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The Profitability-Risk Tradeoff of Just-in-time Manufacturing Technologies

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Qualitative survey studies and a recent quantitative study by Callen et al. (2000) indicate that JIT manufacturing is more profitable than conventional non-JIT manufacturing. This study tests the hypothesis that the excess profitability of JIT manufacturing just compensates for the additional operational risks of JIT technology relative to conventional manufacturing. An often-suggested alternative hypothesis is that JIT manufacturing dominates conventional manufacturing in reducing costs and increasing revenues and that risk is not an issue. The multivariate results unambiguously reject the hypothesis that excess JIT profits are compensation for additional risk. We find that profitability is inversely related to risk, *especially for JIT plants*. We also find that the JIT plants in our sample are more profitable than non-JIT plants *even after adjusting for risk*, consistent with the dominance argument. Copyright © 2003 John Wiley & Sons, Ltd.

INTRODUCTION

Conventional wisdom, based almost exclusively on survey data, case studies and anecdotal evidence, suggests that just-in-time (JIT) manufacturing in the North American context conveys substantial financial benefits.[1] These benefits include reduced costs of inventory investment, materials handling, and plant and warehouse space, and increased revenues from the competitive advantage of lower manufacturing lead times and customer satisfaction from higher quality products. In one of the few studies to date to use quantitative (as well as qualitative) plant-level data, Callen *et al.* (2000) (hereinafter CFK) find in fact that JIT manufacturing is associated with reduced work in process and finished goods inventory usage, lower average total and average variable costs, and higher profits.[2]

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There are two potential explanations for the relatively higher profitability of JIT manufacturing over conventional manufacturing. One explanation posits that by minimizing work in process and finished goods buffer stocks, JIT manufacturing is subject to greater operating risks than conventional manufacturing. Therefore, firms will not adopt JIT in their plants unless the additional operating risk is expected to be offset by additional profitability. This risk–profitability argument is rarely offered by JIT adherents or operations management scholars. Nevertheless, it is a *sine qua non* of financial economics that risk and return are positively related.[3] The alternative traditional explanation is that JIT manufacturing simply dominates conventional non-JIT manufacturing in reducing costs and/or increasing revenues and that risk is not a factor. In other words, for any level of operational risk, JIT is more profitable than conventional non-JIT manufacturing.

The purpose of this study is to investigate the risk-profitability tradeoff of JIT manufacturing relative to conventional non-JIT manufacturing. The major hypothesis tested in this study is

whether the risk–profitability tradeoff can or cannot be rejected as an explanation for the superior profitability of JIT manufacturing. More specifically, the null and alternative forms of the hypothesis can be stated as follows:

H_0 (*Null hypothesis*): The excess profitability of JIT manufacturing plants over conventional (non-JIT) manufacturing plants is *unrelated* to the additional risk that JIT manufacturing plants bear in relation to conventional (non-JIT) manufacturing plants.[4]

H_{1A} (*Alternative hypothesis A*): The excess profitability of JIT manufacturing plants over conventional (non-JIT) manufacturing plants is *positively related* to the additional risk that JIT manufacturing plants bear in relation to conventional (non-JIT) manufacturing plants.

H_{1B} (*Alternative hypothesis B*): The excess profitability of JIT manufacturing plants over conventional (non-JIT) manufacturing plants is *negatively related* to the additional operating risk that JIT manufacturing plants bear in relation to conventional (non-JIT) manufacturing plants.

Rejection of the null hypothesis suggests two potential explanations for the excess profitability of JIT plants depending upon the sign of the relationship between risk and profitability for JIT plants. If profitability is significantly and *positively* related to risk for JIT plants (H_{1A}), this implies that the excess profitability of JIT manufacturing is due to compensation for risk rather than to the dominance of JIT manufacturing over conventional manufacturing in maximizing profits. On the other hand, if profitability is significantly and *negatively* related to risk for JIT plants (H_{1B}), this implies that excess profitability is not compensation for additional risk. Instead, excess profitability of JIT manufacturing is likely driven by JIT manufacturing dominance over conventional manufacturing in maximizing profits, as traditionally claimed. The negative relationship implies that the dominance of JIT manufacturing is mitigated by plant operating risk. Although JIT plants dominate conventional plants overall in terms of profitability, riskier JIT plants are less able to capitalize on this dominance than less risky JIT plants.

Non-rejection of the null also suggests (as was the case for H_{1B}) that excess JIT profitability is probably due to JIT manufacturing dominance over conventional manufacturing as traditionally claimed and not to risk considerations. However, rejection of the null in favor of the alternative H_{1B} comprises far more powerful statistical evidence against the hypothesis that excess JIT profitability is compensation for additional risk, than non-rejection of the null.[5]

Measuring the relationship between risk and profitability requires quantitative data. This study employs the CFK database to investigate the relationship between manufacturing technologies and their risk–profitability tradeoffs. Although the CFK database has a number of weaknesses, as described below, it does contain the requisite quantitative data for the study at hand.

This paper is organized as follows. The following section briefly describes the sample and its strengths and weaknesses. The next section defines the risk–profitability metrics. The penultimate section analyzes empirically the risk–profitability tradeoffs for JIT and conventional non-JIT manufacturing plants. The last section concludes.

CHARACTERISTICS OF THE DATABASE

Initially, 132 plants in the automotive parts and electronic components manufacturing industries residing in Southern Ontario, Canada were contacted to participate in the study. These two industries were chosen because they contain a mix of JIT and conventional non-JIT plants operating simultaneously in the same geographical area. Of these 132 plants, 100 eventually completed the study.

Two sets of data were collected from each plant: production-related survey data and financial data for the year 1990 denominated in Canadian dollars. The production survey data include plant production practices and various JIT–TQM characteristics adopted by each plant. The financial data set contains the information mandated by the Canadian government in its annual Census of Manufacturing.[6]

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 emphasizes the stockless production aspect of JIT and defines 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.

Self-selection for classifying the JIT plants could be problematic if plants did not define JIT with some degree of consistency. Plants that were classified by their plant managers as JIT on the basis of the narrow definition *and* that had adopted JIT for at least one full year were further tested for the extent of JIT use, utilizing the JIT–TQM data from the production survey. The survey identifies 17 characteristics designed to capture the extent of JIT–TQM implementation. These 17 characteristics and the selection procedure are rooted in the findings of Flynn *et al.* (1995) indicating that JIT techniques interact with and are difficult to distinguish from common infrastructure and total quality management (TQM) practices.[7]

Participants were asked to indicate the extent of plant usage of each of the JIT–TQM characteristics 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. A plant is classified as JIT for purposes of this study if the plant manager classified the plant as JIT based on the narrow JIT definition *and* if both of the following two criteria are satisfied as well: (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 plants.

Of the 61 survey responses from the auto-parts manufacturing plants, 19 plants declared themselves to be non-JIT. Of the remaining 42 auto-parts plants, three 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 manufacturing plants. Of the 39 survey responses from the electronic-parts manufacturing plants, 18 declared themselves to be non-JIT and 21 JIT. None of these plants had to be reclassified. Table 1 summarizes the 17 JIT–TQM characteristics for the sample of 60 JIT plants (39 auto-parts and 21 electronic components).

Table 1. JIT–TQM Characteristics Techniques Used in JIT Plants

JIT-TQM techniques	Mean	S.D.
Kanban	2.97	1.15
Integrated product design	2.61	1.28
Integrated suppliers network	3.13	1.13
Plan to reduce setup time	2.67	0.84
Quality circles	2.72	1.12
Focused factory	2.55	1.16
Preventive maintenance programs	4.20	0.48
Line balancing	3.25	0.77
Education about JIT	1.93	0.66
Level schedules	3.12	1.08
Stable cycle rates	3.05	0.79
Market-paced final assembly	3.31	0.91
Group technology	2.50	0.85
Program to improve quality (Product)	4.81	0.39
Program to improve quality (Process)	4.82	0.39
Fast inventory transportation system	4.00	0.69
Flexibility of worker's skill	2.51	0.70

The table lists mean scores (and standard deviations) of 17 JIT–TQM characteristics for 60 JIT plants. All scores are based on a five point Likert scale where 5 = always used and 1 = never used.

This database offers four distinct advantages. First, the data are at the plant level rather than the firm level. This is crucial because many manufacturing firms are multi-plant and it is not unusual for the same firm to operate JIT plants and other conventional non-JIT plants simultaneously. This fact implies that it is not meaningful to define firms as JIT. Only plants are JIT. Second, sample plants are classified as JIT on the basis of 17 measures of JIT and TQM characteristics, as opposed to most other studies that classify plants as JIT even though these plants may have adopted only one or a few elements of the JIT philosophy.[8] Third, plants in the database operate in two industries only. Although this potentially limits the generality of the results, it minimizes noise arising out of data heterogeneity. Specifically, the power of the statistical tests are likely to be weaker if the sample plants operate in a large number of different industries, potentially masking the underlying statistical relationships among the variables of interest.[9] Lastly, all plants in the database are situated in the same geographic location, which again mitigates against noise in the data due to differential transportation costs and differential labor costs among the sample plants.

Along with these strengths, the database has four weaknesses. First, the quantitative data are

cross-sectional in nature with only 1 year of data available. In particular, this means that causality issues cannot be addressed and only statistical associations are testable. Second, the quantitative data are limited to flow data; in particular, balance sheet data are not available. This limits the sorts of metrics that can be computed. For example, in the absence of balance sheet data, a plant's return on equity cannot be calculated. Third, and arguably the most troublesome, is that the database does not include market return data. Of course, market return data at the plant level would be rare in any case. More to the point is the fact that the firms whose plants are included in the database are, with a few exceptions, privately owned so that market return data are unavailable even at the firm level. Although the lack of market return data would seem to be a fatal flaw in any risk–profitability analysis, as we shall see, the database is sufficiently comprehensive to provide proxies for systematic risk. Fourth, all plants are in two industries thereby potentially limiting the generality of the results of this study.

MEASURING RISK AND PROFITABILITY

Lev (1974), Mandelker and Rhee (1984), and Mensah (1992) show empirically that management decisions about real asset investments affect the systematic risk borne by the firm's shareholders.[10] Their results imply that different manufacturing technologies are likely to have a differential effect on the firm's systematic risk. In order to measure the differential impact of the production technology on systematic risk, we utilize the model developed by Gahlon and Gentry (1982). They show that inter-firm differences in the systematic risk borne by shareholders (Φ) arising out of management decisions about real asset investments can be measured by the product of four variables: a measure of financial risk, a measure of operating risk and two measures of business risk. More specifically, they demonstrate that

$$\Phi = \mathrm{DFL} * \mathrm{DOL} * \mathrm{CV(REV)} * \rho(\pi, \pi_{\mathrm{M}}), \tag{1}$$

where DFL is the degree of financial leverage, DOL the degree of operating leverage, CV(REV) the coefficient of variation of revenues and $\rho(\pi, \pi_{\mathrm{M}})$ the correlation of the firm's cash flows with the market.

Given the cross-sectional nature of the CFK database, computing these measures forces one to assume that plant revenues are a random walk.[11] DOL then can be computed as the ratio of the plant's contribution margin to its operating income before financing charges:

$$\mathrm{DOL} = \frac{\mathrm{REV} - \mathrm{VC}}{\mathrm{REV} - \mathrm{VC} - F}, \tag{2}$$

where REV is the sales revenues, VC the total variable expenses and F the total fixed expenses.

Similarly, DFL is computed as the ratio of the plant's operating income before financing charges to operating income after financing charges:

$$\mathrm{DFL} = \frac{\mathrm{REV} - \mathrm{VC} - F}{\mathrm{REV} - \mathrm{VC} - F - \mathrm{I}}, \tag{3}$$

where I = interest charges. The coefficient of variation of sales revenues is computed as the cross-sectional standard deviation of sales revenues over the sample plants in the industry (auto-parts or electronic components, respectively) divided by the plant's sales revenues

$$\mathrm{CV(REV)} = \frac{\mathrm{S.D.(REV)}}{\mathrm{REV}}, \tag{4}$$

where S.D.(REV) denotes the (cross-sectional) standard deviation of sales revenues. Lacking the requisite data, the business risk metric measured by the correlation of the firm's net income with the return on the market portfolio $\rho(\pi, \pi_{\mathrm{M}})$ cannot be computed directly. Instead, an industry dummy variable is included in the regressions that follow to help control for business risk.

Multiplying the three measures in Equations (2)–(4) together yields the composite risk measure

$$\begin{aligned}\mathrm{CRISK} &= \mathrm{DOL} * \mathrm{DFL} * \mathrm{CV(REV)} \\ &= \frac{(1 - \mathrm{VC/REV}) * \mathrm{S.D.(REV)}}{\mathrm{REV} - \mathrm{VC} - F - \mathrm{I}}.\end{aligned} \tag{5}$$

CRISK is a proxy for systematic risk (Φ) and is used in the empirical work that follows.

Profitability (PROFITS) is measured as operating income before interest, taxes and depreciation normalized by the value of annual production at retail prices. Since risk is measured after depreciation and financing charges, we elected to measure profitability on a pre-interest and pre-depreciation basis in order to minimize the overlap between the two measures. The normalization is a control for potential heteroskedasticity.

EMPIRICAL RESULTS

Univariate Statistics

Table 2 lists the mean and median values of DOL, DFL, CRISK and PROFITS for the entire sample and for each of the JIT and non-JIT sub-samples. The *t*- and Wilcoxon statistics test for significant differences across the two sub-samples for each variable. Table 2 indicates that operating leverage has a greater impact on overall plant risk than does financial leverage. As expected, JIT plants are significantly more profitable than conventional non-JIT plants. The results are mixed regarding the composite risk measure. Conventional non-JIT plants are significantly riskier than JIT plants at the 5% level on the basis of the Wilcoxon test but not the *t*-test.[12]

Table 3 replicates Table 2 after controlling for industry type. Panel A focuses on the auto parts industry while panel B focuses on the electronic components industry. Table 3 suggests that sub-sample differences are sensitive to business risk as proxied by industry type. Only in the auto parts industry are JIT plants more profitable than non-JIT plants (at less than the 2% significance level for both tests). Table 3 also shows that only in the electronic components industry is the DOL component of risk significantly larger for non-JIT plants than for JIT plants at the 5% level for the *t*-test and the 10% level for the Wilcoxon. All other differences are not significant at conventional levels.

Table 4 summarizes the correlation among the variables used in the regressions in the section that follows. (See the next section) JIT is a dummy variable equal to 1 if the plant is JIT and 0 otherwise. IND is a dummy variable equal to 1 if the plant is in the auto parts industry and 0 otherwise. Table 4 shows that the independent variables JIT, IND and CRISK are not significantly correlated with each other so that multicollinearity does not appear to be at issue. All correlations with PROFIT (the dependent variable) are significant.

Multivariate Results

Two ordinary least squares regressions are estimated in Table 5. In the base line regression, plant profitability is regressed on JIT type, industry type and CRISK. This regression estimates the risk–profitability relationship after controlling for industry type and the plant manufacturing technology (JIT versus conventional non-JIT). Given the documented literature that JIT manufacturing is more profitable than conventional manufacturing, we should expect a positive coefficient for the JIT variable. The sign for IND will depend on whether the auto parts industry is more or less profitable than the electronic components industry. The sign of the coefficient for CRISK depends upon the relationship between profitability and operating risk.

The results for the base line regression show that JIT plants are significantly more profitable than non-JIT plants as expected. Also, electronic component manufacturing plants are significantly more profitable than auto parts manufacturing plants. Although the estimated coefficient on the risk variable (−0.004) is statistically significant, it

Table 2. Summary Statistics

	All plants		JIT plants		Non-JIT plants		JIT versus non-JIT plants	
	N	Mean (median)	*N*	Mean (median)	*N*	Mean (median)	*t*-test (*p*-value)	Wilcoxon (*p*-value)
DOL	100	1.351 (1.263)	60	1.319 (1.266)	40	1.400 (1.259)	0.450 (0.655)	0.588 (0.559)
DFL	100	1.092 (1.041)	60	1.077 (1.033)	40	1.113 (1.047)	0.560 (0.579)	0.082 (0.935)
CRISK	100	1.869 (1.035)	60	1.268 (0.961)	40	2.770 (1.356)	1.180 (0.244)	1.995 (0.046)**
PROFIT	100	0.318 (0.319)	60	0.337 (0.331)	40	0.290 (0.273)	2.680 (0.009)*	2.382 (0.017)**

*Significant at the 1% level, two tailed.
**Significant at the 5% level, two tailed.
N is the number of observations, DOL the degree of operating leverage, DFL the degree of financial leverage, CRISK the composite risk measure, and PROFIT the earnings before interest, taxes and depreciation normalized by the value of goods produced (at retail prices).

Table 3.

	All plants		JIT plants		Non-JIT plants		JIT versus non-JIT plants	
	N	Mean (median)	*N*	Mean (median)	*N*	Mean (median)	*t*-test (*p*-value)	Wilcoxon (*p*-value)
Panel A: auto parts manufacturing								
DOL	61	1.509 (1.352)	39	1.445 (1.352)	22	1.623 (1.341)	0.560 (0.584)	0.548 (0.584)
DFL	61	1.145 (1.076)	39	1.115 (1.075)	22	1.197 (1.080)	0.720 (0.478)	0.654 (0.513)
CRISK	61	2.263 (1.144)	39	1.346 (1.022)	22	3.889 (1.513)	1.110 (0.280)	1.525 (0.128)
PROFIT	61	0.303 (0.294)	39	0.325 (0.319)	22	0.263 (1.264)	2.650 (0.012)*	2.381 (0.016)*
Panel B: electronic components manufacturing								
DOL	39	1.104 (1.085)	21	1.084 (1.078)	18	1.128 (1.101)	2.17** (0.039)	1.704*** (0.088)
DFL	39	1.009 (1.000)	21	1.007 (1.000)	18	1.011 (1.000)	0.840 (0.406)	0.156 (0.876)
CRISK	39	1.252 (1.008)	21	1.123 (0.8726)	18	1.4028 (1.129)	1.030 (0.309)	1.226 (0.223)
PROFIT	39	0.342 (0.347)	21	0.359 (0.347)	18	0.322 (0.345)	1.430 (0.162)	1.169 (0.245)

*Significant at the 2% level, two tailed.
**Significant at the 5% level, two tailed.
***Significant at the 10% level, two tailed.
N is the number of observations, DOL the degree of operating leverage, DFL the degree of financial leverage, CRISK the composite risk measure, and PROFIT the earnings before interest, taxes and depreciation normalized by the value of goods produced (at retail prices).

Table 4. Pearson Correlations (*p*-values)

	JIT	IND	CRISK	PROFIT
JIT	1.000	0.100 (0.320)	−0.144 (0.152)	0.270* (0.007)
IND		1.000	0.097 (0.339)	−0.225** (0.024)
CRISK			1.000	−0.278* (0.005)
PROFIT				1.000

*Significant at the 1% level, two tailed.
**Significant at the 5% level, two tailed.
JIT is 1 if the plant is JIT, 0 if the plant is not JIT, IND is 1 if the plant is in the auto-parts industry, 0 if the plant is in electronic components industry, CRISK the composite risk measure and PROFIT the earnings before interest, taxes and depreciation normalized by the value of goods produced (at retail prices).

is not economically significant. A straightforward calculation shows that at the mean profit and risk levels, a 1% increase in risk reduces profits (per dollar of production) by only about 0.02%. Thus, there appears to be almost no relationship between profitability and risk for the average plant.

The second regression is crucial for our purposes because it tests the null hypothesis (H_0) stated earlier against the alternatives (H_{1A}, H_{1B}). This regression is similar to the base line regression with the addition of two interaction terms, an interaction term between the JIT type and CRISK and between JIT type and industry type.[13] If the coefficient for the interaction term JIT*CRISK is not significant then the null hypothesis of no relationship between profitability and risk for JIT plants cannot be rejected. Such a result suggests that excess profitability is not compensation for risk but rather that JIT manufacturing dominates conventional manufacturing in minimizing costs and maximizing revenues, as claimed by JIT adherents. A similar (but statistically more powerful) conclusion is obtained if the null is rejected because the coefficient estimate of the cross-product term JIT*CRISK is significantly negative. However, in this latter case, we would also conclude that the dominance of JIT manufacturing over conventional manufacturing is mitigated by plant operating risk in that the riskier JIT plants are less able to capitalize on their dominance in generating excess profits. On the other hand, if the coefficient estimate of the cross-product term JIT*CRISK is significantly positive,

Table 5. Estimated Risk–Profitability Tradeoff

Baseline regression

PROFIT	= 0.322	+	0.046 JIT	−	0.040 IND	−	0.004 CRISK	
	(20.57)*		(2.78)*		(−2.47)**		(−2.33)**	
$N = 100$	AdjR^2 = 0.16				$F = 7.17$		p-value = 0.0002	

Regression with interaction terms

PROFIT	= 0.326	+	0.067 JIT	−	0.052 IND	−	0.003 CRISK	−	0.028 JIT*CRISK	+	0.025 JIT*IND	
	(17.99)*		(2.47)**		(−2.10)**		(−1.88)**		(−2.73)**		(0.76)	
$N = 100$	AdjR^2 = 0.20				$F = 6.10$		p-value < 0.0001					

*Significant at the 1% level, two tailed.
**Significant at the 5% level, two tailed.
***Significant at the 10% level, two tailed.
Figures in parentheses are t-values. JIT is the 1 if the plant is JIT, 0 if the plant is not JIT, IND is 1 if the plant is in the auto-parts industry, 0 if the plant is in the electronic components industry, CRISK the composite risk measure, and PROFIT the earnings before interest, taxes and depreciation normalized by the value of goods produced (at retail prices).

resulting again in a rejection of the null, this would imply that the excess profitability of JIT over conventional non-JIT manufacturing reflects compensation for risk.

The empirical results for the second regression in Table 5 indicate that for conventional non-JIT plants there seems to be almost no relationship between profitability and risk. Although the coefficient on CRISK (−0.003) is significant statistically, it is economically insignificant. In contradistinction, the coefficient of JIT*CRISK (−0.028) is negative and both statistically and economically significant, consistent with H_{1B}, and rejection of the null hypothesis. Thus, we reject the hypothesis that the excess profitability of JIT manufacturing reflects compensation for additional risk.

There is also some direct evidence that JIT manufacturing dominates conventional manufacturing in maximizing profits irrespective of risk. Specifically, we find that JIT plants are more profitable than conventional non-JIT plants *even after adjusting for risk*. At the mean risk level, JIT plants are over 3% more profitable (per dollar of production) than equivalent non-JIT plants. Thus, although less risky JIT plants are more profitable than riskier JIT plants, overall JIT manufacturing dominates conventional manufacturing in terms of maximizing profits for all risk levels.

SENSITIVITY ANALYSIS

To ensure that these inferences are robust, a number of potential problematic issues were examined. The regressions were investigated for influential outliers using the criteria outlined in Belsley *et al.* (1980). The DFFITS, h matrix and RSTUDENT metrics indicated potential influence of two data points. However, when these observations were dropped from the regression, the re-estimated parameters were qualitatively similar to those of Table 5. The collinearity diagnostics suggested by Belsley *et al.* (1980) did not indicate a collinearity problem. Nevertheless, when the residuals in these regressions were tested for normality using a Shapiro–Wilks small sample test, normality was rejected. A probability plot and box and whiskers diagram of the residuals also indicated lack of normality. The residuals appeared to be skewed to the right.

To mitigate the lack of normality of the residuals, the regressions in Table 5 were re-estimated after transforming the non-dummy variables by natural logarithms. Again, influential outliers did not appear to be an issue nor did multicollinearity. Most importantly, normality of the residuals could not be rejected on the basis of a Shapiro–Wilks small sample test. Visual diagnostics also supported the normality of the residuals.

Table 6 provides the re-estimated regressions. The log-linear base regression results are similar to the linear regression results of Table 5 except that the coefficient on the CRISK variable is now economically as well as statistically significant. Again, risk has a negative impact on profitability. Although the coefficients of the log-linear regression inclusive of the interaction terms are similar to the base line log-linear regression, the coefficients are not as statistically significant. In

Table 6. Estimated Risk–Profitability Tradeoff Log linear Case

Baseline regression

LPROFIT =	−	1.146	+	0.092 JIT	−	0.092 IND	−	0.144 LCRISK
		(−26.57)*		(1.98)**		(−2.02)**		(−4.85)*
$N = 99$		AdjR^2 = 0.27				$F = 13.20$		p-value = 0.0001

Regression with interaction terms

LPROFIT =	−	1.142	+	0.080 JIT	−	0.113 IND	−	0.125 LCRISK	−	0.036 JIT*LCRISK	+	0.032 JIT*IND
		(21.81)*		(1.12)		(−1.56)		(−2.95)*		(−0.60)		(0.35)
$N = 99$		AdjR^2 = 0.26				$F = 7.87$		p-value < 0.0001				

*Significant at the 1% level, two tailed.
**Significant at the 5% level, two tailed.
Figures in parentheses are t-values. JIT is 1 if the plant is JIT, 0 if the plant is not JIT, IND is 1 if the plant is in the auto-parts industry, 0 if the plant is in the electronic components industry, LCRISK the log of composite risk measure, LPROFIT the log of earnings before interest, taxes and depreciation normalized by the value of goods produced (at retail prices).

particular, the JIT*CRISK is not statistically significant. In this case, non-rejection of the null again provides (weaker) evidence that the excess profitability of JIT manufacturing appears to be due to JIT manufacturing dominance over conventional manufacturing rather than compensation for additional risk.

Following the suggestion of Aiken and West (1991) regarding interaction terms, the second regression of Table 5 was re-estimated after demeaning the composite risk variable. The results were similar to Table 5 except that JIT plants were found to be a little over 1.5% more profitable (per dollar of production) than equivalent non-JIT firms at the mean risk level rather than 3%.

JIT was measured by a dummy variable in the regressions. In an alternative approach, the 17 JIT characteristics for each JIT plant were combined in an index of 'JITness' using principal component analysis. The regressions using this index measure of JIT yielded qualitatively similar empirical results.

To ensure that the regression results are not driven by the specific normalization, sales revenues rather than the value of production at retail was used to normalize profits. This too yielded qualitatively similar results.

CONCLUSION

Both qualitative and quantitative evidence indicate that JIT manufacturing is more profitable than conventional manufacturing. This study tests the hypothesis that the excess profitability of JIT plants compensates for the additional risks of JIT manufacturing relative to conventional manufacturing. The multivariate results unambiguously reject the null hypothesis. We find that although JIT firms are more profitable than non-JIT firms even after adjusting for risk, profitability is inversely related to risk *especially for JIT plants*. This contradicts the null hypothesis that the excess profitability of JIT plants is simply compensation for additional risk and suggests instead that JIT manufacturing dominates conventional non-JIT manufacturing in terms of minimizing costs and maximizing revenues.

We have noted a number of weaknesses of the database used in this study (as well as some of its strengths). Clearly, these weaknesses should be borne in mind when evaluating the results of this study. A potentially more important caveat involves the distillation of the JIT success into two parameters: profitability and risk. JIT success necessarily involves other factors such as quality of the labor force, managerial skills, and corporate culture to name only a few. In the absence of data to control for these factors, we are forced to assume either that they impact randomly on the sample or that they are subsumed somehow by profitability and risk. Future research should try to incorporate these factors formally into the research design.

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NOTES

1. Studies based solely on survey data include Billeshbach (1991), Mehra and Inman (1992), White

(1993), and Deshpande and Goldhar (1995) and Fullerton and McWatters (2002).

2. Flynn *et al*. (1995) also use plant-level quantitative data but they limit their analysis a priori to 'world class' JIT plants and are thus subject to sample selection bias. Huson and Nanda (1995), Balakrishnan *et al*. (1996), and Kinney and Wempe (2002) use firm level rather than plant-level quantitative data. Unfortunately, their selection procedures—based on annual accounting reports, news extracts, and trade journal cases—fail to exclude multi-plant firms that often consist of JIT and non-JIT plants operating simultaneously.
3. This insight is first attributable to Markowitz (1952)—who won the Nobel prize for this insight and its implications for portfolio management. There is no necessary causal link between risk and return. Rather, the firm's shareholders (owners) are worse off should the firm adopt a riskier technology without the expectation of a commensurate gain. Thus in equilibrium, firms that in fact adopt JIT should show increased profits on average.
4. The additional operating risk of JIT manufacturing plants over conventional plants is measured by the cross-product variable JIT*CRISK defined further below. The null is rejected if the regression of plant profitability on this variable (and on others) is statistically and economically significant.
5. This is of course a general property of hypothesis testing. See for example Berenson and Levine (1999, p. 413.)
6. Most plant managers were unwilling to provide other financial data. Although mandated, these data are published in aggregate form only. The federal government is restricted by law from disclosing the data publicly at the plant or at the firm level.
7. 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 (1992, p. 24)]
8. For example, White (1993) defines a plant as JIT if it uses at least one of ten JIT characteristics. Fullerton and McWatters (2002) is an exception.
9. Industry dummy variables are fairly blunt instruments and may not adequately control for industry differences. They also reduce the limited degrees of freedom.
10. Systematic risk is that risk borne by the firm's shareholders (owners) that cannot be diversified away by holding a well-diversified portfolio.
11. This is because DOL and DFL are defined in terms of expected revenues. Absent time-series data expected revenues are necessarily estimated as current revenues.
12. Normality could not be rejected for each of the variables in Table 1 on the basis of a Shapiro–Wilks small sample test.
13. Removing the interaction term between JIT type and industry type has no effect on the substantive empirical results.

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