Reducing Inventory and Improving Productivity: Evidence from the PIMS Data

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1. Introduction

Under today's rapidly changing competitive environment, cost effectiveness and high quality are no longer enough to sustain competitive advantage. A company's business processes must also be more responsive and flexible than

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those of its competitors. Tougher competitive situations have led to increasing attention being paid to customer satisfaction, of which timely and customized services are the key concepts.

Innovative ways must be sought continuously to provide technology to support motivated, adaptable work groups dedicated to meeting or exceeding customers' requirements in the shortest possible time. Moreover, North American manufacturers in almost every industry have found themselves involved in increasingly fierce competition with foreign companies, particularly those from Japan, Germany, and the East Asian Newly Industrialized Countries.

In responding to the challenge of primarily Japanese competition with manufacturing excellence championed by Toyota production system (Ohno, 1988; Shingo, 1989), North American companies have tried a number of approaches to business process innovation, particularly in the area of inventory management and logistics. By simultaneously redesigning information flows, work processes, and authority structures, the company has radically improved not only the cost and quality of its delivery system, but also its flexibility.

One key element of process innovation in inventory management and logistics is the stockless production: production is executed as ordered and delivered as needed. This kind of stockless production has been called the Zero Inventory System (Hall, 1983; Zangwill, 1987), the Just-In-Time System (Lubben, 1988), or the Lean Production System (Krafcik, 1988).

Stockless production has two core components: (1) reducing setup time and (2) reducing WIP (Work-In-Process) inventory. There are several positive effects from these actions: lot-size reduction through setup time reduction that brings the benefit of reduced inventory level as well as quality improvement (Porteus, 1982, 1985; Rosenbalt and Lee, 1986). The reduction of inventory holding costs (thus, the total cost reduction) is the most obvious benefit associated with these actions, and the other benefit is productivity increase through continuous improvement (Fine and Porteus, 1989).

There exists a body of research on the effectiveness of Japanese production methods in the automobile industry. MIT's five-year intensive study on the future of the automobile produced an extensive body of research findings (e.g., Krafcik, 1988; Womack et al., 1990). Womack et al. (1990) found that Japan's lean production helped Japanese automobile companies forge ahead in the global auto markets. Krafcik (1988) found that the key to competitiveness is not ownership of the company but the management style, which implies the applicability of the lean production system concept to the United States.

Lieberman et al. (1990) also examined the determinants of improving productivity for six major U.S. and Japanese automobile companies-General Motors, Ford, Chrysler, Toyota, Nissan and Mazda- from the early 1950s through 1987. They considered several determinants of productivity growth, such as economies of scale, adoption of JIT manufacturing and changes in top management. They found that (i) efficient utilization of labor is the key to productivity improvement, (ii) significant shifts in growth rate and level of firm productivity have followed changes in top management. However, they found no significant relationship between inventory level and labor productivity.

However, these studies are limited in the sense that their research is based entirely on data from the automobile industry. Despite the significance and popularity of the JIT system, most empirical investigations concerning the effectiveness of stockless production are case studies or based on anecdotal evidence or studies confined to a specific industry, such as automobiles.

The major contribution of this paper is to examine the effectiveness of inventory reduction based on a large data set that covers a variety of manufacturing activities from the early 1970s to late 1980s. We conduct our empirical analysis utilizing the Profit Impact of Market Strategy (PIMS) Database from the Strategic Planning Institutes. The PIMS Research Database provides us with a unique opportunity to empirically examine the relationship between inventory reduction and productivity since (i) The PIMS Database contains more than 2,000 Strategic Business Units (SBU) involved in manufacturing business from many industries or sectors[1], (ii) the several hundred corporations that participated in the PIMS program cover most of Fortune 500 enterprises in North America, not Japan, and (iii) we can also examine how the relationship is affected by other factors, such as the position in the product life cycle, product line width, and characteristics of production processes. For a general description of the PIMS data and a summary of empirical findings based on the PIMS data, see Buzzell and Gale (1987).

This paper proceeds as follows. Section II provides the theoretical basis for the effectiveness of inventory reduction by examining literature from several fields. Section II also sets up a basic equation for our empirical analysis. Section III explains about the sample population and variables used in this research. Section IV reports estimation results and discussion, and Section V concludes the paper.

2. Determinants of Productivity: Theories and An Empirical Model

In this section, we will discuss the theoretical basis of the proposition that the reduction of Work-In-Process (WIP) inventory contributes to the productivity improvement. We will also discuss other factors such as the position in the product life cycle and the characteristics of industries and production processes.

2.1 Inventory Reduction and Productivity

Our main interest is to investigate the impact of WIP changes on labor

1) The concept of SBU will be explained in the detail in Section III.

productivity. In particular, we hypothesize that lower level of WIP will positively contribute to the productivity per employee as follows:

Hypothesis 1: *Reductions in Work-In-Process inventory positively contributes to (workers') productivity.*

We postulate that there are possibly two different mechanisms through which reducing WIP increases productivity: a dynamic learning process (i.e., continuous improvement) and a better monitoring and control (i.e., more effort by the workers).

Problem Discovery and Learning Process

How can reducing inventories improve productivity? One possible mechanism is the dynamic learning process. In particular, WIP inventory reduction helps to achieve a higher learning rate through a clearer exposition and easier identification of problems.

Reductions in WIP inventories help to expose hidden problems to employees. In other words, reductions in WIP increase the probability of problem detection, thus, contribute to productivity increase. A popular analogy is to compare the production process to a river and the inventory level to the water level of the river. When the water level is high, it covers the rocks. By analogy, if the inventory level is high, it masks all of the problems. However, once the inventory level is reduced, the problems are uncovered as rocks become visible as the water level is lowered.

There are few models which explicitly explain the above mechanism through which the reduction of inventories contributes to productivity improvement. Fine and Porteus (1989) explicitly modeled the dynamic process improvement using a Markov process model. Ocana and Zemel (1990) consider an inventory model in which the production technology improves with a sequential learning process controlled by firms. Ocana and Zemel (1990) showed that the JIT system with emphasized the relationship between the inventory reduction and the productivity improvement. Suri and De Treville (1986) analyzed the optimal management of inventories under the assumption that learning takes time, so that gains in inventory reduction must be balanced against the temporary loss of efficiency that results when operators of a production system are confronted with a new production environment.

This mechanism of a dynamic learning process is based on the fact that reductions of WIP lead to an increasing awareness of problems, thus, problem solving capability and productivity. Aoki (1988) classified the organization of production systems into the J-mode and the H-mode. Then, he showed that the J-mode organization of production system utilizes the on-site information better than the H-mode, thereby contributing to the productivity improvement.

Observability and Less Incentive to Shirk

The first mechanism is mainly concerned with learning induced by inventory reduction and implicitly assumes that every worker is doing his or her best to improve productivity (i.e., no shirking). However, when there is information asymmetry between manager and line workers, the line workers have an incentive to utilize private information for their utility, and not for the efficiency of the production system.

Information asymmetry between the line workers and the supervisor will create incentive problems, which negatively contribute to productivity improvement. From the manager's perspective, elimination of such incentive problems will help improve the productivity, and thus the performance of the production system.

One way to avoid information and incentive problems is to monitor the line workers. However, monitoring can be very costly. We postulate that the reduction of WIP inventory will alleviate the problems caused by information asymmetry since the reduction of WIP inventories will make the production process easier to monitor and control (thus, less costly to monitor and control) thanks to the improved visibility of the work flow on the shop floor. Aoki (1988; 1990) and Itoh (1991) explain how the Japanese human resource management system has tried to provide the appropriate incentives for workers to increase their efforts. However, Aoki's and Itoh's discussion is primarily from the job specification and promotion policy. They did not deal with the role of inventory reduction in productivity improvement from the workers' incentives perspective.

Alchian and Demsetz (1972) argue that the less observable a worker's effort is the more likely it is that he or she will try less and hence the less productive he or she will be. Following Alchian and Demsetz's reasoning, higher observability will likely force the line workers to try harder. Thus, reduction of WIP inventories will help to mitigate the incentive problem through better exposition and monitoring of problems on the shop floor. Consequently, the WIP reduction will help improve productivity.

This mechanism has been more or less undertreated in the literature on production and operations management. However, we argue that incentives also play a very important role in the productivity and competitiveness of the firm as suggested by the real life example of the Lincoln Electric Company (Harvard Business School, 1975).

2.2 Product Life Cycle, Product Line Width, and Process Characteristics

We also posit that environmental factors such as the characteristics of production processes affect the relationships between WIP and productivity. In this section, we make a hypothesis about the impact of the product's position in the product life cycle, product line width, and the characteristics of production processes on the relationships between the WIP and productivity. Let us first look at the stage of the product life cycle and the impact of inventory reduction on productivity.

Hypothesis 2: *As the product matures, the impact of WIP reduction on productivity becomes more important.*

As the product matures, process improvement becomes more important since the focus on competition shifts new product introduction to cost-cutting operations management. Thus, cost competition and process improvement becomes more important as the product becomes standardized. Hayes and Wheelright (1979) suggested the position of "distinctive competence" in different stages of the product life cycle based on the product-process life cycle model.

Hypothesis 3: *As a production process becomes more like a continuous process, the impact of WIP reduction on productivity becomes more important.*

Hypothesis 4: *As companies develop a wider product line, the impact of WIP reduction on productivity becomes less important.*

It is generally the case that the more complex a system, the less noticeable a change in the system is. The above two hypotheses concern the relationship between the complexity of the production processes and the visibility or observability of WIP inventory reductions within the system. Continuous production processes and narrower product lines are, in general, less complex. Thus, *other things being equal*, WIP reduction will be more important to the line workers with continuous process and narrow (specialized) product line, thereby making WIP inventory reduction more effective.

From the perspective of production process, the impact of WIP inventory level changes for a continuous process is more directly visible than for assembly line or batch processes. This is because the disruption of a stage in the continuous process immediately affects the adjacent stages. On the other hand, the impact of changes in WIP inventory levels on the job shop or the batch process is less visible since the disruption or breakdown in one workstation does not have immediate effects on other workstations thanks to the buffer provided by the WIP inventories waiting for the next operations during job process.

Just-In-Time implementation typically requires the conversion of production processes to a more continuous line system. This helps to reduce the WIP inventories and expose problems. Better problem specification helps managers to better control and monitor line workers as well as workers to identify the problem.

2.3 The Testing Model

We can express the hypotheses discussed in the previous section by utilizing the following equation:

$$Y(t) = exp[\beta_1 W(t) + \sum_{i=2}^{i=n} \beta_i X_i(t)] \quad (1)$$

Where $Y(t)$, W(t), and $X_i(t)$ denote the productivity at time t, the level of the WIP inventories at time t, and the control variable i at time t which affects the productivity, respectively. Note that the relationship is expressed at a given time point t. This is because we are explicitly concerned with the underlying dynamic relationship given in equation (1).

After taking the logarithmic transformation of both sides of equation (1), we have

$$\log Y(t) = \beta_1 W(t) + \sum_{i=2}^{i=n} \beta_i X_i(t) \quad (2)$$

When we differentiate equation (2) with respect to time t in order to examine the relationship over time, we get:

$$\frac{\frac{dY(t)}{Y(t)}}{dt} = \beta_1 \frac{dW(t)}{dt} + \sum_{i=2}^{i=n} \beta_i \frac{dX_i(t)}{dt} \tag{3}$$

For our empirical analysis, we can rewrite equation (3),

$$PY = \beta_1 PW + \sum_{I=2}^{i=n} \beta_i PX_i + \sum_{j=1}^{i=m} [\gamma_j D_j + \theta_j PW \times D_j] + \varepsilon \tag{4}$$

Where $PY = \frac{\frac{dY(t)}{Y(t)}}{dt}$, $PW = \frac{dW(t)}{dt}$, $PX_i = \frac{dX_i(t)}{dt}$, D_j denotes the dummy variable.

Note that the terms in equation (4) are all expressed as the change in each variable over time since equation (4) is a specification in the first difference. This specification not only allows us to focus on dynamic relationship, but also helps us overcome possible problem of firm-specific effects without explicitly estimating those effects.

Also, the above specification allows us to examine the change of WIP inventories level possibly affected by environmental characteristics expressed by dummy variables. The terms $\theta_j PW \times D_j$ are included to examine how the effectiveness of inventory reduction is affected by environmental factors such as product life cycle stage, characteristics of the production processes, and the product line width.

3. Data and Testing Procedure

3.1 The PIMS Research Database

The PIMS program was initiated by the Strategic Planning Institute (SPI) in

Cambridge, Massachusetts in 1972 for the purpose of helping research on competitive strategies with the belief that managers and analysts can have better comprehension on general relationships between strategies and performance through analyzing the experience of many companies across various industries. Since that time, more than 450 companies have documented the strategies and financial results of their Strategic Business Units (SBUs) for periods ranging from 2 to 12 years. Marshall (1987) concluded that strategic studies based on the PIMS Database are also supported by the FTC Line of Business Data.

The SBU is the core concept in the PIMS Database. A business unit is defined as a division, product line, or other profit center of a company that

- ◆ produces and markets a well-defined set of related products and/ or services,
- ◆ serves a clearly defined set of customers, in a reasonably self-contained geographic area,
- ◆ competes with a well-defined set of competitors.

For each SBU, the financial data are compiled from accounting records. Measures or estimates of the size of a business unit's served market, its historical growth rate, competitor's sales, and other competitiveness-related data are supplied by the unit's general manager, marketing executives, and appropriate staff member.

This research utilizes the SPI Research Database which is part of the PIMS Database program. The SPI Database is a collection of line-of-business data which describes business units and their markets served. Each record in the database represents a single business unit over a given time-span, and contains 500 variables which have been constructed from the basic data collected on the PIMS Data Forms.

There are not many empirical studies that utilize the PIMS for the issues related to production and/or operations management. Cohen (1988) discussed the relevance of the PIMS Database to the empirical study of manufacturing and operations issues. Tombak (1988) examined the relationship between manufacturing flexibility and firm performance in the growing and mature phase of the product life cycle. Kekre and Srinivasan (1990) examined the impact of product line breath decision making on the market share and production cost. Kim (1990) examined the role of product grouping in demand variability reduction and capacity utilization.

3.2 Data and Variable Selection

We first select 2,746 observations, one observation for each SBU in the SPI Research Database by selecting the most recent ones for each SBU. Among these 2,746 SBUs, we exclude non-manufacturing SBUs which are classified as service industries such as distribution/retail or other services. This leaves us with 2,569 manufacturing SBUs. These observations are utilized in our examination of empirical data.

Based on the models that we discussed above, we select the following variables for our analysis:

- ◆ the percentage change in employee productivity measured at the constant dollars (PRODY).
- ◆ the change in the ratio of raw materials and WIP inventories to revenue (WIP).
- ◆ the change in wage rates or the wage index (WAGE).
- ◆ the change in the capacity utilization ratio (CAPUTIL).
- ◆ the change in the gross book value of plant & equipment per employee measured at the constant dollars (CAPINTEN).

- the percentage of employees unionized (UNION).
- dummy variables for the stage in the product life cycle defined by: P1=introductory stage; P2=growth stage; P3=mature stage. Thus the SBU is in the decline stage if P1=P2=P3=0.
- the dummy variable for the production process characteristics (PRC). It becomes 1 if the percentage of the total production produced in a continuous line process is larger than that of small batches.
- dummy variables for the product line width as defined by: NR=narrower than the competitor; EQ=equal to the competitor. Both NR and EQ are 0 if the SBU has a wider product line than that of the competitor.

It is clear that the capital-labor intensity will positively contribute to productivity. Thus, capital-labor intensity is included as a control variable. In addition, we choose the worker's compensation, capacity utilization, and unionization of labor as the control variables. Buzzell and Gale (1987) found that the gross book value of plant and equipment per employee has a significant positive effect on the productivity per employee. From the perspective of incentives affecting the labor productivity. In general, we expect that higher compensation results in higher productivity. In our analysis, wage compensation is used as a proxy for labor compensation.

Higher capacity utilization yields higher productivity per employee in given period of time. Thus, higher capacity utilization will positively affect the productivity per employee (Buzzell and Gale, 1987). How is this possible? First, higher capacity utilization means more units produced in a given period of time (usually a year), which makes the average quantity produced per employee higher. Thus, a higher capacity utilization ratio contributes to the employee's productivity from an accounting perspective. Second, it might also capture possible learning effects, if any. Therefore, the variable, capacity utilization, controls the portion of an employee's productivity that does not relate to the change in labor usage or the change in worker's efforts or the change in the capital intensity per employee. Unionization has been regarded as a negative factor for improving the labor productivity. Buzzell and Gale (1987) also found that unionization negatively contributes to the productivity per employee.

We also construct the dummy variables, P1, P2, P3, PRC, NR, and EQ using the variables in the PIMS Database. The PIMS Database includes the position of the SBU's products in the product cycle that can be classified into four stages. Based on that variable, we can construct three dummy variables for each stage of the product life cycle. We also utilize the PIMS variable at the product line width for the construction of dummy variables, NR and EQ.

The dummy variable PRC deserves more explanation. The PIMS Database contains a description of the SBU's production processes. It contains the variables denoting the percentage of the business's sales derived from the products manufactured in small batches, in large batches or an assembly line, and in a continuous process. Using these variables we construct a dummy for the characteristics of the SBU's production processes. The descriptive statistics for the variables used in our analysis and the detailed description of these variables from the PIMS variables are provided in the Appendix.

3.3 Estimation Methods

Typically there is a problem of heteroskedasticity in cross-section studies such as ours. If heteroskedasticity exists, OLS (Ordinary Least Squares) estimator, while still linear and unbiased, is no longer efficient and the estimated variance of the estimators is biased, so the usual tests of statistical significance (the t and F tests) are no longer valid. Therefore, it is important to correct for possible heteroskedasticity.

WLS (Weighted Least Squares) estimator can correct this heteroskedasticity problem if we know the appropriate weights assigned to each variable. However, WLS require some knowledge of the possible weights. On the other hand, White (1980) suggested consistent variance-covariance matrix estimators for the OLS estimator so that the statistical significance of OLS estimates can be judged appropriately without specifying the heteroskedasticity structure in the model. We adopt White's approach to overcome the problem of statistical inference caused by heteroskedasticity in our analysis.

4. Analysis Results and Discussion

First, we estimated the following equation by OLS; the results are reported in the OLS column of Table II-1:

$$\text{PRODY} = \alpha\,\text{CONST.} + \beta_1\text{WIP} + \beta_2\text{WAGE} + \beta_3\text{CAPUTIL} + \beta_4\text{CAPINTEN} + \beta_5\text{UNION} + \varepsilon \, . \quad (5)$$

Since we suspected heteroskedasticity, we employed the Breusch-Pagan test (Breusch and Pagan, 1979) and White test (White, 1980) for the test of heteroskedasticity. Both tests strongly reject the null hypothesis that the residuals are homoskedastic.[2] Thus, we used White's method for heteroskedasticity-corrected estimation. The results are reported in the HLS column of Table II-1. As we can see, the estimated coefficients are the same but the *t*-values are different since standard errors are corrected for heteroskedasticity by White's method.

4.1 Control Variables

As we expected, increases in wage rate, capacity utilization, and capital

2) We omit the details of both tests here due to space limitation. The test procedures and results are available from the author upon request.

intensity per employee positively contribute to improving employee productivity. All the coefficients of these terms presented in Table II-1 are positive and significant at the 0.01 level with high t-values. It is easy to understand why increases in the wage rate and capital intensity positively contribute to the employee's productivity. Indeed, capacity utilization means more units produced in a given period of time (usually a year), which makes average quantity of production per employee higher. Thus, a higher capacity utilization ratio contributes to employee productivity from an accounting perspective. Therefore, the variable, capacity utilization, controls the portion of an employee's productivity that has nothing to do with the change in labor usage, the change in workers efforts, or the change in capital intensity per employee.

In the case of unionization, a negative value of the estimated coefficient indicates the negative impact of unionization on the improvement of employee productivity. Even though it is not significant at the 0.10 level by the two-tail test, the coefficient is marginally significant at the 0.10 level when we apply the one-tail test to the coefficient of unionization. However, the magnitude of its negative impact is relative small: -0.0089 of the coefficient implies that a one percent increase in unionization decreases the employee productivity improvement by 0.009 percent, which is less than 1/100 percent. Therefore, the impact of unionization on the (workers) productivity turns out to be insignificant in our analysis.

4.2 WIP Inventory Reduction and Productivity

Reductions in WIP (and raw materials) inventory indeed helps to improve (worker) productivity. The estimated coefficient for the WIP term is negative and significant at the 0.01 level. In fact, its t-value (-10.5342) suggests its significance even at the 0.001 level. The significantly negative coefficient of the WIP term supports our first hypothesis that reductions in WIP help to improve employee productivity. In particular, the magnitude of the coefficient, -1.4068, means that one point reduction in the ratio of the raw materials and WIP inventories to total sales will bring about 1.4 percent improvement in employee productivity.

4.3 The Product Life Cycle and Inventory Reduction

In this section, we examine how the impact of inventory reduction on employee productivity improvement changes over the different stages of the product life cycle. For that purpose, we formulated the following equation:

$$\begin{aligned} PRODY = & \alpha CONST. + \beta_1 WIP + \beta_2 WAGE + \beta_3 CAPUTIL \\ & + \beta_4 CAPINTEN + \beta_5 UNION + \gamma_1 P1 + \gamma_2 P2 + \gamma_3 P3 \\ & + \theta_1 (WIP \times P1) + \theta_2 (WIP \times P2) + \theta_3 (WIP \times P3) + \varepsilon . \end{aligned} \quad (6)$$

The results are reported in the column for equation (6) of Table II-2.

Here, we use the decline stage as the basis for comparison, Thus, the estimated coefficient of β_1 denotes the impact of WIP inventory reduction on productivity improvement at the decline stage. On the other hand, β_1 and θ_1 (i.e., $\beta_1 + \theta_1$), β_1 and θ_2 (i.e., $\beta_1 + \theta_2$), and β_1 and θ_3 (i.e., $\beta_1 + \theta_3$) give the magnitude of the impact of WIP reductions on the productivity improvement at the introductory, growth, and mature stage of the product life cycle, respectively. From Table II-2, we can see that the estimated coefficient of θ_1 is not significant while the estimated coefficients of θ_2 and θ_3 are significant and positive. These results imply that the impact of the WIP reduction on the productivity improvement increases as we move from the growth to mature stage and from the mature to the decline stage in the product life cycle.

However, we observe that the impact of reducing WIP on improving productivity decreases as we move from introductory stage to growth stage (i.e., the estimated coefficient of θ_1 is negative and not significant). One possible reason for this decrease is that there is a tendency toward rapid learning until the production process becomes standardized and reaches normal operation at the initial production stage of a new product, which contributes to more rapid improvement in employee productivity. Thus, the intrinsic characteristics of the product life cycle contributes to a more rapid improvement in the introductory stage than the growing stage where the production process is already somewhat standardized and geared toward mass production. Once the production process is regularized (i.e., more stable production methods for mass production are discovered and improved through trial and error by the initial stage of production), the improvement and learning associated with reducing WIP becomes more incremental in nature and related to the production process itself. In other words, there might be possibly two different kinds of learning associated with WIP reductions before and after the production process is standardized.

4.4 Continuous Production Process and Inventory Reduction

As we explained above, we set a new dummy variable PRC for the characteristics of the reduction processes. Among 2,567 samples, 2,096 SBUs reported the percentage of the business's sales derived from products manufactured in small batches, in large batches or by assembly line, and in a continuous process. Thus, our estimation in this subsection is based on a sample size of 2,096 observations. The following equation is used for the estimation:

$$\begin{aligned} \text{PRODY} = {} & \alpha\,\text{CONST.} + \beta_1 \text{WIP} + \beta_2 \text{WAGE} + \beta_3 \text{CAPUTIL} \\ & + \beta_4 \text{CAPINTEN} + \beta_5 \text{UNION} + \delta_1 \text{PRC} \\ & + \delta_2 \text{WIP} \times \text{PRC} + \varepsilon . \end{aligned} \quad (7)$$

The results of estimation are reported in the column for equation (7) in Table II-2. We found that the impact of WIP reductions on productivity becomes greater as the production process is more like a continuous process. The estimated coefficient of δ_2 is 1.0606 and significant at the 98 percent level. We interpret this to mean that the effectiveness of WIP reductions increases with a continuous production process probably because the disruption caused by the reduction in WIP is more visible, thereby requiring more attention and allowing less shirking by line workers.

4.5 Product Line Width and Inventory Reduction

The complexity of the production process is also partly dependent upon the product line width. In general, the complexity increases as the production process becomes wider (or less focused). We used the following equation for the test:

$$\begin{aligned} PRODY = & \alpha CONST. + \beta_1 WIP + \beta_2 WAGE + \beta_3 CAPUTIL \\ & + \beta_4 CAPINTEN + \beta_5 UNION + \zeta_1 NR + \zeta_2 EQ \\ & + \eta_1 WIP \times NR + \eta_2 WIP \times EQ + \varepsilon . \qquad (8) \end{aligned}$$

Again, estimated coefficients are reported in the column for equation (8) in Table II-2. We found that product line width brings no significant differences in the impact of WIP reduction on productivity. Coefficients of η_1 and η_2 are not significant at the 90 percent level by the two-tail test. This result fails to support our hypothesis on the relationship between product line width and the effectiveness of the WIP reduction.

One possible reason for such results is that the variable used in the analysis may have some problems. The variable for the product line width is not without limitations. The original variable for the product line width reported in the PIMS

Database is measured in terms of competitors, which does not directly reflect the actual width of a production line: a relative width may not be an appropriate proxy variable for the complexity of actual production processes.

In a competitive market, the relative width of a product line is thought to be important to the market share and profitability of SBUs, which is verified by Kekre and Srinivasan (1990). On the other hand, Kerke and Srinivasan (1990) that the product line width has no impact on costs may be due to manufacturing strategies of firms that mitigate potentially adverse impacts on production costs. At the same time, it is also possible that a variable measured in relative terms fails to capture the actual complexity of the production processes which is more relevant to production costs. However, this interpretation is only a conjecture since we do not have a measure of the actual width of a product line to test the hypotheses.

5. Conclusion

This research utilized the PIMS Research Database to examine the impact of work-in-process (and raw materials) inventory reductions on productivity improvements. The empirical results support the robustness of the principle of "Lean Production" or JIT system (also referred to as "Stockless Production"). In other words, the effectiveness of work-in-process (and raw materials) inventory reduction is empirically proven to exist across different industries in various regions and over time.

We also find that the overall environment in which manufacturing strategic business units operate is an important factor in determining the different degrees of effectiveness of the work-in-process (and raw materials) inventory reductions. In particular, we find that the effectiveness of the work-in-process reduction varies according to the position in the product life cycle as well as the complexity and characteristics of the production processes.

The results of our analysis, based on the PIMS Data, imply that stockless production is indeed a general principle that can be applied to manufacturing environments in other places rather than a unique product of Japanese culture since the PIMS Database covers mostly firms in North America and small number in Europe, not ones in Japan.

There are some limitations to this approach, which must be considered in the interpretation and discussion of the analysis. First, there is the potential for errors in measurement due to the nature of self-reported data. As already discussed by Kekre and Srinivasan (1990), econometric procedures are of limited use in addressing the problems of errors on measurement of variables. Thus, the results and discussion must be considered within this context. Second, we do not try to explicitly model the process through which reducing work-in process inventory affects employee productivity even though we hypothesize about the learning process involved in the relationship. However, there are not many theoretical models that deal with this issue as we discussed in Section II.

Finally, we believe that this paper also demonstrates the possible usage of the PIMS Database for empirical investigations of the issues related to production and operations management. Despite the potentials of the PIMS Database (Cohen 1989), there are not many studies which examine the issues related to production and operations (Tombak, 1988; Kekre and Srinivasan, 1990; Kim, 1990). One possible contribution of the PIMS Database in this field will be empirical examination of the issues related to manufacturing and operations strategies.

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Appendix I

<Table I-1> Descriptive Statistics

Variable	No. of Obs.	Mean	Stad. Error	Minimum	Maximum
PRODY	2569	2.8333	11.3545	-20.000	40.000
WIP	2569	-0.2524	1.8986	-7.000	5.000
WAGE	2569	8.7622	3.8055	1.000	25.000
CAPUTIL	2569	0.0281	6.1036	-15.000	15.000
CAPINTEN	2569	3.4293	7.4952	-10.000	40.000
UNION	2569	45.0958	33.5569	0.000	100.00

<Table I-2> Correlation Coefficients Among Variables

	PRODY	WIP	WAGE	CAPUTIL	CAPINTEN	UNION
PRODY	1.000					
WIP	-0.279	1.000				
WAGE	0.060	0.001	1.000			
CAPUTIL	0.266	-0.257	-0.091	1.000		
CAPINTEN	0.120	0.113	-0.002	-0.211	1.000	
UNION	-0.023	0.021	0.159	-0.047	0.032	1.000

<Table I-3> Description of PIMS Variables

Description of the Variable	Variable Name in the PIMS Database
the percentage change of the employee productivity measured at the constant dollar value of 1980	*EMP PRODY $80%*
the point change of the ratio of raw materials and WIP inventories to revenue	*RM & WIP INV/REV P*
change of wage rates	*WAGE RATES P*
change of capacity utilization	*CAPACITY UTIL P*
change of the gross book value of plant & equipment per employees measured at the constant dollar value of 1980	*GRS BK/EMP $80 P*
percentage of employees unionized	*%EMP UNIONIZED*
category variable for industry classification	*TYPE OF BUS C*
position in the product life cycle stage	*LIFECYC STAGE O*
percentage of the business's sale from the products manufactured in small batches	*% SMALL BATCHES*
percentage of the business's sale from the products manufactured in assembly line	*% ASSEMBLY LIN*
percentage of the business's sale from the products manufactured in continuous process	*% CONTIN PROC*
percentage of the business's sale from non-manufacturing activities	*% NOT MANUFACT*

Appendix II

<Table II-1>

	OLS	HLS
Constant	-0.4695 (0.5657)+	-0.4695 (-0.7858)
WIP	-1.4068*** (-12.5530)	-1.4068*** (-10.5342)
WAGE	0.2621*** (4.7795)	0.2621*** (4.1959)
CAPUTIL	0.4738*** (13.3107)	0.4738*** (11.6612)
CAPINTEN	0.3041*** (10.8353)	0.3041*** (7.1688)
UNION	-0.0089 (-1.4510)	-0.0089 (-1.4513)
R-Square	0.1615	0.1615
D-W Statistic	1.8522	1.8522
Sample	2569	2569

+ : the t-statistics in the parenthesis.
***: significant at the .001 level by the 2-tail test.
** : significant at the .005 level by the 2-tail test.
* : significant at the .10 level by the 2-tail test.

<Table II-2>

Equation (6)		Equation (7)		Equation (8)	
CONST.	-0.2581 (0.5657)+	CONST.	-0.4890 (-7564)	CONT.	-0.4602 (-0.7397)
WIP	-2.2963*** (-4.7215)	WIP	-1.4085*** (-8.9199)	WIP	-1.2452*** (-6.4033)
WAGE	0.2621*** (4.7795)	WAGE	0.2726*** (4.0855)	WAGE	0.2585*** (4.1109)
CAPUTIL	0.4738*** (13.3107)	CAPUTIL	0.4628*** (10.0178)	CAPUTIL	0.4669*** (11.5153)
CAPINTEN	0.3041*** (10.8353)	CAPINTEN	0.2615*** (5.2365)	CAPINTEN	0.3039*** (7.1849)
UNION	-0.0089 (-1.4510)	UNION	-0.0157** (-2.3524)	UNION	-0.0088 (-1.4210)
P1	-3.7806 (-1.1723)	PRC	0.9313 (-2.3142)	NR	0.1965 (0.3744)
P2	0.7149 (-0.7072)			EQ	-0.0879 (-0.1914)
P3	-0.5401 (-0.6197)				
WIP×P1	0.2386 (-1632)	WIP×PRC	-1.0606** (-2.3142)	WIP×PRC	-0.0123 (-0.03944)
WIP×P2	1.0586* (1.8527)			WIP×ER	-0.4886 (-1.5852)
WIP×P3	0.9034 (1.7762)				
R-Square D-W Statistic Sample Size	0.1633 1.8482 2569		0.1590 1.8328 2096		0.1617 1.8542 2569

\+ : the t-statistics in the parenthesis.
***: significant at the .001 level by the 2-tail test.
** : significant at the .005 level by the 2-tail test.
* : significant at the .10 level by the 2-tail test.