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An Empirical Study on the Impact of Sustainable Manufacturing Practices and Innovation Performance on Environmental Sustainability

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Abstract

This study analyzes the causal relationship between sustainable manufacturing practice (SMP) and environmental sustainability as well as determines the mediating effect of innovation performance (IP) on the relationship between SMP and environmental sustainability. Adaptation from the changing business environment, manufacturing firms are facing great challenge on producing more products with less resource consumption, pollution emitted and waste generated. Using structural equation modeling, the survey data collected from 150 Malaysian manufacturing firms has been analyzed in this study. The empirical results show that both types of SMP have a positive and significant impact on environmental sustainability with external SMP is greater than internal SMP. However, there is no significant evidence to prove IP as a mediator for SMP-environmental sustainability linkage. The findings of this paper have important implication in both theoretical and practical perspectives. While provide better understanding of the phenomena by simultaneously analyzing a series of dependence relationships among SMP, IP and environmental sustainability, these results could help managers to understand the types of practices that would improve their environmental performance.

Keywords: Sustainable manufacturing, sustainable manufacturing practice, innovation performance, environmental sustainability

1.0 INTRODUCTION

Sustainability becomes a part of the national agenda which is highlighted in the 11th Malaysia Plan. The efforts towards environmental sustainability dramatically widened the responsibilities of the manufacturing firms in doing business. Besides producing products for fulfilling economic demands and needs, they need to become a driving force for the creation of sustainable society by designing and implementing sustainable practices that allow them to eliminate or significantly reduced their environmental impacts as well as they can produce products that contribute to better environmental performance in other sectors [1]. With the growing global concerns in the issues of sustainability such as scarcity of natural resources and rapid environmental degradation, sustainable manufacturing (SM) strategies have drawn attention. Various studies from different countries were conducted to define sustainability (including environmental sustainability) and SM, and to identify the variables that contribute to the achievement of environmental sustainability in a manufacturing context.

Through a literature review, a series of sustainable practices in manufacturing industries that possibly contribute to the greater level of environmental sustainability are identified such as cleaner production, eco-efficiency, green supply chain management, corporate social responsibility, closed-loop production and industrial ecology. While some studies found a positive relationship between such practices and environmental sustainability, others have found no relationship at all. The mixed results might be due to the differences in operationalizing the variable (i.e. sustainable manufacturing practice) across studies. Majority of the studies tend to focus on the specific context of sustainable manufacturing practice (SMP), either environmentally friendly practices (also called green practices) or socially responsible practices (also called corporate social responsibility practices). Studies in the wider context of SMP to cover both environmentally friendly and socially responsible practices are very scarce in the literature.

Another imperative indicative of the mixed results of the previous studies is that, there are more complex relationship between SMP and environmental sustainability. Many of the past studies focused on the

direct effect of SMP on environmental sustainability but overlooked the importance of indirect effect in that relationship. The statistical association between SMP and environmental sustainability needs to be explained. There are possibilities that the other variables mediate the relationship between these two variables. Since the significant relationships of innovation performance (IP) with SMP and environmental sustainability were found in some previous studies [2,3,4], there is a possibility that IP mediates the relationship between SMP and environmental sustainability. Therefore, the lack of studies in investigating whether the achievement of firms in introducing a new or significantly improved product, or a new or improved way in making product, a new marketing method, or a new organizational method in business practices, workplace organization or external relations provides a causal link between SMP and environmental sustainability is an important research gap.

Considering the direct and indirect effects, the main objectives of this study are to analyze the causal relationship between SMP and environmental sustainability as well as to analyze the mediating effect of SMP on environmental sustainability through IP by using primary data collected from Malaysian manufacturing firms.

2.0 LITERATURE REVIEW AND HYPOTHESES

2.1 Sustainability and Sustainable Manufacturing

The concept of sustainability has emerged in the 1970's when the issue of business ethics was debated [5]. Sustainability is not a fixed concept but it evolves as a consequence of adaptation to changing circumstances. In response to the issues of global inequality, resource distribution and global population impacts, World Commission on Environment and Development of the United Nations (WCED) proposed the concept called sustainable development (SD) in 1987 which is define as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Although it is quite broad, this definition is the most extensively adopted to describe sustainability and SD in various discipline of studies.

Sustainability is complex and multi-faceted which recognizes the interdependence of the three pillars (i.e. economic, environmental, and social) that frequently referred to as the Triple Bottom Line (TBL). The TBL approach suggests that apart from concentrating on economic goals, organizations necessitate to engage in activities that positively affect the environment and social performance [6]. While economic sustainability refers to the extent to which a firm improves operational and business performance, social sustainability widen the corporate responsibilities beyond the boundaries of the firm and normally address the demands and needs of other key stakeholders such as governments, suppliers, customers, local communities and non-government organizations [7,8]. With regard to cover "green" issues from natural environment conservation to energy consumption, environmental sustainability refers to the ability of firms in reducing the level of resource usage, pollution emitted and waste generated [7,8]. Reduced the level of resources consumption such as water, energy, non-renewable resources and hazardous inputs as well as the creation of wastes and polluting emissions are indicators of environmental performance of a firm. The three pillars of sustainability create a balance in the organizations that makes their operations and actions become sustainable.

Considering the wider context of sustainability, in this study, SM is viewed as a broad notion which is developed through the integration of sustainability concepts into the manufacturing system with an aim to achieve sustainability in industrial production.

2.2 Sustainable Manufacturing Practice

Since the last decades, the concept of manufacturing has been evolved from the substitution-based of traditional manufacturing to a lean manufacturing which focus on waste reduction, environmentally-benign of green manufacturing, and sustainable manufacturing [9]. The growing concern about the impact of manufacturing operations on environmental and social performance has given rise to a series of sustainable practices in manufacturing industries, from the application of technology for the treatment of pollution at the end of the pipe to more integrated systems of production.

Generally, the development of sustainable practices in manufacturing industries can be seen at the three levels encompassing product, process and system [10]. At the product level, the traditional 3R concept (*reduce, reuse, recycle*), promoting the adoption of green manufacturing, is expanded to a more sustainable 6R approach (*reduce, reuse, recycle, recover, redesign, remanufacture*). The emerging of new concept seems to enhance potential effectiveness achieved in advancing SM. The transformation from 3R to 6R allows for the changing paradigm of single life cycle (open-loop system) to multiple life cycles (closed-loop system). At the process level, numerous efforts have been made recently with an aim to attain sustainable manufacturing processes. Firms bear a responsibility to optimize their technological improvements and process planning for reducing resource consumption, waste generation and occupational hazards as well as improving product life [9]. System level is the third element that needs to be highlighted in explaining the development of sustainable practices in manufacturing industries. Transformation on the orientation of sustainable practices can be seen in recent decades, from a mere focus on manufacturing operations and cooperation between departments within a firm, sustainable considerations have expanded exceeding the conventional organizational boundaries to include the entire supply chain and beyond the chain of production. The need for firms to consider the environmental impact of their activities beyond the manufacturing facility to the entire product life cycle or beyond the value system has laid the basis for a range of proactive environmental initiatives and business models such as green supply chain management (GSCM), closed-loop production and industrial ecology [1]. Meanwhile, the pressure for firms to be accountable for their environmental and social responsibilities has led to the concept and practice of corporate social responsibility (CSR) [1].

Considering the evolution of sustainable practices in manufacturing industries as well as the wider context of sustainability to include economic, environmental and social performance, sustainable manufacturing practice (SMP) can be defined as a firm's intra- and inter-organizational practices that integrate environmental, economic and social aspects into operational and business activities. Differentiated based on the orientation of sustainable thinking, there are two types of SMP namely internal SMP and external SMP. While internal SMP focuses on the sustainable practices within a firm's level such as cleaner production, eco-efficiency and employee relation, external SMP refers to the inter-organizational practices within the value system and beyond the chain of production to improve economic, environmental and social sustainability simultaneously such as supplier relation, customer relation, community relation, industrial relation and close-loop production.

2.3 SMP and Environmental Sustainability

Strong commitment to the social responsibility particularly on the natural environment, reflected by the implementation of proactive environmental strategies such as internal SMP and external SMP, provides significant benefits to the environment. A number of studies, conducted in different countries by using various types of statistical methods and techniques, found that considering social and environmental aspects into technical and organizational activities undertaken by firms would increase environmental performance [11,12,13,14,15].

Analyzing the relationship between the three dimensions of circular economy practices and environmental performance among Chinese manufacturing firms using structural equation modeling (SEM) approach, Zhu *et al.* [13] found that internal environmental management, eco-design and corporate asset management and recovery have direct effects on environmental performance. Internal environmental management such as cleaner production and eco-efficiency as well as corporate asset management and recovery (i.e. closed loop production) which aim for preventing or at least minimizing pollution at source would improve operational efficiency and environmental sustainability compared to the traditional end-of-pipe solutions by reducing the level of resource usage, pollution emitted and waste generated.

In order to achieve greater environmental sustainability, firms need to take a much broader perspective on sustainable practices to go beyond organizational boundaries. It appears that the best result of environmental sustainability occurs when the entire supply chain and industrial networks (i.e. nearby organizations) are taken into considerations instead of just focus on the firm itself. External SMP such as environmental collaboration with supply chain partners would lessen product and process environmental burdens by reducing unnecessary wastes and inefficiencies in performing activities across the supply chain [16].

Extending the application of inter-organizational environmental management cooperation beyond the chain of production, a number of studies found the positive relationship between external SMP (i.e. industrial ecology) and improved environmental performance. For example, Fichtner *et al.* [11] discovered the favorable implications of inter-company supply concepts in a network of five energy-intensive industrial firms located in the area near the Rhine Harbor in Karlsruhe and cooperation between a German car manufacturer and its disposal firm on economic and environmental performance. Interestingly, they found that noticeable improvements in terms of environmental performance may attain by firms which had adopted inter-organizational environmental management compared to the optimal strategies independently implemented by the individual firms [11]. Conducting a case study on the application of industrial ecology in Baogang Group, iron and steel enterprise in Inner Monglia, Yongwei *et al.* [12] supported this result by noting that Baogang Group gains great achievement in energy-saving and emission reduction resulting from the inter-organizational cooperation.

Based on the empirical evidences of the previous studies pertaining to the significant relationship between both internal and external SMP and environmental sustainability, the following hypothesis is proposed:

H1: SMP has a positive and significant impact on environmental sustainability.

2.4 SMP, Innovation Performance and Environmental Sustainability

Empirical evidence on the linkage between SMP and environmental sustainability appears to be inconclusive. While some studies found positive and significant results, there are some other studies who failed to prove the significant role of SMP on predicting environmental sustainability [8,17]. The mixed results might be due to the differences in operationalizing the variables across studies. Although several studies have investigated the linkage between sustainable practices and sustainability performance in a manufacturing firm, the majority of the studies tend to focus on the specific context of SMP, either green practices or corporate social responsibility practices. Studies in the broader context of SMP which include both environmental friendly and socially responsible practices are very scarce in the literature. Clearly, operationalizing SMP in a wider context to include economic, environmental and social aspects is crucial to provide a clearer picture of the role of the SMP in explaining the variability of environmental sustainability of a firm.

In addition, insufficient statistical evidence to prove significant causal relationship between SMP and environmental sustainability indicates that there may be a more complex relationship exists between these two variables. When screened through the lens of intra and inter-organizational collaboration within and beyond the supply chain partners, the adoption of SMP may lead to better innovation performance (IP) of a firm that eventually would improve environmental sustainability. IP thus can serve as a mediator that explains the relationship between SMP and environmental sustainability.

Implementing proactive environmental management and social responsibility practices may foster the development of innovation which forms the basis for firm's competitive advantage [18]. In compliance with regulations and code of practice set by various regulatory institutions, firms are encouraged to implement sustainable practices in their business operations [19,20]. Previous studies have recognized the potential impact of such regulations and standards on supporting and promoting favorable innovation outcomes [21,22]. Responding to the current issues of sustainability and increasing pressures exerted by various stakeholders for being more responsible, the rules and standard of practice become more stringent, stimulates the considerable adoption of environmental and social responsibility strategies, which in turn have a positive effect on innovation performance [23]. Investigating the major environmental risks through water pollution disputes in Siaoli River, Tu and Yujung [24] argued that current environmental standards, targeting the traditional industrial pollutants, are too outdated to effectively handle the high-technology pollution problems. Although the electronics industries of high technology have played an important role in driving the global economy, manufacturing high-technology products cause hundreds of chemicals released and thousands of tons of waste water generated per day. In this sense, SMP must be improved continuously to be compatible as it may have been outdated and less effective in addressing the current problems associated with environmental pollution and other sustainability issues. The development of SMP to improve sustainability performance is expected to increase R&D activities as well as other innovative initiatives, thus leading to improve IP of the organization.

In a different context, SMP implementation would contribute to enhance IP through better intra- and inter-organizational relationships [25,26]. Through SMP which promote integration and collaboration with various parties, organizationally relevant information, knowledge, and expertise are spread and exchanged among individual members or units within and outside organization with accuracy and efficiency. As found by Lin and Chen [27] from their study of the relationships between internal and external integrations, shared knowledge, innovation capabilities and product competitive advantage among 245 high technology firms in Taiwan, high level of shared knowledge of internal capabilities, customers and suppliers would create better innovation capability. The transfer of knowledge from external parties promotes the development of new capabilities which may not be possible for a single firm to achieve with their own resources [28]. Successful sharing of valuable information among members within and outside organization could be seen in various aspects that support innovation success such as quick response to market changes and technology advancements, and better understanding of the needs of employees, customers, suppliers, and society at large [8,29,30].

The role of innovation in promoting carbon emissions reduction programs and mitigation of climate change is generally acknowledged [31]. Recognizing innovation as valuable, rare, non-substitutable and unique organizational resources, the ability to successfully implement creative ideas within an organization offers significant benefits for gaining greater environmental sustainability. Incorporating social responsibility and environmental management principles when creating new or improved products, production processes, technologies and organizational systems, firms may enhance environmental sustainability by reducing the level of resource consumption, pollution emitted and waste generated. Based on their cause-effect analysis between environmental performance and changes on workplace organization, Longoni *et al*. [32] provide statistical evidences indicating the significant impact of organizational innovation on environmental sustainability. Analyzing the effect of eco-innovation types on firms' ecological performance using empirical data from 245 Chinese firms, Dong *et al*. [3] found that end-of-pipe solutions, product innovation, process innovation and organizational innovation are significant determinants of environmental performance with process innovation as the strongest predictor.

Based on the extant arguments and empirical results regarding a series of dependence relationships among SMP, IP and environmental sustainability, the following hypothesis is proposed:

H2: IP mediates the relationship between SMP and environmental sustainability.

3.0 METHODOLOGY

3.1 Research Design

The population for this study consists of manufacturing firms in Malaysia. Deriving from the directory of Federation of Malaysian Manufacturers (FMM), a total of 600 from 2,415 registered manufacturing firms encompassing various industries are randomly selected as a sample for this study [33]. Considering the issue of generalizability of the findings, the simple random sampling procedure, which assures that each firm has an equal chance of being chosen as part of the sample within the population, has been chosen in this study. Following the Cochran [34] formula, 241 firms need to be selected as a sample in order to represent the overall population of 2,415 firms. However, the oversampling approach has been applied in this study, resulting the sample size increase by more than 145% to account for undelivered mails and uncooperative subjects.

The unit of analysis of this study is the individual in which the data are gathered from each individual firm and treating each respondent's response as an individual data source. In order to get valid and accurate data, the need for choosing the right respondent cannot be overemphasized. Considering the level of knowledge, skills and experience with the variables studied, the targeted respondent in this study is personnel who holds managerial position in a firm and involves in the operational activities.

3.2 Survey Instrument

A questionnaire survey was used to gather primary data in this study. The questionnaire is structured into four sections with 107 indicator variables. A five-point scale, anchored by one for '*strongly disagree*' and five for '*strongly agree*', is applied to measure the degree of implementation of SMP within the firm. In total, eight observed variables have been used to measure SMP for both internal and external SMP. Three observed variables (i.e. *Int1 Cleaner production*, *Int2 Eco-efficiency* and *Int3 Employee relation*) with 18 indicators are assigned to measure internal SMP while external SMP is reflected in five observed variables embracing the relations with suppliers, customers, communities as well as closed-loop production with 30 indicators. After reviewing how performance is measured in different studies of environmental sustainability, this study draw up a scale that includes 7 indicators to access the performance of firm in reducing the level of resource usage, pollution emitted and waste generated in the last three years that is considered as attributable to the implementation of the SMP. The innovation performance of firms normally is described in term of the number of new products or the number of patents. However, a broader perspective is deemed to be more appropriate to the context of this study. As a result, IP has been formulated into 24 indicators in four observed variables that capture the extent to which a firm successfully performs in product innovation, process innovation, organizational innovation, and marketing innovation in the last three years. Again, a five-point scale, anchored by one for '*strongly disagree*' and five for '*strongly agree*' is used to measure the firm's performance in both environmental sustainability and innovation.

The operationalization of SMP, environmental sustainability and IP is based on the combination of scales developed by previous researchers [8,29,35,36]. However, because of the lack of established scales, some self-administered indicators have been undertaken for several observed variables such as *Ext5 Industrial relation* and *IP3 Organizational innovation*. The indicators are carefully developed based on the theoretical definition that corresponds to the respective observed variables. All of the observed variables and indicators for SMP, environmental sustainability and IP, as listed in Appendix A, were initially validated by a panel of experts consisting of six academic professors and senior lecturers, and two industry professionals.

3.3 Response Analysis

Supplementing with cover letter and self-addressed, stamp-attached envelope, a set of questionnaire was initially mailed to 600 potential respondents. Out of the total questionnaires sent, three were returned as undeliverable, reducing the sampling frame to 597. A month later, a second round of questionnaire was conducted to all non-respondents. After screening the responses for extreme outliers and incomplete survey forms, the survey yielded 150 usable responses, or a 25.13% response rate. Such response rate is acceptable as greater than the suggested cutoff of 20% [37].

The responses were received from various manufacturing industries, size of firms and technological intensity. Most of respondents come from four industries, encompassing electrical and electronics (34.7%), transport equipment (19.3%), chemical (16.0%), and metals (12.0%). The remaining 17.3% are from food products and beverages (7.3%), machinery and equipment (4.7%), wood based (3.3%) and textiles and apparel (2.7%). As expected, the findings show that the majority of the responding firms are large-sized (70.0%), while 17.3% and 12.0% are medium and small organizations, respectively. In the context of technological intensity, more than 40% of the firms are classified as medium-high technology (41.3%), whereas 28.0% are high technology, 17.3% are medium-low technology and the remaining 13.3% being low technology.

In order to detect any potential non-response bias that may happen when some of the targeted respondents do not take part in the survey, the independent groups t-test and chi-square test have been performed in this study. Following the recommendation by Armstrong and Overton [38] and Lambert and Harrington [39], the 150 respondents are differentiated into two groups based on their response time, i.e. early respondents and late respondents. It is assumed that the late return of surveys is similar to that of non-respondents. As a result, the 61 responses received from the first round of questionnaires are assigned into the former group while the 89 responses obtained from the second round of questionnaires reflect the latter group. The findings of the T-test indicate that there are no statistically significant differences between early respondents and late respondents in each indicator of SMP, environmental sustainability and IP, except for the indicator of S2.2 at the 0.05 level. Similarly, the chi-square analysis shows no significant differences between those two groups in term of industrial classification, size of the firm and technological intensity. The potential of common method bias (CMB) is the other issue that needs to be assessed in adopting survey-based method. In this study, Harman's single factor test has been performed to detect the presence of the CMB. However, the result is not significant, confirming that CMB is not a critical concern in this study. Finally, having confirmed the quality of the responses through some series of testing, the full data set of 150 responses is valid and usable for subsequent analysis.

4.0 DATA ANALYSIS

4.1 Measurement Model Validation

The hypothesized models developed for the purpose of this study have been tested using the SEM approach. Following the validation guidelines for reflective measurement model suggested by Urbach and Ahlemann [40] and Hair *et al.* [41], the measurement model of this study has been tested for uni-dimensionality, indicator reliability, internal consistency reliability, convergent validity and discriminant validity. The test for uni-dimensionality is performed to verify that a set of indicator variables, are strongly associated with each other and represent a single construct or observed variable. Since PLS-SEM cannot measure the uni-dimensionality directly, the confirmatory factor analysis (CFA) in SPSS Statistical 19 has been applied in this study. The results found that all set of indicator variables for each construct of SMP, EnS and IP loaded on only one factor except *Int2 Eco-efficiency*. Then, the result of *Int2 Eco-efficiency* is further analyzed to check for the indicator that has a low correlation with other indicators and a low factor loading that provides candidate for removal in the second run of CFA. As a result, the indicator variable of *Int2.1* was removed from the second run of the analysis and the result is uni-factorial. Having confirmed the uni-dimensionality, the remaining indicators have been tested for further validation analyses in SmartPLS. The results are tabulated in Table 1.

Table 1 Measurement model results

Construct	Loading: 1st order model	Loading: 2nd order model	CR	AVE
Internal SMP			0.89	0.72
Cleaner production	0.55 - 0.85	0.85	0.89	0.58
Eco-efficiency	0.61 - 0.88	0.86	0.89	0.62
Employee relation	0.72 - 0.88	0.84	0.92	0.67
External SMP			0.90	0.64
Supplier relation	0.78 - 0.89	0.80	0.94	0.73
Customer relation	0.77 - 0.85	0.76	0.92	0.65
Community relation	0.72 - 0.90	0.85	0.92	0.67
Closed-loop production	0.77 - 0.89	0.84	0.93	0.67
Industrial relation	0.69 - 0.83	0.75	0.89	0.58
Environmental sustainability	0.82 - 0.90		0.95	0.75
Product innovation	0.78 - 0.90		0.93	0.71
Process innovation	0.82 - 0.89		0.95	0.74
Organizational innovation	0.83 - 0.90		0.95	0.75
Marketing innovation	0.79 - 0.88		0.94	0.73

[a] See Appendix A for indicator or item description
CR=Composite reliability; AVE=Average variance extracted

The indicator reliability refers to the extent to which the indicators have consistency in measuring the corresponding construct. Factor loadings have been applied in assessing the indicator reliability in this study. Referring to Table 1, all of the factor loadings in both first- and second-order model are well above the minimum threshold value of 0.50 [42], confirming the indicator reliability of each construct in the measurement model.

Composite reliability (CR) has been analyzed for all constructs of SMP, environmental sustainability and IP to determine the internal consistency reliability. As presented in Table 1, the values of CR are ranging from 0.89 to 0.95, indicating the high internal consistency reliability of the thirteen constructs in the first-order model and eight constructs in the second-order model [40,41].

Convergent validity assesses the extent to which the indicator variables reflecting a construct converge in comparison to the indicators measuring other constructs. It examines whether a particular indicator exactly measures the designated construct. In this study, the average variance extracted (AVE) value has been used to ascertain convergent validity. All AVE estimates shown in Table 1 are well above the minimum required level of 0.50 [40,41], thus proving the convergent validity of each construct in the measurement model.

Following the Fornell-larcker criterion procedure for establishing discriminant validity, the AVE of each construct is compared with the inter-construct squared correlations associated with that construct. Discriminant validity refers to the extent to which a construct is truly different from another constructs. In contrast with convergent validity, discriminant validity ensures that a construct is unique and its indicators do not measure other construct unintentionally. The results presented in Table 2 through Table 4 confirming the discriminant validity for all constructs since their AVEs are greater than the corresponding inter-construct squared correlations [40,41].

Table 2 Comparison of the AVE and squared correlation between constructs for SMP at first-order model [a]

	Int1	Int2	Int3	Ext1	Ext2	Ext3	Ext4	Ext5
Int1	**0.58**							
Int2	0.44	**0.62**						
Int3	0.27	0.32	**0.67**					
Ext1	0.20	0.36	0.17	**0.73**				
Ext2	0.45	0.54	0.35	0.23	**0.65**			
Ext3	0.25	0.33	0.24	0.32	0.35	**0.67**		
Ext4	0.21	0.38	0.23	0.31	0.32	0.37	**0.67**	
Ext5	0.09	0.18	0.18	0.30	0.14	0.35	0.34	**0.58**

[a] Diagonal elements are Average variance extracted (AVE) of each construct; Off diagonal elements are the squared correlation between constructs
Int1=Cleaner production; Int2=Eco-efficiency; Int3=Employee relation; Ext1=Supplier relation; Ext2=Customer relation; Ext3=Community relation; Ext4=Closed-loop production; Ext5=Industrial relation

Table 3 Comparison of the AVE and squared correlation between constructs for SMP at second-order model

	Internal SMP	External SMP
Internal SMP	**0.72**	
External SMP	0.58	**0.64**

[a] Diagonal elements are Average variance extracted (AVE) of each construct; Off diagonal elements are the squared correlation between constructs

Table 4 Comparison of the AVE and squared correlation between constructs for IP and environmental sustainability

	IP1	IP2	IP3	IP4	EnS
IP1 Product innovation	**0.71**				
IP2 Process innovation	0.50	**0.74**			
IP3 Organizational innovation	0.39	0.50	**0.75**		
IP4 Marketing innovation	0.36	0.38	0.44	**0.73**	
EnS Environmental sustainability	0.17	0.19	0.24	0.13	**0.75**

[a] Diagonal elements are Average variance extracted (AVE) of each construct; Off diagonal elements are the squared correlation between constructs

Based on the above discussions, the five forms of validation (i.e. unidimensionality, indicator reliability, internal consistency reliability, convergent validity, and discriminant validity) verify that all sets of indicator variables for each construct of SMP, environmental sustainability and IP are statistically strong. It is proven that, while they are internally consistent in their measurements, those sets of indicators truly represent the theoretical constructs of SMP, environmental sustainability and IP. Thus, the validated data sets of SMP, environmental sustainability and IP, consist of 78 indicator variables of 150 responses, are worthy for further structural model analysis with regard to meeting specified objectives in this study.

4.2 Structural Model Assessment

Once the validation of measurement model in this study is verified, the proposed structural models indicating the interrelationships among SMP, environmental sustainability and IP are assessed. The assessment is based on three criteria namely the coefficient of determination (R^2), path coefficients (β) and predictive relevance (Q^2). The results of structural model analysis are presented in Table 5 and Table 6.

Table 5 Structural model of internal SMP, IP and environmental sustainability results

Structural path	β [a]	R^2 [b]	Q^2 [c]
Internal SMP→Environmental sustainability (path c)	0.25**	0.41	0.30
Internal SMP→IP (path a) Outcome variable:			
Product innovation	0.10	0.27	0.19
Process innovation	0.21	0.31	0.23
Organizational innovation	0.19*	0.40	0.29
Marketing innovation	0.16*	0.33	0.24
IP→Environmental sustainability (path b) Causal variable:		0.41	0.30
Product innovation	0.11		
Process innovation	0.05		
Organizational innovation	0.15*		
Marketing innovation	-0.13		
Internal SMP→Environmental sustainability (path ć)	0.22**	0.41	0.30

[a] * $p < 0.1$, ** $p < 0.05$, ** $p < 0.01$
[b] R^2 values represents the explained variance for the endogenous variables.
[c] $Q^2 > 0$ indicates that the model has predictive relevance, $Q^2 < 0$ implies that the model is lacking predictive relevance.

Table 6 Structural model of external SMP, IP and environmental sustainability results

Structural path	β [a]	R^2 [b]	Q^2 [c]
Internal SMP→Environmental sustainability (path c)	0.40***	0.41	0.30
Internal SMP→IP (path a) Outcome variable:			
Product innovation	0.44***	0.27	0.19
Process innovation	0.38***	0.31	0.23
Organizational innovation	0.47***	0.40	0.29
Marketing innovation	0.44***	0.33	0.24
IP→Environmental sustainability (path b) Causal variable:		0.41	0.30
Product innovation	0.11		
Process innovation	0.05		
Organizational innovation	0.15*		
Marketing innovation	-0.13		
Internal SMP→Environmental sustainability (path ć)	0.32***	0.41	0.30

[a] * $p < 0.1$, ** $p < 0.05$, ** $p < 0.01$
[b] R^2 values represents the explained variance for the endogenous variables.
[c] $Q^2 > 0$ indicates that the model has predictive relevance, $Q^2 < 0$ implies that the model is lacking predictive relevance.

As presented in Table 5 and Table 6, environmental sustainability has been predicted quite well by internal SMP, external SMP and IP, with R^2 value of 0.41. Exceeding the recommended minimum value of 0.1 [43], this value indicates that SMP (i.e. internal SMP and external SMP) and IP explain almost half of the variance of environmental sustainability, demonstrating the considerable explanatory power of the proposed models. The significance level of path coefficients (β) in this study is determined by using re-sampling bootstrap procedure with 1000 subsamples. Meanwhile, the positive values of Q^2 in all structural models in this study demonstrate good predictive relevance of SMP and IP on environmental sustainability.

Hypothesis 1 proposes that SMP has a positive and significant impact on environmental sustainability. This hypothesis attempts to test whether greater level of implementation of both types of SMP (i.e. internal SMP and external SMP) would lead to achieving better performance on environmental sustainability. As presented in Table 5 and Table 6, internal SMP (c = 0.25, $p < 0.05$) and external SMP (c = 0.40, $p < 0.01$) have significant predictive power on environmental sustainability. Since the total effect of both internal SMP and external SMP on environmental sustainability is positive and significant, the first hypothesis in this study is supported.

Hypothesis 2 suggests that IP mediate the relationship between SMP and environmental sustainability. This hypothesis attempts to test whether the four types of IP (i.e product innovation, process innovation, organizational innovation and marketing innovation) have a significant mediating effect on the relationship between both types of SMP (i.e. internal SMP and external SMP) and environmental sustainability. Referring to Table 5, the results show that internal SMP has significant effect only on the three hypothesized mediating variables, i.e. process innovation (a = 0.21, $p < 0.05$), organizational innovation (a = 0.19, $p < 0.1$) and marketing innovation (a = 0.16, $p < 0.1$). While, external SMP significantly predicts all of the four types of IP, i.e. product innovation (a = 0.44, $p < 0.01$), process innovation (a = 0.38, $p < 0.01$), organizational innovation (a = 0.47, $p < 0.01$) and marketing innovation (a = 0.44, $p < 0.01$), as displayed in Table 6. However, when controlling the SMP, organizational innovation is the single hypothesized mediating variable which significantly predicts environmental sustainability with b = 0.15, $p < 0.1$. The estimated direct effect of internal SMP and external SMP on environmental sustainability is ć = 0.22, $p < 0.05$ and ć = 0.32, $p < 0.01$, respectively. The indirect effect (ab) of internal SMP and external SMP on environmental sustainability through organizational innovation is 0.03 and 0.07, respectively. For 95% bootstrapped confidence intervals, the indirect effect of each type of SMP on environmental sustainability through all types of IP are include zero and thus are not statistically significant. Accordingly, the second hypothesis in this study, proposing the significant mediation effect of IP on the causal relation of SMP on environmental sustainability is rejected.

5.0 DISCUSSION AND CONCLUSION

Environmental sustainability refers to the ability of firms in reducing the level of resource usage, pollution emitted and waste generated. Theoretically, this study suggests that the greater the level of implementation of both types of SMP (i.e. internal SMP and external SMP) in a manufacturing firm, the greater the achievement of environmental sustainability to be achieved by the firm. The empirical results found in this study prove the positive impact of both internal SMP and external SMP on environmental sustainability as proposed in hypothesis 1. Considering a wider context of SMP to include environmentally friendly and socially responsible practices, the results of this study extend the findings by previous researchers who confirmed the significant impact of the specific context of sustainable practices, i.e. green practices, in improving environmental performance [13,14,15]. Implementing cleaner production and eco-efficiency strategies in daily operations as well as emphasizing on closed-loop production and industrial ecology would protect the natural environment by generating less waste, fewer resources and energy consumption, and less environmental pollution. While improving resource productivity by identifying and eliminating waste would lower the costs of productions, it is also directly leads to reduce resource usage, pollution emitted and waste generated. Pursuing economic and environmental excellences, firm should move from focusing on traditional end-of-pipe solutions to aggressively concentrate on pollution prevention practices (i.e. cleaner production, eco-efficiency, closed-loop production and industrial ecology).

In order to achieve greater environmental sustainability, firms need to take a much broader perspective on sustainable practices to go beyond the organizational boundaries. Supporting the finding by Fichtner *et al*. [11] who conducted case studies on industrial symbiosis, the results of this study reveal that the best result of environmental sustainability occurs when the entire supply chain, nearby organizations and local communities are taken into considerations instead of just focus on the firm itself. The impact of external SMP on improving environmental sustainability is greater than internal SMP. External SMP such as environmental collaboration with supply chain partners would decrease product and process environmental burdens by reducing unnecessary wastes and inefficiencies in conducting activities across the supply chain [16]. Extending the application of inter-organizational environmental management cooperation beyond the chain of production, inter-organizational practices such as sharing inputs, outputs and by-products among nearby and synergistic firms would yield environmental sustainability. The result of this study extends the finding by Yongwei *et al.* [12] who discovered inter-organizational cooperation as a source of energy-saving and emission reduction when conducting a case study on the application of industrial ecology in Baogang Group.

With regard to the mediation analyses, theoretically, it is suggested that having better performance on product, process, organizational and marketing innovations resulting from the adoption of SMP would lead to improving environmental sustainability. However, the results of this study conclude that there is no significant mediated effect of SMP on environmental sustainability through all of the four types of IP. A plausible reason for the insignificant findings is that although the range and quality of products, technologies, manufacturing processes, marketing strategies as well as organizational method in business practices, workplace organization or external relations may have been continuously improved but they still less effective in addressing the current problems associated with environmental issues. For instance, while the electronics industries of high technology have played an important role in economic development, manufacturing high-technology products cause hundreds of chemicals released and thousands of tons of waste water generated per day [24]. Chemical compounds released from the manufacturing firms may have great impacts on the community and environmental health. Complying with the current environmental standards which target traditional industrial pollutants, the application of new production processes may still not be able to effectively handle the high-technology pollution problems [24].

The findings of this study offer a number of significant contributions and implications that are beneficial for both academicians and practitioners. While the study contributes to the body of knowledge by providing statistical evidences relating to a series of dependence relationships related to the three different variables encompassing SMP, IP and environmental sustainability, the ability to simultaneously examine these relationships is valuable for better understanding of the phenomena. The results of this study empirically verify the positive effect of both types of SMP on environmental sustainability with external SMP is greater than internal SMP. In addition, there is no convincing evidence that IP is a mediator of the relationship between SMP and environmental sustainability. There may be other factors that explain the impacts of SMP on environmental sustainability. Through rigorous testing processes, this study develops valid and reliable model for measuring the extent of SMP adopted as well as organizational performance achieved in the context of innovation and environmental sustainability at a manufacturing firm level. This measurement model may help industrial practitioners in understanding the diverse aspects of SMP implementation, identifying strengths and weaknesses of their current practices and setting the indicators of both innovation and environmental performance. In addition, the measurement model which has been developed in this study is useful for other researchers. They could extend the scope of application of this measurement model to other environments such as research in different countries and further development of research in the area of sustainable manufacturing and innovation management.

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Appendix A. Scale And Indicators

A.1. Internal SMP

Indicate the extent to which you agree with the following statements as they relate to current practice in your organization on a scale from one for *strongly disagree* to five for *strongly agree*.

Dimension 1: Int1 Cleaner Production

Int1.1 Substitution of non-environmental friendly materials
Int1.2 Optimization of manufacturing processes to reduce solid waste and emissions
Int1.3 Process design focused on reducing energy and natural resources consumption in operations
Int1.4 Product design focused on reducing energy and materials consumption
Int1.5 Acquisition of clean technology/equipment
Int1.6 Good housekeeping practices

Dimension 2: Int2 Eco-efficiency

Int2.1 Reuse of products/components
Int2.2 Recycling of materials internal to the company
Int2.3 Cross-functional cooperation for environmental improvements
Int2.4 Total quality environmental management is in place
Int2.5 Environmental compliance and auditing programs are in place
Int2.6 The company's efforts in relation to the environmental matters have exceeded the requirements of the relevant regulations

Dimension 3: Int3 Employee Relation

Int3.1 Guaranteed observation of industry safety regulations
Int3.2 Fair payment of employees
Int3.3 Care for employee's personal development
Int3.4 Supporting work-life balance
Int3.5 Involving employees into making important decisions
Int3.6 Cooperation with unions and labour representatives

A.2 External SMP

Indicate the extent to which you agree with the following statements as they relate to current practice in your organization on a scale from one for *strongly disagree* to five for *strongly agree*.

Dimension 1: Ext1 Supplier Relation

Ext1.1 Choice of suppliers by environmental criteria
Ext1.2 Guiding suppliers to set up their own environmental programs
Ext1.3 Bringing together suppliers in the same industry to share their know-how and problems
Ext1.4 Informing suppliers about the benefits of cleaner production and technologies
Ext1.5 Urging suppliers to take environmental actions
Ext1.6 Sending internal auditors to appraise environmental performance of suppliers

Dimension 2: Ext2 Customer Relation

Ext2.1 Environmental friendly waste management
Ext2.2 Environmental improvement of packaging
Ext2.3 Eco labeling of products
Ext2.4 Providing credible information about product biography
Ext2.5 Integration of customer feedback into business activity
Ext2.6 Prevention of products causing danger for customers

Dimension 3: Ext3 Community Relation

Ext3.1 Active involvement in the creation of better general conditions in local community
Ext3.2 Cooperation with third party (e.g., public authorities, scientific institutions, NGOs) towards environmental protection
Ext3.3 Continuous dialogue with municipalities to know the most important problems of the local community
Ext3.4 Providing information about corporate social responsibility (CSR) projects and expected benefits
Ext3.5 Encouraging employees to get involved in charitable projects
Ext3.6 Regularly providing donation or sponsorship

Dimension 4: Ext 4 Closed-loop Production

Ext4.1 Increase the product's useful life
Ext4.2 Design the product to accommodate multiple future uses/application
Ext4.3 Design the product for easy material recovery
Ext4.4 Ensure that infrastructures for product recovery exist
Ext4.5 Establish recycling procedures
Ext4.6 Establish remanufacturing procedures

Dimension 5: Ext5 Industrial Relation

Ext5.1 Using waste or by-products of other industrial firms as input materials
Ext5.2 Exchange of waste or by-products with other industrial firms
Ext5.3 Share in the management of utilities (e.g., energy, water, waste treatment) with other industrial firms
Ext5.4 Share knowledge (e.g., technological, managerial, environmental) with other industrial firms
Ext5.5 Share ancillary services (e.g., transportation, landscaping, waste collection) with other industrial firms
Ext5.6 Cooperate with local communities towards environmental protection

A.3. Innovation Performance

Indicate the extent to which you agree with the following statements as they relate to innovation performance of your organization in the last three years on a scale from one for *strongly disagree* to five for *strongly agree*.

Dimension 1: IP1 Product Innovation

IP1.1 Increased number of new products introduced to the market
IP1.2 Increased number of new products that are first-to-market (early market entrants)
IP1.3 Use the latest technology for new product development
IP1.4 Increased speed of new product development
IP1.5 Reduced cost of new product development
IP1.6 Able to produce greater level of newness (novelty) of new products

Dimension 2: IP2 Process Innovation

IP2.1 Increased technological competitiveness
IP2.2 Use up-to-date technology in manufacturing processes
IP2.3 Increased speed of adoption of the latest technological innovations in manufacturing process
IP2.4 Increased the number of new production methods introduced
IP2.5 Able to change rapidly in manufacturing processes
IP2.6 Able to change rapidly in manufacturing techniques

Dimension 3: IP3 Organizational Innovation

IP3.1 Better knowledge management system
IP3.2 Increased organizational flexibility
IP3.3 Stronger external relations
IP3.4 Increased speed of adoption of new organizational methods
IP3.5 Increased the number of new organizational systems introduced
IP3.6 Apply up-to-date organizational methods

Dimension 4: IP4 Marketing Innovation

IP4.1 New products often take us up against new competitors
IP4.2 Increased the number of new marketing methods/approaches
IP4.3 Products' most recent marketing programme is revolutionary in the market compared with competitors
IP4.4 Higher success rate in new product launch compared with competitors
IP4.5 Increased the number of new market entry
IP4.6 Often at the cutting edge of technology in new product introductions

A.4. Environmental Sustainability

Indicate the extent to which you agree with the following statements as they relate to both operational and business performance of your organization in the last three years on a scale from one for *strongly disagree* to five for *strongly agree*.

ES1 Reduced water usage
ES2 Reduced energy consumption
ES3 Reduced non-renewable resources usage
ES4 Reduced hazardous inputs usage
ES5 Reduced solid waste
ES6 Reduced waste water emissions
ES7 Reduced emissions of polluting gases