financial reports. Given the development of computer spreadsheet and graphics tools, it has become reasonably straightforward to perform such analyses. We hope that our work will help to stimulate other comparative studies of firm-level productivity.

Acknowledgements

This paper was prepared as part of the project, 'Competitiveness in the Global Steel Industry,' funded by the Alfred P. Sloan Foundation and the American Iron and Steel Institute.

Appendix

Multi-factor productivity methodology

The traditional method for measuring total-factor productivity (Solow, 1957; Denison, 1967; Griliches and Jorgenson, 1967) takes it as a residual: the growth of real output net of the growth factor inputs. In this formulation, the relationship at time t between output (or value-added), $Q(t)$, and the two inputs, capital, $K(t)$, and labor, $L(t)$, is expressed in terms of a production function:

$$Q(t) = A(t)\,F[K(t), L(t)], \tag{A.1}$$

where $A(t)$ is a time-varying efficiency parameter that allows for neutral shifts in the production function. Note that if the quantities of the inputs are held constant, the rate of change of output is precisely equal to the rate of change of $A(t)$. Thus, $A(t)$ may be identified as a measure of the level of total factor productivity.

Taking the logarithmic derivative of Eq. (A.1), and rearranging, gives the rate of growth of total factor productivity:

$$\frac{\dot{A}}{A} = \frac{\dot{Q}}{Q} - e_k\frac{\dot{K}}{K} - e_l\frac{\dot{L}}{L}, \tag{A.2}$$

where dots refer to time derivatives and e_k and e_l are the production elasticities with respect to capital and labor.

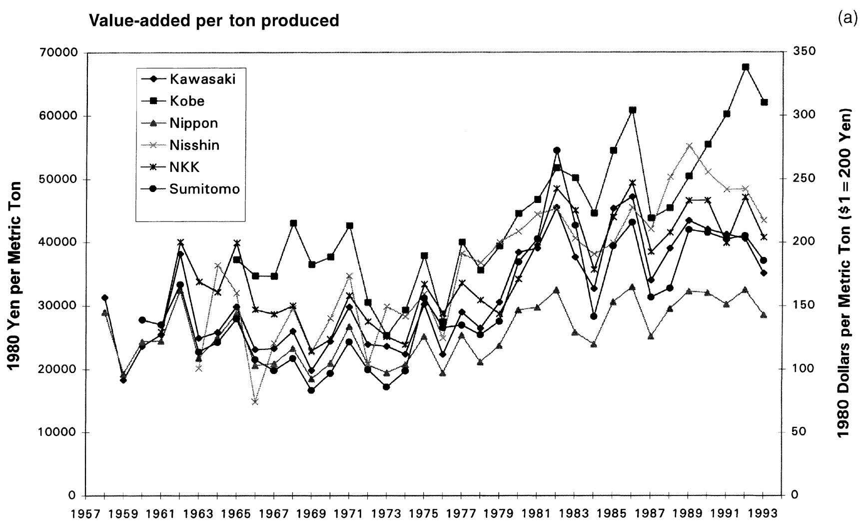
The growth rates of output and inputs are directly observable. The production elasticities are not, and must be estimated. Under the assumption of constant returns to scale, $e_k + e_l = 1$. If output and factor markets are competitive, so that capital and labor are paid their respective marginal products, then the production elasticities, e_k and e_l, are identical to the income shares of capital and labor, s_k and s_l. Data on labor's income share, s_l, are commonly available but data on capital's share are not.[36] Assuming constant returns to scale, capital's income share can be estimated as the residual, $1 - s_l$.[37] Under these assumptions, the growth rate of total factor productivity can be computed as:

$$\frac{\dot{A}}{A} = \frac{\dot{Q}}{Q} - (1 - s_l)\frac{\dot{K}}{K} - s_l\frac{\dot{L}}{L}. \tag{A.3}$$

Approximating the continuous growth rates on the right hand side of Eq. (A.3) by annual differences in the natural logarithms of the variables gives:

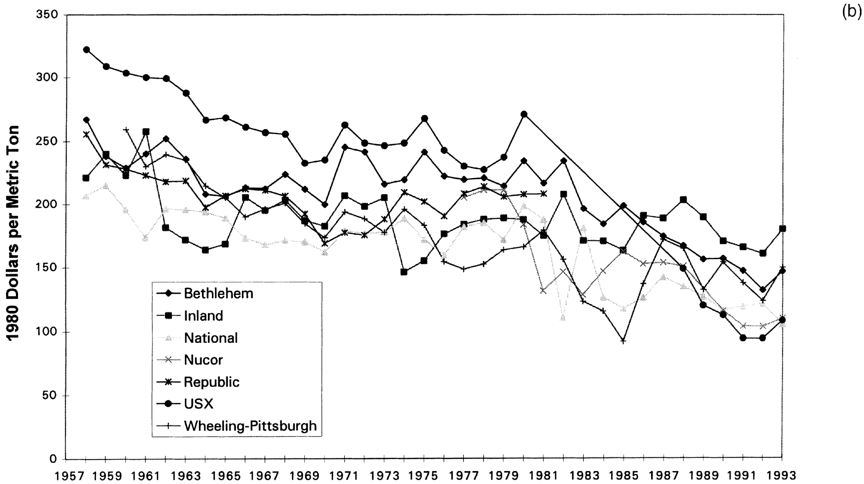
$$\frac{\dot{A}}{A} = [\ln Q_t - \ln Q_{t-1}] - (1 - \bar{s}_l)[\ln K_t - \ln K_{t-1}] - \bar{s}_l\,[\ln L_t - \ln L_{t-1}] \tag{A.4}$$

where $\bar{s}_t = \frac{1}{2}(s_{l,t} + s_{l,t+1})$. This is the representation of multi-factor productivity used for this study. (For an expanded discussion, see Lieberman et al. (1990).)



[36] In this study, s_l was taken as the fraction of value-added that was paid out to the firm's employees.

[37] Increasing returns to scale may be a more plausible assumption for the steel industry. In this formulation, any savings attributable to scale economies will appear as part of the measured gain in productivity.



References

Baber, W.R., Y. Ijuri, S.H. Kang, 1993, Financial analyses of the U.S., Japanese and Korean steel industries, Global study of the steel industry working paper 024, Carnegie Mellon University.

Baldwin, C.Y., 1983, Labor unions and productivity: an application of the theory of self-enforcing contracts, Journal of Business LVI, 155–185.

Baldwin, C.Y., Tribendis, J.J., Clark, J.P., 1984. The evolution of market risk in the U.S. steel industry and implications for required rates of return. Journal of Industrial Economics, 33, 73–98.

Bank of Japan, Research and Statistics Department, 1985, Historical Statistics of Japan. Tokyo, Japan.

Barnett, D.F., Schorsch, L., 1983, Steel: Upheaval in a Basic Industry. Ballinger, Cambridge, MA.

Crandall, R.W., 1981, The U.S. Steel Industry in Recurrent Crisis. Brookings Institution, Washington, DC.

Denison, E.F., 1967, Why Growth Rates Differ: Post-war Experience in Nine Western Countries. Brookings Institution, Washington, DC.

Griliches, Z., Jorgenson, D.W., 1967. The explanation of productivity change. Review of Economic Studies, 34, 249–283.

Hasegawa, H., 1996, The Steel Industry in Japan: A Comparison with Britain. Routledge & Kegan Paul, London.

Hoerr, J.P., 1988, And the Wolf Finally Came. University of Pittsburgh Press, Pittsburgh, PA.

Hoshi, T., Kashyap, A., Scharfstein, D., 1991. Corporate structure, liquidity, and investment: evidence from Japanese industrial groups. Quarterly Journal of Economics, 106, 33–60.

Hulten, C.R., Wykoff, F.C., 1981. The measurement of economic depreciation, In: Hulten, C.R. (Ed.), Depreciation, Inflation, and the Taxation of Income from Capital, The Urban Institute Press, Washington, DC.

Jorgenson, D.W., Kuroda, M., Nishimizu, M., 1987. Japan-U.S. industry-level productivity comparison, 1960-1979. Journal of the Japanese and International Economies, 1, 1–30.

Iron Age, 1980, Annual review of prices.

Lieberman, M.B., Lau, L.J., Williams, M.D., 1990. Firm-level productivity and management influence: A comparison of U.S. and Japanese automobile producers. Management Science, 36, 1193–1215.

O'Brien, P.A., 1986, Coordinating Market Forces: The Anatomy of Investment Decisions in the Japanese Steel Industry. University Microfilms International, Ann Arbor, MI.

Solow, R.M., 1957. Technical change and the aggregate production function. The Review of Economics and Statistics, 39, 312–320.

Tiffany, P.A., 1988, The Decline of American Steel, Oxford University Press, New York.

Torii, A., Caves, R.E., 1992. Technical efficiency in Japanese and U.S. manufacturing industries, In: Caves, R.E. (Ed.), Industrial Efficiency in Six Nations, MIT Press, Cambridge, MA.

United States Government, Council of Economic Advisers, Annual Issues, Economic Report of the President, Washington, DC, GPO.

Weinstein, D.E., Yafeh, Y., 1995. Japan's corporate groups: collusive or competitive? An empirical investigation of keiretsu behavior. Journal of Industrial Economics, 43, 359–376.

Yonekura, S., 1994, The Japanese Iron and Steel Industry, 1850–1990, St. Martin's Press, New York.

Yonekura, S., 1995, Technological innovation in the steel industry: Recognizing potential in innovations, In: Minawi, R., Kim, K.S., Makino, F., Seo, J.H. (Eds.), Acquiring, Adapting and Developing Technologies, New York, St. Martin's Press.