AN EMPIRICAL ANALYSIS OF QUALITY, PRODUCTIVITY AND PROFITABILITY

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ABSTRACT

The relationship between quality, productivity and profitability receive a lot of attention. Yet the debates go on as to the compatibility of these elements and whether they are mutually reinforcing. Empirical research is difficult in this area because the relevant data (proprietary and confidential) are difficult to come by. In the early days, the research focused on manufacturing settings; more recently, it was shifted toward service businesses (airlines, banks, food services, retail businesses, etc.) This research is based on a unique data set of a manufacturing company as part of the semiconductor supply chair. We are able to test hypotheses using regression analysis techniques and obtain interesting insights into how quality, productivity and profitability relate to each other. We find out that a positive link could be established among the three key factors of success. We also derive convincing indicator of quality performance along the way.

INTRODUCTION

Competitive advantages comes from differentiation, focus and/or cost leadership (Porter, 1980). Differentiation can be accomplished by providing better quality products and services than what competitors can offer. The source of cost leadership can be found in improved productivity. Therefore quality and productivity are recognized as the key weapons against competitors. In the short run, quality will impact cost structure and productivity; in the long run, price, sales, even market share are all affected.

This research wants to explore the relationship between quality, productivity and profitability in a more concrete way by looking into a case company that has been part of a semiconductor supply chain. We manage to obtain 57 monthly observations in 2002-2007 for all the relevant variables to run regression analysis. In the following sections, we reviewe literature and develop hypotheses, describe variables used and run regression, analyze the results, and provide insights for future research. Please note that all figures and tables mentioned in the text can be found in the Appendix at the end of the paper.

LITERATURE REVIEWS AND HYPOTHESIS DEVELOPMENT

Quality is usually a fuzzy concept. Juran and Gryna (1980) consider quality to be conformance to specification and fitness for use. Morse, Roth and Poston (1987) introduce three factors concerning quality: customer expectation, product specification and actual product. Then design quality can be considered as the discrepancy between customer expectation and design specification, and conformance quality as the discrepancy between product specification and actual product. For the purpose of this research, the concept of conformance quality will be adopted for easier measurement.

Over the years, quality improvement regimes evolve around Juran, Deming, Crosby, among others, and mature into the Japanese style of management (Fine, 1985; Shank & Govindarajan, 1994). The concepts of continuous improvement (or Kaizen), total quality control or management, and zero defects are extensively discussed and applied in businesses (see Kaplan, 1983; Schelb, Snyder & Sparling, 1992; Blocher et al., 1999 for example).

Productivity (= Output / Input) measures how resources are utilized to produce output. One clear way of improving productivity is by way of quality improvement. Schmenner and Cook (1985) find out that factories which pay closer attention to quality usually exhibit higher productivity (see also Schmenner, 1988). Hayes and Clark (1986) conclude that less waste and lower defect rate lead to improved total factor productivity. More recently, Roth and Jackson (1995) and Anderson et al. (1997) study the effect of productivity on performance improvement.

The assertion that quality and productivity should be positively related, however, is usually met by skeptical managers. In service context, quality and productivity are sometimes considered conflicting roles (Luria, Yagil & Gal, 2014). Lee, Beruvides, and Chiu (2007) tentatively verifiy their relationship by developing a mathematical model and empirically testing the model using industry data. In light of the uncertain relationship between quality and productivity, we develop the following hypothesis:

H1 *The lower the nonconformance quality, the higher the productivity.*

Quality costs, according to Juran and Gryna (1980), include prevention, appraisal, internal and external failures. Prevention and appraisal costs are considered discretionary and together called conformance costs; internal and external failure costs are reactionary and together called nonconformance costs (Crosby, 1984).

Conventional wisdom dictates that quality costs money, which implies that we can only afford quality to some extent. However, from a strategic point of view, better quality (in the sense of conformance quality) can be competitive in terms of lower quality costs and higher perceived value for customers, leading to improved profitability (Buzzill & Gale, 1987; Morse, Roth & Poston, 1987). More recent studies regarding Chinese industrialization (Yu, Dosi, Grazzi & Lei, 2017), in airline industry (Scotti & Volta, 2017) and in banking industry (Watson & Nossuli, 2015) provide a positive link; however, Riahi-Belkaoui (1999) finds that productivity does not necessarily point to future profitability. As long as it is yet to be settled, we develop the following hypothesis for testing.

H2 *Productivity and profitability are positively correlated.*

In service organizations, the connection between quality, customer satisfaction and performance is also studied (see Zhao et al., 2004 and Voss et al., 2005, for example). Empirical results suggest that the link between quality and profitability be solid (Rust et al., 1995; Loveman, 1998; Voss et al., 2005). In particular, Parast and Fini (2010) study the effect of productivity and quality on profitability in airline industry and finds a positive relation between productivity and profitability (but no link between quality and profitability). The following hypothesis intends to address the possible link between quality and profitability.

H 3 The lower the nonconformance quality, the higher the profitability.

Quality improvement, by itself, is expected to reduce quality costs (Chang, 2005) as a direct result. In addition, quality activities tend to streamline the production process, resulting in less waste. Therefore, less inputs in the form of materials, labor and overhead will be needed to generate the same amount of output, meeting the goal of improved productivity. The following four corollary hypotheses will also be tested.

H 4 Nonconformance quality and nonconformance costs are positively correlated.

H 5 The lower the nonconformance costs, the higher the productivity.

H 6 The higher the nonconformance quality, the worse the quality-related operational efficiency.

H 7 The better the quality-related operational efficiency, the higher the productivity.

In summary, this research tentatively provides a framework linking quality, productivity and profitability (see Figure 1). The series of hypotheses are superimposed onto the framework to test the validity of the connections among them.

VARIABLES AND DATA COLLECTION

Semiconductor industry is the aggregate collection of companies engaged in the design and fabrication of semiconductor devices. The industry is characterized by fierce competition at a global scale, continuous growth in a cyclical patter with high volatility, high degree of flexibility and innovation, and rapid change in the market. Semiconductors are materials which have a conductivity between conductors and nonconductors or insulators.

The Asian company in the case study was established in the early 1990s with ISO 9002 certification. This high-tech company reaches annual sales of about $150 million, capital of $135 million and 900 salaried employees. According to Hwang and Sheng (2015), there are five major segments that constitute the semiconductor industry supply chain: IC design, Masking, IC manufacturing, IC packaging and Final testing. The subject company's main products (lead frame and mother board) feed into IC packaging process. The company is organized into nine business units with stamping and etching being its two major production processes. Using the time-series analysis adopted by Hayes and Clark (1986), this research collects firm-specific proprietary data related to quality, productivity, profitability and externally available financial data over 57 monthly observations (August 2002 – April 2007). In addition, interviews and factory visits are conducted to better understand the work flows within. The variables used in the research and their characteristics are described below.

Quality Variables

This study adopts firm-specific variables to measure quality performance. Due to data availability, quality is measured in a negative way called nonconformance quality. That is, the lower the nonconformance quality, the higher the quality in the normal sense. Four proxies for nonconformance quality are available. Defect rate and defect loss rate are internally driven variables, while customer complaint rate and customer complaint loss rate are affected by external forces due to customers and market condition. Defect rate represents the percentage of output that does not meet product specifications, while defect loss rate measures the same concept in monetary terms. Customer complaint rate is based on the percentage of sales in quantity that suffers from customer complaints, and the customer complaint loss rate is similarly measured in sales dollars. In summary,

$$\text{Defect Rate} = \frac{\text{Defective units}}{\text{Total production units}};$$

$$\text{Defect Loss Rate} = \frac{\text{Costs of salvage due to defects}}{\text{Total costs of production units (both good and defective)}};$$

$$\text{Customer Complaint Rate} = \frac{\text{Number of sold units subject to customer complaints}}{\text{Total sales in units}};$$

$$\text{Customer Complaint Loss Rate} = \frac{\text{Sales dollars subject to customer complaints}}{\text{Net sales}}.$$

Figures 2 to 5 depict the four quality variables in time series over the study period.

Quality-related Operational Efficiency Variable

Better quality is expected to improve production efficiency with less disruptions in scheduling, less idle time, and less buildup of buffer inventory, among others. A clear indicator of such efficiency improvement can be found in the faster work in process (WIP) turnover rate, calculated as

$$\text{WIP Turnover Rate} = \frac{Monthly\ production\ costs\ of\ finished\ units}{(\text{Beginning WIP} + \text{Ending WIP})/2}.$$

Figure 6 shows the monthly WIP turnover rate over the study period.

Nonconformance Cost Variable

Nonconformance costs are also called failure costs and include both internal failure and external failure costs. Nonconformance costs in practice are consisted of salvage, rework, hidden costs due to defects, customer service costs due to complaints, return and opportunity costs, re-inspection, price concession and others (lawsuits, insurance claims, reimbursements, etc.)

Figure 7 provides the monthly nonconformance costs in thousand dollars over the study period.

Productivity Variable

Total factor productivity (TFP), in economic terms, is a variable which accounts for effects in total output growth relative to the growth in traditionally measured inputs of labor and capital. In this research, TFP is calculated as

$$\text{TFP} = \frac{\text{Monthly output x Base−period average price}}{\text{Total costs of materials, labor and overhead (adjusted for base period)}}.$$

Figure 8 shows the monthly TFP over the study period.

Profitability Variable

Gross profit is the difference between net sales and cost of goods sold. Monthly gross profit rate is an accounting measure used as the proxy for profitability in this research. That is,

$$\text{Gross Profit Rate} = \frac{\text{Gross profit}}{\text{Net sales}}.$$

Figure 9 indicates the monthly gross profit rate over the study period.

Control Variables

There are three control variables in this study: average unit price, total production volume and the economic factor.

Average unit price: Gross profit rate is influenced by both the unit price and the unit production cost. To isolate and study unit production cost as a possible result of quality and productivity improvements, the unit price has to be constrained. In addition, unit price is constantly adjusted to reflect shifts in market and strategic goals which are beyond the control of the company under study or its manufacturing process.

Total production volume: In order to differentiate between lower unit cost due to quality and productivity improvements, and lower unit cost due to economy of scale, the total production volume is utilized as a control variable to signify the impact of quality and productivity initiatives.

Economic factor: This is a dummy variable used to reflect the fluctuating and rapidly changing market conditions in the semiconductor industry whenever profitability is evaluated. When the global IC industry experiences a positive growth in sales during the study period, the economic factor is designated as "1;" otherwise it was assigned "0." The relevant source of information comes from the World Semiconductor Trade Statistics (WSTS) over the study period.

REGRESSION MODELS AND RESULTS

H1 The lower the nonconformance quality, the higher the productivity.

The regression model used to test the hypothesis is

$$Y = \alpha + \beta X_i + \varepsilon,$$

where Y: TFP; X_1: Defect rate; X_2: Defect loss rate; X_3: Customer complaint rate; X_4: Customer complaint loss rate.

The results are in Table 1. Three of the four quality measures weakly support the hypothesis; that is, the lower the nonconformance quality (the better the quality), the more productive the company becomes.

H2 Productivity and profitability are positively correlated.

The regression model used for this hypothesis is

$$Y = \alpha + \beta_1 X + \beta_2 CV_1 + \beta_3 CV_2 + \beta_4 CV_3 + \epsilon,$$

where Y: Gross profit rate; X: TFP; CV_1: Average unit price; CV_2: Total production volume; CV_3: Economic factor. There are three control variables in the model.

The regression results are in Table 2. The significant and positive relation between productivity and gross profit rate provides strong support for the hypothesis. Also, the higher the unit price as a control variable, the higher the gross profit, as expected. The negative correlation between total output and gross profit points to the importance of improving productivity and lowering unit cost before mass production can reach its goal.

H3 The lower the nonconformance quality, the higher the profitability.

The regression model adopted for this hypothesis is

$$Y = \alpha + \beta_1 X_i + \beta_2 CV_1 + \beta_3 CV_2 + \beta_4 CV_3 + \epsilon,$$

where Y: Gross profit rate; X_1: Defect rate; X_2: Defect loss rate; X_3: Customer complaint rate; X_4: Customer complaint loss rate; CV_1: Average unit price; CV_2: Total production volume; CV_3: Economic factor.

Table 3 shows the results. The most significant result comes from the use of defect loss rate as the independent variable whose relation with the gross profit provides strong support for the hypothesis. That means that better quality will lower production cost and improve gross profit. The other three quality indicators (defect rate, customer complaint rate and customer complaint loss rate) show insignificant and contrary results.

The three control variables are positively correlated with the gross profit rate, as expected.

It seems that the monetary-based quality indicator such as defect loss rate offers better gauge of quality than the quantity-based measures such as defect rate and customer complaint rate. Customer complaint loss rate, however, suffers potential underestimation and becomes less reliable as a quality proxy.

H4 Nonconformance quality and nonconformance costs are positively correlated.

This hypothesis tests the direct link between nonconformance quality and nonconformance costs. The regression model used is

$$Y = \alpha + \beta X_i + \varepsilon,$$

where Y: Nonconformance costs; X_1: Defect rate; X_2: Defect loss rate; X_3: Customer complaint rate; X_4: Customer complaint loss rate.

The results are in Table 4. This regression studies whether nonconformance quality affects nonconformance costs and in what direction. The result shows that defect loss rate significantly and positively influences nonconformance costs. Both the customer-related quality indicators provide some support of the hypothesis. The defect rate violates the hypothesis but is not significant. Consistent with Hypothesis 3 results, the defect loss rate provides a very good proxy for quality measurement.

H5 The lower the nonconformance costs, the higher the productivity.

The regression model used to test the hypothesis is

$$Y = \alpha + \beta X + \epsilon,$$

where Y: TFP; X: Nonconformance costs.

The result is in Table 5. The regression result points to moderate support of the hypothesis showing negative correlation between nonconformance costs and productivity. Hypotheses 4 and 5 together tell us that the linkage between quality and productivity is directly and partially influenced by nonconformance costs.

H6 The higher the nonconformance quality, the worse the quality-related operational efficiency.

The regression model for this hypothesis is

$$Y = \alpha + \beta_1 X_i + \beta_2 CV + \epsilon,$$

where Y: WIP turnover rate; X_1: Defect rate; X_2: Defect loss rate; X_3: Customer complaint rate; X_4: Customer complaint loss rate; CV: Economic factor.

The results are shown in Table 6. In the regression, the quality-related operational efficiency uses as proxy the work in process turnover rate. Of the four quality indicators, only the defect loss rate is consistent with the hypothesis and moderately significant. However, the overall results indicate what we already learned from Hypothesis 3. That is, the choice of quality indicators may not consistently and correctly reflect the company's true quality profile. Relatively speaking, the defect loss rate again does a good job as a better proxy for quality in this study.

H7 The better the quality-related operational efficiency, the higher the productivity.

The regression model for the hypothesis is

$$Y = \alpha + \beta X + \epsilon,$$

where Y: TFP; X: WIP turnover rate.

The result in Table 7 shows a positive and highly significant relation between the company's work in process turnover and productivity, providing a strong support of the hypothesis. That is, the better the quality-related operational efficiency, the more productive it will become. It can also be concluded (from Hypotheses 6 and 7 together) that the linkage between nonconformance quality and productivity is somewhat indirectly influenced by the quality-related operational efficiency.

CONCLUSIONS

This research sets out to study the relationship between quality, productivity and profitability in a manufacturing environment with a unique data source. The regression models are used to test the hypotheses. It seems that nonconformance quality and productivity are somewhat negatively correlated, productivity and profitability are strongly and positively correlated, while nonconformance quality and profitability are highly and negatively correlated. It provides a fuller picture of the three key factors of success for any business. Also, the results demonstrate that quality influencea productivity by way of both direct (via nonconformance costs) and indirect (via quality-related operational efficiency) impacts.

Since the proxies used for quality measurement shows inconsistent results, we would recommend the use of defect loss rate to better reflect the case company's quality performance. In reality, the financial impact of poor quality is better received by the management while the nonfinancial indicators (defect rate, customer complaint rate) provides employees with clearer guidance for future improvement.

The conclusions drawn are obviously limited by the data source and the time frame involved. However, this research does point out the clear connection between quality, productivity and profitability in a high-tech manufacturing setting. The findings are also consistent with other empirical studies in both manufacturing and service industries. For future research, more in-depth case studies and large-scale statistical analyses will help clarify the issues further.

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APPENDIX

Figure 1
A framework of quality, productivity and profitability

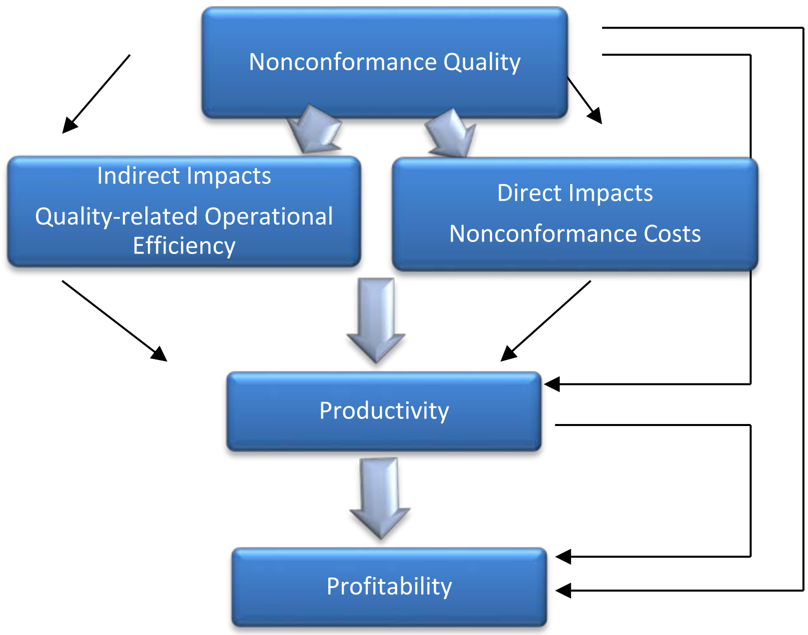

Figure 2
Defect Rate

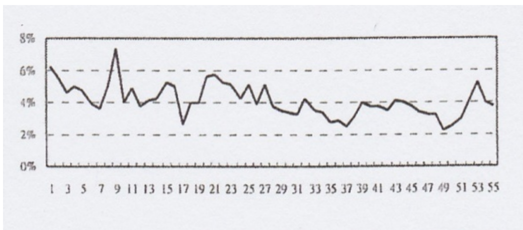

Figure 3
Defect Loss Rate

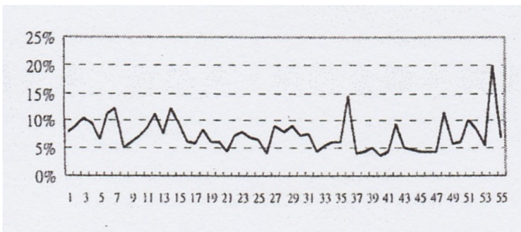

Figure 4
Customer Complaint Rate

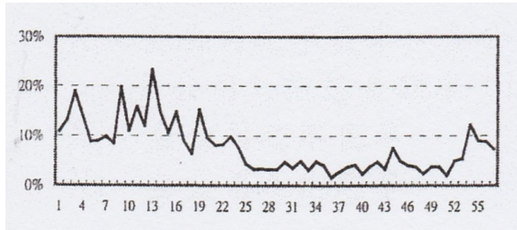

Figure 5
Customer Complaint Loss Rate

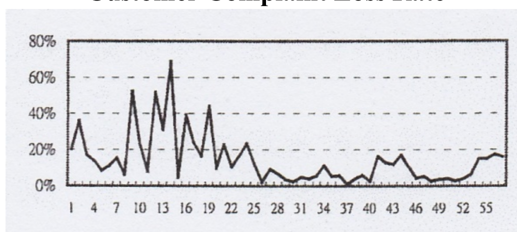

Figure 6
WIP Turnover Rate

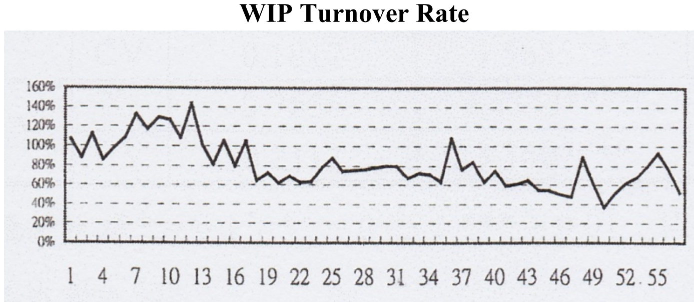

Figure 7
Noncomformance Costs

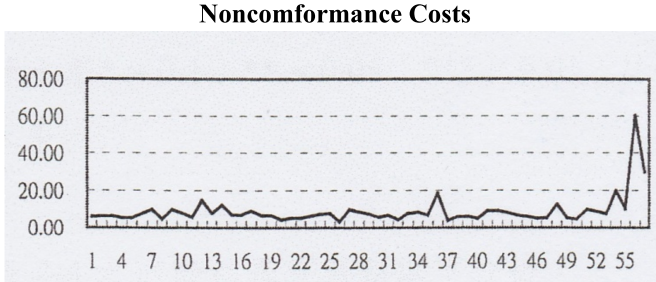

Figure 8
Total Factor Productivity (TFP)

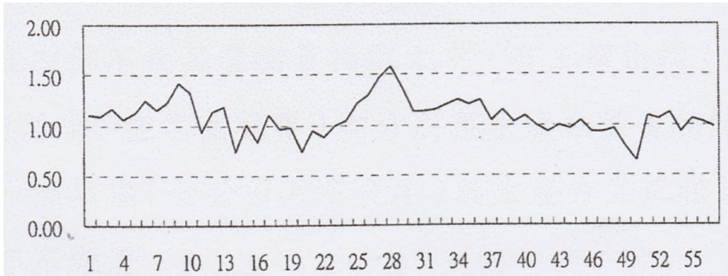

Figure 9
Gross Profit Rate

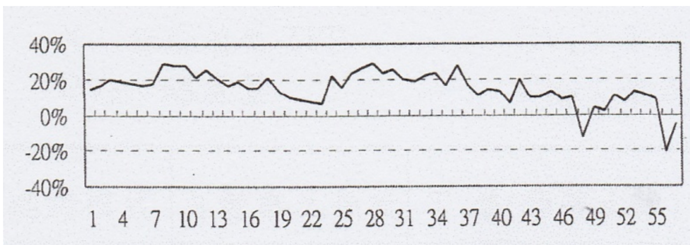

Table 1
Regression Results between Nonconformance Quality (X) and Productivity (Y)

		Coefficients	t	Adjusted R^2
Y	X_1	1.7680	0.7520#	0.0102
Y	X_2	-0.1272	-0.4774	0.0041
Y	X_3	-0.2927	-0.5971	0.0064
Y	X_4	-0.1412	-8.8245	0.0122

Significance Level *: 0.1; **: 0.05; ***: 0.01; #: Contrary to expectation

Table 2
Regression Results between Productivity (X) and Profitability (Y)

		Coefficients	t	F	Adjusted R^2
Y	X	0.3969	6.0955***	12.0462***	0.4410
	CV_1	0.3763	2.1503**		
	CV_2	-0.0000	-1.8615*#		
	CV_3	-0.0014	-0.0612#		

Significance Level *: 0.1; **: 0.05; ***: 0.01; #: Contrary to expectation

Table 3
Regression Results between Nonconformance Quality (X) and Profitability (Y)

		Coefficients	t	F	Adjusted R^2
Y	X_1	0.8692	0.6519#	1.7277	0.0494
	CV_1	0.3404	1.4373		
	CV_2	0.0000	0.2142		
	CV_3	0.0442	1.5834		
Y	X_2	-0.7084	-6.4006***	13.1172***	0.4640
	CV_1	0.5182	3.0006***		
	CV_2	0.0000	1.9875*		
	CV_3	0.0646	3.1416*		
Y	X_3	0.0557	0.1804#	1.6175	0.0422
	CV_1	0.3569	1.3347		
	CV_2	0.0000	0.1122		
	CV_3	0.0479	1.7503*		
Y	X_4	0.0459	0.4619#	1.6683	0.0456
	CV_1	0.3349	1.3383		
	CV_2	0.0000	0.0874		
	CV_3	0.0497	1.8152*		

Significance Level *: 0.1; **: 0.05; ***: 0.01; #: Contrary to expectation

Table 4
Regression Results between Nonconformance Quality (X) and Nonconformance Costs (Y)

		Coefficients	t	Adjusted R^2
Y	X_1	-46.6688	-0.4533#	0.0034
Y	X_2	86.7918	27.3015***	0.9313
Y	X_3	8.4156	0.3771	0.0026
Y	X_4	8.4533	1.0915	0.0212

Significance Level *: 0.1; **: 0.05; ***: 0.01; #: Contrary to expectation

Table 5
Regression Results between Nonconformance Costs (X) and Productivity (Y)

		Coefficients	t	Adjusted R^2
Y	X	-0.0004	-0.1315	0.0003

Significance Level *: 0.1; **: 0.05; ***: 0.01; #: Contrary to expectation

Table 6
Regression Results between Nonconformance Quality (X) and Quality-Related Operational Efficiency (Y)

		Coefficients	t	F	Adjusted R^2
Y	X_1	12.0201	4.0940***#	12.8517***	0.2974
	CV	0.1498	2.4806**		
Y	X_2	-0.6626	-1.7512*	5.1394***	0.1288
	CV	0.2090	3.0341***		
Y	X_3	3.4163	6.6202***#	28.0948***	0.4918
	CV	0.1817	3.5635***		
Y	X_4	0.7656	3.4343***#	10.0546***	0.2444
	CV	0.2112	3.3607***		

Significance Level *: 0.1; **: 0.05; ***: 0.01; #: Contrary to expectation

Table 7
Regression Results between Quality-Related Operational Efficiency (X) and Productivity (Y)

		Coefficients	t	Adjusted R^2
Y	X	0.2937	3.5945***	0.1755

Significance Level *: 0.1; **: 0.05; ***: 0.01; #: Contrary to expectation