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The Interaction Effect of Manufacturing Flexibility and Quality Management on Environmental Performance

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ABSTRACT

Previous research suggested that manufacturing capability played an important role in enhancing environmental performance. The two dimensions of manufacturing capability, namely manufacturing flexibility and quality management, have been suggested as drivers for environmental performance. Unlike previous studies, we use a sample of 597 firms in Korea to investigate manufacturing flexibility, quality management, and their interaction international effect on environmental performance. It was found that manufacturing flexibility and quality management are positively associated with environmental performance. Additionally, their interaction was negatively related to environmental performance due to the trade-offs between the two, such as regarding organizational structure and culture. This study offers a novel perspective to the literature on environmental management by revealing such negative interaction because manufacturing flexibility and quality management are the main elements of manufacturing capability, and thus, firms should handle both appropriately.

Keywords: *environmental performance, interaction effect, manufacturing flexibility, quality management*

1. INTRODUCTION

"Being environmentally friendly" or "going green" has been one of the trendy catchphrases of the last decade. Accordingly, numerous business studies regarding environmental performance have been conducted and shared to shed light on the era of societal or stakeholder business philosophy. We defined environmental performance as the extent to which a firm's activities, such as strategies, operations, and routines, align with protecting the natural environment (Becker, 2007; Weng *et al*., 2015). Considering the tightening of regulations and expectations on environmental protection from diverse stakeholders, firms try to respond to these pressures by adopting new strategies or utilizing their current capabilities. Furthermore, recent studies suggest that sustainable supply chain practices can improve organizational performance and competitiveness both in the long term and short term (e.g., Sharma and Singla, 2021).

Hart (1995) suggested that both innovation and manufacturing capabilities are important for a firm's environmental performance. Innovation capabilities help firms develop new products or processes better suited for environmental performance, whereas manufacturing capabilities enable firms to implement newly developed processes effectively and efficiently. Although a significant amount of research has focused on innovation capability for environmental improvement, Hart's (1995) study stresses that manufacturing capabilities also play an important role in environmental performance. Therefore, we investigate the effect of manufacturing capabilities on environmental performance.

Specifically, this study focuses on two dimensions of manufacturing capabilities: quality management and manufacturing flexibility. Quality management is a basic element in manufacturing capabilities in that quality management aims to achieve operational objectives such as cost and quality (Dow *et al*., 1999). On the other hand, manufacturing flexibility enables firms to react to varying customer demands and external conditions. Most research on environmental performance has paid attention to one dimension of production capabilities, advancing the positive effect of quality management or manufacturing flexibility. For instance, based on cases studies in the manufacturing industry Malsinghe *et al*., (2022) demonstrated that quality process excellence including Total Quality Management and Six Sigma has a positive impact on sustainable supply chain performance, and Das (2020) empirically showed the positive relationship between manufacturing flexibility and environmental sustainability. However, we suspect that the impacts of the two dimensions may differ or even conflict. Thus, quality management and manufacturing flexibility must be examined simultaneously.

We attempt to contribute to the body of work on environmental management by revealing the effect of quality management and manufacturing flexibility. More importantly, we examined the negative interaction between both dimensions, the under-explored area of environmental management literature. Both quality management and manufacturing flexibility are required for a high level of manufacturing capability. However, internal structures, including human resource management, policy, leadership, and organizational culture supporting quality management and manufacturing flexibility, are quite different. The conflicting nature of internal structure for both dimensions brings about the management of dual internal structures for quality management and manufacturing flexibility.

The remainder of this paper is organized as follows. We developed theoretical arguments on the relationship between manufacturing flexibility and quality management and environmental performance. Then, we delineate the interaction effect between the dimensions of manufacturing capability. Next, we describe the data, empirical model, and results in the method part. Finally, the implications and limitations of this study are discussed in the conclusion.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1 The Drivers of Environmental Performance from the Manufacturing Capability Perspective

Environmental performance measures the influence of a company's activities on the natural environments, such as "the inclusion of recyclable materials in products, reduced pollution emissions, and waste at the source, improvements in energy efficiency, and reduction of environmentally hazardous substances, and more" (Weng *et al*., 2015, p. 5002). According to Berrone and Gomez-Mejia (2009), a firm displays robust environmental performance when it has strong manufacturing capabilities, such as reduced operating costs, higher flexibility, improved access to resources, and reduced employee turnover. In addition, strong environmental performance can bring about strong financial performance as consumers in the societal marketing era demand environmentally friendly products and services.

This study's first focus is on how manufacturing capabilities help firms implement environmentally friendly systems that produce good environmental performance. Environmental performance requires firms to incorporate environmental aspects into production processes, from developing products or services to final examination (Jimennez and Lorente, 2001). Therefore, we argue that the core factors of manufacturing capability, such as quality management and manufacturing flexibility in production, impact environmental performance. However, the two required capabilities are not complementary but conflict (Da Silveira and Slack, 2001). Such a characteristic makes it more challenging for firms to handle both simultaneously. Thus, it is worthwhile to investigate the relationship between the two main drivers of manufacturing capability, i.e., manufacturing flexibility and quality management and environmental performance, as well as the interaction effect between them.

2.2 The Relationship between Manufacturing Flexibility and Environmental Performance

Conceptually, manufacturing flexibility is defined as the ability to make various products in the quantities that customers demand without exorbitant expenses, time, organizational interruptions, or performance losses (Zhang *et al*., 2003). Various quantities of products imply growing the range of products available, enhancing a firm's ability to react quickly, and accomplishing good performance over that wide range of products (Upton, 1995). Therefore, manufacturing flexibility help firms rapidly adapt to changing environmental regulations and technologies and new customer demands affected by environmental concerns. Adopting new manufacturing processes or systems based on flexibility is needed to enhance environmental performance (Schrettle *et al*., 2014).

There are many different concepts scattered around the topic of manufacturing flexibility, including value chains, machines, resources, systems, a mix of various products, the volume of production, routing, spanning, and process flexibility (Day, 1994; Zhang *et al*., 2003). Often, these concepts are confusing because they overlap and intersect. Several researchers pointed out that clear definitions can be used by separating attributes of flexibility from components of flexibility (Barad, 1992; Benjaafar, 1994). For example, Zhang *et al*. (2003) categorize flexible manufacturing capability into volume flexibility and mix flexibility. We use this typology in this study.

Volume flexibility refers to the organization's ability to operate at various batch volumes and production output levels economically and effectively (Goyal and Netessine, 2011). It exhibits the firm's competitive potential to increase or decrease production volume to meet increasing or declining demand and keep inventory low when demand drops (Gerwin, 1993). In other words, the most critical aspect of volume flexibility is that it increases sales by consistently meeting customer demand in a timely manner and decreases costs by simultaneously reducing unnecessary inventory in the supply chain. Furthermore, environmental performance can be improved by conforming to the rules and requirements for environmental protection. Therefore, the ability of volume flexibility to quickly respond to customers also helps firms respond similarly to changes in government rules or requirements. In other words, with volume flexibility, firms could generate less waste by reducing inventory levels (Klassen and Angell, 1998). It is also analytically shown that capacity flexibility is a key factor for the sustainability performance (Das, 2020).

Product mix flexibility or mix flexibility is the organization's ability to produce different lines of products efficiently and effectively at a given certain capacity (Upton, 1995). It enables a firm to create customer satisfaction by promptly delivering the types of products that customers demand. Mix flexibility must be considered within the existing production system configuration without considering important facility modifications. The range of mix flexibility consists of the degree of differentiation of products and the number of different products produced. Companies with strong product mix flexibility can produce a wide variety of products without excessive time delays, premium prices, or declines in quality. Mix flexibility is critical to customer satisfaction because it is directly related to customization capability (Kathuria, 2000; White, 1996). The result of improved mix flexibility includes reducing the time to modify existing products and implement changes to the engineering order, quick changes to the product mix, and increases in the number of products handled and markets served (Klassen and Angell, 1998). By increasing mix flexibility, firms can rapidly adapt to changes in product regulation, use new recycled material easily, and serve new green customers and markets (Klassen and Angell, 1998). Therefore, increased mix flexibility will lead to improved environmental performance.

Hypothesis 1: *Manufacturing flexibility is positively associated with a firm's environmental performance.*

2.3 The Relationship between Quality Management and Environmental Performance

Quality management is defined as the improvement of processes within an organization, using quantitative methods and human resources to satisfy customer needs (Sousa and Voss, 2001). Researchers in quality management have identified two logics of how quality management leads to a competitive advantage. First, quality management enables firms to have higher internal operational capabilities to enhance quality performance (Reed *et al*, 2000). Quality management based on the efficient utilization of human resources supported by the top management team and appropriate organizational structures will lead to increased quality productivity (Capezio and Morehouse, 1995; Dow *et al*., 1999; Sousa and Voss, 2001). Second, the pursuit of quality management needs firms to be more market driven (Pipatprapa *et al*., 2017). In turn, such market-driven capabilities help firms differentiate themselves from competitors.

Such logic can apply to environmental performance. Firms need to sense the environmental changes regarding environmentally related laws or requirements. Market-driven capabilities from quality management enable firms to spot environmentally related needs. In addition, firms with appropriate operational capabilities for quality improvement can simultaneously resolve environmental issues. In fact, quality management and environment management share common goals, such as reducing waste and defects, increasing operational efficiency, decreasing energy consumption, and saving control costs (Carvalho *et al*., 2011; Farias *et al*., 2019; Verrier *et al*., 2016). Focusing on continuous improvement concepts and getting things right from the start also benefit from the environmental perspective (Shrivastava, 1995). Therefore, generating pollution is a signal of inefficiency (Kleiner, 1991)

Recent research has provided plenty of evidence that quality management can improve environmental performance. For example, total quality management, originally adopted to improve operational efficiency and effectiveness, enables firms to improve environmental performance (Corbett and Culter, 2000; Kitazawa and Sarkis, 2000). Shashi *et al*. (2019) showed that quality management and innovation significantly impact financial and environmental performance. Furthermore, Cherrafi *et al*. (2018) demonstrated that quality management practices, such as just-in-time, setup time reduction, and elimination of waste can improve green supply chain performance. Novitasari and Agustia (2022) also empirically showed that material quality and product quality, measured as green supply chain management, affect competitiveness and firm performance. Therefore, we argue that quality management positively affects environmental performance.

Hypothesis 2: *Quality management is positively associated with a firm's environmental performance.*

2.4 The Interaction Effect between Quality Management and Manufacturing Flexibility on Environmental Performance

We argued that manufacturing flexibility positively impacts environmental performance due to a firm's ability to quickly respond to changing environmental requirements from legislators or customers. In addition, quality management has a positive effect due to a firm's capability to efficiently implement measures to ensure environmental performance. However, the above two effects may arouse conflicts or paradoxes because the processes for achieving quality management and manufacturing flexibility are considerably different.

Quality management aims at increasing efficiency and effectiveness through repetition and economies of scale (Kim and Park, 2013). Efficiency also comes from the increased reliability of the manufacturing process, achieved by minimizing errors or mistakes. Therefore, firms tend to build bureaucratic structures and strong organizational cultures to align with operational objectives. High standardization, formalization, specialization, and hierarchical levels are also needed to pursue quality management (Adler *et al*., 1999).

On the other hand, manufacturing flexibility enables firms to respond to changing demands at the expense of efficiency. The operational system is built not to minimize errors but to increase quick responses to customers' changing needs. Thus, firms that pursue manufacturing flexibility create less hierarchical organizational structures and less rigid supporting cultures. Diversity, not repetition, is consistent with flexibility (Kim and Park, 2013).

The contrasting nature of quality management and manufacturing flexibility make it difficult for firms to implement both simultaneously. This argument aligns with the trade-off perspective on key factors (costs, quality, dependability, and flexibility) for manufacturing excellence (Burgos and Lorente, 2001). According to Schmenner and Swink (1998, p. 106–107), "a manufacturing plant cannot simultaneously provide the highest levels among all competitors of product quality, flexibility, and delivery, at the lowest manufactured cost." Researchers observed the trade-off between quality management and flexibility. Boyer and Lewis (1997) empirically demonstrated an inverse relationship between efficiency and flexibility. Furthermore, Hindo (2007) also showed a trade-off relationship between quality management and flexibility. The relationship is due to the fundamental difference in the sources of each capability (Burgos and Lorente, 2001). Therefore, we suggest that simultaneously executing quality management and manufacturing flexibility negatively affects environmental performance.

Hypothesis 3: *The interaction between quality management and manufacturing flexibility is negatively associated with a firm's environmental performance.*

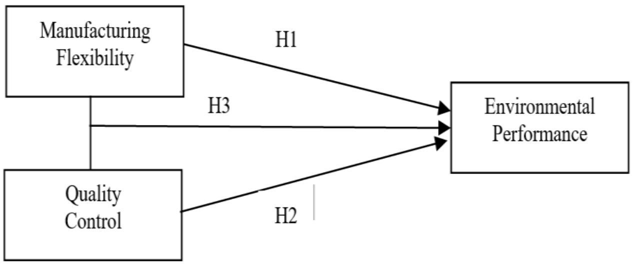

Figure 1 Research Model

3. METHODOLOGY AND MEASUREMENT

3.1 Data Collection

The data was obtained from the Korean manufacturing panel survey conducted in 2013. In this regard, 601 firms responded out of the 2,000 contacted in the first stage. Also, we excluded four firms from the sample due to the missing data, leaving us with 597 firms as a final sample. Eighty percent of the 597 firms are small and medium-sized across four industries: the automobile, machine, shipbuilding, and telecommunication industries. These firms were exposed to external pressures, including environmental regulations such as the Waste Electric and Electronic Equipment (WEEE) and Restriction of Hazardous Substances (RoHS) Directives. Therefore, firms needed to demonstrate flexibility in responding to environmental changes. In addition, these firms also need to pay attention to quality management, which is the main part of the manufacturing industry. Hence, we think our sample aligns with the study's objective.

3.2 Measures

Environmental performance: The dependent variable, environmental performance, was measured by assessing the degree of reduction regarding firms' environmental impacts in four categories, including non-renewable resources, energy, emissions, and inputs to air and water (Griliches, 1998; Wagner and Schaltegger, 2004). The survey questionnaire asked respondents about the extent to which a firm reduced its environmental impact in the four categories, using a scale of "1" (no reduction) to "7" (extensive reduction).

Manufacturing flexibility: We measure manufacturing flexibility using three items: "To what extent is your firm able to respond to the volume change?", "To what extent does your firm produce a variety of products?" and "To what extent is your firm able to respond to the changes of product specifications" using a seven-point Likert scale ranging from "1" (very low) to "7" (very high). Notably, Cronbach's alpha was .91, representing high reliability.

Quality management: Quality management was measured using five items: "To what extent does your manager encourage the enhancement of product quality?", "To what extent does your firm systematically use quality management programs such as total quality management or Six Sigma?", "To what extent are all employees, not just employees in the production department, involved in quality improvement?", "To what extent are the data for quality management measured and managed effectively?" and "To what extent are recurrence prevention programs operated to prevent recurring problems?" using a seven-point Likert scale ranging from "1" (very low) to "7" (very high). In this regard, Cronbach's alpha was .90, indicating high reliability.

Control variables: We created some control variables at the firm and industry levels. At the firm level, we made a revenue variable logged to reduce skewness. Firm age was created using the number of years a firm has operated, and firm size was created using the number of employees. A dummy variable for industry classification was created to reflect the variance among the diverse industries.

4. RESULTS

In **Table 1**, descriptive statistics and correlations were displayed. Some significant correlations were found among variables. The manufacturing flexibility was associated with environmental performance. We conducted a confirmatory factor analysis with 21items to check the validity of variables (environmental performance, manufacturing flexibility, and quality management). The results suggested that all of factor loading value is over .5 satisfying the criteria and a three-factor model consisting of the three variables fits data better than four, two, and one factor models ($\chi 2 = 348.435$, df = 55, $p < .01$; Comparative Fit Index [CFI] = .67, root mean square error of approximation [RMSEA]=.10). Variance inflation factors (VIF) were calculated to detect problems of multicollinearity. The range of VIF was between 1.25 and 1.27, which is well below the rule-of-thumb cut-off point of ten, indicating that the results of our analyses were not affected by multicollinearity.

Table 1 Means, Standard Deviations, and Correlation Coefficients

No	Variable	Mean	SD	1	2	3	4	5	6
1	Environmental performance	4.20	1.16	1					
2	Manufacturing flexibility	4.94	1.16	0.26*	1				
3	Quality management	0.53	0.50	0.11*	0.00	1			
4	Revenue	3.96	1.03	-0.12*	0.00	-0.05	1		
5	Firm age	18.53	11.31	0.1*	0.06	0.09*	-0.04	1	
6	Firm size	4.65	0.88	0.12*	0.1*	0.06	0.01	0.34*	1

*p<.05; N=597

Table 2 presents the results of the ordinary least squares (OLS) regression analyses. The baseline model (Model 1) contained control variables. Regarding the effect of the manufacturing flexibility, Model 3 showed that manufacturing flexibility is positive and significant (β=0.262, p<0.001), supporting Hypothesis 1. Regarding the effect of quality management on environmental performance, Model 2 displayed a positive and significant coefficient (β=0.145, p<0.05), supporting Hypothesis 2. This outcome implies that a firm's effort to control quality positively affects environmental performance. Lastly, we examined the interaction effect between quality management and manufacturing flexibility. Model 4 showed that the interaction between quality management and product mix flexibility is negative and significant (β=-0.219, p<0.05), supporting Hypothesis 3.

The results regarding Hypotheses 1 and 2 are in line with the previous research (e.g., Cherrafi *et al*., 2018, Das, 2020, Klassen and Angell, 1998, and Shashi *et al*., 2019) in that quality management and manufacturing flexibility are positively associated with a firm's environmental performance. However, the result regarding Hypothesis 3, the interaction between quality management and manufacturing flexibility is negatively associated with a firm's environmental performance, has not been shown in the previous research, and thus provides new insights to the literature.

Table 2 Results of OLS Regression Analysis

Variable	Model 1	Model 2	Model 3	Model 4
Revenue	-0.132**	-0.127**	-0.134**	-0.136**
	(0.05)	(0.05)	(0.04)	(0.04)
Firm age	0.005	0.004	0.003	0.003
	(0.00)	(0.00)	(0.00)	(0.00)
Firm size	0.145*	0.141*	0.109+	0.106+
	(0.06)	(0.06)	(0.06)	(0.06)
Quality management		0.204*	0.201*	1.280**
		(0.09)	(0.09)	(0.44)
Manufacturing flexibility			0.262***	0.389***
			(0.04)	(0.07)
Quality management × manufacturing flexibility				-0.219* (0.09)
_cons	3.993***	3.887***	2.778***	2.173***
	(0.33)	(0.33)	(0.37)	(0.44)
F	5.875	5.743	9.801	9.501
R square	0.056	0.064	0.118	0.127
N	597	597	597	597

†p< 0.10, *p<0.05, **p<0.01, ***p<0.01 ; N=597; Standard errors are in parentheses.

5. CONCLUSIONS

The present study aims to investigate the effects of two dimensions of manufacturing capabilities (quality management and manufacturing flexibility) on environmental performance. Previous research has focused on a single dimension because each dimension has a distinct effect on environmental performance. For example, manufacturing flexibility is adopted to respond to varying demands for or regulations regarding environmental protection. On the other hand, quality management enhances efficiency and effectiveness in implementing the process or product for environmental performance. However, we argue that both dimensions are required to have a high level of manufacturing capability. More importantly, the impact of quality management and manufacturing flexibility may conflict. Thus, it is worthwhile to investigate the interaction effect between the two.

We found that manufacturing flexibility positively affects environmental performance (H1). The results also showed that quality management was significantly and positively associated with environmental performance (H2). Both manufacturing flexibility and quality management, which are basic elements of manufacturing capability, improved environmental performance. More importantly, we found that the interaction effect between the two on environmental performance was negative, implying that the implementation of both negatively affected environmental performance (H3).

The key contribution of this study is to examine the negative interaction effect of quality management and manufacturing flexibility. As the industrial environment becomes increasingly dynamic, the speed of customers' changing demand quickens, and the product life cycle shortens. Thus, firms need to have a high level of flexibility. On the other hand, as the degree of competition among firms intensifies, the expectation for high quality has also risen, implying that the effort to improve quality must be continuously pursued. Under such conditions, firms need to handle both well. However, simultaneously managing both is challenging. Quality management requires a bureaucratic organizational structure, repetition, standardization, formalization, specialization, and hierarchy, which are not attributes for manufacturing flexibility (Adler *et al*., 1999). We empirically demonstrated this conflict interaction effect on environmental performance. Future studies must investigate more detailed antecedents or mechanisms to resolve such conflict.

This study has some limitations. First, the empirical setting centred on Korean manufacturing firms. Considering the increased pressures for high levels of environmental performance in Korea, the research setting fits the research goal. However, subsequent studies need to be done to ensure the current study's external validity in other contexts, such as the service industry and countries with different regulatory environments. Second, three items for manufacturing flexibility were used in this study. However, there are more aspects to manufacturing flexibility, such as manufacturing flexibility of resources or systems (Day, 1994; Zhang *et al*., 2003). Therefore, we recommended that future studies use more dimensions of manufacturing flexibility to generalize these findings.

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