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Int. J. Production Economics 63 (2000) 277–301

international journal of production economics

www.elsevier.com/locate/dsw

Just-in-time: A cross-sectional plant analysis

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Received 1 February 1999; accepted 15 March 1999

Abstract

This paper uses a data base of quantitative and qualitative *plant-level* cross-sectional data to analyze the relative performance of Just-in-time (JIT) and non-JIT plants operating in two distinct manufacturing industries: electronic components and auto-parts. A number of conjectures made by the literature concerning the relationship between JIT manufacturing and plant inventory holdings, costs and profits are tested. Consistent with many of these conjectures, the results suggest that JIT manufacturing at the plant level is associated with greater productivity in inventory usage, lower total and variable costs, but not fixed costs, and higher profits. The success of JIT plants along these dimensions is found to be related to the length of experience with JIT manufacturing, and process quality and leanness but unrelated to product quality, quality control or the extent of plant unionization.

Keywords: Just-in-time; Manufacturing; Empirical analysis

1. Introduction

It often is asserted that Just-in-time (JIT) manufacturing is associated with greater plant productivity, improved quality of processes and products, lower costs, and higher profits.[1] Beyond qualitative survey data, however, there is very little corroborating quantitative evidence. This paper uses a Canadian data base of *plant-level* cross-sectional quantitative and qualitative data to analyze the relative performance of JIT and non-JIT plants operating in two distinct manufacturing industries: electronic components and auto-parts. Auto-parts and electronic components manufacturing industries were targeted for this study (a) because of the relatively large number of plants in these industries that have adopted JIT and (b) because these JIT plants co-exist and compete in the same geographic area with a fairly large number of non-JIT plants.

With the successful implementation of JIT systems by many Japanese manufacturers beginning in the 1950s [2], JIT began to receive increasing attention in North America during the 1980s in the professional and popular presses. Hoping to emulate the apparent Japanese successes, growing numbers of North American manufacturers have attempted to incorporate JIT concepts in their manufacturing facilities [3].

Skeptics have questioned whether JIT can be transplanted effectively into the North American

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[1] For a review of JIT manufacturing, see [1].

0925-5273/00/$ - see front matter
PII: S0925-5273(99)00025-0

manufacturing milieu because of the substantive differences between North American and Japanese cultures and business behaviors [4–7].[2] Even the apparent successes of the Japanese experience have been challenged [9].

The extant empirical assessment of the North American experience to date is mixed. In his survey of 1035 US firms that had adopted JIT techniques, White [10] reports that 86.4% of respondents indicated that JIT provides an overall net benefit to their organization, regardless of size or type of process employed. Most firms report increased product quality, productivity, and efficiency, along with improved communication and significant reductions in costs and waste. Huson and Nanda [11] analyze a sample of 55 firms that publicly disclosed adoption of JIT production. Pooling time series and cross-sectional observations of these JIT firms with corresponding SIC industry averages, they estimate a simultaneous equations model of manufacturing performance by three-stage least squares. The estimated coefficients suggest that JIT implementation increases inventory turnover, unit manufacturing costs, and earnings per share, while reducing the number of employees and operating margins per sales dollar. Balakrishnan et al. [12] analyze a sample of 46 firms that publicly disclosed adoption of JIT production. Using a matched pair sample of non-JIT firms, they find no significant differences in inventory utilization for the two samples prior to JIT adoption. JIT firms, however, show superior utilization of overall and work-in-process inventories relative to their control firm counterparts after adopting JIT production. Nevertheless, they find that these benefits by and large do not translate into significant Return on Asset (ROA) changes.[3]

The evidence provided by these studies is problematic, however. The White study is based entirely on survey data. The Huson and Nanda [11] and Balakrishnan et al. [12] studies are based on firm level rather than plant level data. Moreover, neither of these two studies limit their sample to firms composed entirely or even primarily of JIT plants.[4] In one example, a firm labeled JIT by Balakrishnan et al. [12] is composed of 3 JIT plants and 9 non-JIT plants.

The definition of a JIT firm differs significantly across these studies and this is problematic as well. White [10] defines a JIT organization as one that has implemented at least *one* of the ten JIT management practices (quality circles, total quality control, kanban, and so on) identified in [16]. Thus, a firm employing one technique, which does not signify extensive JIT usage, is included in the same sample as a firm using all ten techniques. Huson and Nanda [11] classify firms as JIT adopters based on a search of news extracts from leading newspapers, supplemented by anecdotal evidence and trade journal case studies of JIT implementation. Balakrishnan et al. [12] classify firms as JIT adopters based on the firms' public disclosure of JIT production in their annual financial reports and on improvement of inventory utilization as measured by balance sheet data. News extracts and annual financial reports, however, provide only anecdotal evidence that JIT adoption is a significant and material event that could affect overall firm performance.

In what follows, Section 2 describes the strengths and weaknesses of our data base. Section 3 describes the data collection procedure and the sample profile. Section 4 provides some descriptive data and univariate test results. Section 5 is the heart of the paper. It uses a multivariate regression framework to test hypotheses concerning the relationship between JIT manufacturing and inventory usage, costs and profits using quantitative and qualitative plant level data. Section 6 concludes the

[2] For example, Hall [8] describes the difficulty of Kanban adoption in the US where workers often feel that the card system is "silly".

[3] They attribute this to customer bargaining power. The firm's ability to flow-through JIT savings to ROA is limited by the extent of customer ability to appropriate the gains from JIT adoption.

[4] There are relatively few empirical plant level studies in the JIT literature. Exceptions include Flynn et al. [13] and Brox and Fader [14,15]. The relevance of the former study for our analysis is discussed further below. The Brox and Fader [14,15] studies are not directly relevant. They estimate mixed CES-Translog cost functions for auto-parts and electronic components manufacturing plants and find that some of the input elasticities of substitution differ significantly between JIT and non-JIT plants.

paper. The survey instrument used to obtain the data is included in an appendix.

2. Characteristics of the data base

The data base utilized in this study has four distinguishing characteristics. First, the data are at the *plant* level rather than the firm level. This distinction is important because a multi-plant firm will not necessarily adopt JIT in all or even most of its plants. Even when the plant is JIT, it is important to know when JIT was first implemented. As shown below, experience with the JIT philosophy may be an important determinant of effectiveness. Multi-plant firms are known to implement JIT in different years in different plants. For example, in our sample, two electronics plants that belong to the same firm implemented JIT in different years, one in 1985 and the other in 1987. Obviously, this distinction is meaningless if JIT is defined at the firm level. Furthermore, the relationship between the manufacturing process and JIT becomes blurred at the firm level, because firms with more than one plant typically employ a mix of processes, especially if the firm operates in more than one industry [10,17].

Second, in order to identify significant differences between JIT and non-JIT plants, it is important to be able to classify plants as belonging to one of these two groups.[5] This is not necessarily straightforward, nor is it entirely helpful that a firm or plant defines itself as JIT. For example, if one plant uses only one component of the JIT philosophy (and refers to itself as JIT) while another plant adopts a global implementation of JIT, putting both in the same technological group induces heterogeneity within the sample. Therefore, a second distinguishing characteristic of the data base is that it allows for a meaningful classification of plants into JIT non-JIT categories. Specifically, we classify a plant as JIT if it has been established that it is a *global* JIT user.[6]

Third, to minimize product heterogeneity concerns and yet allow for the analysis of industry–JIT interactions, the data base includes observations from two industries only: auto-parts and electronic components manufacturing.[7] This is in contrast to other studies that analyze a diverse set of industries.[8]

Fourth, the plants in this study are situated in the same geographic location, thereby minimizing the noise induced by cross-sectional differences in input prices and freight charges. Thus, differences in inventory and production costs can be ascribed more readily to the JIT technology. In particular, all plants in the sample reside in Southern Ontario, Canada, between Windsor and Oshawa.

Along with these four strengths, the data base has two major weaknesses. First, the data are cross-sectional in nature. This necessarily limits the questions one can ask. For example, unlike Balakrishnan et al. [12], we are unable to compare directly the financial position of a given firm (plant) before and after JIT adoption. Nevertheless, some indirect time series inferences can be made because the data base does include some quantitative as well as qualitative data about the success of JIT adoption along a number of dimensions. Second, the financial data obtained from these privately owned plants are limited primarily to flow data such as annual cost, production and sales revenue data whose disclosure is mandated by the federal Canadian government.[9] Balance sheet data were not available so that no measures of incremental investment could be computed.

[5] It could be argued that instead of just two groups, plants lie along a continuum of JIT characteristics. Unfortunately, the nature of the data collected does not permit us to adequately explore this approach.

[6] See the technical definition in Section 3.2 below.

[7] Auto-parts manufacturing plants in the sample (4-digit SIC code) produce such products as plastic blow molded components, stamping and welded assemblies, filters, electroplated and heat treated parts, and tubing. The electronic components manufacturing plants in the sample (3-digit SIC code) produce items such as capacitors, resistors, printed circuit boards, and LCDs.

[8] Huson and Nanda [11], for example, use observations from 15 2-digit SIC codes.

[9] These data are disclosed to the federal government and then published in aggregate form. There is no requirement that the data be disclosed publicly at the plant or even firm level and, in fact, they are not.

3. Data collection and sample profile

3.1. Data collection

The Automotive Parts Manufacturers' Association (APMA) is Canada's national association representing producers of parts, equipment, tools, supplies, and services for the auto industry. This organization publishes an annual directory that is the guide to the Canadian auto-parts industry. Plants were selected for contact from this directory based on geographical proximity to Toronto. Lacking a similar centralized source for the electronic components manufacturers, these plants were identified using the yellow pages for towns close to Toronto.[10]

Besides geographic proximity, to be included in the study, each plant had to be an autonomous profit center with pricing determined by market conditions. In this way, transfer pricing was not an issue. Plants also were required to have at least 50 employees. In addition, care was taken (within the constraints imposed by data accessibility) to balance the mix of JIT plants and non-JIT plants in any given sub-industry so that no one sub-industry classification dominated either the JIT or non-JIT categories. For example, the proportion of plants producing printed circuit boards is similar in the two categories.

Plants were contacted by telephone and then visited when participation in the study was accepted. Of the 132 firms contacted initially, 29 (22%) declined to participate. Six firms (21% of telephone refusals) declined to participate because they were "... reorganizing and restructuring". All six were non-JIT auto parts manufacturing plants.[11] The remaining firms declined to be interviewed because they "did not have time" or "were not interested in participating". Of the 103 firms (78% of all firms contacted) that agreed to the interview, 100 (or 97%) actually completed the survey.[12]

Two sorts of data were collected: 1990 quantitative financial data and production related qualitative survey data. The financial data set contains the information mandated by the Canadian government in its annual Census of Manufacturing. We felt that more plants would participate in the study if most of the quantitative data were readily available and to some extent non-proprietary. In fact, it was made quite clear by many of the plant managers that no other purely quantitative data would be forthcoming. These annual 1990 financial data include: total revenues, annual production valued at retail, annual production valued at cost, beginning and ending inventories of work-in-process, finished goods, and fuel, direct materials at cost, fuel consumption at cost, book value of machinery and equipment manufactured by own labor force for own use, book value of new construction, depreciation, rental expense, interest expenses on inventory and capital, as well as employment – broken into average number employed and average hourly rate of pay for employees in manufacturing and administration, along with gross salaries paid.[13]

The 1990 production survey data include data on plant production practices and on 17 JIT and Total Quality Management (TQM) characteristics. These 17 JIT-TQM characteristics are rooted in the findings by Flynn et al. [13] indicating that JIT techniques interact with and are difficult distinguish from common infrastructure and TQM practices.[14]

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[10] The initial contacts also provided names of other plants in the area.

[11] One could infer from the telephone conversation that several of these firms were in financial distress. This raises the issue of potential sample selection bias. Unlike the Flynn et al. [13] study, however, we did not limit our sample to successful firms. In fact, at least one of the JIT plants in our sample went bankrupt subsequently.

[12] Three firms did not return the survey after agreeing to participate. These responses were promised in follow up telephone conversations, but never received.

[13] All amounts reported are in 1990 Canadian dollars.

[14] Their findings are consistent with a broader definition of JIT as in the following quotation:

"*JIT is a philosophy of manufacturing based on planned elimination of all waste and continuous improvement of productivity. It encompasses the successful execution of all manufacturing activities required to produce a final product, from design engineering to delivery and including all stages of conversion from raw material onward. The primary elements include having only the required inventory when needed; to improve quality to zero defects; to reduce lead time by reducing setup times, queue length, and lot size; to incrementally revise the operations themselves; and to accomplish these things at minimum cost*". American Production and Inventory Control Society ([18], p. 24).

In addition, the survey also elicited responses about the success of JIT implementation. Answers were obtained to questions such as, "By what percentage has worker flexibility improved since JIT implementation", and, "By what percentage have defect rates been reduced?"

Interviews took place with either the plant manager or production manager. Occasionally, an owner/CEO was interviewed instead. In most cases, a brief tour of production facilities was arranged. The survey then was either completed on the spot, or left in the hands of the manager who typically would fill in the production information, and then send it to the accounting department for completion of the financial data.

3.2. Classification of plants

In order to be classified as a JIT user, the plant had to employ a global JIT philosophy. Initially, plant (production) managers were asked in the survey instrument to classify their plant as JIT or non-JIT based on a narrow definition of JIT. This narrow definition emphasized the stockless production aspect of JIT and defined JIT as "a system of manufacturing in which materials, parts and components are produced and delivered just before they are needed.... The goal of JIT production is to come as close as possible to the concept of ideal – or zero inventory – production". Plants that were classified by their plant managers as non-JIT on the basis of this narrow definition were in fact deemed to be non-JIT and no JIT-TQM data were collected from them. Plants that were classified by their plant managers as JIT on the basis of this definition and had adopted JIT for at least one full year were further tested for global JIT use, utilizing the JIT-TQM data from the production survey.

Participants were asked to indicate the extent of their use of each of the 17 techniques (e.g., Kanban system of production control, quality circles, market-paced final assembly rate, preventive maintenance program) using a five point Likert scale where 5 = always used and 1 = never used. A sum of 85 indicates that the plant utilizes all 17 techniques all of the time. A sum of 17 indicates that the plant never uses any of the listed JIT-TQM techniques.

For purposes of this study, a plant was classified JIT if the plant manager classified the plant as JIT based on the narrow JIT definition *and* if both of the following two criteria were satisfied: (1) a sum of 51 or greater was scored on the survey indicating that *on average* the plant uses all JIT techniques half the time (a score of 3 per technique) and (2) the plant uses two-thirds of the techniques at least half of the time. These criteria help to insure – but do not guarantee – that JIT was both broadly applied and intensively used by each of the sample JIT firms.[15]

Of the 61 survey responses from the auto-parts manufacturing plants, 19 plants declared themselves to be non-JIT. Of the remaining 42 plants, 3 were reclassified as non-JIT on the basis of the above criteria, resulting in a final sample of 39 JIT and 22 non-JIT auto-parts manufacturers. Of the 39 electronics plants that agreed to participate, 21 declared themselves JIT users with no need for reclassification because these plants satisfied both criteria for global JIT use. Thus, the final sample of electronics manufacturers consists of 21 JIT plants and 18 non-JIT plants. Panel A of Table 1 summarizes the final sample.

The year of JIT adoption by these plants is relatively homogeneous. Panel B of Table 1 presents the temporal distribution of JIT adoptions: 85% of the JIT plants in the sample adopted JIT in the three years prior to 1990, with over 46% adopting in 1988.[16]

4. Descriptive statistics and univariate results

4.1. Tables and tests

Panels A and B of Table 2 provide summary statistics on a number of plant characteristics for

[15] Because data were collected for 1990, a plant that had started JIT implementation in 1990 was classified as non-JIT due to start-up and change-over problems. This re-classification affected only one plant.

[16] According to plant managers, there was no external pressure by customers to force adoption of JIT. Since the adoption of a new technology can be risky, a number of plants may have adopted JIT simultaneously after observing the successful adoption by industry leaders.

Table 1
Sample description

Panel A: Plant typology

	Electronics	Auto-parts	Total
JIT	21	39	60
non-JIT	18	22	40
Total	39	61	100

Panel B: Temporal distribution of JIT adoptions

Year of adoption	Electronics	Auto-parts	Total
1985	1	2	3
1986	3	3	6
1987	6	4	10
1988	8	20	28
1989	3	10	13
Total	21	39	60

each of the auto-parts and electronic components industries, respectively. The t-statistic in these tables test the equality of the means between JIT and non-JIT plants. The non-parametric Wilcoxon z-statistic test the equality of the medians.

4.2. Size

Size is said to be a potentially important factor in the success of JIT adoptions. In particular, the argument often is made that the implementation of JIT manufacturing practices is difficult for small manufacturing organization because of the lack of sufficient influence over suppliers to schedule shipments, or the inability to afford JIT due to high initial costs [19–21]. The market value of output produced by plants in 1990 is used as a proxy for size. Based on the t-statistics and Wilcoxon z-statistics of panels A and B of Table 2, JIT plants are significantly larger than non-JIT plants in the auto-parts industry. There are no significant size differences between JIT and non-JIT plants in the electronic components industry.

4.3. International

Plants whose firms own additional production facilities outside of Canada are defined to be international. We felt that such plants are likely to have access to cheaper direct materials and, therefore, might have a different cost structure from non-international plants. Electronics plants are much more likely to be international than auto-parts plants. Twenty-six out of 39 electronics plants declared themselves to be international as compared to only 20 out of the 61 auto-parts plants. Panels A and B of Table 2 show that there are no significant differences on the international dimension between JIT and non-JIT plants in either industry.

4.4. Unionization

Like the international dimension, there is a significant industry difference with respect to worker unionization but it too is unrelated to JIT. In particular, auto-parts workers are much more likely to be unionized than are electronics workers.

At least in theory, unionization could affect the success of JIT implementation. Non-union employees are more likely to enjoy flexible work arrangements, merit-based promotion rules, and formal performance appraisals [22]. This has led many to argue that the presence of unions is an obstacle to successful JIT implementation. There is, however, very little empirical evidence regarding the validity of this argument [7,23].

4.5. Number of manufacturing and non-manufacturing workers

The number of workers employed directly in manufacturing is significantly greater for JIT plants than non-JIT plants in the auto-parts industry but not significantly different in the electronics industry.

The JIT dichotomy is not significant for non-manufacturing workers in both of the industries. Not surprisingly, however, there is a strong industry effect. The number of non-manufacturing workers in electronics (plant median of 21) is significantly greater than in auto-parts (plant median of 44). This undoubtedly stems from the more technologically advanced nature of electronic components manufacturing and the consequent need for more support staff.

Table 2
Descriptive statistics comparing JIT and non-JIT plants

Item	Sample	Mean (Median)	Min	Max	*t*-statistic (*p*-value)	Wilcoxon (*p*-value)
A. Auto-parts industry						
Size	JIT	26.7	4.5	70.3		
		(23.4)			1.78	2.50
	non-JIT	19.4	3.4	63.4	(0.08)	(0.01)
		(13.9)				
International	JIT	0.38	0.00	1		
		(0)			1.30	1.24
	non-JIT	0.23		1	(0.20)	(0.22)
		(0)				
Union	JIT	4	1	5		
		(5)			0.08	0.14
	non-JIT	4	1	5	(0.93)	(0.88)
		(5)				
No. of	JIT	277	44	677		
mfg. workers		(256)			1.80	2.28
	non-JIT	207	42	639	(0.08)	(0.02)
		(170)				
No. of	JIT	30	6	128		
non-mfg. workers		(22)			0.99	1.58
	non-JIT	25	6	107	(0.33)	(0.11)
		(19)				
B. Electronics industry						
Size	JIT	31.7	7.2	113.0		
		(26.3)			0.91	0.97
	non-JIT	25.4	5.3	84.0	(0.37)	(0.33)
		(20.8)				
International	JIT	0.71	0.00	1		
		(1)			0.66	0.66
	non-JIT	0.61		1	(0.51)	(0.51)
		(1)				
Union	JIT	2.38	1	5		
		(1)			0.62	0.51
	non-JIT	2.78	1	5	(0.54)	(0.61)
		(1)				
No. of	JIT	267	43	594		
mfg. workers		(290)			0.14	0.65
	non-JIt	261	41	393	(0.89)	(0.52)
		(251)				
No. of	JIT	73	10	322		
non-mfg. workers		(50)			0.79	0.97
	non-JIT	55	11	212	(0.43)	(0.33)
		(35)				

Notes: The *t* and Wilcoxon statistics test for the equality of means and medians, respectively.
Size is measured by the value of annual production at retail prices.
International is a dummy variable taking on the value one if the plant's firm owns production facilities outside of Canada.
Union measures the extent to which unionized workers are employed in the plant based on a five point Likert scale.

Table 3
Techniques used in JIT plants by industry

JIT-TQM techniques used	Means (and Std. dev.) on a five point scale (5 = always used, 1 = never used)			χ^2 test of industry differences auto vs elect.
	Mean (All)	Mean (Auto)	Mean (Elec.)	
Kanban	2.97 (1.15)	2.82 (1.02)	3.23 (1.34)	(More Elec.) 17.85 (4)[b]
Integrated product design	2.61 (1.28)	3.03 (1.22)	1.86 (1.01)	(More Auto) 13.51 (4)[b]
Integrated suppliers network	3.13 (1.13)	2.64 (0.99)	4.05 (0.74)	(More Elect) 24.36 (4)[b]
Plan to reduce setup time	2.67 (0.84)	2.34 (0.72)	3.09 (0.89)	N/S
Quality circles	2.72 (1.12)	2.26 (0.75)	3.57 (1.21)	(More Elect) 24.17 (4)[b]
Focused factory	2.55 (1.16)	2.84 (1.25)	2.00 (0.71)	(More Auto) 12.47 (4)[a]
Preventive maint. programs	4.20 (0.48)	4.17 (0.39)	4.24 (0.62)	N/S
Line balancing	3.25 (0.77)	3.18 (0.60)	3.38 (1.02)	(More Elect) 17.05 (4)[a]
Education about JIT	1.93 (0.66)	1.97 (0.63)	1.86 (0.72)	N/S
Level schedules	3.12 (1.08)	3.46 (1.05)	2.48 (0.81)	(More Auto) 21.34 (4)[b]
Stable cycle rates	3.05 (0.79)	3.05 (0.72)	3.05 (0.92)	N/S
Market-paced final assembly	3.31 (0.91)	3.36 (0.93)	3.23 (0.89)	N/S
Group technology	2.50 (0.85)	2.18 (0.60)	3.09 (0.94)	(More Elect) 16.28 (4)[a]
Program to improve quality (product)	4.81 (0.39)	4.82 (0.39)	4.81 (0.40)	N/S
Program to improve quality (process)	4.82 (0.39)	4.84 (0.37)	4.76 (0.43)	N/S
Fast inventory transportation system	4.00 (0.69)	4.03 (0.67)	3.95 (0.74)	N/S
Flexibility of worker's skill	2.51 (0.70)	2.25 (0.59)	3.00 (0.63)	(More Elect) 16.40 (4)[b]

Note: Figures in the brackets represent standard deviation and degrees of freedom in the χ^2 column.
N/S: Industry differences are not significant.
[a]Significant at the 5% level.
[b]Significant at the 1% level.

4.6. JIT-TQM techniques

Table 3 lists the mean responses regarding the 17 JIT-TQM techniques employed to classify JIT plants. Each characteristic was measured on a five point Likert scale from "always used" to "never used". It is noteworthy that 8 of the 17 JIT-TQM measures had median scores of less than 3.0; on average, JIT firms used more than half of the techniques less than half of the time. Moreover, on average, only four measures are used more than 75% of the time. In order of usage, these are: (1) "programs to improve process quality" = 4.82, (2) "programs to improve product quality" = 4.81, (3) "preventative maintenance programs" = 4.20, and (4) "fast inventory transportation systems" (e.g., automated materials-handling systems) = 4.00. The first three measures are the essence of the TQM philosophy while the fourth is not necessarily particular to JIT. Consistent with Flynn et al. [13], these results suggest that what is important in controlling production in a JIT plant is not necessarily JIT inventory control techniques *per se* but rather TQM techniques which often are an integral part of JIT manufacturing.

There are industry differences here as well. Auto-parts manufacturers utilize more integrated product design, focused factory, and level schedules (significant differences based on a χ^2 test) than do electronics firms. On the other hand, electronics plants use more kanban, integrated suppliers network, line balancing, group technology and flexibility of worker skill, than auto-parts plants.

The differences between the two industries are likely due to differences in the products produced and the human relations/labor relations environment. For example, group technology is practiced by electronics plants about half of the time (mean of 3.09). The move to group technology may reduce labor requirements but the remaining workers must be more flexible. The fact that electronics plants emphasize worker flexibility much more than auto-parts plants is, therefore, not surprising given the higher unionization of auto-parts plants in the sample. In unionized shops, workers tend to have rigid job descriptions and tend to be less flexible. As far as the products produced are concerned, electronics firms usually require a large number of materials and parts from suppliers (thus, the high use of integrated supplier networks), while auto-parts plants, by definition, are suppliers for an auto assembler and typically will have fewer suppliers.

The minimal emphasis placed on JIT education appears somewhat surprising. One should remember, however, that the plants in the sample already had their JIT systems in place for at least one full year and workers' education occurs mostly before or during the implementation period.

4.7. Reported production improvements resulting from JIT

JIT respondents were asked to estimate the extent to which JIT had improved eleven aspects of their production environment using a six point Likert scale.[17] The results in Table 4 provide qualitative evidence that positive improvements were experienced by both industries as a direct result of JIT.[18] For auto parts, the biggest improvement by far is in "defect rate reduction" at a mean score of 4.79 (about 40% improvement) while this is the second largest improvement for electronics with a score of 3.05 (about a 15% improvement). Somewhat surprisingly, materials and finished goods inventories reductions are fairly modest for both auto parts (about 1% and 4%) and electronics (about 8% and 4%).

Many of the (significant) industry differences concerning improvements are fairly intuitive. Auto-parts plants report an average improvement of over 50% for scrap and defects reductions as compared to an improvement of only 6–10% and 11–20% in the same categories reported by electronics plants. On the other hand, electronics plants report an average lead time improvement of between 21% and 50% as compared to only an average minimal improvement of between 1% and 5% reported by auto-parts plants. More surprisingly, auto-parts plants experienced no improvement (mean of less than 0.5) or minimal improvement (mean between 0.5 to 1.5) in four categories: setup time, lead time, material inventory, and workers skill, as compared to above minimal improvement reported for all categories by electronics plants.

Both industries report significant improvements in quality, number of defects, and production process improvements. Electronics plants also report significant improvements in lead time while auto-parts plants report major reductions in scrap. Gains from reduced inventories are less significant but are consistent, nevertheless, with those obtained by Balakrishnan et al. [12] (Table 3). Specifically, reductions of production materials inventories from 1% to 5% for auto-parts and from 11% to 20% for electronics are reported. As for final goods inventories, reductions of 6% to 10% in auto-parts and 1% to 5% in electronics are also reported.

It is worth noting that worker skills in the auto-parts supply industry did not become significantly more flexible as a result of JIT (a mean of only 0.38). This is consistent with a notion that worker flexibility is not important (or not possible) for auto-parts plants.

5. Multivariate regression results

5.1. Hypotheses

It often is asserted that JIT manufacturing is associated with greater plant productivity, improved quality of processes and products, lower costs, and higher profits. The primary purpose of this section is to test a number of these claims using the quantitative and qualitative data described above in a multivariate regression framework. These hypotheses can be arranged into three distinct categories; namely, hypotheses involving inventory utilization, hypotheses involving plant profitability and hypotheses involving production costs.

[17] Other benefits also were listed by many respondents. These include enhanced leadership skills, better communications between departments, less work in progress, and better delivery compliance.

[18] The data for Quality Circles might be tainted. The term "Quality Circle" was seemingly ambiguous in that "continuous improvement" often was written in.

Table 4
Improvements since JIT implementation

	Means (and Std. dev.) on a six point scale (5 = more than 50%; 4 = 21–50%; 3 = 11–20%; 2 = 6–10%; 1 = 1–5%; 0 = no improvement)		
	Mean (Auto)	Mean (Elec)	χ^2 test results auto vs electronics
Setup times reduced by	0.64 (0.87)	2.57 (1.32)	28.21 (5)[b]
Automation increased by	2.28 (0.83)	2.00 (0.95)	N/S
Quality control increased by	3.08 (0.35)	3.04 (0.67)	7.73 (2)[a]
Scrap reduced by	4.74 (0.55)	2.00 (0.55)	54.72 (4)[b]
Defect rate reduced by	4.79 (0.47)	3.05 (0.74)	42.87 (3)[b]
Lead times reduced by	1.18 (0.64)	3.76 (0.94)	45.93 (5)[b]
Materials inventory reduced by	0.97 (0.96)	2.66 (0.97)	32.24 (4)[b]
Workers flexibility increased by	0.34 (0.75)	2.52 (0.81)	39.86 (4)[b]
Final good Inventory reduced by	1.82 (0.91)	1.81 (0.93)	N/S
Production process improved by	3.79 (0.57)	2.52 (0.75)	31.50 (4)[b]
Product returns reduced by	2.25 (1.16)	1.85 (0.57)	N/S

Note: Figures in the brackets represent standard deviation or degrees of freedom in the χ^2 column.
N/S: Industry differences are not significant.
[a]Significant at the 5% level.
[b]Significant at the 1% level.

5.2. Inventory utilization

JIT by its very nature is designed to reduce work-in-process and finished goods inventories. By ordering raw materials and components to demand and by producing to demand, the JIT philosophy is geared to minimizing both inventory types. This leads to the following hypotheses expressed in the alternative form:

(H1) JIT plants hold less work-in-process and finished goods inventories than do non-JIT plants.

It is claimed that JIT is especially effective in an environment where the quality of production is deemed important because quality minimizes the need for buffer stocks both in production and to satisfy ultimate demand. Although measured quality performance results could not be obtained from the plants in our sample, plant managers were asked to rate the importance of quality and on-time delivery in evaluating the performance of their manufacturing system using a five point Likert scale. Intuition suggests that the more important is quality in evaluating the plant's performance, the more likely it is that the plant will have higher quality performance in fact. This in turn implies less need for buffer stocks. Similarly, the more important is on-time performance in evaluating the plant's performance, the more likely it is that the plant will have better on-time performance in fact. This in turn implies a greater need for buffer stocks in order not to run out of product when required. These considerations lead to the following hypothesis:

(H2) Plants that perceive quality and/or on-time delivery to be more important in evaluating performance, hold less work-in-process and finished goods inventories.

The two inventory-related hypotheses developed thus far involve both JIT and non-JIT firms. The remaining inventory-related hypotheses concern the subsample of JIT firms only. Specifically, it is well known from the literature on "learning by doing" that experience with new manufacturing technologies can be an important determinant of plant cost structure [24]. Since one of the major cost savings purported to be a consequence of JIT is the reduced investment in inventories, one should expect inventory usage in a JIT plant to be inversely related to the length of JIT manufacturing experience. This consideration leads to the next hypothesis.

(H3) Plants that have more experience with JIT, hold less work-in-process and finished goods inventories.

If the JIT philosophy yields a truly effective manufacturing system, then those plants that claim to have been successful in exploiting the JIT manufacturing philosophy should show reduced inventories, lower costs and higher profits by comparison to plants less successful at adapting the JIT philosophy. The survey instrument includes questions concerning eleven potential improvements arising out of JIT adoption – see Section 4.7 above – each measured on a six point Likert scale from no improvement to more than 50% improvement.

Although one could try to relate inventory usage to each type of improvement, many of the improvement types are correlated in clusters and are not truly independent improvements. To mitigate the clustering and to reduce the dimensionality of these eleven improvement categories, principal components analysis was performed on the eleven improvement categories in an attempt to determine the underlying constructs (factors). Three factors with eigenvalues greater than one obtained, with factor solutions preserving 70% of the total variance in the data. The first factor loads on both process quality improvements (e.g., reduction in scrap) and process leanness improvements (e.g., reduction in setup time). These two clusters are negatively correlated (not shown). It is not surprising, therefore, that the factor loadings on these measures are also of opposite sign. In short, process quality and process leanness appear to be substitutes in production.[19] The second factor measures product quality (e.g., reduction in product returns). The third factor loads almost exclusively on one measure, namely, improvement in quality control.

The hypotheses that follow relate the factors obtained from the principal component analysis to inventory usage. Specifically, an increase (reduction) in process quality (leanness) should be negatively related to inventory usage since the greater (lesser) the process quality (leanneness), the less need for buffer stocks. Similarly, we expect that inventory holdings are negatively related to product quality and quality control, the other two factors. This yields the following hypothesis:

(H4) JIT plants that are more (less) successful at improving process quality(leanness), and/or product quality and/or quality control hold less work-in-process and finished goods inventories.

In the regressions which follow, in order to mitigate heteroskedasticity concerns, all (non-qualitative) variables are normalized by a size measure, either revenues or the value of production at retail prices, depending on the context. JIT is measured by a qualitative variable taking on the value of zero for non-JIT firms and time since JIT adoption (measured backwards from 1990) for JIT firms.[20] To account for potential industry differences, an industry dummy intercept variable – one for auto-parts and zero for electronic components – was included in the regressions. A control variable to account for the potential impact of unionization on JIT was also included in the regressions. This variable measures the extent to which unionized workers are employed in the plant based on a five-point Likert scale.

Regression (1) in Table 5 regresses average work-in-process inventory (normalized by the value of production at retail) on JIT type, industry type and the extent of plant unionization.[21] The expected signs of the coefficients – see the hypotheses above – are found beside each regressor. The bracketed figures are p-values. Consistent with H1, JIT plants utilize significantly less work-in-process inventory by comparison to non-JIT firms. The auto-parts industry uses significantly less work-in-process inventory than electronic components

[19] In addition to principle components analysis (orthogonal factors), we also tried oblique rotation of the factor solution with very similar results.

[20] The regressions were also run with an alternative dummy variable definition for JIT type. The results were qualitatively similar. Nevertheless, the multi-valued qualitative JIT variable typically yields more significant coefficients than does the dummy variable definition. Both regressors could not be run simultaneously because they are highly correlated.

[21] All regressions in this paper are Ordinary Least Squares.

Table 5
Regressions models explaining inventory utilization

	Work-in-Process			Finished Goods		
	(1)	(2)	(3)	(4)	(5)	(6)
Intercept	0.0691 (0.0001)	0.1013 (0.0382)	0.0451 (0.0001)	0.0975 (0.0001)	0.0121 (0.8549)	0.0607 (0.0003)
JIT (−)	− 0.0091 (0.0007)	− 0.0089 (0.0010)	—	− 0.0076 (0.0346)	− 0.0080 (0.0278)	—
Industry (?)	− 0.0159 (0.0519)	− 0.0145 (0.1245)	—	− 0.0345 (0.0025)	− 0.0417 (0.0016)	—
Union (+)	− 0.0007 (0.7334)	− 0.0010 (0.6500)	—	− 0.0010 (0.7252)	− 0.0003 (0.9088)	—
Elapsed Time (−)	—	—	− 0.0051 (0.0482)	–	—	− 0.0039 (0.5292)
Perceived Quality (−)	—	− 0.0062 (0.4823)	—	—	0.0089 (0.4590)	—
Perceived Ontime (+)	—	− 0.0007 (0.9294)	—	—	0.0097 (0.3786)	—
Product Quality (−)	—	–	− 0.0038 (0.1607)	—	—	− 0.0011 (0.8677)
Quality Control (−)	—	—	− 0.0010 (0.7140)	—	–	− 0.0112 (0.0902)
Process Quality-Leanness (−)	—	—	− 0.0068 (0.0152)	—	—	− 0.0214 (0.0021)
R^2-adj.	0.1287	0.1155	0.1125	0.1247	0.1466	0.1394
F value	5.873	3.586	2.870	5.700	3.027	3.389
(p value)	(0.0010)	(0.0052)	(0.0313)	(0.0012)	(0.0176)	(0.0150)
n	100	100	60	100	100	60

Parentheses denote p-values.
Work-in-Process is the average of beginning and ending work-in-process inventories divided by the value of production at retail.
Finished Goods is the average of beginning and ending finished goods inventories divided by the value of production at retail.
JIT is equal to zero for non-JIT plants and elapsed time for JIT plants.
Elapsed time equals 1990 minus the year of JIT adoption. For example, JIT = 5 if the plant adopted JIT in 1985.
Industry is a dummy variable with a value of 1 for auto-parts plants and 0 for electronics plants.
Union measures the extent to which unionized workers are employed in the plant based on a five-point Likert scale.
Perceived Quality measures the importance of quality in evaluating the performance of the plant's manufacturing system as measured on a five-point Likert scale.
Perceived Ontime measures the importance of On-time delivery in evaluating the performance of the plant's manufacturing system as measured on a five-point Likert scale.
Product Quality is derived from a principal components analysis. The factors loadings are primarily on two dimensions: Reduction in Product Returns and Reduction in Final Goods Inventory. Each dimension is measured along a six point scale from no improvement to more than 50% improvement since implementing JIT.
Quality Control is derived from a principal components analysis. The factors loadings are primarily on one dimension: Increase in Quality Control. Each dimension is measured along a six-point scale from no improvement to more than 50% improvement since implementing JIT.
Process Quality-Leanness is derived from a principal components analysis. The factors loadings are primarily on seven dimensions. The process quality dimensions are: Reduction in Scrap, Reduction in Defects, Improvement in Production Process. The process leanness dimensions are: Reduction in Setup Times, Reduction in Lead Times, Reduction in Production Materials Inventory and Increase in Worker Skill Flexibility. Each dimension is measured along a six-point scale from no improvement to more than 50% improvement since implementing JIT.
n is the number of data points.

industry. Unionization appears to have no impact on inventory utilization.

Regression (2) replicates regression (1) but with two additional regressors: the perceived importance of quality and ontime delivery. Neither of these two additional regressors are significant. This could be because neither quality nor on-time performance affect work-in-process utilization, contrary to expectations, or because the perceived importance of quality and ontime delivery in evaluating plant performance are poor proxies for realized quality and ontime performance.[22]

Unlike the prior two regressions that utilize the entire sample, regression (3) applies to the subsample of JIT firms only. Regression (3) regresses average work-in-process inventory (normalized by the value of production at retail) on length of time since JIT implementation, and on the three (orthogonal) factors which are assumed to measure process quality leanness, product quality and quality control, respectively. The elapsed time since JIT implementation is significant and negative confirming the hypothesis that experience with JIT is important in reducing inventories. Success in improving product quality by JIT firms and in improving quality control seem to have no impact on work-in-process inventory. On the other hand, more (less) success in improving process quality (leanness) yields significantly less work-in-process inventory. Thus, in contradistinction to product quality and quality control, process quality-leanness appears to be an important factor in JIT manufacturing.

Regressions (4)–(6) in Table 5 replicate regressions (1)–(3), respectively, with average finished goods inventory (normalized by the value of production at retail) replacing average work-in-process inventory as the dependent variable. Regression (4) shows that JIT plants utilize significantly less finished goods inventory than do non-JIT plants. There is a pronounced significant industry effect as well in that auto-parts plants use significantly less finished goods inventory by comparison to electronic components plants. Neither unionization nor the perceived performance variables have any impact on finished goods inventory. Even more so than in the case of work-in-process inventory, finished goods inventory in JIT plants is reduced significantly the greater (lesser) is the improvements in process quality (leanness). Surprisingly, as in the case of work-in-process inventory, finished goods inventory is not significantly affected by improvements in product quality or quality control. Unlike work-in-process inventory, experience with JIT has no significant impact on finished goods inventory.

Overall, with the exception of JIT experience, the regression results for finished goods inventory and work-in-process inventory are similar. However, the relative magnitudes of the coefficients (and p-values) for the JIT and the Elapsed Time variables in Table 9 indicate that just-in-time manufacturing is more strongly related to work-in-process inventory than to finished goods inventory. This is to expected. The gains from JIT manufacturing are more pronounced in reducing work-in-process than finished goods because work-in-process inventory requires less coordination with out-siders (suppliers and customers) and provides the greatest potential for reducing manufacturing lead times and improving manufacturing flexibility, since the shop floor is where the conversion (material and labor) costs are incurred. This finding is also consistent with the empirical results of Balakrishnan et al. [12].

In addition to the regressions shown, other perturbations were tried including adding a size variable to all regressions, removing unionization, and adding an industry dummy and unionization to regressions (3) and (6). The results were qualitatively similar.

5.3. *Profitability*

If JIT is as effective as its adherents claim, then JIT plants should be more profitable than non-JIT plants. There are at least three ways by which JIT adoption is expected to increase firm profitability: (a) enhanced competitive advantage in the firm's product markets arising from increased manufacturing flexibility, higher production quality, and lower manufacturing lead time; (b) lower

[22] Another alternative is that there is less variation among the sample firms in these variables. This is likely the case for ontime delivery with a sample coefficient of variation (standard deviation/mean) of 0.21 but less likely for quality with a coefficient of variation of 0.58.

investment in inventories and (c) the freeing up of investment in physical assets (such as warehouses).

Of the two studies to date that test this hypothesis, albeit at the firm level, Balakrishnan et al. [12] find essentially no significant differences in the ROA (and also the Return on Sales) of JIT firms relative to non-JIT firms.[23] On the other hand, Huson and Nanda [11] find that earnings per share increase after JIT implementation, although unit costs increase and operating margins per sales dollar decrease.

Although we are unable to compute ROA from our data base, we can measure alternative indices of plant level profitability. In particular, we are able to compute operating profits and the contribution margin (sales revenue less variable costs) at the plant level. This allows us to test hypotheses concerning plant profitability that parallel the hypotheses developed earlier for inventory utilization. These hypotheses are:

(H5) JIT plants are more profitable (as measured by profit margin and contribution margin ratios) than non-JIT plants.

(H6) Plants that perceive quality and/or on-time delivery to be more important in performance evaluation are more profitable.

(H7) Plants that have more experience with JIT are more profitable.

(H8) JIT plants that are less (more) successful at improving process quality (leanness) and/or product quality and/or quality control are more profitable.

The regressions to test the profitability hypotheses are similar in form to the regressions for testing inventory holdings. Regression (1) in Table 6 regresses the plant's profit margin ratio (operating profits normalized by sales) on JIT type, industry and unionization. Regression (2) adds the variables perceived importance of quality and ontime performance. Regression (3) tests for the impact of JIT experience, process quality-leanness, product quality and quality control on the operating profits of JIT plants. Although intuition suggests that improvements in both process quality and process leanness should increase plant profits, the finding in this paper that these production characteristics are inversely related mitigates against such a result. Rather, since increased process leanness is likely to reduce manufacturing costs whereas increased process quality is likely to increase manufacturing costs, we predict that improvements in process leanness lead to higher profits and improvements in process quality lead to lower profits. Regressions (4)–(6) of Table 6 replicate regressions (1)–(3), respectively, with the contribution margin ratio replacing the operating profit margin ratio.

The explanatory power of the Table 6 regressions are quite high, especially for the profit margin. Overall, the profit margin and contribution margin regressions are qualitatively similar. JIT plants are significantly more profitable than non-JIT plants. There also appears to be a significant industry effect; auto-parts are less profitable than electronics. This is to be expected because auto-parts suppliers tend to operate in large volume competitive industries (e.g., tires) or supply to major auto makers who can exert significant monopsony power. The electronics components manufacturing industry, on the other hand, typically supplies to wholesale customers with less bargaining power than automakers or to small market niche retailers operating in less competitive industries.[24] Again, there is a learning effect. Plants that adopted JIT earlier are (significantly) more profitable. All other variables are insignificant except that the profit margin is significantly smaller for those JIT plants that are more (less) successful at process quality (leanness) improvements.[25]

[23] However, they do find that JIT firms have a smaller decline in ROA (between the pre- and post-adoption period) than non-JIT firms after controlling for customer concentration (measured as a dummy variable and based on the SFAS No.14 disclosure when a single customer accounts for more than 10% of sales).

[24] For example, only a select few retailers sell GPS units or radar equipment.

[25] These results are robust to alternative perturbations such as adding a size variable to all regressions, removing unionization, and adding an industry dummy and unionization to regressions (3) and (6).

Table 6
Regression models explaining profitability

	Profit margin			Contribution margin		
	(1)	(2)	(3)	(4)	(5)	(6)
Intercept	0.2774	0.2293	0.1567	0.3118	0.0243	0.2431
	(0.0001)	(0.0301)	(0.0001)	(0.0001)	(0.0141)	(0.0001)
JIT (+)	0.02836	0.0283	—	0.0281	0.0278	
	(0.0001)	(0.0001)		(0.0001)	(0.0001)	—
Industry (−)	− 0.1055	− 0.1123	—	− 0.0328	− 0.0397	—
	(0.0001)	(0.0001)		(0.0471)	(0.0384)	
Union (−)	− 0.0028	− 0.0025	—	− 0.0036	− 0.0030	
	(0.5292)	(0.5929)		(0.3925)	(0.4769)	—
Elapsed Time (+)	—		0.0433	—	—	0.0406
		—	(0.0001)			(0.0001)
Perceived Quality (+)	—	− 0.0009	—	—	0.0048	—
		(0.9610)			(0.7860)	
Perceived Ontime (+)	—	0.0117	—		0.0103	—
		(0.5048)		—	(0.5292)	
Product Quality (+)	—	—	0.0101	—	—	0.0082
			(0.2200)			(0.3082)
Quality Control (+)	—	—	0.0016			0.0002
			(0.8401)			(0.9778)
Process Quality-Leanness (−)	—	—	− 0.0486	—		− 0.0110
			(0.0001)		—	(0.1798)
R^2-adj.	0.4154	0.4059	0.5850	0.2537	0.2427	0.3645
F value	24.451	14.529	21.789	12.218	7.344	9.461
(p-value)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
n	100	100	60	100	100	60

Parentheses denote p-values.
Profit Margin is Operating Profits divided by sales revenue.
Contribution Margin Ratio is the contribution margin divided by sales revenue.
JIT is equal to zero for non-JIT plants and elapsed time for JIT plants.
Elapsed time equals 1990 minus the year of JIT adoption. For example, JIT = 5 if the plant adopted JIT in 1985.
Industry is a dummy variable with a value of 1 for auto-parts plants and 0 for electronics plants.
Union measures the extent to which unionized workers are employed in the plant based on a five-point Likert scale.
Perceived Quality measures the importance of quality in evaluating the performance of the plant's manufacturing system as measured on a five-point Likert scale.
Perceived Ontime measures the importance of On-time delivery in evaluating the performance of the plant's manufacturing system as measured on a five-point Likert scale.
Product Quality is derived from a principal components analysis. The factors loadings are primarily on two dimensions: Reduction in Product Returns and Reduction in final goods inventory. Each dimension is measured along a six-point scale from no improvement to more than 50% improvement since implementing JIT.
Quality Control is derived from a principal components analysis. The factors loadings are primarily on one dimension: Increase in Quality Control. Each dimension is measured along a six-point scale from no improvement to more than 50% improvement since implementing JIT.
Process Quality-Leanness is derived from a principal components analysis. The factors loadings are primarily on seven dimensions. The process quality dimensions are: Reduction in Scrap, Reduction in Defects, Improvement in Production Process. The process leanness dimensions are: Reduction in Setup Times, Reduction in Lead Times, Reduction in Production Materials Inventory and Increase in Worker Skill Flexibility. Each dimension is measured along a six-point scale from no improvement to more than 50% improvement since implementing JIT.
n is the number of data points.

At this point, it worth noting an important caveat regarding the potential interpretation of the regressions in Table 6. Although the regressions indicate that JIT plants are more profitable than non-JIT plants, one cannot conclude necessarily that the adoption of JIT causes plants to be more profitability. What we have done is to document a positive relationship between JIT and profits but not causality. Our results are equally consistent with the interpretation that profitable plants have sufficient wealth to adopt new technologies like JIT.

5.4. *Cost structure*

The potential impact of JIT manufacturing on total costs is conceptually ambiguous. Although JIT likely reduces variable costs (such as direct materials costs which invariably represent the largest proportion of manufacturing variable costs) and certain fixed costs such as warehousing, the adoption of JIT, it is often argued, goes hand in hand with additional investment in new technologies (e.g., flexible manufacturing) and a concomitant shift from variable to fixed costs. Nevertheless, overall, it is expected that JIT reduces total costs.[26] These considerations yield the following hypotheses.

(H9) JIT plants incur lower total costs than non-JIT plants.

(H10) JIT plants incur lower variable costs than non-JIT plants.

(H11) JIT plants incur higher fixed costs than non-JIT plants.

The regressions in Table 7 also show fairly high explanatory power. Regressions (1), (3) and (5) show regressions of total, variable and fixed costs (all normalized by the value of production at retail) on JIT type, industry and unionization. Although total and variable costs are significantly lower for JIT plants than non-JIT plants, fixed costs are not significantly different. Again, there is a marked industry effect in that all costs are greater for auto-parts than electronics. Unionization has no incremental explanatory power with respect to costs. Regressions (2), (4), and (6) show that earlier adopters of JIT have significantly lower total and variable costs but not fixed costs – potentially indicative of costs shifting from variable to fixed by JIT adopters. Also, the more (less) successful the JIT plant in terms of process quality (leanness) improvements, the higher are total and fixed costs. The other factors are insignificant once more.

The quantitative data are sufficiently detailed to provide a breakdown of manufacturing variable costs into three cost components. It is of interest to see how these individual variable manufacturing cost components are related to those factors assumed to affect plant cost structure. Table 8 regresses the three components of variable manufacturing costs (normalized by the value of production at retail) on the variables of interest. The components of variable manufacturing costs are direct material costs, direct energy costs and direct labor costs.[27] JIT plants have significantly lower costs for all variable manufacturing cost components compared to non-JIT plants. Again, there are some significant industry effects. Plants that have more experience with JIT manufacturing show significantly lower costs for all variable manufacturing cost components (based on one-tailed tests). Product quality improvements significantly reduce material costs but not the other costs components. The more (less) successful the JIT plant in terms of process quality (leanness), the higher are energy and manufacturing labor costs. Again, improvements in product quality and quality control have no significant effects on costs.

5.5. *Summary of the multivariate regression analysis*

In summary, the multivariate analysis yields the following results:

1. JIT plants use significantly less work-in-process and finished goods inventory by comparison to non-JIT plants.

[26] See, for example, the quotation in footnote 14 above.

[27] As a percentage of variable manufacturing costs, direct materials are 88%, direct labor 2% and direct energy 10% on average for the entire sample.

Table 7
Regression models explaining total, variable and fixed costs

	Total Cost		Variable Costs		Fixed Costs	
	(1)	(2)	(3)	(4)	(5)	(6)
Intercept	0.7224 (0.0001)	0.8418 (0.0001)	0.6882 (0.0001)	0.7556 (0.0001)	0.0342 (0.0001)	0.0862 (0.0001)
JIT (−), (+ for 5)	−0.0273 (0.0001)	—	−0.0271 (0.0001)	—	−0.0002 (0.9220)	—
Industry (?)	0.1050 (0.0001)	—	0.0325 (0.0450)	—	0.0726 (0.0001)	—
Union (+)	0.0023 (0.5966)	—	0.0031 (0.4494)	—	−0.0008 (0.5545)	—
ElapsedTime (−)	—	−0.0424 (0.0001)	—	−0.0398 (0.0001)	—	−0.0026 (0.3523)
Product Quality (+)	—	0.0108 (0.9170)	—	−0.0088 (0.2719)	—	0.0020 (0.4883)
Quality Control (+)	—	−0.0014 (0.8603)	—	−0.0000 (0.9998)	—	−0.0014 (0.6234)
Process Quality-Leanness (+)	—	0.0490 (0.0001)	—	0.0113 (0.1680)	—	0.0377 (0.0001)
R^2-adj.	0.4140	0.5849	0.2474	0.3610	0.6980	0.7474
F value	24.310	21.780	11.847	9.334	77.260	44.631
(p-value)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
n	100	60	100	60	100	60

Parentheses denote p-values.
Costs (total, variable and fixed) are divided by the value of production at retail.
JIT is equal to zero for non-JIT plants and elapsed time for JIT plants.
Elapsed Time equals 1990 minus the year of JIT adoption. For example, JIT = 5 if the plant adopted JIT in 1985.
Industry is a dummy variable with a value of 1 for auto-parts plants and 0 for electronics plants.
Union measures the extent to which unionized workers are employed in the plant based on a five-point Likert scale.
Perceived Quality measures the importance of quality in evaluating the performance of the plant's manufacturing system as measured on a five-point Likert scale.
Perceived Ontime measures the importance of On-time delivery in evaluating the performance of the plant's manufacturing system as measured on a five-point Likert scale.
Product Quality is derived from a principal components analysis. The factors loadings are primarily on two dimensions: Reduction in Product Returns and Reduction in final goods inventory. Each dimension is measured along a six-point scale from no improvement to more than 50% improvement since implementing JIT.
Quality Control is derived from a principal components analysis. The factors loadings are primarily on one dimension: Increase in Quality Control. Each dimension is measured along a six-point scale from no improvement to more than 50% improvement since implementing JIT.
Process Quality-Leanness is derived from a principal components analysis. The factors loadings are primarily on seven dimensions. The process quality dimensions are: Reduction in Scrap, Reduction in Defects, Improvement in Production Process. The process leanness dimensions are: Reduction in Setup Times, Reduction in Lead Times, Reduction in Production Materials Inventory and Increase in Worker Skill Flexibility. Each dimension is measured along a six-point scale from no improvement to more than 50% improvement since implementing JIT.
n is the number of data points.

Table 8
Regression models explaining variable manufacturing cost components

	Material Costs		Energy Costs		Mfg. Labor Costs	
	(1)	(2)	(3)	(4)	(5)	(6)
Intercept	0.2922 (0.0001)	0.3089 (0.0001)	0.0212 (0.0001)	0.0421 (0.0001)	0.0057 (0.0001)	0.0066 (0.0001)
JIT	– 0.0113 (0.0011)	—	– 0.0035 (0.0022)	—	– 0.0003 (0.0041)	—
Industry	0.0084 (0.4255)	—	0.0366 (0.0001)	—	0.0007 (0.0106)	—
Union	0.0037 (0.1692)	—	– 0.0010 (0.2197)	—	– 0.0000 (0.6807)	—
Elapsed Time	—	– 0.0103 (0.0826)	—	– 0.0038 (0.0513)	—	– 0.0005 (0.0025)
Product Quality	—	– 0.0122 (0.0539)	—	– 0.0013 (0.5374)	—	0.0001 (0.2877)
Quality Control	—	– 0.0014 (0.8171)	—	– 0.0007 (0.7234)	—	0.0001 (0.3617)
Process Quality	—	0.0100 (0.1173)	—	0.0137 (0.0001)	—	0.0003 (0.0401)
R^2-adj.	0.1148	0.1184	0.5658	0.4745	0.1150	0.2061
F value	5.280	2.980	44.002	14.318	5.288	4.829
(p-value)	(0.0021)	(0.0268)	(0.0001)	(0.0001)	(0.0020)	(0.0021)
n	100	60	100	60	100	60

Parentheses denote p-values.
Material and Energy Costs are divided by the value of production at retail.
Mfg. Labor Costs are calculated by multiplying average number of manufacturing employees times the average hourly wage rate by the number of hours in a standard week times 52 and dividing the result by the value of production at retail.
JIT is equal to zero for non-JIT plants and elapsed time for JIT plants.
Elapsed time equals 1990 minus the year of JIT adoption. For example, JIT = 5 if the plant adopted JIT in 1985.
Industry is a dummy variable with a value of 1 for auto-parts plants and 0 for electronics plants.
Union measures the extent to which unionized workers are employed in the plant based on a five-point Likert scale.
Perceived Quality measures the importance of quality in evaluating the performance of the plant's manufacturing system as measured on a five-point Likert scale.
Perceived Ontime measures the importance of On-time delivery in evaluating the performance of the plant's manufacturing system as measured on a five-point Likert scale.
Product Quality is derived from a principal components analysis. The factors loadings are primarily on two dimensions: Reduction in Product Returns and Reduction in final goods inventory. Each dimension is measured along a six-point scale from no improvement to more than 50% improvement since implementing JIT.
Quality Control is derived from a principal components analysis. The factors loadings are primarily on one dimension: Increase in Quality Control. Each dimension is measured along a six-point scale from no improvement to more than 50% improvement since implementing JIT.
Process Quality-Leanness is derived from a principal components analysis. The factors loadings are primarily on seven dimensions. The process quality dimensions are: Reduction in Scrap, Reduction in Defects, Improvement in Production Process. The process leanness dimensions are: Reduction in Setup Times, Reduction in Lead Times, Reduction in Production Materials Inventory and Increase in Worker Skill Flexibility. Each dimension is measured along a six-point scale from no improvement to more than 50% improvement since implementing JIT.
n is the number of data points.

2. JIT plants have significantly lower variable and total costs (but not fixed costs) by comparison to non-JIT plants.
3. JIT plants are significantly more profitable than non-JIT plants.
4. JIT plants that adopted JIT earlier are significantly more successful at reducing work-in-process inventory, minimizing costs and maximizing profits.
5. The perceived importance of quality and ontime performance in evaluating plant performance is unrelated to inventory usage, costs and profits both for JIT and non-JIT plants.
6. JIT plants that are more successful at controlling process quality (leanness) are significantly more (less) successful in minimizing work-in-process and finished goods inventories. On the other hand, JIT plants that are more successful at controlling process leanness (quality) are significantly more (less) successful at minimizing costs and maximizing profits.
7. JIT plants that are more successful at controlling product quality are *not* more successful at minimizing work-in-process inventory, minimizing costs or maximizing profits
8. Unionization has neither a negative nor a positive impact on JIT.
9. The relationship between JIT and inventories, costs and profits is generally a function of industry differences.

6. Conclusion

This study uses a data base of cross-sectional qualitative and quantitative data to analyze the relative performance of JIT and non-JIT plants operating in the auto-parts and electronic components manufacturing industries. Univariate tests showed significant differences between JIT and non-JIT firms across a number of quantitative and qualitative dimensions. Significant industry differences also obtained for both JIT and non-JIT firms.

Many of these differences corresponded to intuition. For example, JIT plants consider inventory turnover and scrap/waste reduction to be more important metrics than do non-JIT plants. Auto-parts plants consider scrap/waste reduction to be more important than do electronic components plants. Among the JIT techniques, auto-parts manufacturers use more integrated product design, focused factory, and level schedules than do electronics plants. On the other hand, electronics plants use more kanban, integrated suppliers network, line balancing, group technology and flexible worker skills, than do auto-parts plants.

The multivariate tests show that JIT plants use significantly less work-in-process and finished goods inventories than do non-JIT plants. JIT plants are significantly more profitable in terms of (operating) profit margins and contribution margin ratios than non-JIT plants. JIT plants have significantly smaller variable and total costs than do non-JIT plants, but not fixed costs.

JIT plants exhibit significant learning effects in that earlier adopters of JIT use smaller inventories and are more profitable than later adopters. JIT plants that claimed to be more (less) successful at controlling process quality (leanness) also tended to have significantly lower work-in-process inventory, higher total costs and lower profits. On the other hand, JIT plants that claimed to be more successful at controlling product quality or quality control by and large were not significantly different from other JIT plants. Finally, unionization seemed to have no impact on the relative performance of JIT and non-JIT plants.

Overall, these results suggest that JIT manufacturing is associated with greater plant productivity in inventory usage, improved quality of processes, lower total and variable costs, and higher profits. Although these benefits for JIT manufacturing have been conjectured by the literature, this study is the first to document these associations for a fairly large sample of plants.

Acknowledgements

We wish to thank seminar participants at Baruch College, Tel-Aviv University and Ben-Gurion University for comments on an earlier draft.

Appendix A. Data survey questionnaire

SECTION A

1. What product(s) does this plant manufacture?______________________________

____

2. Are you an international firm? YES___ NO___

3. Is this location a headquarters?___, a division?___.

4. Does your firm use any of the following in-house productivity measures?
(Check all that apply)

___a) Total Productivity = Output/Input
___b) Labour Productivity = Output/Labour
___c) Profitability = Profit/Total Investment
___d) Quality = # Acceptable Units/Total Processing Cost + Total Correction Cost
___e) Other

5. If your firm uses other productivity measures, what are they and how are they calculated or determined?

____

____

____

6.a) Does your firm use JUST-IN-TIME? JIT - a system of manufacturing in which materials, parts and components are produced and delivered just before they are needed. (Stockless production is a name sometimes used to describe the same thing). The goal of JIT production is to come as close as possible to the concept of ideal - or zero inventory - production. The JIT framework constantly promotes the simplest, least costly means for every possible aspect of manufacturing practice.

YES___ NO___ Year Began JIT_____

6.b) Does your firm use MATERIALS REQUIREMENT PLANNING, (MRP - an information system for managing inventories and production scheduling)?

YES___ NO___ Year Began MRP_____

6.c) Does your firm use some other production control system? (please specify):

____

7. How important are the following measures in evaluating the performance of your manufacturing system?
(please circle the appropriate number)

	Importance				
	Extreme	Considerable	Some	Little	No
Inventory Turns	5	4	3	2	1
Equipment Utilization	5	4	3	2	1
Labour Utilization	5	4	3	2	1
On-Time Delivery	5	4	3	2	1
Scrap/Waste	5	4	3	2	1
Quality	5	4	3	2	1

IF YOU DO NOT USE JIT, PLEASE CONTINUE TO SECTION C, PAGE 4.

SECTION B

Please use the following scale to indicate the extent of use of the techniques listed below:	Always Used	Usually Used	Used Half the Time	Occasionally Used	Never Used
	5	4	3	2	1

1. This firm has, or uses a(n):

a)	Kanban system of production control (a card system to signal the need to deliver, or to produce)	5 4 3 2 1
b)	Integrated product design, where people at all levels are involved with the design process	5 4 3 2 1
c)	Integrated supplier network, where the emphasis is placed on few suppliers	5 4 3 2 1
d)	A study and action procedure to reduce setup times	5 4 3 2 1
e)	Unionized workers	5 4 3 2 1
f)	Quality circles	5 4 3 2 1
g)	Focused factory, where competency is developed in a narrowly focused area, with little vertical integration	5 4 3 2 1
h)	Preventive maintenance program	5 4 3 2 1
i)	Line balancing, where work is reassigned or redesigned to make work cycle times at all stations approximately equal	5 4 3 2 1
j)	Education programs about JIT	5 4 3 2 1
k)	Level schedules, where the use of all parts in materials is as evenly distributed over time as possible	5 4 3 2 1
l)	Stable cycle rate, where the time between completion of two units of production is constant	5 4 3 2 1
m)	Market-paced final assembly rate	5 4 3 2 1
n)	Group technology, where groups of dissimilar machines are are set up in a cell so they can be set up on the same job with little transport distance between them	5 4 3 2 1
o)	A program to improve quality of the product	5 4 3 2 1
p)	A program to improve quality of the process used to make the product	5 4 3 2 1
q)	Fast inventory transportation systems to reduce lead times	5 4 3 2 1
r)	Flexibility of worker skills, to make labour more able to float from one station to another	5 4 3 2 1

2. a) Has there been a change in your firm's financing requirements as a result of JIT?
YES__ NO___ (if no, please continue to question 2, next page)

b) Has your firm required MORE__ or LESS___ total financing?

c) Has your firm changed its short-term financing requirements as a result of JIT?
MORE___ LESS___ NO CHANGE__

c) Has your firm changed its long-term financing requirements as a result of JIT?
MORE___ LESS___ NO CHANGE__

Please use the following scale to indicate the extent to which JIT has improved production.	**more than 50%**	**21-50 %**	**11-20 %**	**5-10 %**	**1-5 %**	**no improvement 0%**
	5	**4**	**3**	**2**	**1**	**0**

3. Since implementing JIT:

a)	Setup times have been reduced by	5 4 3 2 1 0
b)	Automation has increased by	5 4 3 2 1 0
c)	Quality control has increased by	5 4 3 2 1 0
d)	Scrap has been reduced by	5 4 3 2 1 0
e)	Defects have been reduced by	5 4 3 2 1 0
f)	Lead times have been reduced by	5 4 3 2 1 0
g)	Production materials inventories have been reduced by	5 4 3 2 1 0
h)	Worker skills flexibility has been increased by	5 4 3 2 1 0
i)	Final goods inventories have been reduced by	5 4 3 2 1 0
j)	The production process has been improved by	5 4 3 2 1 0
k)	Product returns have been reduced by	5 4 3 2 1 0

Please use the following scale to indicate the importance of the JIT characteristics to your firm.	**Extremely Important**	**Very Important**	**Somewhat Important**	**Of little Importance**	**Not at all Important**
	5	**4**	**3**	**2**	**1**

4. Please assess the importance of the following JIT characteristics to your firm now and in the future:

		CURRENT	**FUTURE**
a)	Reduction of set up times	5 4 3 2 1	5 4 3 2 1
b)	Increased automation	5 4 3 2 1	5 4 3 2 1
c)	Quality control	5 4 3 2 1	5 4 3 2 1
d)	Reduction of scrap	5 4 3 2 1	5 4 3 2 1
e)	Reduced defect rate	5 4 3 2 1	5 4 3 2 1
f)	Reduced lead times	5 4 3 2 1	5 4 3 2 1
g)	Production materials inventory reduction	5 4 3 2 1	5 4 3 2 1
h)	Increased worker skills flexibility	5 4 3 2 1	5 4 3 2 1
i)	Final goods inventory reduction	5 4 3 2 1	5 4 3 2 1
j)	Improvements in the production process	5 4 3 2 1	5 4 3 2 1
k)	Reduction of product returns	5 4 3 2 1	5 4 3 2 1

5. Please list any other benefits of JIT that you have experienced, or expect to experience.

SECTION C

A copy of your firm's CENSUS OF MANUFACTURING could be substituted in place of the information requested in this section. Please note that all firm level data will be held in the *STRICTEST CONFIDENCE.* Only aggregate data will be used for analysis.

1. Total value, at final selling price, of products sold in 1990. (Gross Sales)__________

2. Total value, at final selling price, of all goods produced in 1990.__________

3. Quantity of goods produced in 1990. (Please specify units)__________

4. Consumption of Purchased Fuel and Electricity: $ Cost at this establishment:__________

Coal	metric tonne
Natural Gas	cubic metres
Oil (fuel, heat, diesel)	litres
Gasoline	litres
Liquified petroleum (propane etc.)	litres
Electricity purchased	1000 kW.h
Steam	gigajoule

5. Manufacturing Inventory.

	Inventory for 1990	
	Opening ($)	Closing ($)
Inventory of fuel		
Inventory of goods in process		
Inventory of finished products		

6. Total cost ($) of raw materials and components purchased and used in manufacturing operations in 1990: ______________________

7. Book value of machinery and equipment manufactured by own labour force for own use: ______________________

8. Book value of new construction by own labour force for own use: ______________________

9. 1990 Depreciation: ______________________

10. Rental of capital ($): ______________________

11. 1990 Interest expenses a) inventory__________

b) capital__________

12. Employment in 1990:

	Employees in manufacturing operations	Executive, administrative and sales staff
Average number employed		
Average hourly rate of pay		
Number of hours in a standard work week		

13. Gross salaries, wages, commissions, bonuses etc. ($) paid during 1990 to all persons of this establishment: ______________________

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