

# Effects of Green Operations and Green Innovation on Firm's Environmental Performance

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## ABSTRACT

This study examines how green operations affect firm's environmental performance with green innovation as a mediator in the context of electronic industry. We carry out an empirical study with 141 valid questionnaires collected from high-tech manufactures in Taiwan. The results show that positive relationships exist among green operations, green innovation and environmental performance (in both operational performance and managerial performance). However, an integration of green operations with green innovation would influence firm's environmental performance more positively than the sole effects of green operations. It suggests that high-tech manufacturers should pay greater attention to green innovative strategies in order to cope with customer demand and, thereby, enhancing customer satisfaction and sustainable operations. This study has contributed to the extant literature by providing valuable academic references and pragmatic guidelines for firms to gain competitive advantages through green operations and green innovation.

Keywords: Green Operations, Green Innovation, Environmental Performance, High-Tech Industry

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## 1. INTRODUCTION

Incessant changes in technologies coupled with rapid growths in the worldwide economics have placed a tremendous burden on the ecosystems and the limited natural resources. In recent years, an increase in environmental awareness has led many countries to introduce laws to curtail environmental harms and promote green products through such directives as the Waste Electrical and Electronic Equipment (WEEE) and the Restriction of Hazardous Substance (RoHS). These directives have in effect prompted manufacturers to focus more on green production techniques to avoid losing their competitive advantages (Russo and Fouts, 1997). Taiwan, one of the world's largest export-oriented electronic original equipment manufacturers (OEM) and original design manu-

facturers, has long maintained close relationships with the European Union, the United States, and Japan. This study intends to investigate environmental issues in Taiwan due to the importance of green issues in this country and the fact that most Taiwanese manufacturers are OEM organizations that must comply with the regulations from downstream customers. To achieve sustainable competitiveness and ensure customer satisfaction and market leadership, the Taiwanese manufacturers must pay special attention to environmental issues throughout the holistic manufacturing processes.

Green operational management refers to a close cooperation between upstream and downstream manufacturers in the supply chain management (SCM) by adopting 'green' as a prerequisite to reduce environmental damage. In addition to the conventional emphasis of SCM

on cost, flexibility, speed, and quality, the green operational management adds environmental criteria to the purchase of raw materials, packaging decisions, product design, manufacturing, reuse, and recycling. This holistic operational model can help manufacturers to meet legislative requirements with ultimate goals to promote energy conservation, reduce emissions, and reduce environmental degradation, while enhancing product values.

Industries nowadays are facing tremendous challenges in meeting the green legislative requirements. As a result, manufacturers have begun requesting that suppliers and customers pay more attention to environmental issues. A review of the extant literature revealed a large number of studies on SCM and organizational performance (Chien and Shih, 2007; Hervani *et al.*, 2005; Zhu and Sarkis, 2004). Green innovation, which is defined as an organization's implementation of new ideas, products, and processes, has also gained prominence as a topic of research (Qi *et al.*, 2010; Rao and Hult, 2005). However, few studies have investigated whether the launching of green operations could affect green innovation or the environmental performance of organizations. This study aims to reveal the impact of green operations on green innovation and environmental performance of organizations. The remainder of this paper is organized as follows. Section 2 presents the literature review and research hypotheses. Section 3 provides the research methodology. Section 4 presents the statistical results and analyses. Section 5 offers conclusions and management implications.

## 2. LITERATURE REVIEW AND RESEARCH HYPOTHESES

### 2.1 Green Operations

The concept of green operations, aka green supply chain management (GSCM), has been lauded as an effective means to enhance sustainability and open up distribution channels between manufacturers and suppliers (Cooper and Ellram, 1993; Van Weele, 2002). Green operations extend environmental protection into a management system through the introduction of 'green' notions to the supply chain (Winn and Roome, 1993). By examining internal practices and external relationships with suppliers, green operations can significantly reduce waste (Sarkis, 2003). In view of shorter product lifecycles and more quantities of waste due to expansion of high-tech industries, many firms have paid higher attention to environmental protection by seeking effective GSCM measures, including improving the management of raw material purchases, increasing efforts to promote recycling, reuse, and remanufacturing, and providing green packaging alternatives (Geyer and Jackson, 2004; Hanna and Newman, 1995). These measures provide businesses with numerous opportunities to achieve sustainable competitiveness through the reduction of environ-

mental damage (Green *et al.*, 1996; Narasimhan and Carter, 1998).

Green operations include green design, green production, green marketing, and reverse logistics (Bhamra, 2004; Hervani *et al.*, 2005; Peattie, 1992). Green design, or eco-design, places a strong emphasis on reducing the amount of raw resources consumed throughout the lifecycle of the product. In this manner, green design focuses on sustainability throughout the product lifecycle by directly employing the 3R's: reduce, reuse, and recycle (Gupta, 1995). Based on a blueprint of sustainable development, green marketing can propel green consumption into the mainstream, while promoting industrial competitiveness (Chen *et al.*, 2006). Reverse logistics can be defined as the process of transforming used products into re-usable products (Fleischmann *et al.*, 1997). It differs from traditional logistics by considering cost and recycle value of products and components in order to maximize reuse value (Hervani *et al.*, 2005). GSCM practices may cover a wide range of aspects; however, this study will focus mainly on internal operational management processes. Therefore, green operations in this study will refer to managerial operations capable of enhancing information shared among employees, as it is believed that such cooperation can expand green operations (Frentzel and Sease, 1996; Zhang and Li, 2009).

### 2.2 Green Innovation

Green innovation is defined as an organization's implementation of new ideas, products, and processes capable of reducing environmental impact or aiming at specific eco-targets (Chen, 2008; Klemmer *et al.*, 1999; Oltra and Saint Jean, 2009; Rennings, 2000). It is associated with energy savings, pollution prevention, waste recycling, green products designing, and corporate environmental management (Chen *et al.*, 2006).

This study adopts the notions presented by Klemmer *et al.* (1999), Rennings (2000), Chen (2008), and Oltra and Saint Jean (2009), in which green innovation can be divided into green product innovation, green process innovation, and green administrative innovation. Green product innovation is defined as product innovation closely associated with environmental concerns, including energy saving, pollution prevention, waste recycling, not producing toxicity, and green product designs (Chen *et al.*, 2006). In other words, green product innovation is a means of reducing environmental impact during the entire lifecycle of products by reducing toxic waste, controlling power consumption, minimizing emissions, and extending useful phase of products in recyclability (Kammerer, 2009). Green process innovation refers to the modification of current operating processes and systems, aiming at producing new or significantly improved green products with a reduced environmental impact (Meeus and Edquist, 2006). Green administrative innovation refers to the update of management practices

in accordance with the tenets of environmental awareness, by reducing office waste, building sustainable facilities, and promoting environmental issues in the workplace (Birkinshaw *et al.*, 2008).

### 2.3 Environmental Performance

Environmental performance directly involves managerial performance and organizational strategy policy, members, legislative activities, measures, procedures and decisions that can provide and improve the capabilities and efforts on business aspects, such as modified measures of training, legislative demand, resource usage, environmental cost management, purchases, product R&D, and electronic-documents. According to ISO 14030, environmental performance refers to a systematic procedure of measuring and assessing environmental performance at the industry level. ISO 14031 includes environmental performance indicators within operational performance indicators and management performance indicators.

Following Papadopoulos and Giama (2007) and Chien and Shih (2007), environmental performance can be divided into environmental operational performance and environmental managerial performance. Environmental operational performance refers to the measures used to evaluate the consumption of energy and resources as well as the progress made in reducing emissions and unnecessary waste; while environmental managerial performance refers to the measures used to improve the relationship between manufacturers and communities as well as the image of participants in a given industry. Environmental operational performance emphasizes the import of raw material, energy usage, and services. It also involves an organizational facilities' hardware and design, install, operation, and maintenance and the output during operational processes (e.g., product, service, waste, emission) (Papadopoulos and Giama, 2007). In contrast, environmental managerial performance reflects the efforts of management to improve environmental operational performance. It benefits the evaluation of management efficiency and improves environmental performance, decision-making and motivation (Chien and Shih, 2007).

### 2.4 Hypotheses Development

#### 2.4.1 Green operations and green innovation

The main aim of green product innovation is to minimize environmental harm through green production practices. Shrivastava (1995) pointed out that the integration of concepts related to environmental protection into the design of green products could help to promote green product innovation. Wagner (2008) also indicated that the engagement of a firm in green production and green marketing could have a positive effect on green manufacturing innovation and green administrative innovation. Winn and Roome (1993) suggested that industry leaders should expand the concept of green adminis-

trative innovation to encompass the management of the entire supply chain and marketing. Thus, green marketing efforts could increase the demand for green products among consumers, resulting in positive benefits for green product innovation (Belz and Bilharz, 2005). In response to pressures of resolving environmental protection problems, industry leaders should implement green marketing strategies in order to promote green administrative innovation (Newman and Breeden, 1992; Peattie, 1992; Wagner, 2008). Thus, this study establishes the first hypothesis as follows:

**H<sub>1</sub>:** Green operations have a positive impact on green innovation.

#### 2.4.2 Green innovation and environmental performance

Porter (1991) stated that pressures from environmental regulations and the needs to reduce costs have forced manufacturers to pursue green product innovation, green manufacturing innovation, and green administrative innovation. According to Geffen and Rothenberg (2000), green product innovation, green manufacturing innovation, and green administrative innovation should be the main focus in improving environmental operational performance. Specifically, green product innovation helps firms to comply with regulatory requirements, advancing the effective use of resources, and enhancing the image of the industry (Dangelico and Pontandolfo, 2010). These efforts also reduce the likelihood of environmental problems throughout the lifecycle of the product by minimizing toxic material and electrical consumption (Kammerer, 2009). In other words, green product innovation has a positive impact on environmental operational performance in each stage of the product's lifecycle. In addition, innovation in green manufacturing has been widely perceived as an effective means by which to improve environmental operational performance by promoting green manufacturing processes (Klassen and McLaughlin, 1996). Ren (2009) observed that green manufacturing innovation effectively reduces gas emissions and increases energy utility rates in the petrochemical industry. Finally, Chen *et al.* (2006) and Shrivastava (1995) promoted green administrative development as a tool to help firms increase competitive benefits, reduce costs, enhance product quality, drive manufacturing innovation, enhance industrial image, and promote environmental managerial performance. It should be noted that green managerial innovation positively influences environmental managerial performance (Kim and Srivastava, 1998). Therefore, this study proposes the following hypotheses:

**H<sub>2</sub>:** Green innovation has a positive impact on environmental operational performance.

**H<sub>3</sub>:** Green innovation has a positive impact on environmental managerial performance.

### 2.4.3 Green operations and environmental performance

Steger (1993) stated that green operations could help firms to reduce costs, increase market opportunities, promote efficiency in the use of resources, and prevent pollution. These effects benefit industry by improving regulatory compliance, promoting employee motivation, reducing risk, supporting environmental responsibility, and information flow distribution. Schoell *et al.* (1993) indicated that green marketing enhances organizational environmental image. Taylor (1992) claimed that green environmental management emphasizes the adoption of positive attitudes in order to overcome potential problems during marketing processes. It has also been widely accepted that industries that implement green environmental management and green innovation can promote environmental operational performance, reduce costs and achieve more effective environmental protection, helping firms avoid the expense of environmental disputes and customer boycotts (Taylor, 1992). Moreover, Ken and Martin (2007) stated that green marketing focuses mainly on minimizing negative environmental impact throughout the lifecycle of the product, resulting in a positive impact on environmental operational performance.

The main purpose of green operations is to enable the manufacture of green products that are or will be renewed, recycled, and reused. Green products can facilitate a reduction in materials, waste, and pollution emissions and enhance the use of resources. Chien and Shih (2007) found that green production has a positive influence on environmental operational performance and managerial performance. Tsoufas and Pappis (2006) claimed that the reuse of materials could considerably reduce internal costs, exploit new markets, and enhance competitive advantage. Theyel (2001) and Rao and Holt (2005) proposed that, by recycling and reusing, industries can save on materials, water, and energy, thereby improving organizational environmental performance. As a result, this study establishes the following hypotheses:

**H<sub>4</sub>:** Green operations have a positive impact on environmental operational performance.

**H<sub>5</sub>:** Green operations have a positive impact on environmental managerial performance.

Figure 1 presents the conceptual research framework, which reveals the aforementioned hypothesized relationships among green operations, green innovation, and environmental performance.

## 3. RESEARCH METHODOLOGY

### 3.1 The Questionnaire

This study divides the questionnaire into four sections: 1) green operations—reducing environmental impact and testing the eco-friendly attitudes of top managers and employees, 2) green innovation—minimizing environmental pollution in the SCM process, 3) environmental operational performance, and 4) environmental managerial performance. Items are modified according to pre-test interviews with five managers in the semi-conductor and computer-related industries. Following the procedure recommended by Churchill (1979), the pre-test interviews have indicated that the questionnaire is appropriate to test the mediating effect of green innovation on green operations and environmental performance. A five-point Likert scale (1 ‘totally disagree’ to 5 ‘totally agree’) is used to measure items related to green operations, green innovation, and environmental performance. Manipulation of the measurement variables is presented in the Appendix 1.

### 3.2 Data Collection

Participants of this study include managers from the semi-conductor, information communications technology, and computer-related industries in Taiwan. Ques-

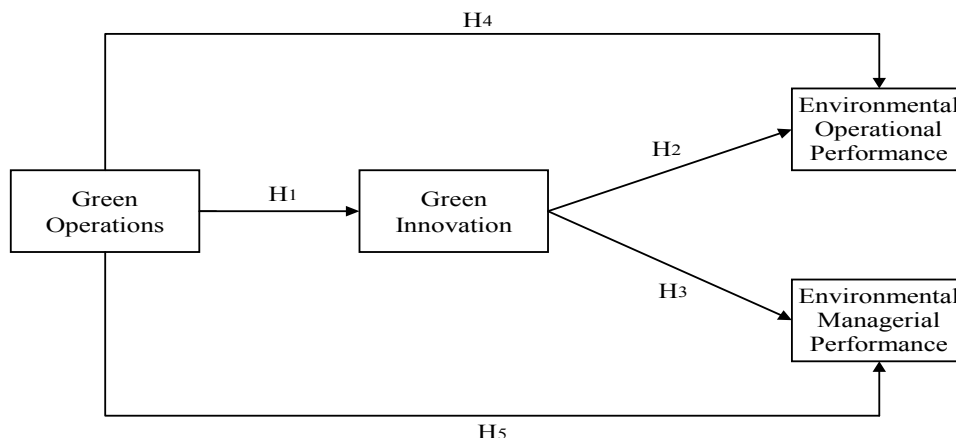


Figure 1. The conceptual framework.

tionnaires are sent to 587 general managers selected from the list of ‘Largest 5000 Corporations in Taiwan.’ We obtain 141 valid responses from 150 returned questionnaires, indicating a valid response rate of 24%.

### 3.3 Reliability and Validity Analysis

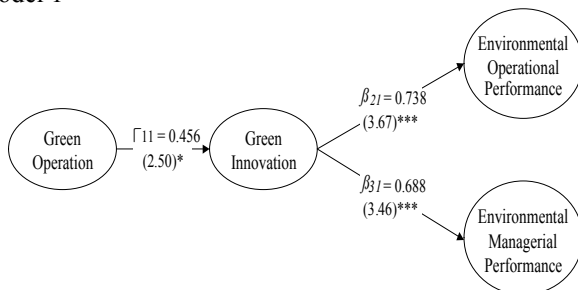
This study uses SPSS ver. 12.0 and AMOS ver. 18.0 for data analysis (SPSS Inc., Chicago, IL, USA). The reliability and validity of each latent construct are assessed using a two-step structural equation modeling (SEM) procedure, which includes a measurement model and a structural model (Anderson and Gerbing, 1988). Results show that factor loading coefficients are above 0.5, which fit the benchmark of 0.5 (Hair *et al.*, 2010), the squared multiple correlation (SMC) values are between 0.324 and 0.797, which exceed the benchmark of 0.2 (Bentler and Wu, 1993), and the Cronbach’s  $\alpha$  coefficients are between 0.812 and 0.859, which exceed the benchmark of 0.7 (Nunnally, 1978). These results suggest a high degree of internal consistency, thereby confirming the reliability of each construct. The average variance extracted (AVE) values are all above 0.5, indicating the high convergent validity of the measurement indicators (Hair *et al.*, 2010). This study follows the methods outlined by Gaski and Nevin (1985) and by Fornell and Larcker (1981). The results fit the above stipulations, thereby supporting the discriminant validity of the instrument.

## 4. STATISTICAL RESULTS

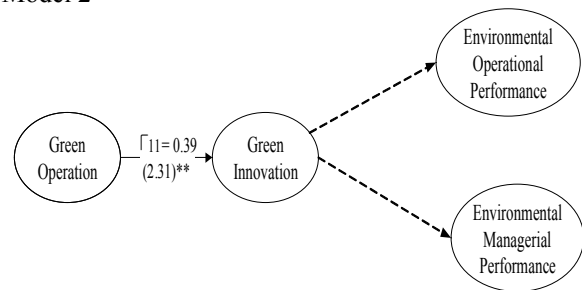
### 4.1 The Rival Models

Hair *et al.* (2010) recommended using rival models to verify the optimal hypothesis model, and then performing individual path coefficient tests to confirm hypotheses. Accordingly, this study designs four rival models as shown in Figure 2. Model 1 is an entirely mediated model exploring the mediating impact of green innovation between green operations and environmental performance. Model 2 is a partially mediated model exploring the impact of green operations on green innovation, disregarding the paths related to environmental operational performance and environmental managerial performance. Model 3 is a partially mediated model examining the impact of green innovation on environmental operational performance and environmental managerial performance, disregarding the paths related to green operations. Model 4 is also a partially mediated model examining the direct impact of green operations on environmental operational performance and environmental managerial performance, disregarding all the paths of indirect impacts. The hypothetical model is partially mediated, including the impact of green operations on environmental operational performance and environmental managerial performance through the mediator of green innovation and the direct impact of green operations on environmental operational performance

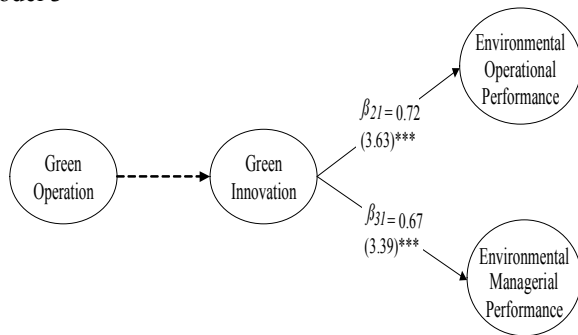
Model 1



Model 2



Model 3



Model 4

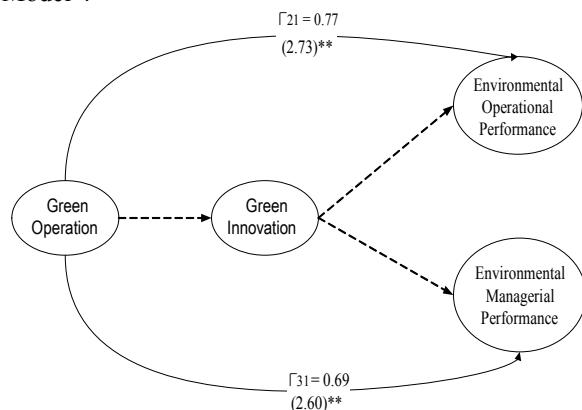


Figure 2. The rival models.

and environmental managerial performance. Table 2 presents the fit statistics of rival models. After comparing the path analyses of Models 1–4, the hypothetical model is found to fit well with the data, indicating that green innovation should be added between green operations and environmental operational performance and environmental managerial performance.

#### 4.2 Overall Model Fit

Following the method presented by Hair *et al.* (2010), this study selects absolute fit measures, incremental fit measures, and parsimonious fit measures to test model fitness. Absolute fit measures are used to measure overall goodness-of-fit for both the structural and measurement models. Table 2 presents the values for absolute fit measures:  $\chi^2/df = 1.24$ , goodness-of-fit index (GFI) =

0.865, adjusted GFI (AGFI) = 0.833, root mean square residual (RMR) = 0.020, and root mean square error of approximation (RMSEA) = 0.042, indicating goodness-of-fit. Incremental fit measures refer to goodness-of-fit in which the current model is compared to a specified independent model to determine the degree of improvement over the null model. In Table 2, the values obtained for incremental fit measures are as follows: normed fit index (NFI) = 0.702, incremental fit index (IFI) = 0.924, Tucker-Lewis index (TLI) = 0.910, and comparative fit index (CFI) = 0.920. NFI is lower than the standard value of 0.9. Parsimonious fit measures refer to goodness-of-fit measures, representing the degree of model fit per estimated coefficient. The results of parsimonious fit are: parsimony NFI (PNFI) = 0.620 and parsimony GFI (PGFI) = 0.698, indicating overall good model fit.

**Table 1.** Correlation of latent variables

Variable	Green operations	Green innovation	Environmental operational performance	Environmental managerial performance	Composite reliability	AVE
Green operations	0.736	-	-	-	0.904	0.542
Green innovation	0.548**	0.712	-	-	0.858	0.507
Environmental operational performance	0.549**	0.624**	0.730	-	0.820	0.533
Environmental managerial performance	0.441**	0.555**	0.633**	0.766	0.850	0.586
Cronbach's $\alpha$	0.838	0.812	0.848	0.859	-	-

AVE: average variance extracted.

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

**Table 2.** Comparison of rival models

Fit indicator	Model 1	Model 2	Model 3	Model 4	Hypothetical model	Limiting value	Fit result
Absolute fit measure							
$\chi^2/df$	1.250	1.690	1.317	1.565	01.24	1–5	Yes
GFI	0.863	0.816	0.858	0.836	0.865	>0.8	Yes
AGFI	0.832	0.776	0.827	0.799	0.833	>0.8	Yes
RMR	0.029	0.043	0.032	0.040	0.020	<0.05	Yes
RMSEA	0.042	0.071	0.048	0.640	0.042	<0.05	Yes
Incremental fit measure							
NFI	0.672	0.550	0.652	0.587	0.702	>0.9	No
IFI	0.911	0.748	0.886	0.797	0.924	>0.9	Yes
TLI (NNFI)	0.896	0.708	0.868	0.764	0.910	>0.9	Yes
CFI	0.907	0.737	0.881	0.789	0.920	>0.9	Yes
Parsimonious fit measure							
PNFI	0.599	0.495	0.585	0.526	0.620	>0.5	Yes
PGFI	0.703	0.761	0.702	0.684	0.698	>0.5	Yes

GFI: goodness-of-fit index, AGFI: adjusted GFI, RMR: root mean square residual, RMSEA: root mean square error of approximation, NFI: normed fit index, IFI: incremental fit index, TLI: Tucker-Lewis index, NNFI: non-normed fit index, CFI: comparative fit index, PNFI: parsimony NFI, PGFI: parsimony GFI.

### 4.3 The Hypothetical Structural Model

The technique of SEM is applied to test the causal relationship between latent variables. Figure 3 presents the path analysis of the hypothesized structural model. Statistical results show that green operations have a positive impact on green innovation ( $\gamma_{11} = 0.40, t = 2.27, p < 0.05$ ), green innovation has a positive impact on environmental operational performance ( $\beta_{21} = 0.55, t = 3.36, p < 0.001$ ), green innovation has a positive influence on environmental managerial performance ( $\beta_{31} = 0.51, t = 3.39, p < 0.001$ ), green operations have a positive impact on environmental operational performance ( $\gamma_{21} = 0.37, t = 2.11, p < 0.05$ ), and green operations have a positive influence on environmental managerial performance ( $\gamma_{31} = 0.33, t = 2.03, p < 0.05$ ).

Previous studies focused on the impact of green operations on environmental performance and the correlations among green innovation, environmental operational performance, and environmental managerial performance. However, little research has been performed on the mediating influence of each of the dimensions (green operations, green innovation, environmental operational performance, and environmental managerial performance), which is the main interest of this paper. The statistical results of all structural paths strongly support the proposed hypotheses, as shown in Table 3.

First, hypothesis H<sub>1</sub> is strongly supported, stating

that green operations have a positive impact on green innovation. These results confirm that the more green operations are practiced the more high-tech firms can accelerate green innovation.

This study supports hypotheses H<sub>2</sub> and H<sub>3</sub>, which state that green innovation has a positive impact on environmental performance—both operational performance and managerial performance. Thus, we conclude that considering the ease of recycling and reusing as well as the decrease of emissions in the design of products can help save resources, improve internal administration and information delivery, and ensure industrial safety.

Our findings support H<sub>4</sub> and H<sub>5</sub>, stating that green operations have a positive impact on environmental performance—both operational performance and managerial performance. Designs intending to extend the life-cycle of products can encourage supervisors and employees to implement environmental issues in daily operations and manufacturing activities by establishing systems for the categorization of waste materials. Simultaneously, green products can substantially reduce air pollution, greenhouse emissions, and costs while increasing production output.

Finally, we sought to explore the mediating effect of green innovation on green operations and environmental performance. Our empirical results show that the implementation of green operations can improve environmental

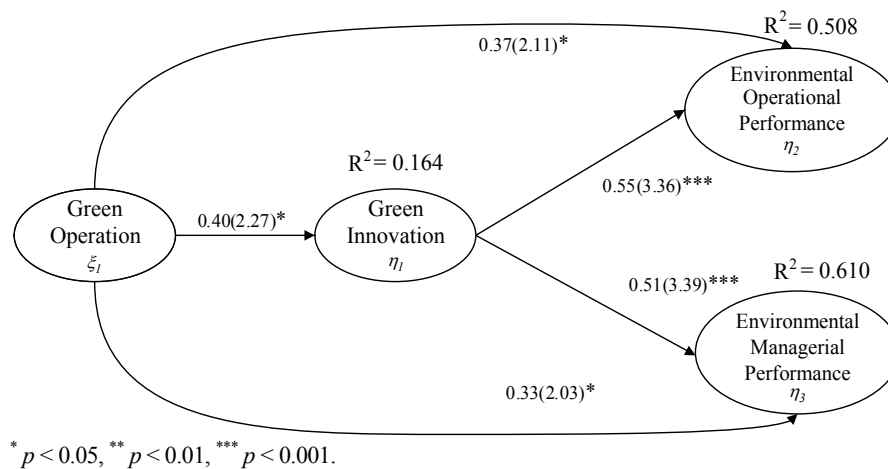


Figure 3. Path analysis of the hypothetical structural model.

Table 3. Path coefficients and hypotheses testing

	Hypothesis	Path coefficient	t value	Result
H <sub>1</sub>	Green operations → Green innovation	0.40	2.27*	Supported
H <sub>2</sub>	Green innovation → Environmental operational performance	0.55	3.36***	Supported
H <sub>3</sub>	Green innovation → Environmental managerial performance	0.51	3.39***	Supported
H <sub>4</sub>	Green operations → Environmental operational performance	0.37	2.11*	Supported
H <sub>5</sub>	Green operations → Environmental managerial performance	0.33	2.03*	Supported

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

operational performance and environmental managerial performance by strengthening green innovation.

## 5. CONCLUSIONS AND IMPLICATIONS

The current study shed new light on whether the implementation of green operation models in high-tech industries would affect the environmental performance of organizations via green innovation. By verifying the hypothetical models, we clarify the relationships between the variables and all research questions raised. The results show that the adoption of green operations positively influences green innovation. This finding strongly supports previous studies stating that green operational models have a positive impact on green innovation (Ottman, 1999; Wagner, 2008; Winn and Roome, 1993). Second, this study confirms that strengthening green innovation can exert a positive influence on environmental operational performance, implying that manufacturers should strongly encourage green innovation in order to obtain better environmental operational performance. This finding is also consistent with previous research stating that green innovation exerts a positive influence on environmental operational performance (Dangelico and Pontrandolfo, 2010; Geffen and Rothenberg, 2000). Third, our results suggest that the enhancement of green innovation exerts a positive influence on environmental managerial performance, which supports previous findings (Shrivastava, 1995). Fourth, improving green operations can serve as a means to enhance environmental operational performance, which also supports the findings of previous studies (Chien and Shih, 2007; Theyel, 2001). Finally, this study finds that implementing green operations can improve environmental managerial performance, also confirming the results obtained in previous research (Chen, 2008; Chien and Shih, 2007).

This study provides several useful contributions with important academic implications. First, this study has contributed to the extant literature by illustrating an empirical study of the relationships among green operations, green innovation, and environmental performance. Second, our results suggest that manufacturers should pay greater attention to developing innovative strategies to cope with customer demand, thereby enhancing customer satisfaction, promoting sustainable operations, and gaining competitive advantages in environmental performance.

Many manufacturers set goals without considering the needs for environmental protection, which causes serious damage to the environment. This study finds that green operations have a direct, positive impact on green innovation. In other words, the implementation of green operations can lead to benefits through the promotion of green innovation, thereby creating their own competitive advantages, reducing environmental damage, and promoting a win-win situation for industry and the envi-

ronment. We also found that green operations have a direct, positive impact on environmental performance through green innovation.

Inevitably, this study has a number of limitations which call for further exploration. The sample in this study was limited in size and scope. Future research is encouraged to expand the sample into different industries. In addition, because too many questionnaire items regarding green operations, green innovation, and environmental performance could cause respondents to lose patience, the assessment items should perhaps be reassessed and shortened. In the future study, it is suggested that data be collected using vertical sections and time-series methods and explorations be made on the interactions among variables in different time situations. Finally, comparative analysis may be an effective method to obtain reliable empirical data relating to the impact of various factors and statistical results.

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**Appendix 1.** Suvery questionnaires

Factor	Measurement item
Green operations (GO)	GO <sub>1</sub> : Reducing the impact on environment in manufacturing process of each lifecycle
	GO <sub>2</sub> : Meeting energy saving ways in manufacturing process
	GO <sub>3</sub> : Continually modifying product technology and promoting enviromental manufacturing process stardard
	GO <sub>4</sub> : Supervisors and employees have environmental concept
	GO <sub>5</sub> : Regarding ‘green’ as a long-term mission
	GO <sub>6</sub> : Using modified green product as the foundation of green image
	GO <sub>7</sub> : Establishing categorizing system of waste
	GO <sub>8</sub> : Recycling and reusing waste
Green innovation (GI)	GI <sub>1</sub> : Producing the minimum pollution products in comparison with competitors in R&D and design process
	GI <sub>2</sub> : Considering the ease of recycle and reuse in comparison with competitors in R&D and design process
	GI <sub>3</sub> : Comparison with competitors regarding the elimination of noxious odors and waste materials in the manufacturing process
	GI <sub>4</sub> : Comparison with competitors regarding the reducing material in manufacturing process
	GI <sub>5</sub> : Actively adopting new policy of improving environmental performance in comparison with competitors
	GI <sub>6</sub> : Adjusting departmental duty coordinates with environmental demand in comparison with competitors
Enviornmental performance (EP)	EP <sub>1</sub> : Air pollution control is improved considerably
	EP <sub>2</sub> : Reducing greenhouse gases is improved considerably
	EP <sub>3</sub> : Economizing on water is promoted considerably
	EP <sub>4</sub> : Using raw materials is promoted considerably
	EP <sub>5</sub> : Internal management and information communication is promoted considerably
	EP <sub>6</sub> : Substantially increasing the quantity of eco-friendly product/service
	EP <sub>7</sub> : Substantially reducing frequency of environmental industrial accidents
	EP <sub>8</sub> : Substantially reducing cost

A five-point Likert scale (1 ‘totally disagree’ to 5 ‘totally agree’).