J-0184a

MANAGERIAL AND DECISION ECONOMICS, VOL. 18, 73–85 (1997)

Inventory Reduction and Productivity Growth: A Comparison of Japanese and US Automotive Sectors

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This study assesses the inventory and productivity performance of the Japanese and US automotive industries in recent decades. Within each country we distinguish between vehicle assemblers and parts suppliers. In Japan, assemblers and suppliers made dramatic inventory reductions and productivity gains, particularly during the 1970s. By comparison, we find an unbalanced pattern for the United States: American assembly plants have been streamlined, but parts suppliers have stagnated. In both countries our findings suggest a strong association between inventory reduction and productivity growth
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Manage. Decis. Econ. 18: 73–85 (1997)

No. of Figures: 6 No. of Tables: 2 No. of References: 31

INTRODUCTION

In recent decades the automotive industries of Japan and the United States have experienced dramatic transformations. One major development has been the adoption of a set of process innovations commonly known as 'just-in-time' (JIT) manufacturing. Pioneered by Toyota in the late 1950s, JIT methods were widely implemented in Japan starting in the late 1960s, making their way to North America about a decade later (Im and Lee, 1989; Nakamura, Sakakibara and Schroeder, 1994).

A central feature of JIT is the ability to operate with minimal levels of inventory. Inventory reduction exposes defects in the manufacturing process, forcing managers and workers to eliminate sources of variability and waste (Schonberger, 1982). Operations managers commonly view inventory levels as indicators of process capability and efficiency. An analysis of Japanese auto assemblers and suppliers (Lieberman and Demeester, 1995) shows that inventory reductions were followed by significant gains in productivity, with an average lag of about one year. Thus, inventory levels are important indicators of manufacturing performance.

Concurrent with the diffusion of JIT, various researchers have drawn productivity comparisons between the Japanese and US automotive industries.[1] Most studies have concluded that Japenese producers attained a significant productivity advantage over North American automakers by the early 1980s, with the gap subsequently narrowing. Other work has documented the close links between vehicle assemblers and parts suppliers in Japan, identifying these as a key factor in Japan's success.[2]

This paper compares the Japanese and US automotive industries in recent decades, with specific focus on relative inventory levels and rates of productivity growth. We use available data from national censuses and company financial reports to compute benchmark measures of inventory and productivity. Within each country, we distinguish

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Contract grant sponsor: MIT International Motor Vehicle Program, UCLA Center for International Business Education and Research.

CCC 0143–6570/97/020073–13 $17.50
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between the auto assemblers and their component suppliers. Prior comparisons of the Japanese and US automotive industries have tended to emphasize the assemblers, often ignoring the larger parts supply sector.[3] Our analysis reveals radical differences in performance between suppliers and assemblers in the United States. This contrasts with the situation in Japan, where the two groups have improved in parallel.

In particular, we show that Japanese automotive suppliers and assemblers have made remarkably similar progress over a long period of time, whereas US suppliers and assemblers have not. The evidence suggests that in recent years the American assemblers (with the possible exception of General Motors) have made substantial gains, reaching parity with average Japanese levels of inventory and productivity. Typical US suppliers, though, have stagnated. This disparity in performance within the US automotive sector has many possible explanations, but it highlights the relative success of the Japanese companies in coordinating and improving operations along the entire production supply chain.

The remainder of this paper is organized as follows. The next section describes the types of inventories within the automotive supply chain, and how they are related to the time required for materials flow and processing. The third section utilizes census data to compare the magnitude of inventories in Japan and the USA. It begins with an assessment of the total inventories within the automotive supply chain, which are then disaggregated into two components: (1) work-in-process held internally by parts suppliers and vehicle assemblers, and (2) inter-firm inventories. The fourth section compares the productivity growth of Japanese and US assemblers and suppliers, based on data from census and company financial reports. The final section concludes the paper with a summary of the findings and discussion of their implications.[4]

INVENTORIES WITHIN THE AUTOMOTIVE SUPPLY CHAIN

To achieve JIT production, inventories must be reduced to minimal levels. In the automotive supply chain, the relevant inventories are (1) work-in-process (WIP) held internally by parts suppliers and vehicle assemblers, and (2) buffer inventories between firms. The latter can be divided into finished goods (FG) held by the upstream supplier, and raw materials (RM) held by the downstream customer. The amount of time required to convert basic materials into finished products depends directly on the magnitude of these inventories.

Figure 1 is a diagram which represents the inventories in a simplified automotive supply chain. A final assembler at the end of the chain obtains parts

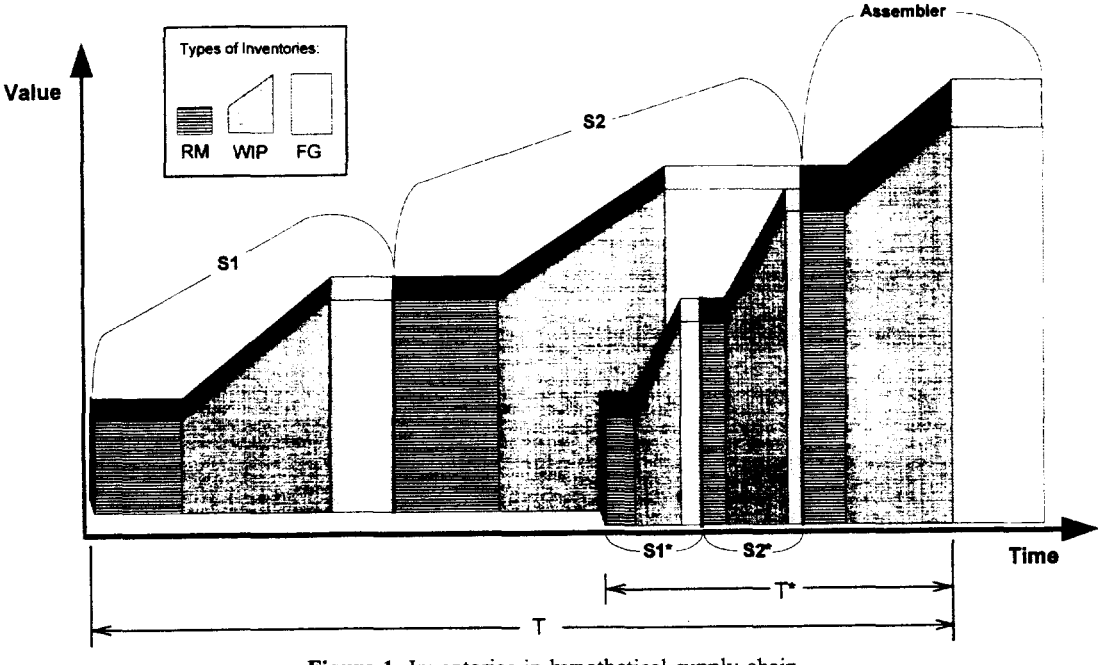

Figure 1. Inventories in hypothetical supply chain

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from two suppliers (S2 and S2*), each of which has an additional upstream supplier (S1 and S1*). To facilitate comparison, assume that the two sets of suppliers provide identical components to the assembler. The vertical axis of the diagram represents the accumulation of product value; the horizontal axis represents elapsed time. Inventory stocks, by definition, are proportional to areas under the graph. Trapezoidal areas correspond to work-in-process inventories. (The slope rises as products accumulate value during processing.) Rectangular areas correspond to inter-firm inventories (finished goods and raw materials).

The diagram suggests how inventory levels are related to the speed of materials flow. The two sets of suppliers in Fig. 1 differ drastically in their inventory levels. The supplier pair, S1/S2, suffers from long processing times, leading to high levels of WIP inventory. Moreover, these firms hold substantial stocks of raw materials and finished goods, which may be needed as a buffer if process breakdowns or other problems occur frequently. By comparison, the S1*/S2* supplier pair produces an identical product in a much shorter period of time. By eliminating sources of production variability and delay, this supplier pair is able to operate with substantially less inventory. As drawn in Fig. 1, the total 'cycle time' (measured from the receipt of materials by the upstream supplier, to completion of the vehicle by the assembler) equals T for the first set of suppliers, but only T^* for the second. In general, for a given volume of output, the amount of inventory in the supply chain rises in proportion to the cycle time.

INVENTORY ANALYSIS

Our analysis of automotive supply chain inventories is based on annual data from the *Census of Manufactures (Kogyo Tokei-hyo)* of Japan, and the *US Annual Survey of Manufactures*.[5] We define total supply chain inventories as the sum of raw materials (RM), work-in-process (WIP), and finished goods (FG) held by parts suppliers, plus raw materials and work-in-process held by automotive assemblers. We exclude inventories of finished automobiles.

The Japanese and US Censuses subdivide the assembler and supplier categories, respectively. In Japan, where automotive assembly is often subcontracted, separate figures are reported for 'contract' and 'core' assemblers. (Core assemblers have their own design capability and market under their own name.[6]) The US Census provides separate classifications for 'motor vehicle parts and accessories' (SIC 3714) and 'automotive stampings' (SIC 3465), as well as several minor parts categories.[7] In both countries, the Census figures are aggregated from information collected from individual manufacturing plants. Thus, the parts supply operations of the US 'Big-3' automakers are incorporated into the Census classifications for automotive components. We limit our definition of the supply chain to categories that can be clearly identified as automotive parts, sold primarily as original equipment rather than aftermarket replacement.[8]

Our analysis covers the period from 1967 through 1993. The start date is motivated by the fact that the *US Annual Survey of Manufactures* did not provide separate inventory data on auto suppliers and assemblers until 1967. Moreover, the late 1960s marks the initial spread of JIT methods in Japan (Lieberman, Demeester and Rivas, 1995).

Total Supply Chain Inventories

Figure 2 is a graph that compares the total inventories in the automotive supply chain in Japan and the USA from 1967 to 1993. Total inventories were obtained by adding the inventories held by parts suppliers (RM + WIP + FG) and vehicle assemblers (RM + WIP), and dividing by the assemblers' annual sales. Table 1 reports numerical results of these calculations with data averaged over the initial four years (1967–70) and the final four years (1990–93) of the sample.

Supply chain inventories have been declining significantly in both Japan and the USA. Important differences are nevertheless apparent. Table 1 shows that in the late 1960s, total supply chain inventories (per unit of final sales) were about 50% larger in the USA than in Japan. Over the next two decades these inventories fell by 44% in Japan, but only 34% in the USA. Thus, by the early 1990s the automotive supply chain in the USA held nearly twice as much inventory as in Japan.[9]

Figure 2 reveals some additional features when inventory changes are viewed over shorter periods. During the 1970s, when JIT became widely adopted in Japan, the inventory differential between Japan and the USA reached its widest point. The gap has since narrowed, as JIT met with diminishing returns in Japan while being increasingly implemented in the USA. Both countries have seen cyclical fluctuation in inventories, stemming from oil shocks (in late 1973 and 1979) and other business cycle effects.

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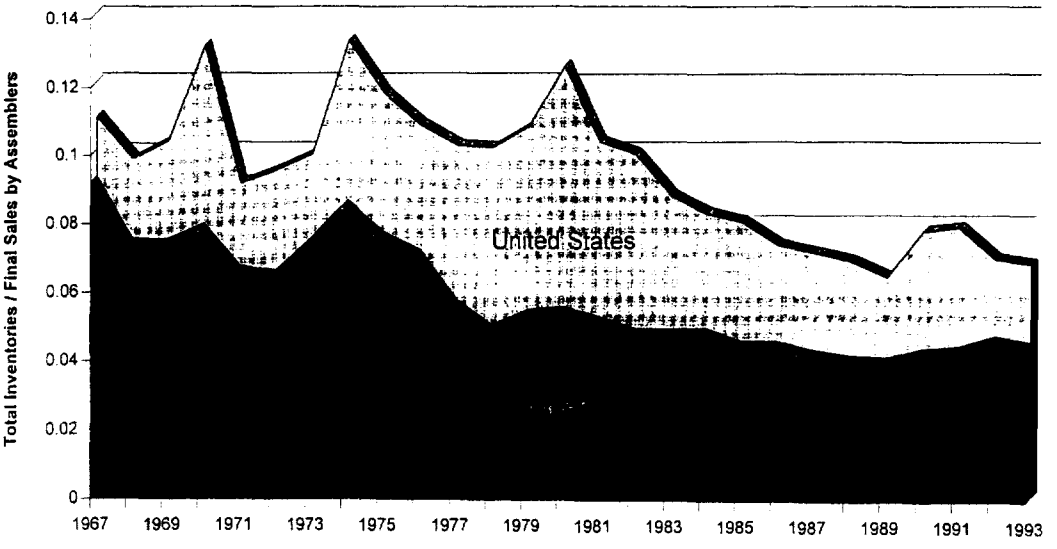

Figure 2. Total automotive supply chain inventories: Japan versus the United States. (*Sources: Annual Survey of Manufactures* (USA), *Census of Manufactures* (Japan).

The supply chain inventories illustrated in Fig. 2 can be subdivided into: (1) inter-firm buffers, consisting of raw materials and finished goods, and (2) internal work-in-process inventories needed to accommodate variability and delay in manufacturing processes.[10] Below, we examine these two types of inventories in greater detail.

Inter-firm Inventory

Figures 3(a) and 3(b) show the magnitudes of inter-firm inventories in Japan and the USA, measured as a proportion of assemblers' final sales. Comparison of Fig. 3(a) with Fig. 2 reveals that in Japan, the total supply chain inventory has been split fairly evenly between internal work-in-process and inter-firm inventories. The latter have been held mostly by suppliers. From the late 1960s through the early 1990s, Japanese suppliers cut these inventories by 32% (RM) and 40% (FG). Inventories rose slightly in the late 1980s to accommodate a trend by Japanese assemblers toward greater product variety.

Interestingly, the largest percentage reductions were made by the contract assemblers, who cut their raw materials stocks by more than 71% (as compared with a 45% reduction by the core assemblers). The contract assemblers typically produce relatively low-volume vehicles, which tend to require more inventory per unit of sales. The inventories of contract assemblers were extremely high relative to sales in the 1960s. Since then, substantial improvements in their manufacturing operations have enabled major inventory cuts. For example, Kanto Auto Works, a Toyota contract assembler and early adopter of JIT, reduced its raw materials inventory from more than 1.2% of sales in 1967 to less than 0.3% of sales by 1991.

Figure 3(b) shows that inter-firm inventories have been relatively high in the USA—typically more than twice the levels of Japan. This is due, in part, to greater physical distance between plants in the USA, leading to greater variability in the timing of parts deliveries.[11] Moreover, storage costs are lower in the USA, given cheaper land prices and fewer space constraints. Nevertheless, much of the differential may be attributed to the more limited adoption of JIT. In the USA from the late 1960s through the early 1990s, inter-firm inventories fell by 21%, or half the rate of Japan. This reduction was due entirely to cuts made by the US assemblers in their raw materials holdings during the 1980s. In the late 1960s the assemblers' stocks of raw materials were more than twice as large as the suppliers' stocks of finished goods. By the early 1990s, however, these supplier and assembler inventories were approximately equal. As US assemblers cut their stocks of raw materials, the finished goods inventory of their suppliers actually increased (Table 1). Comparison between countries shows that Japanese suppliers held more

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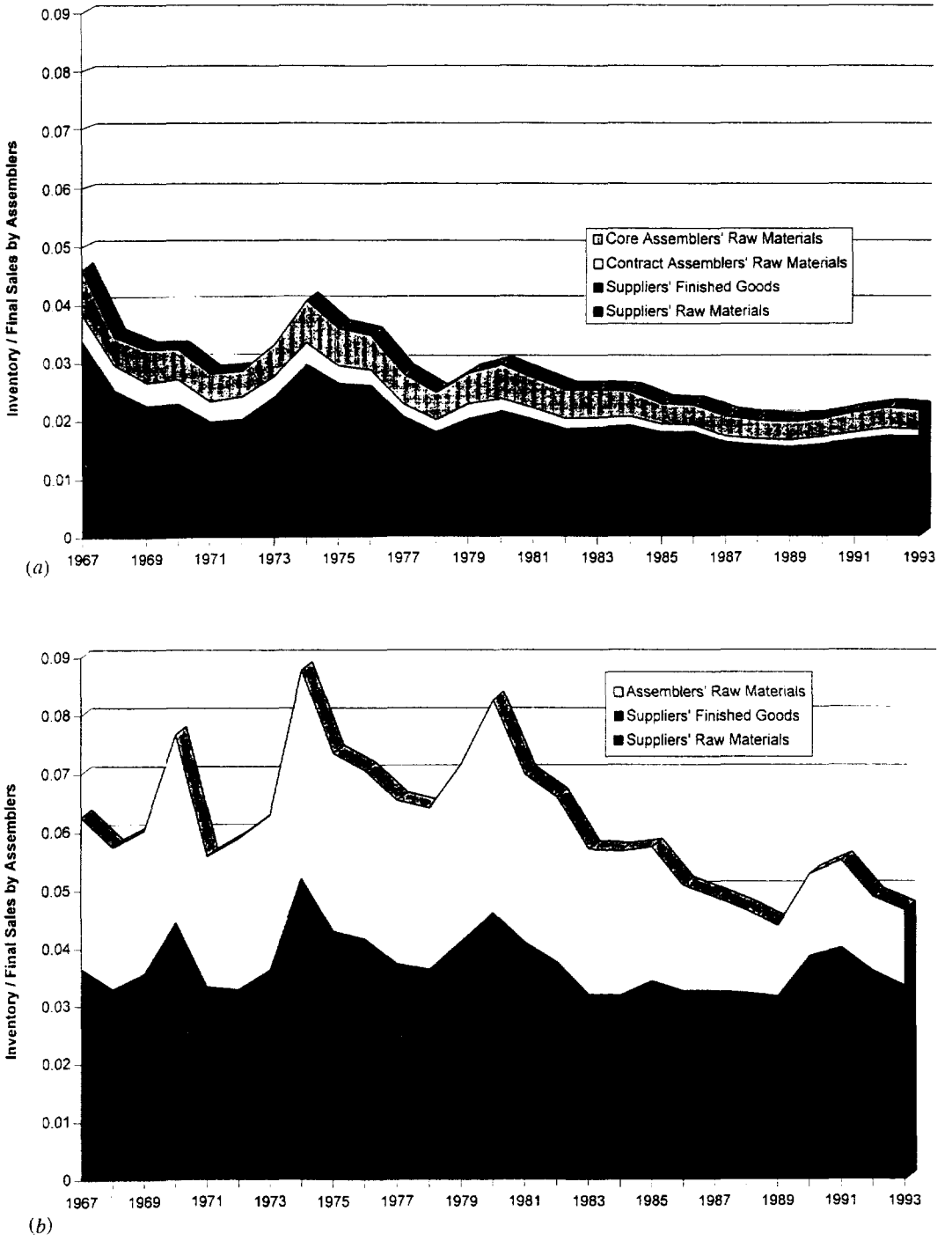

Figure 3. Inter-firm inventories: (a) Japan, (b) United States. (Sources: *Japanese Census of Manufactures, US Annual Survey of Manufactures.*)

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Table 1. Inventories in the Automotive Supply Chain (as a proportion of final vehicle sales)

Japan		Average 1967–70	Average 1990–93	Percent change
Parts suppliers	RM	0.012	0.008	−32
	WIP	0.019	0.012	−38
	FG	0.015	0.009	−40
	Total	0.045	0.028	−37
Contract assemblers	RM	0.004	0.001	−71
	WIP	0.004	0.002	−56
	Total	0.009	0.003	−63
Core assemblers	RM	0.006	0.003	−45
	WIP	0.020	0.010	−52
	Total	0.026	0.013	−50
Industry Total	Inter-firm WIP	0.036	0.021	−42
		0.043	0.023	−46
	Total	0.080	0.044	−44
USA		Average 1967–70	Average 1990–93	Percent change
Parts suppliers (SIC 3714)	RM	0.019	0.020	6
	WIP	0.023	0.016	−34
	FG	0.012	0.013	9
	Total	0.054	0.049	−11
Stampings suppliers (SIC 3465)	RM	0.006	0.003	−51
	WIP	0.005	0.003	−30
	FG	0.001	0.001	51
	Total	0.011	0.007	−35
Assemblers	RM	0.027	0.014	−49
	WIP	0.029	0.011	−62
	Total	0.056	0.025	−56
Industry Total	Inter-firm	0.064	0.051	−21
	WIP	0.057	0.030	−48
	Total	0.121	0.081	−34

Sources: Annual Survey of Manufactures (USA), *Census of Manufactures* (Japan).

finished goods inventory than their US counterparts in the 1960s, but less by the 1980s.

These statistics must be interpreted with caution, as it may be arbitrary whether suppliers or assemblers hold title to the inventories which serve as a buffer between their manufacturing operations. Indeed, the US assemblers have always owned a much larger proportion of these inventories than has been typical in Japan. Nevertheless, the data imply that in the USA, efforts to cut inter-firm inventories have been initiated by the assemblers. What remains unclear is whether (1) suppliers have failed to fully adopt JIT methods, or (2) the burden of inventory-holding has simply been shifted back on the suppliers. We suspect that both apply, although the extent varies from case to case.

Work-In-Process Inventory

Figure 4 compares the levels of work-in-process inventory for parts suppliers in Japan and the USA over the period from 1967 to 1993. These levels were computed as the ratio: total supplier WIP/total supplier sales.[12] This WIP/sales ratio may be considered as an approximate measure of average production cycle time (Lieberman, Demeester and Rivas, 1995).

Since the 1960s, Japanese and US parts suppliers have made significant WIP reductions. There are, however, important differences between the two countries. The Japanese suppliers made fairly steady improvements from the 1960s through the late 1980s, when increases in product variety led to an incremental rise in inventory. In the USA, by contrast, parts suppliers achieved significant inventory reductions in the early 1980s but subsequently reached a plateau. US parts suppliers currently hold nearly twice as much WIP per unit of sales as their counterparts in Japan.

Figure 5 focuses on work-in-process inventory held by the automotive assemblers. It plots the ratio: total assembler WIP/total assembler sales. Comparison of the US automotive companies with the core assemblers in Japan shows that both groups held comparable amounts of WIP inventory in the early 1970s. In the mid-1970s the Japanese made dramatic reductions and began to lead the US firms by a considerable margin. By the 1990s, however, the US assemblers had caught up and possibly even pulled ahead, holding less WIP inventory as a fraction of sales than their counterparts in Japan. Viewed over the entire 1967–93 period, the data show that the US assemblers cut their WIP inventory more gradually than the Japanese but have made similar progress overall.

Thus, the US and Japanese assemblers have made substantial WIP reductions, which presumably reflect underlying improvements in their manufacturing operations. In making international comparisons between assemblers, however, a number of issues must be considered. One is product variety: within a given plant, greater variety normally leads to higher requirements for WIP inventory. This is confirmed by the difference between core and contract assemblers in Japan. The contract assemblers produce a more diverse array of lower-volume vehicles and have historically held significantly greater amounts of WIP. Compared with both types of assemblers in Japan, the US assemblers generally operate more

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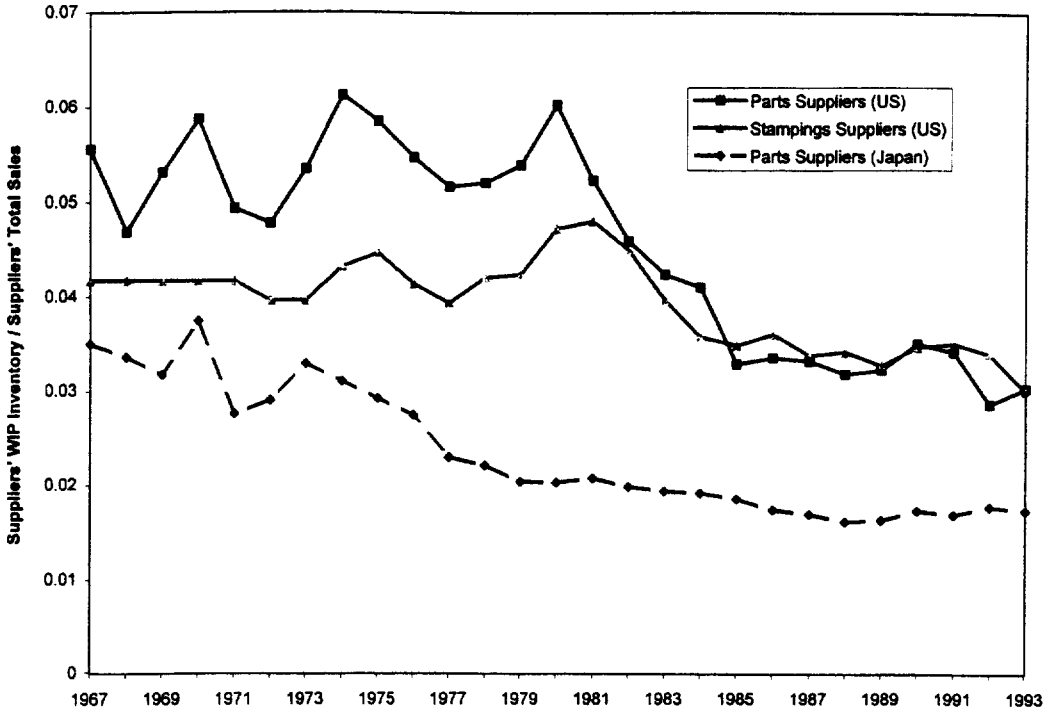

Figure 4. Suppliers' WIP inventories in the United States and Japan.

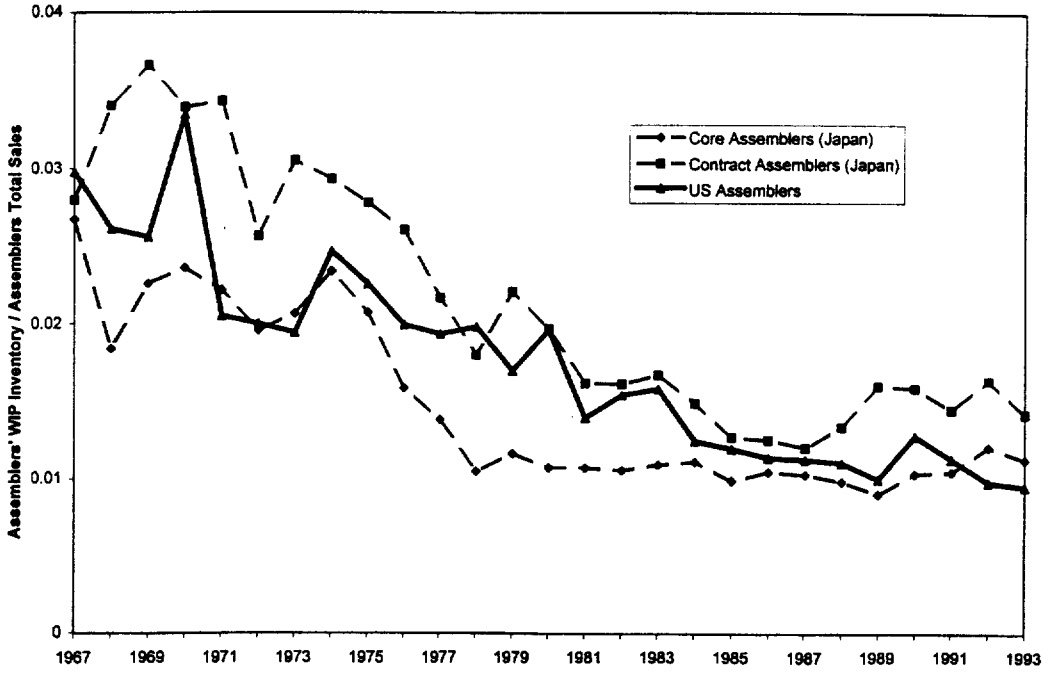

Figure 5. Assemblers' WIP inventories in the United States and Japan.

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dedicated plants, with less product variety. This would, other things equal, give rise to lower WIP inventory requirements. Thus, the low WIP of US assemblers may be partly attributable to the more homogeneous product mix of US assembly plants.[13]

COMPARATIVE PRODUCTIVITY

We now turn to the productivity performance of automotive suppliers and assemblers in Japan and the United States. If inventory reductions are linked to productivity growth, the inventory patterns documented above should be accompanied by changes in productivity. In particular, substantial productivity growth should be observed for assemblers and suppliers in Japan through the mid-1980s. In the US, we would expect to see sizable productivity growth for assemblers in recent years, but less growth for suppliers.

Our objective is not to present detailed productivity computations, but rather to assess the general trends of productivity change since the 1960s for suppliers and assemblers in the two countries. We begin with such an assessment in Japan, followed by the United States.

Labor Productivity: Japan

Figure 6a plots the labor productivity of Japanese parts suppliers and core assemblers from 1967 to 1993.[14] Table 2 reports average growth rates of labor productivity during the first and second half of this period. Labor productivity is defined as value-added per employee in constant yen.[15] Estimates have been derived from two alternative sources: (1) the *Census of Manufacturing*, and (2) company annual financial reports.[16]

As shown in Figure 6a, the estimated levels of labor productivity differ between the Census and annual report data, particularly for the assemblers. The main reason for this disparity is that the Census data omit employees located in auxiliary units (headquarters and support facilities), whose value-added is included in the manufacturing plant totals. Labor productivity estimates derived from the Census data are therefore biased upward. Comparable estimates from company reports have other drawbacks: they cover only a sample of larger firms, and they include diversified activities. Fortunately, the growth rates of labor productivity are similar for the two sets of data (Table 2).

Table 2. Productivity Growth of Japanese and US Parts Suppliers and Assemblers

		Average Annual growth rate (%)	
		1967–80	1980–93
Japan			
Parts	LP(Census)	11.4	4.3
suppliers	LP(AR)	10.5	3.6
Contract	LP(Census)	9.1	3.3
assemblers	LP(AR)	9.9	3.6
Core	LP(Census)	7.9	4.0
assemblers	LP(AR)	7.8	2.4
USA			
Parts	LP(Census)	1.1	2.6
suppliers	TFP	−1.0	−0.3[a]
Sampings	LP(Census)	1.1	3.7
suppliers	TFP	−0.2	0.2[a]
Assemblers	LP(Census)	1.3	8.8
	TFP	1.5	1.8[a]
GM	LP(AR)	1.2	4.0
Ford	LP(AR)	3.8	8.9
Chrysler	LP(AR)	2.7	5.7

[a]Calculations are for 1980–91. LP = labor productivity (value-added per employee in constant currency). TFP = total factor productivity. Census = *Annual Survey of Manufactures* (USA), *Census of Manufactures* (Japan). AR = Company Annual Reports (Japan AR sample includes: 39 parts suppliers, three contract assemblers, eight core assemblers).

Ignoring biases in estimated productivity levels, the Japanese data show a strong general pattern: the productivity of both suppliers and assemblers grew rapidly from the late 1960s through the late 1980s. As would be expected, there was some slowing of growth in percentage terms. Based on the Census data, prior to 1980 the labor productivity of parts suppliers rose at an average annual rate of 11.4%, falling to 4.3% for the subsequent period. Core assemblers' productivity rose by 7.9% per annum prior to 1980, slowing to 4.0% thereafter. These figures reveal that in Japan, parts suppliers enjoyed faster labor productivity growth than assemblers. The average labor productivity level of suppliers was roughly half that of the assemblers in the mid-1960s, but the difference had virtually disappeared by the 1990s.

Labor Productivity: USA

The pattern of productivity growth in the US auto industry since the 1960s has been quite different from that observed in Japan. Figure 6(b) plots labor productivity levels for the USA companies (value-added per employee, in constant dollars[17]) from 1967

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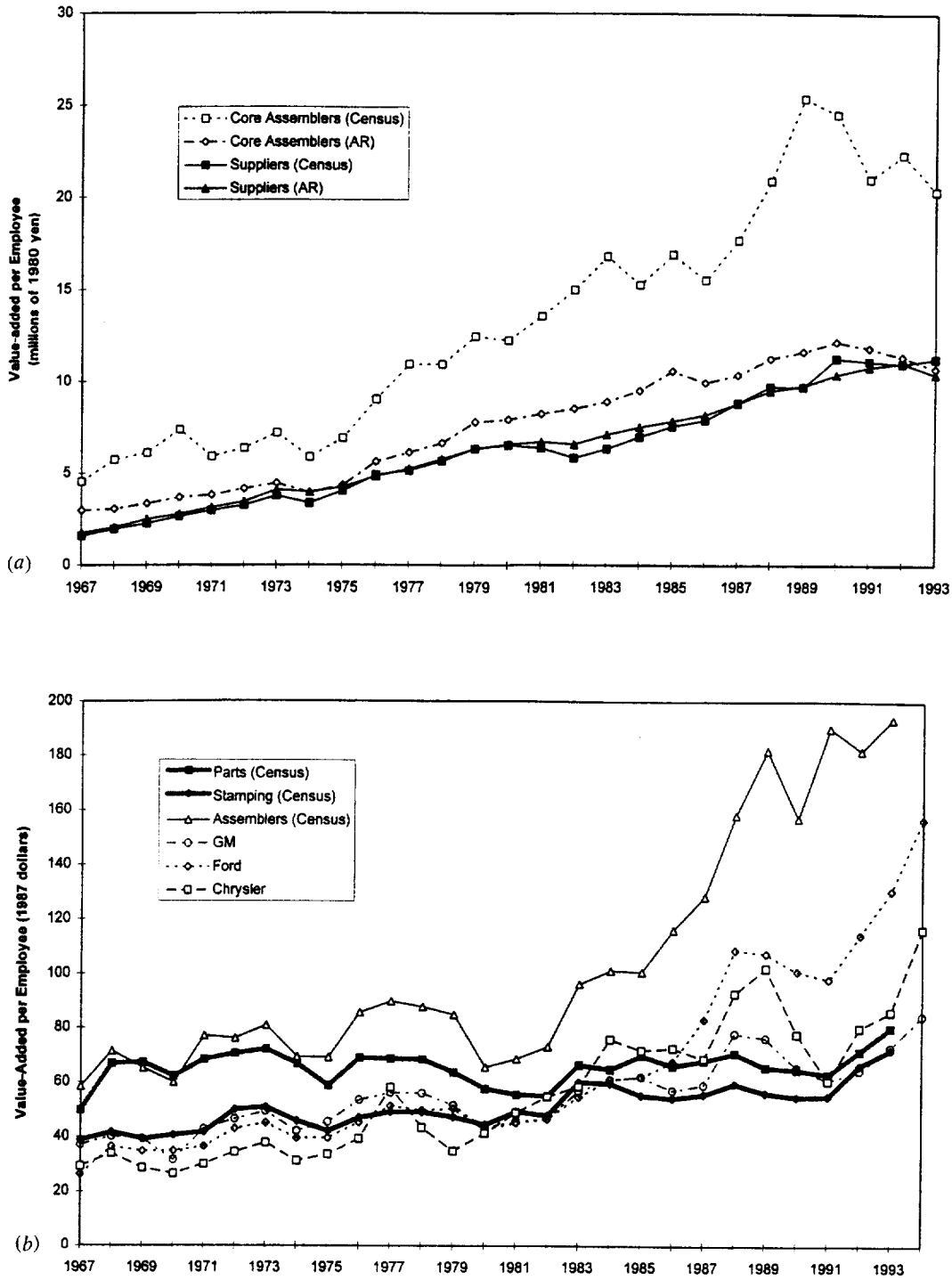

Figure 6. Labor productivity of (a) Japanese and (b) US parts suppliers and assemblers.

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to 1993. Estimates are derived from Census data for automotive stampings plants, other parts plants, and assembly plants. We also include estimates developed from annual reports covering each of the Big 3 assemblers. A comparable sample could not be constructed from annual reports for US parts suppliers, as financial statements in the US typically do not provide sufficient information to allow value-added to be estimated.[18]

The data show a pattern of productivity divergence between the US assemblers and their suppliers. The assemblers have experienced significant productivity growth, particularly since the early 1980s.[19] Within the Big 3, however, differences are apparent, with GM failing to share in the productivity gains enjoyed by Ford and Chrysler in recent years. Post-1980 productivity growth rates ranged from 4.0% per year at GM, to 8.9% at Ford, based on data from annual reports. GM's poor performance may be partly attributable to the company's heavy involvement in parts-making operations, which cannot be distinguished from assembly operations in the annual reports.[20] Indeed, the Census data, which are specific to US assembly plants, show a 1980–93 productivity growth rate of 8.8% for these plants, close to the rate estimated from the annual reports for Ford. We suspect, however, that the Census rate may be biased upward by an increasing fraction of Big-3 employment assigned to auxiliary units (design, R&D, and administration) located outside of manufacturing plants.

The productivity trends of US automotive suppliers have been very different from those of the assemblers. Since the 1960s, US supplier productivity has been stagnant.[21] Table 2 shows that average labor productivity growth of suppliers was 1.1% per year in the 1967–1980 period, rising to 2.6% (automotive parts) and 3.7% (stampings) in the 1980–1993 period. These figures fall below those of the assemblers, particularly in the later period. On the positive side, most of the supplier productivity growth was recorded from 1991 to 1993, so it is possible that this recent upward trend will continue.

Comparison between the two countries shows that since the early 1980s, the US auto assemblers have enjoyed higher labor productivity growth than their Japanese counterparts, suggesting a pattern of productivity convergence. US parts suppliers, though, appear to have been falling behind. The labor productivity growth of US suppliers has lagged behind that of suppliers in Japan and assemblers in both countries.[22] These patterns of productivity growth tend to mirror the rates of inventory reduction described earlier.

Total Factor Productivity: USA

Labor productivity denotes utilization of a single input and hence provides only a partial index of manufacturing efficiency. Total factor productivity (TFP), which attempts to measure the change in output net of changes in all inputs, is commonly regarded as a more appropriate measure of productivity. Table 2 presents estimates of growth in TFP, taken from the NBER database covering US manufacturing industries through 1991 (Bartelesman and Gray, 1994). These TFP figures represent the annual growth in output, net of changes in various types of inputs: labor, capital, energy and materials.

Table 2 shows that since the 1960s, TFP for the US assemblers has grown at a respectable rate averaging about 1.7% per year. For the US parts suppliers, though, TFP growth has been negative. Thus, the pattern indicated by TFP is similar to that shown for labor productivity: substantial growth by US assemblers, but mediocre performance on average by suppliers. Unfortunately, we do not have comparable data on Japanese TFP.[23]

CONCLUSIONS

This study has presented measures of inventory and productivity in the Japanese and US automotive industries, distinguishing the performance of parts suppliers from that of vehicle assemblers. The measures reveal radical differences in performance between suppliers and assemblers in the United States. Since the 1980s, the US auto assemblers have made drastic cuts in inventory and have enjoyed rapid productivity growth, whereas US parts suppliers have stagnated along both dimensions. In Japan, by contrast, assemblers and suppliers have long made steady, parallel improvements in their manufacturing operations.

Recent studies have described the successful adoption of Japanese manufacturing methods by US vehicle assemblers (MacDuffie and Pil, 1995), as compared with the slow convergence of parts suppliers in the two countries (McMillan, 1990; Cusumano and Takeishi, 1991; Helper, 1991; Asanuma, 1992; Helper and Sako, 1995). Our findings clarify these trends as reflected by firms' inventory levels. We have also shown that produc-

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tivity growth and inventory reduction have tended to coincide for broad classes of suppliers and assemblers in Japan and the USA.

Our most striking findings relate to the poor performance of American automotive suppliers. While these findings could, conceivably, be due to errors of measurement, the broad pattern is consistent with evidence from other sources. Prior studies have pointed to a failure of incentives and institutions in the automotive supply chain of the USA.[24] Compared with Japan, US supplier–assembler relations have long been characterized by mistrust and adversarial relations. This has limited the extent of information sharing and collaborative, long term investments. Moreover, the US has lacked Japanese-style 'supplier associations' to promote dissemination of best-practice manufacturing methods. This situation may, however, be transient: the productivity data suggest strong improvements by US suppliers beginning in the 1990s, so it is possible that catch-up by US suppliers, while belated, is now starting to occur.

Acknowledgements

We are grateful for support from the MIT International Motor Vehicle Program, the UCLA Center for International Business Education and Research, and the Institute for International Economic Studies in Tokyo, Japan. We thank Hideki Yamawaki for helpful comments.

NOTES

1. See, for example, Cusumano (1985), Womak, Jones and Roos (1990), Lieberman, Lau and Williams (1990), Fuss and Waverman (1992), Fujimoto and Takeishi (1995), McDuffie and Pil (1995).
2. Representative studies include Asanuma (1985, 1989), Smitka (1991), Nishiguchi (1994), Fruin and Nishiguchi (1994), Sako (1996) and Dyer (1996a, 1996b).
3. Parts plants account for 74% of total automotive employment in Japan and 65% in the United States, based on estimates for 1990 by McKinsey Global Institute (1993).
4. This paper is part of a broader investigation of the automotive supply chain in Japan and the United States. Lieberman, Demeester and Rivas (1995) presents historical data on the process of inventory reduction by specific Japanese companies. Using these data, Lieberman and Demeester (1995) apply statistical methods to characterize the link between work-in-process inventory reductions and productivity gains. A third study, Lieberman, Helper and Demeester (1996), uses survey information on North American parts suppliers to assess the determinants of inventory levels in manufacturing plants.
5. In related studies we use data from company annual financial reports. The Census data have the advantage that they cover the entire industry, rather than a sample of firms. Moreover, the Census data are collected at the level of individual manufacturing plants, which avoids problems relating to companies diversification and vertical integration. (For example, the major auto assemblers are typically integrated into parts manufacturing, with some international operations and diversification outside the automotive sector.) Thus, the Census data allow for more comprehensive analysis of the entire automotive supply chain within a given country and a more precise measure of how inventories are divided between parts and assembly plants. A comparison of supplier inventory ratios computed from the two data sources is provided in Lieberman, Helper and Demeester (1996, Table 2). The corresponding ratios are nearly identical, except in the category of finished goods where they appear larger using the annual report data which include warehouse inventories held remotely from manufacturing plants.
6. The term "core assembler" is from Asanuma (1989).
7. The minor categories, which are excluded from our analysis, are "carburetors, pistons, rings and valves" (SIC 3592), "engine electrical equipment" (SIC 3694), "motor vehicle hardware" (SIC 34296) and "automotive screw machine products" (SIC 34511). The first two categories include a sizable proportion of aircraft and truck parts. The latter two categories are defined at the five-digit SIC level, for which inventory data are unavailable. In 1993, these four categories had a total value of shipments of $13 billion, as compared with $85 billion for SIC 3714 and $18 billion for SIC 3465. Omission of the minor parts categories leads to an underestimate of about 10% in our figures for total US supply chain inventories.
8. Thus, we exclude tire, battery and glass producers, important categories of suppliers that sell to the assemblers directly. A comprehensively defined supply chain would encompass a broad range of upstream operations such as mining, steelmaking, chemical processing, etc., which are also omitted here.
9. Nakamura and Nakamura (1989) report similar findings for other manufacturing industries, indicating that Japanese firms tend to have lower desired inventory/sales ratios and higher speeds of adjustment than US firms.
10. See Lieberman, Helper and Demeester (1996) for an extended discussion of the functions of automotive inventories.
11. In 1989, the average frequency of parts delivery was every six days in the USA, as compared with less than one day in Japan. By 1993 the US delivery frequency had fallen below four days. The US trend toward small lot deliveries has, however, been offset by increased supplier stockpiling of finished goods (Helper and Sako, 1995; Lieberman, Helper and Demeester, 1996).
12. The supply chain comparisons presented earlier use assembler sales as the denominator.

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13. Another issue to be considered in making these comparisons is that there is considerable variation in the WIP levels of specific producers and plants. For example, Toyota and Honda lie substantially below the Japanese industry averages shown in Table 1 and Fig. 5 (Lieberman, Demeester and Rivas, 1995).
14. For simplification, the contract assemblers are excluded.
15. To adjust for inflation we used the wholesale price deflator for transport equipment, published by the Bank of Japan.
16. The annual report data cover eight core assemblers, three contract assemblers and 41 parts suppliers, as described in Lieberman, Demeester and Rivas (1995). The group averages shown in Table 2 and Fig. 6 mask substantial heterogeneity among firms. For example, Toyota's labor productivity in the 1980s was about 50% above the average of other Japanese assemblers.
17. We used output price deflators for automotive parts (SIC 3714), stampings (SIC 3465) and assembly (SIC 3711) from the NBER database developed by Bartlesman and Gray (1994).
18. The missing information typically pertains to employee compensation.
19. The 1980 sample midpoint tends to understate the early growth rates and overstates the later rates, as 1980 was a recession year.
20. GM is also the most internationally diversified of the US assemblers, which tends to reduce its average labor productivity.
21. A detailed study using confidential, plant-level Census data (Herzenberg and Campbell, 1993) considers potential data problems that may lead to an underestimate of automotive supplier productivity. These include the need to adjust for changes in capacity utilization, price-cost margins, product quality, relative wages, environmental regulation, and output mix. Herzenberg and Campbell conclude that adjustment for these factors cannot account for the meager productivity growth shown by US automotive suppliers. Further, they find that captive suppliers had lower productivity growth than independents. The tails of the productivity distribution became fatter between 1978 and 1988, suggesting the coexistence of very high-performing and very-low performing plants.
22. This pattern of poor relative performance by US suppliers is corroborated by a recent study by McKinsey Global Institute (1993).
23. Estimates of Japanese automotive TFP are available but without separate breakdown for suppliers and assemblers. Fuss and Waverman (1992) give TFP comparisons covering the Japanese and US automotive sectors as a whole. Lieberman, Lau and Williams (1990) compare labor productivity, capital productivity and TFP for auto assemblers in the US and Japan.
24. Japan–USA differences in supply chain incentives and organization are discussed at length by McMillian (1990), Asanuma (1992), Sako (1996), and Dyer (1996a,b).

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