Inventory Reduction and Productivity Growth: Evidence from the Japanese Automotive Sector

Marvin B. Lieberman

Anderson Graduate School of Management
UCLA
Los Angeles, CA 90024-1481
Tel.: (310) 206-7665
E-mail: MLIEBERM@AGSM.UCLA.EDU

and

Lieven Demeester

Anderson Graduate School of Management
UCLA
Los Angeles, CA 90024-1481
E-mail: LDEMEEST@AGSM.UCLA.EDU

May 9, 1995

We are grateful for financial support from the International Motor Vehicle Program, the Institute for International Economic Studies, and the Center for International Business Education and Research at UCLA. The Daiwa Securities Corporation and the Japan Development Bank kindly provided access to data.

Abstract

The literature on JIT production suggests a causal link between work-in-process inventory and manufacturing productivity. Such a connection has been described in numerous case studies but never tested statistically. This paper uses historical data for 52 Japanese automotive companies to evaluate the inventory-productivity relationship. We find that inventory reductions stimulated gains in productivity, rather than vice versa. On average, each 10% reduction in inventory led to about a 1% gain in labor productivity, with a lag of about one year. Significant differences are found among company groups: Toyota affiliates had a shorter lag; while Nissan affiliates demonstrated no productivity effect. Firms that made inventory reductions typically saw an increase in their productivity rank.

Keywords:
- Inventory
- Productivity
- Just-In-Time Manufacturing
- Auto Industry
- Japan
- Empirical Study

I. Introduction

In recent years manufacturing managers and academic researchers have dramatically changed their view of work-in-process inventories. These inventories, held as a buffer between processing steps in manufacturing plants, were once considered essential for maintaining a steady production flow. But the wide acceptance of "just-in-time" (JIT) production has led to the contrary view that these inventories prevent the discovery of problems on the shop floor and can thus be detrimental to productivity. According to this new perspective, inventory reductions expose defects in the manufacturing process, forcing managers and workers to eliminate (rather than accommodate) sources of process variability.

Various authors have described the causal mechanisms linking inventory reduction to productivity growth (e.g., Schonberger, 1982; Hall, 1983). Nevertheless, many questions remain unanswered. Does inventory *reduction* lead to productivity gains, or does it merely serve as an *indicator* that process variability has been reduced (so that less buffer stock is required)? Or does *low inventory* facilitate observation of the manufacturing process, thereby inducing more problem solving activity? And if inventory reductions lead to productivity gains, how quickly do the gains appear, and what is the magnitude of effect?

Details of JIT implementation have been addressed in numerous case studies.[1] Nevertheless, there have been few statistical analyses of the connection between work-in-process inventory and manufacturing productivity.[2] In this paper we investigate this connection using data for 52 Japanese automotive assemblers and parts suppliers over the period from 1965 to 1991.

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[1] See, for example, Monden (1981, 1983) and the surveys by Im and Lee (1989) and Voss and Robinson (1987).

[2] Lieberman (1990), a precursor of the present study, documents a negative correlation between WIP inventory and labor productivity for Japanese automotive assemblers in the mid-1970s. Sakakibara, Flynn and Schroeder (1993) outline a much broader statistical investigation of JIT-performance relationships, based on survey data for US manufacturing plants.

We employ several statistical approaches to evaluate the nature and magnitude of the link between WIP inventory and productivity. First we explore the cross-sectional correlation between inventory levels and labor productivity. Our cross-section regressions show a negative correlation between inventory levels and productivity for the auto assemblers which has persisted since the 1970s. A more transient correlation is found for parts suppliers, whose operations are comparatively heterogeneous. Second, we report the results of time series analyses, in particular, tests of "Granger causality." These tests show that WIP inventory reductions were followed by significant productivity gains for both suppliers and assemblers, with a typical lag of about one year. The causality tests imply that inventory reductions led to productivity growth, rather than vice versa. Significant differences are found among company groups; in particular, Toyota affiliates had a shorter gestation lag, while Nissan affiliates had no significant productivity effect. Third, we apply an algorithm to the inventory data for suppliers to identify periods of substantial WIP reduction. Suppliers are found to have (1) increased their productivity rank during their inventory reduction period, and (2) exhibited significantly higher rates of productivity growth during this period. In general, these alternative statistical methods point to a significant and relatively rapid link between WIP reduction and productivity growth.

II. Data

The sample, which is described in detail in Lieberman, Demeester and Rivas (1995), includes a total of 52 Japanese automotive companies. The sample covers nearly all of the Japanese assemblers and most of the largest parts producers. Hence, findings are likely to be representative of the Japanese automotive industry. The historical time series is sufficient to allow observation of the adoption of JIT methods, which were introduced in Japan mostly from the late 1960s to the early 1980s.

Firms in the sample can be subdivided as follows. Eight are "core" assemblers. (A core assembler, such as Nissan or Toyota, is a company that assembles and sells finished automobiles under it's own name.) Three are "contract assemblers," companies that assemble automobiles as subcontractors for the core assemblers. The remaining 41 companies are "first-tier" parts suppliers, i.e., firms that supply parts directly to the assemblers. As discussed in Lieberman, Demeester and Rivas (1995), about half of these parts suppliers maintain close links with either Toyota or Nissan and can be classified as close affiliates of those assemblers.

The data are from Japanese annual financial reports covering the period from 1965 to 1991. The specific data items used in this study are: total company sales, value-added, total employment, fixed investment, and work-in-process inventories. These data are reported on a consistent basis by all publicly-traded manufacturing firms in Japan.[3]

Productivity Measure

Labor productivity, defined as real value-added per employee, is the productivity measure used in this study. (Value added equals the firm's sales during the fiscal year, minus the costs of purchased materials and services.) For each firm and year, the productivity measure was computed by first converting the firm's reported value-added into constant yen (based on the Japanese wholesale price index for transport equipment), and then dividing by the average of beginning- and end-of-year employment. This yields real value-added per employee, a standard measure of labor productivity.

Since the 1960s, Japanese automotive firms have scored impressive gains in labor productivity. Nevertheless, the rate of productivity growth has been diminishing over time. On average across the sample, labor productivity grew at 10.7% per year from 1965 to 1980, declining to 4.3% per year from 1980 to 1991.[4]

In the mid-1960s the core assemblers had nearly twice the labor productivity of parts suppliers. Since then, convergence has occurred. Over the period from 1965 to 1991, labor productivity grew at an average annual rate of 6.2% for the core assemblers versus 8.5% for the parts suppliers. The core assemblers have typically been more capital-intensive than parts suppliers, which explains much of their labor productivity differential. Within the ranks of both assemblers and suppliers, productivity variation has been substantial. Toyota, for example, appears as an outlier, with labor productivity nearly 50% higher than the average of other assemblers in recent years.

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[3] The specific data used in this study are from the *Analysts' Guide* published annually by the Daiwa Securities Corporation, with supplementary detail for the 1965-1976 period obtained directly from Daiwa Securities Corporation.

[4] Fujimoto and Takeishi (1994) discuss some of the reasons for declining productivity growth in the Japanese automotive sector.

WIP Inventory

Our analysis of JIT adoption focuses on reductions in each firm's work-in-process inventory. Japanese corporate reports give the value of the WIP inventory at the end of the fiscal year. Lieberman, Demeester and Rivas (1995) documents the substantial inventory reductions that have occurred in the Japanese automotive sector since the 1960s. Most companies in the sample cut their WIP/sales ratio by more than 50% during a period of intense activity from the late 1960s to the early 1980s.

Fixed Capital Investment

Labor productivity normally increases with the amount of fixed investment per worker. This relationship holds across firms and over time. Differences in capital intensity reflect basic differences in production processes, as well as managerial choices about the degree of process automation. Much of the productivity growth in Japanese manufacturing since World War II can be attributed to rising investment per worker (Norsworthy and Malmquist, 1981; Jorgenson and Kuroda, 1992; van Ark and Pilat, 1993).

To control for the effect of capital investment on labor productivity, we include a measure of tangible fixed assets per employee in our regression tests. Tangible fixed assets equals the depreciated value of the firm's property, plant and equipment at the end of each fiscal year. This accounting measure was adjusted for inflation and divided by the firm's total number of employees to give an estimate of total investment per employee.

III. Cross-Sectional Analysis of Productivity vs. Inventory Levels

Our first approach to assessing the potential inventory-productivity link was to examine the cross-sectional correlation between labor productivity and the level of WIP inventory for various time periods in the sample. If a link exists, it may appear in such an analysis, even though a cross-sectional correlation can offer little evidence on the direction or nature of causality.

To determine the correlation between the WIP inventory level and labor productivity, we estimated cross-sectional regressions at five-year intervals, as reported in Table 1. The dependent variable is labor productivity, defined as value-added per employee during the observation year. The explanatory variables are: (1) constant terms (separate terms for the core assemblers and the suppliers), (2) fixed capital investment per worker, and (3) the WIP/sales ratio. The regression specification allows assembler and supplier firms to have different inventory coefficients, but it assumes that capital investment affects the productivity of both groups similarly.

The estimates in Table 1 show that higher capital investment per worker had a strong effect on labor productivity, as expected. The coefficients imply that each 10% increase in per capita investment led to about a 3% to 4% gain in labor productivity.

Table 1 also reveals a cross-sectional correlation between WIP inventory and productivity. For the assemblers, the regression coefficient is consistently negative as expected, implying that higher WIP levels were associated with lower labor productivity. Nevertheless, the assembler inventory coefficients are highly significant in only two of the five years examined.

For the supplier firms, the correlation between inventory and productivity appears negative and significant for 1975 only. During the mid-1970s many firms were in the process of adopting JIT methods, so there was unusually high variation across companies with respect to inventory holdings and the extent of JIT adoption. Compared with the assemblers, the suppliers are very heterogeneous with respect to products and processes, and it is conceivable that associated variation in WIP requirements masks the connection between inventory and productivity.[5]

Thus, the annual cross-sections give some evidence of a connection between inventory levels and productivity. The findings are suggestive but inconclusive. Various factors may determine the base level of WIP required for a given firm. To examine the relationship between inventory and productivity in a more definitive way, time-series methods are required.

IV. Time-Series Analysis

For our time-series analysis we performed tests of "Granger causality," a method frequently applied in the econometrics literature to explore the nature of causation between two time-series variables (Granger, 1969; Pierce and Haugh, 1977; Geweke,

[5] In an effort to overcome this problem, we added a set of dummy variables for product type. These measures generally proved insignificant and had little effect on the WIP coefficients. It is, however, difficult to construct a precise set of controls for product type, given that most suppliers produce a range of automotive parts.

Meese and Dent, 1983). Such a test determines whether lagged information on a variable, X, has any role in explaining Y_t, after controlling for lagged Y and other factors.

In the specific context considered here, we examine whether lagged and contemporaneous changes in WIP inventory have any ability to explain labor productivity, after controlling for lagged productivity and changes in sales. The regression equation is:

$$V_t = \alpha + \Sigma^5_{i=1} \beta_i V_{t-i} + \Sigma^3_{i=0} \gamma_i \Delta S_{t-i} + \Sigma^3_{i=0} \eta_i \Delta W_{t-i} + \Sigma^3_{i=0} \lambda_i \Delta K_{t-i} + \varepsilon_t \quad (1)$$

where

V_t is value-added per employee in year t;

ΔS_t is sales in year t, divided by sales in year t-1;

ΔW_t is WIP inventory at the end of year t, divided by WIP at the end of year t-1;

ΔK_t is fixed investment per employee at the end of year t, divided by investment per employee at the end of year t-1;

and ε_t is a random error term.

All variables were measured in logarithms, and the regression equations were estimated by ordinary least squares.

Equation 1 can be viewed as a forecasting equation. Labor productivity for a given firm can be predicted fairly accurately given information on the firm's historical productivity and the current and lagged growth rate of sales. The question posed by the causality test is whether this forecast can be significantly improved using additional information on changes in WIP inventory.

More specifically, one would expect a firm's current productivity, V_t , to be largely determined by its lagged productivity (V_{t-i}) and by short-term fluctuations in sales (ΔS_{t-i}), the latter being typically beyond the control of the firm. The main hypothesis to be tested is whether, after inclusion of these two series in the regression equation, changes in WIP inventory (ΔW_{t-i}) have a detectable impact on productivity (i.e., the η_i terms in Equation 1 are jointly significant). Moreover, one would expect the coefficients for η_i to be negative, assuming that reductions in inventory contribute to an increase in labor productivity.

Equation 1 also incorporates a test for the productivity effects of increasing capital investment per worker. The λ_i coefficients should be positive. These coefficients may also reveal a gestation lag for new investment, as documented previously by Chew et al. (1990, 1991).

The test results are reported in Table 2. Regressions 1 and 2 are based on data for the full sample of 52 firms. The significant coefficients and high R-squared in Regression 1 confirm that current productivity is well-determined by lagged productivity, V_{t-i}, and recent changes in sales, ΔS_{t-i}. Regression 2 shows that after controlling for these factors, reductions in WIP inventory had a significant positive impact on productivity, with an average lag of about one year.[6] The ΔW_{t-1} and ΔW_{t-2} coefficients are negative and significant, while the ΔW_t and ΔW_{t-3} coefficients are essentially equal to zero. This implies that on average, a gestation period of approximately one year was required before productivity gains began to appear, with the effects ending after about two years. The coefficient for ΔW_{t-1} is about three times larger than the coefficient for ΔW_{t-2}, suggesting that most of the productivity change took place about one year after inventories were cut. The total effect is given by the sum of the ΔW_{t-1} and ΔW_{t-2} coefficients, which is about 0.8. This implies that a 10% reduction in WIP contributed to an 0.8% increase in productivity on average across the sample.

We performed tests to determine whether the effects of WIP reduction, as estimated in Regression 2, were consistent across groups of firms and time periods.[7] These tests showed no significant differences between assemblers and parts suppliers, or between the early and later periods of the sample. However, differences were detected on the basis of company affiliation. Regression 3, which is limited to producers with close ties to Nissan, reveals that these firms had no significant productivity gains following reductions in WIP inventory.[8] Excluding the Nissan affiliates from the sample,

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[6] The ΔW coefficients are jointly significant at the .001 level based on an F test or the Wald test recommended by Geweke, Meese and Dent (1983).

[7] Specifically, we added additional sets of ΔW_{t-i} terms to Regression 2, defined for the specific time periods or groups in question. An F-test was used to determine whether these terms were jointly significant. We also performed a number of tests which verified that the pattern of ΔW coefficients is robust to changes in the regression specification. When the contemporaneous terms, ΔS_t and ΔW_t.were omitted from the regression, the remaining ΔW_{t-i} coefficients were not greatly affected. Further omission of the remaining ΔS_{t-i} terms also had no substantial effect. Moreover, the ΔW_{t-i} coefficients were largely unchanged when the dependent variable and V_{t-i} terms were taken as annual differences rather than absolute productivity levels.

[8] This differential between Nissan affiliates and all other firms in the sample is significant at the .10 level, based on the F-test described in the prior footnote.

Regressions 4 and 5 show that Toyota affiliates had a shorter gestation lag than the other firms.[9] Nevertheless, their cumulative productivity effects were identical: the ΔW coefficients sum to 0.1 in both regressions, indicating that on average, a 10% reduction in WIP contributed to a 1% increase in labor productivity. Figure 1, which plots the ΔW coefficients, illustrates these inter-group differences in productivity dynamics. The contrast between Toyota and Nissan affilates is consistent with differences in the operations practices of the two assemblers, as discussed by Cusumano (1985).[10]

The results in Table 2 imply that inventory *reductions* contributed to productivity growth with about a one-year lag. Using the Granger causality model, we performed a series of supplementary tests to evaluate possible alternative patterns of causality linking productivity and WIP inventory. We added terms to Regressions 1 and 2 to reflect the *level* of WIP (taken relative to sales), rather than the annual rate of change. These terms failed to appear statistically significant. Hence, the results imply that it was WIP reduction, rather than a low initial WIP level, which stimulated productivity growth. We also tested whether changes in WIP were induced by changes in productivity, i.e., the reverse of the causality tested implied by Equation 1. No significant evidence of such effects was found.

Regression 6 in Table 2 includes the ΔK terms, which capture the productivity effects of changes in investment per worker. The ΔK coefficients, which are jointly significant, suggest a gestation lag of about one to two years, which is similar to the findings of Chew et al. (1990, 1991).[11] The addition of these controls for capital investment leads to a slight strengthening of the WIP coefficients.

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[9] This differential between Toyota affiliates and all other firms in the sample is significant at the .01 level. If Nissan affiliates are excluded from the sample, the Toyota group differential is significant at the .001 level.

[10] Cusumano (1985, pp. 307-319) compares the Nissan production system with the one developed by Toyota. While Nissan adopted some features of JIT manufacturing, “even in the early 1980s, Nissan differed from Toyota in several areas. It did not employ a ‘pull’ system, ... it produced in relatively large lots, ... (and it) chose to rely more on automation and computers to raise productivity than production-management techniques such as a complete kanban system or the job-cycle rationalization measures and rapid line speeds that Toyota employed.” (p. 307).

[11] The sum of the ΔK coefficients is 0.18, which is about half the magnitude of the equivalent cross-sectional coefficients in Table 1. Such a discrepancy would arise if the year-to-year changes contain a considerable amount of noise (e.g., if the productivity impact varies among types of investment projects).

V. Company-specific Periods of Inventory Reduction

Our third approach to characterizing the connection between WIP reduction and productivity growth is based on the fact that for most companies in the sample, there was a well-defined period when major inventory reductions occurred. After identifying these periods, we examined changes in each firm's relative productivity growth rate and productivity rank. We limited this analysis to parts suppliers to avoid confounding the effects of inventory reduction with other productivity differentials related to firm type.

As described in Lieberman, Demeester and Rivas (1995), we developed an algorithm for identifying periods of substantial WIP reduction, which was implemented as follows. For each firm we prepared the time series on the ratio of WIP inventory to sales. We then found the earliest year, if any, where the WIP/sales ratio for the next six years fell below a trajectory involving 4% annual reduction, or more stringently, 8% annual reduction. To establish the end of the period, we identified the earliest year for which the cycle time fell within 20% of the average cycle time of the remaining years of data.[12] Figure 2 shows the periods of substantial inventory reduction which were identified by the algorithm.

For the parts suppliers, which constitute the bulk of the sample, we used two methods to measure differential productivity growth during the inventory reduction periods. The first method utilizes annual productivity rankings to assess the change in rank of a company that made a substantial reduction in inventory. The second method involves analysis of the relative productivity growth of each company (i.e., its annual productivity growth relative to the average of all other companies in the sample).

In the first method, we ranked all of the parts suppliers in decreasing order of their labor productivity within each observation year. For the suppliers that satisfied the criterion for significant inventory reduction, we recorded their percentile productivity rank in the year prior to the start of substantial WIP reduction and one year after the end of this period.[13]

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[12] One firm, Riken, did not begin making substantial inventory reductions until the mid-1980s. These reductions continued until the end of sample coverage, so we manually extended Riken's period through 1991.

[13] We used the percentile rather than the numerical rank, as the number of suppliers in the sample increases slightly in the early years.

Table 3 reports the results. Of the 41 suppliers in the sample, 35 met the "4% criterion" for substantial inventory reduction. Of these, 25 increased in productivity rank during their WIP reduction period, and 10 decreased in rank (significant at the .01 level). Results are stronger using the more stringent criterion of 8% WIP reduction per annum. This criterion was met by 33 suppliers, of which 26 increased in rank and 7 decreased (significant at the .001 level).

Table 3 also reports the analysis of relative productivity growth during periods of substantial inventory reduction. Within each year of the sample, we subtracted the average rate of supplier productivity growth from the specific value shown for each company to obtain the firm's relative productivity growth rate. During periods of substantial inventory reduction, firms' growth rates exceeded the sample average by about 1.5% to 2.0% depending on the criterion used. These differentials are highly significant statistically.

VI. Discussion and Perspective

Sections III-V above present alternative tests for a connection between WIP inventory and labor productivity, based on historical data for the Japanese automotive sector. The test results are generally consistent, and they provide complementary information that helps to clarify the linkage between WIP inventory and productivity.

To put the findings in perspective, we can compute some rough estimates of the aggregate productivity gains attributable to inventory reduction, as compared with gains arising from other factors such as fixed investment. For a typical firm that made substantial inventory reductions, we can also compare the firm's productivity level with what would be expected in the absence of inventory cuts.

Estimates pertaining to the productivity impact of WIP reductions are provided in Tables 1-3. The cross-sectional coefficients in Table 1 fluctuate from year to year, but the time-series estimates in Tables 2 and 3 are stable and consistent. Summing the ΔW coefficients in Table 2 suggests that each 10% reduction in WIP contributed to an average increase of about 1% in labor productivity. Producers that made substantial inventory reductions, as identified by our algorithm, cut their WIP to about 34% of its initial level, on average, over the course of the sample period. Combining these estimates leads to the conclusion that for such firms, the aggregate productivity gain attributable to inventory reductions was typically about 10%. In other words, labor productivity was 10% higher at the end of the sample period, as compared with the hypothetical case where the firm would have made no inventory reductions at all.

A similar computation can be made using the estimates of relative labor productivity growth shown in Table 3. Firms that made substantial inventory reductions (based on the 4% criterion) experienced productivity growth during this period that was, on average, about 1.5% above the growth rate of other firms. Multiplying this figure by an average reduction period of about 6-7 years, which is consistent with Figure 1, yields a total differential productivity gain of about 10%. Hence, this approach gives an estimate consistent with the one derived from the regression coefficients in Table 2.

While 10% amounts to a sizable productivity differential, it is important to recognize that over the period from 1970 to 1980, when most of the inventory reductions were occurring, labor productivity for the sample companies grew at an average annual rate of 9.0%. Thus, the estimated effects of inventory reduction, while appreciable, correspond to less than one-tenth of the total productivity gains recorded during the 1970s.

The cumulative impact of WIP reduction on labor productivity can also be compared with the effects of increased capital investment. From 1970 to 1980, real fixed capital per worker rose by 5.1% per year on average across the sample. Using an elasticity of 0.35, which is suggested by the regression coefficients in Table 1, this increase in capital intensity translates into a labor productivity gain of about 20% over the course of the decade.[14] Thus, the productivity gain from inventory reduction during the 1970s may have been approximately half the magnitude of the gain from increased capital investment. Presumably, most of the rapid growth in Japanese automotive productivity during the 1970s was derived from process improvements unrelated to capital investment or inventory reduction.[15] During the 1980s, though, when the inventory reduction effects were largely exhausted, capital investment accelerated. Fixed capital per worker grew at 8.7% per year, which translates into a productivity gain of about 35% over the course of the decade.[16] Labor productivity grew by only about 50%

[14] The gain appears smaller if based on the regression coefficients in Table 2, which are likely to be downward biased.

[15] During the 1970s various manufacturing practices, such as quality circles and total quality control, became widely adopted in the Japanese automotive sector.

[16] We assume in these calculations that the relationship between capital investment and labor productivity remained stable over the two decades.

during this period, so capital investment appears to have taken over as the major driver of labor productivity growth.

VI. Conclusions

The findings of this study help to elucidate the relationship between WIP inventory and productivity. We have tested alternative chains of causality and derived quantitative estimates of effects. The results are complementary with the large body of case study evidence on the implementation of JIT manufacturing.

Our analysis implies that productivity gains were stimulated by inventory reductions, rather than low inventory levels. Moreover, inventory reductions were *followed* by productivity gains, rather than vice versa. In quantitative terms, each 10% reduction in inventory led to an average gain of about 1% in labor productivity, with a lag of about one year. There were some significant differences among company groups: Toyota affiliates had a shorter lag; while Nissan affiliates demonstrated no significant productivity effect. Firms that made substantial inventory reductions enjoyed a period of productivity growth 1.5% to 2% higher than that of other companies, on average. Typically, these firms also saw an increase in their productivity rank.

We tested for connections between WIP inventory and productivity in the cross-sectional domain (i.e., looking for a correlation between inventory and productivity *levels*) as well as the time-series domain (testing whether *changes* in inventory are linked to *changes* in productivity). While there is evidence of a cross-sectional correlation, particularly for the final assemblers, the results are more stable and clear-cut based on changes over time.

These findings, while broadly consistent with prior research, offer extensions to our knowledge regarding JIT adoption. Nevertheless, important caveats apply. The findings presented here are aggregate estimates, far removed from details of the shop floor where JIT implementation actually takes place. Such details undoubtedly matter, and the estimates reported in this paper are averages that mask heterogeneity across individual firms, plants and processes.

Most importantly, it is well known that inventory reduction is only one component of JIT; related activities (such as setup time reduction and statistical process control) are essential. It is impossible, and perhaps not meaningful, to distinguish the specific impact of WIP reduction from that of these other activities. Indeed, the WIP reductions observed in this study serve as a proxy for these other activities, with which they are correlated. Thus, the productivity gains attributed to inventory reduction in this paper should be more broadly attributed to a range of related activities. Many of these activities continue long after the end of the inventory reduction period identified here. To the extent that these activities fail to be correlated with inventory reduction, the associated productivity gains are omitted from the estimates obtained in this study. Hence, the quantitative results presented here may be considered as underestimates of the total gains attributable to JIT adoption. In general, the quantitative findings of this study should be kept in perspective and regarded as rough benchmarks only.

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