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Green operations and the moderating role of environmental management capability of suppliers on manufacturing firm performance

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ABSTRACT

The increased pollution arising from different stages of producing, distributing, and disposing of electronics products highlights the importance of green operations (GO) in terms of process and product stewardship to mitigate environmental damages and satisfy the escalating social expectation for environmentally friendly operations in the electronics industry. Drawing on the natural-resource-based view, the purpose of this paper is to examine the boundary spanning role of GO and investigate the influence of environmental management capability (EMC) of suppliers on firm performance and pollution reduction. The findings from a survey of 122 manufacturing firms indicate that the success of GO is contingent on the EMC of suppliers. In addition, we found that process stewardship has a positive influence on performance outcomes and that the EMC of suppliers moderates the relationship between process stewardship and financial performance. These findings indicate that manufacturers should emphasize the EMC of suppliers in their GO to reap financial as well as environmental benefits.

1. Introduction

According to a study conducted by the Office of Solid Waste U.S. Environmental Protection Agency in 2008, only 18% of the end-of-life electronics products, ranging from computers to home appliances, were collected for recycling while 82% of them were disposed to landfills. There are hazards caused by electronics wastes ranging from polluting the environment and damaging the health of workers, to losing production capability (Economy and Lieberthal, 2007) due to the release of toxic substances including lead, mercury, cadmium, beryllium arsenic, barium, chromium, and various flame-retardant chemicals. The importance of a pro-environmental reputation for enterprises to compete internationally has been widely acknowledged (Cole et al., 2006). These electronics wastes highlight the lack of direction by electronics manufacturers on environmental protection in the globalization of their production and marketing activities to gain financial benefits.

Nowadays, environmental consequences are considered strategically essential for business operations with the aim to reduce costs and develop quality products (Atasu et al., 2008; Kleindorfer et al., 2005). The scope of green operations (GO) spans from product development to management of the entire product life cycle involving such environmental practices as eco-design, clean production, recycling, and reuse with a focus on minimizing the expenses associated with manufacturing, distribution, use, and disposal of products (Lai and Wong, 2012; Guide and Van Wassenhove, 2001; Kleiner, 1991). According to the environmental management literature, GO is concerned with both product- and process-oriented environmental practices (Ferguson and Toktay, 2006; Gilley et al., 2000; Rogers and Tibben-Lembke, 2001) to reduce the damage of products and supply chain processes on natural resources (Dechant and Altman, 1994; Porter and van der Linde, 1995a, 1995b).

In product management, GO ensures quality and environmental conformance, preventing negative corporate reputation by environmentally negligent products. In process management, GO emphasizes closed-loop operations involving practices like recuperation and recycling with the objective to reduce waste, capture residual value of products (Ferguson and Toktay, 2006; Rogers and Tibben-Lembke, 2001), and deploy environmental technology and cleaner transportation in the downstream supply chain for pollution prevention. These two distinct components of GO are helpful for firms to comply with environmental regulations, reducing the risk of legal fees, liability costs, and fines (Hunt and Auster, 1990). By embracing GO, firms will reap financial gains by capturing the residual values of their products and

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promote product innovation through analysis of the returned products for possible design improvement (Rogers and Tibben-Lembke, 2001).

Past research on GO is confined to identifying the antecedents (e.g., institutional pressures, regulations, and customer requirements), their influences on the implementation (Lai et al., 2011; Zhu et al., 2011), and the business and environmental values of implementing GO (King, 2007; Min and Galle, 2001; Rothenberg et al., 2001; Zhu et al., 2007). There is a general belief on organizational capability for successful environmental practices and sustainable operations (Bowen et al., 2001; Christmann, 2000; Handfield et al., 1997; Russo and Fouts, 1997; Sarkis et al., 2011), without which the performance outcomes of GO can be compromised (Kovacs, 2008; Porter and van der Linde, 1995a). The literature has acknowledged the value of GO and the internal capability of firms for its success (Corbett and Klassen, 2006; Dechant and Altman, 1994; Handfield et al., 1997; Lai et al., 2010), but the complementary role of upstream suppliers to enhance performance remains under-explored (Pagell et al., 2007; Vachon and Klassen, 2007). A recent study by Lee and Klassen (2008) highlighted the importance of environmental management capabilities (EMC) of suppliers, which reflect the ability of suppliers to improve their performance on environmental issues. Nevertheless, how such capability influences the GO of buying firms was not considered. While the negligent behaviors of suppliers can devastate the GO of their downstream partners (Preuss, 2001), a systematic investigation on supplier role in GO is timely and an important environmental management topic.

Drawing on the natural-resource-based view (NRBV) of a firm, this study examines the boundary spanning role of GO and investigates the influence of EMC of suppliers on manufacturing firm performance and pollution reduction with empirical data collected from electronics manufacturers in Taiwan. A structural equation model and multi-group analysis were used to test these practice–performance relationships. By doing so, this study makes two major contributions to the literature. First, we address the increasing public concern on the electronics wastes causing air, soil, and water pollution by examining the performance implications of GO in terms of product- and process-oriented environmental practices in lessening the environmental damages. Furthermore, we evaluate the EMC of suppliers and determine how it can facilitate the product- and process-related practices of GO in contributing to environmental and financial performance. This study advances theoretical and practical knowledge on evaluating GO and EMC, as well as the environmental practices that form these two organizational capabilities essential for performance gains. The study results will provide managerial insights and useful reference for electronics manufacturers to embark on GO and leverage the EMC of suppliers to succeed. Second, we examine the supplier role in support of their downstream partners for environmental protection, where the EMC of the former is not adequately addressed in prior studies. There is evidence that suppliers are instrumental in complementing the environmental management practices of their downstream partners by offering environmentally friendly inputs and facilitating pollution prevention processes (Corbett and Klassen, 2006). This supplier role sheds light on the importance of EMC in suppliers as external complementary assets for successful implementation of GO, particularly in the electronics industry characterized with highly inter-related and complex manufacturing operations(Yeung et al., 2005).

2. Theoretical development

2.1. Natural-resource-based view

Many studies have sought to define resources, capabilities, and/or competencies based on the resource-based view (Barney, 1991; Marino, 1996; Wernerfeit, 1994), however, a review of the literature suggests concepts such as resources, capabilities, competencies, and core competencies are not clearly identified. Barney (1991) and Marino (1996) attributed a wide range of meanings to resources, including physical resources (e.g. raw materials, equipment, financial endowment, etc.), human resources (e.g. training, experience, skills, etc.), and organizational resources (e.g. firm image, process, routines, etc.). Some resources are tangible and physical including plant and equipment, while others are intangible such as a brand name. While some scholars suggest capabilities are part of resource, others hold opposite views and have therefore sought to differentiate between resources and capabilities (Amit an Schoemaker, 1993; Grant, 1996; Lu, 2007). Capabilities use resources and should thus be viewed as independent of resources (Amit and Schoemaker, 1993). Hart (1995) proposed the NRBV, suggesting that businesses are constrained by and dependent on the conditions and resources of their natural environment to prosper and flourish. NRBV is an adaptation of the resource-based view of the firm, which entails that organizational resources and capabilities that are valuable, rare, and inimitable determine the competitive position of firms with environmental management considerations (Barney, 1991). A firm can achieve superior performance if it has the capability to exploit as well as preserve natural resources in its operating environment. Such capability is either casually ambiguous or socially complex. The casually ambiguous capability is a skill-based resource of firms, suggesting that firms can gain experience and learn skills through repeated practices (Hart, 1995) or develop complementary assets (e.g., technological knowledge) with their environmental management practices for better performance gains (Milgrom et al., 1991). A firm skilled at experience learning and leveraging complementary assets commands an advantageous position in competition due to the barrier of imitation and better use of organizational resources (Das and Teng, 2000). On the other hand, the socially complex capability of firms aimed at preserving their natural resources is developed where partner firms are engaged in coordinated organizational actions to excel. Such capability allows firms to access the resources of their partners. The inherent complexity in the inter-organizational coordination and collaboration are difficult to imitate. The NRBV is useful for explaining the performance outcomes of GO of firms, and in particular the EMC of suppliers as a complementary asset to perform inter-organizational coordinated actions in the process.

2.2. The role of EMC of suppliers

Environmental management capability (EMC) of suppliers is concerned with their ability to perform business activities in an environmentally friendly manner while attaining financial gains (Klassen and Vachon, 2003). EMC of suppliers is generally viewed as their ability to respond to the environmental concerns of their operations as well as the environmental requirements of their buying firms (Lu et al., 2007). Such capability of suppliers is often characterized with their adoption of an environmental management system standard (e.g., ISO 14000), evaluation of their upstream suppliers' environmental performance, and development of an environmental policy to mitigate negative environmental impacts in their operations (Corbett and Kirsch, 2001; Klassen and Vachon, 2003). EMC of suppliers is valuable to electronic manufacturers as the success of electronics manufacturers relies heavily on their supply network to develop complicated electronics products, provide value-added services, implement complex business processes, and meet higher customer expectations (Fawcett and Clinton, 1996; Gunasekaran et al., 2008; Koufteros et al., 2007a, 2007b; Yang et al., 2008, 2009).

EMC of suppliers is important to the implementation of GO because 87% of customers would accuse firms of environmental negligence when their suppliers are environmentally irresponsible, e.g., use harmful chemicals, refuse product recycling (Cotton Incorporated, 2008). Those suppliers convicted of having applied polluting chemicals, carcinogenic substances, and carbon emission processes in different production and distribution activities can damage the reputation of their downstream partners and incur financial loss for the latter due to product recalls, legal fees, claims handling, and so forth (Economy and Lieberthal, 2007). There are popular practices including factory audit and sourcing from ISO 14000 certified suppliers to ensure supplier quality and their inputs (King et al., 2005; Lai and Cheng, 2009). On top of these, electronics manufacturers should pay attention to suppliers' EMC on implementing GO, which gives rise to polluting material sources, carbon footprints in distribution, inventory wastes and obsolesces due to delayed replenishment, and so forth (Lamming and Hampson, 1996).

2.3. Sustainable green operations

As an innovative environmental management approach, GO serves to ensure the quality and environmental compliance of electronics manufacturers' inputs (e.g., electronics components and metals) and outputs (e.g., finished products, carbon emission, waste) (Zhu et al., 2008). GO emphasizes product- and process-oriented environmental practices to balance and improve financial performance as well as pollution reduction. Product-oriented environmental practice of GO, also referred to as *product stewardship*, is concerned with reducing environmental burden with less use of hazardous and nonrenewable materials in products development, considering the environmental impact in product design, packaging, and material used (Snir, 2001). Specifically, it promotes recycling and reuse of product components with eco-design, and using recyclable parts and packaging (Lamming and Hampson, 1996; Reinhardt, 1998). Product stewardship of electronics manufacturers considers the environmental impact of products and their packaging from raw materials acquisition to end-of-life product disposal (Dechant and Altman, 1994). Such practice is geared towards reducing the environmental damage arising from all product-related parts and components.

On the other hand, *process stewardship* is a process-oriented environmental management practice (Christmann, 2000; Porter and van der Linde, 1995b). It is concerned with reducing adverse environmental impact in the processes ranging from production, distribution, to end-of-life product management. It emphasizes waste reduction and contributes to environmental protection through implementing such processes as recycling, reengineering polluting processes, minimizing carbon emission, and so forth (Jabbour, 2008). Electronics manufacturers are increasingly pressurized by the community, both local and global, to control pollution generated by their SC processes. An example to illustrate such pressure is the criticism of Acer by the Taiwanese government for polluting the local community in its SC processes and sourcing from environmentally irresponsible suppliers (GoodElectronics, 2008). Process stewardship is helpful for electronics manufacturers to reduce waste from product disposal and prevent hazardous materials entering the different logistics life cycle stages.

Although both product stewardship and process stewardship are important components of GO, the investigation of product stewardship (Bowen et al., 2001; Christmann, 2000; Preuss, 2001) and process pollution prevention (Drumwright, 1994) are separately conducted without due regard to their co-existence in the implementation of GO (Hart, 1995). The relationships between product stewardship, process stewardship, EMC in suppliers, and their performance effects on electronics manufacturers for empirical examination in this study are summarized in Fig. 1.

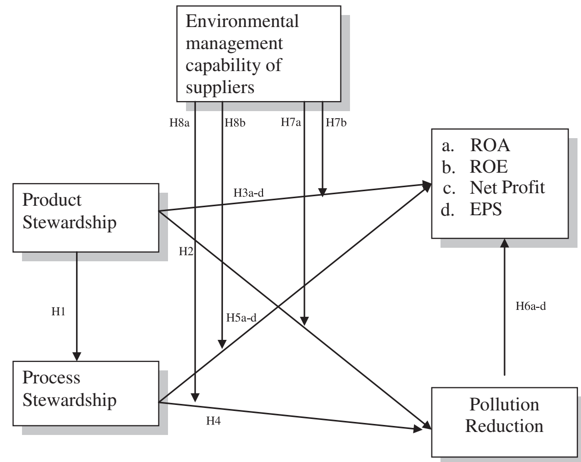

Fig. 1. Structural relationships.

3. Hypotheses development

3.1. Product stewardship and process stewardship

Product stewardship is concerned with environmental protection relating to products and their packaging design and development (Fiksel, 1993). It serves to mitigate the environmental damage of products in the logistics chain from materials and components sourcing, production and distribution, to disposal (Porter and van der Linde, 1995a). With an emphasis on reducing liability and costs, product stewardship of electronics manufacturers involves eco-design of electronics products for easy disassembly of components for reuse or recycling, design of packaging to reduce materials consumption and facilitate the recycling of packaging, and adoption of reusable containers for transportation (Gonzalez-Benito and Gonzalez-Benito, 2005). According to the NRBV, electronics manufacturers embracing these product-related environmental practices to a large extent and utilizing them intensively in their GO stand a higher chance for preserving the natural resources in their environment. Design for reuse or recycling and application of reusable containers for transportation are useful for process stewardship, allowing electronics manufacturers to disassemble component parts for capturing residual values of returned products, reusing containers that have returned products collected from the market, and reducing consumption of new inputs by utilizing reusable parts captured from returned products. From this, the following hypothesis is formulated:

Hypothesis 1. *The implementation of product stewardship by an electronics manufacturer is positively associated with its process stewardship.*

3.2. Product stewardship and pollution reduction

In addition to eco-design, product stewardship involves the selection and evaluation of alternative materials and components in product and packaging development. These practices emphasize the use of renewable, nonhazardous, and/or recyclable materials in product manufacturing (Drumwright, 1994). Such GO of electronics manufacturers ensures that pollution is controlled throughout the life cycle of their products from production and use, to disposal (Dechant and Altman, 1994). This effort is helpful for preventing the use of hazardous materials in electronics products, and subsequently reducing hazardous waste and lowering the chance of environmentally related accidents (e.g., water contamination). Also, eco-design focuses on environmentally friendly production techniques as well as resource and energy conservation in production and use of products (van Hamel and Cramer, 2002). While product stewardship stresses environmental management for the entire product life cycle, it requires cross-functional participation, from procurement and production through to distribution and marketing, in determining the environmental consequences of their products (Carter et al., 2000). Such GO of electronics manufacturers can be a valuable resource that is difficult for their rival counterparts to imitate. Based on the NRBV, through product stewardship, electronics manufacturers are more capable in pollution reduction and the control of accidental polluting/hazardous substance releases. Therefore, this leads to our second hypothesis:

Hypothesis 2. *The implementation of product stewardship by an electronics manufacturer is positively associated with its pollution reduction.*

3.3. Product stewardship and financial performance

The environmental consequences of electronics products in production and distribution can be controlled through preventive measures on inputs (e.g., materials and components) and outputs (e.g., waste formation) through product and packaging eco-design, use of low-impact materials and components, and an energy-efficient product distribution method (van Hamel and Cramer, 2002). Electronics manufacturers can benefit from GO on environmental reputation through news and feature stories, where the improved image is a helpful attraction for environmentally conscious customers (Schuler and Cording, 2006) where Hewlett-Packard and Dell Inc. are successful cases to illustrate. Examples of these environmentally friendly corporate actions include global recycling of their electronics products and a convenient and environmentally sound return and recycling service for their products. These practices have earned them positive publicity and customers' compliments. Another benefit relates to the reduced risk of using polluting materials in product development, where legal penalty and bad public image in the case of regulation violation can be avoided (Buttel, 2000). In addition, eco-design and parts recycling can account for a cost saving of more than 30% (Hindo and Arndt, 2006). Thus, our third hypothesis is formulated as follows:

Hypothesis 3. *The implementation of product stewardship by an electronics manufacturer is positively associated with its financial performance.*

3.4. Process stewardship and pollution reduction

Process stewardship prevents inefficient use of materials and resources along a logistics chain through imposing control on the transportation method, production, carbon emission, and disposal. Such control is a useful mechanism to reduce wastes and preserve the environment through managing the life cycle of product flows from purchasing, storing and shipping, to asset recovery activities. This initiative requires electronics manufacturers to implement recycling processes and develop a returned product collection infrastructure to collect, sort, and disassemble the returned products with the objective to capture reusable parts for new product manufacturing. Under the globalization of production, electronics manufacturers manage inherently complex SC activities that involve a multitude of partners located in different geographical regions. In addition, electronics products tend to be short-lived in a market where flexibility in product development is essential to prevent their inputs and market value becoming obsolete (Wong et al., forthcoming). Proactive pollution prevention in the electronics logistics chain can erect barriers and first-mover advantages that are difficult for competitors to imitate due to the participation requirements by different partners such as suppliers, customers, and logistics service providers for these practices to be successfully implemented (Porter and van der Linde, 1995a). As such, electronics manufacturers who demonstrated environmental efforts in eliminating waste and resources in their SC processes command a better position to achieve environmental performance. Thus, we hypothesized that:

Hypothesis 4. *The implementation of process stewardship by an electronics manufacturer is positively associated with its pollution reduction.*

3.5. Process stewardship and financial performance

Process stewardship through utilization of transportation capacity, reduction of carbon emission, employment of cleaner transportation, and so forth, can benefit enterprises by lowering operations costs while lessening their environmental damage. Such cost savings can be attributable to the use of recycling components and less fuel consumption. With the reduction of carbon emission in its operations, Catalyst Semiconductor Inc., saved $13 million by reducing consumption of fossil fuel by 46% between 2002 and 2005. Nevertheless, process stewardship is complex to implement which requires cross-functional involvement to execute such environmental practices as collection of used and returned electronics products from the market, recycling, and capturing residual values of products before their ultimate disposal (Rogers and Tibben-Lembke, 2001). To replicate successful process stewardship is not easy; it requires the collective efforts of different functions in a SC to excel(Zhu et al., 2011). Due to the financial value of process stewardship through cost reduction and revenue generation, we argue that:

Hypothesis 5. *The implementation of process stewardship by an electronics manufacturer is positively associated with its financial performance.*

3.6. Pollution reduction and financial performance

GO prevents air and water pollution, which in turn reduces risk of production capacity loss due to poor health of workers (Economy and Lieberthal, 2007). Both the product- and process-related environmental protection components of GO are valuable for mitigating the risk of lawsuit and fine. The use of reusable parts and components extracted from returned products represents cost saving opportunities for firms instead of buying new ones. Furthermore, the information embedded in the returned products allows electronics manufacturers to better understand the customer usage patterns and generate ideas for product improvement and new product development. While there is increasing public concern on electronics waste caused by the disposal of televisions, computers, and other electronic devices (The Associated Press, 2008), reduced pollution can improve revenue through appeals to environmentally conscious customers who prefer electronic products with obligations to reduce their negative impact to the environment (Klassen and McLaughlin, 1996). Accordingly, we hypothesized that:

Hypothesis 6. *Pollution reduction of an electronics manufacturer is positively associated with its financial performance.*

3.7. Moderating role of environmental management capability of supplier

As a complementary asset for implementing GO, the EMC in upstream suppliers is essential for deploying environmental technologies (Klassen and Vachon, 2003), evaluating upper-tier supplier environmental performance (Min and Galle, 2001), minimizing waste in business processes (Michaelis, 1995), and partnering with environmentally responsible upper-tier suppliers and service providers (Seuring, 2004). These attributes are instrumental for electronics manufacturers to ensure that their procured items are friendly to the environment. For enterprises operating under a highly competitive and regulated industry (Tan and Litschert, 1994), sourcing from those suppliers with EMC can provide benefit from an environmentally friendly image and cost reduction relating to inspections, factory audits, and materials testing. Moreover, the EMC in upstream manufacturers is valuable for promoting environmental awareness and standards across the supply chain from their procurement through to transportation activities (Russo and Fouts, 1997). By doing so, the EMC in upstream suppliers can complement the implementation of GO by electronics manufacturers through conformance with environmental requirements (e.g., use of ecological materials) specified by the latter in their supply of materials and components as well as in the SC processes. The EMC in suppliers can be leveraged by electronics manufacturers to complement their organizational efforts to implement GO towards the goal of achieving both financial performance and pollution reduction. Based on this complementary perspective of NRBV, we hypothesized that:

Hypothesis 7. *The positive association of the implementation of product stewardship by an electronics manufacturer with (a) pollution reduction, and (b) financial performance is strengthened when the environmental management capability of its upstream suppliers is high.*

Hypothesis 8. *The positive association of the implementation of process stewardship by an electronics manufacturer with (a) pollution reduction, and (b) financial performance is strengthened when the environmental management capability of its upstream suppliers is high.*

4. Research methodology

4.1. Sample and data collection

To examine the business values of the two dimensions of GO, namely product stewardship and process stewardship, and the influence of suppliers' EMC on their performance outcomes, we drew a sample of electronics manufacturers in Taiwan to test the stated hypotheses. The electronics industry is appropriate for this study due to a number of reasons. First, different from other manufacturing sectors (e.g., automobiles), electronics manufacturers enjoy comparatively less tariff protection in international trade and operate in extremely competitive markets (Yeung et al., 2005). In addition to the downward price pressures and severe competition, there are environmental laws governing electronics wastes that urge electronics manufacturers to overcome these financial and regulatory challenges for their operations to succeed (Christmann, 2004). Second, according to the Ministry of Finance in Taiwan, the electronics industry contributed a trade value of US$113.7 billion, accounting for 23% of foreign trade volume (Ministry of Finance, 2009). Electronics products are therefore regarded by Taiwan as being of strategic importance to their industrial development. In addition to its domestic economic contribution, the Taiwanese electronics industry plays a significant role in the international business arena. The manufacturers pioneer in the international information technology development with a leading role in research and development for information technology production, and has risen from 6th to 2nd in the overall ranking of the information technology competitiveness index in 2008 (The Economist Intelligent Unit, 2008). Furthermore, electronics manufacturers in Taiwan are keen on GO in their product development and SC processes due to governmental sponsorship and economic pressure from international competition. The Taiwanese government is aware of the importance of environmentally responsible products to compete in the global market. In the face of environmental degradation due to rapid industrial growth, Taiwan has started various industrial environmental improvement programs, e.g., Industrial Waste Minimization and Green Design Network programs, since the 1980s (Leung, 2004).

We drew the sample of electronics manufacturers from the database of the Taiwan Stock Exchange Corporation (TWSE) market and the Gre Tai Securities Market (GTSM) in Taiwan. These electronics manufacturers produce different technological merchandise ranging from semiconductors, optoelectronics, computers and peripheral equipment, to electronics components. Survey packages including a questionnaire, a cover letter explaining the purpose of the study and the use of data, and a stamp-attached envelop were initially mailed to executives (e.g., presidents, vice-presidents, managers of relevant departments, and so forth) in a total of 677 sampled electronics manufacturers. The initial mailing elicited 74 usable responses. A follow-up mailing of survey packages was sent 2 weeks after the initial mailing. An additional 48 usable responses were returned. A total of 122 usable responses were received, representing a response rate of 18%, which was comparable with prior studies of a similar nature (e.g., Christmann, 2000; Grewal et al., 2009).

4.2. Key informant and non-response bias

In order to obtain accurate assessments by respondents and ensure that they represent and reflect the views of their firms, we asked them to indicate their length of service, knowledge on GO, and experience in managing their own firm's and the supplier's EMC. More than 51% of the respondents had been working in the current firm for 8 years or longer. In all, 42% of the respondents were vice-presidents or presidents, 44% were managers and 12% were supervisors in such departments as environment and safety as well as manufacturing, and 2% were in other positions. This distribution of organizational ranks indicated that the respondents were knowledgeable organizational informants. In addition, an interview with suppliers of ASUS and Acer computer companies indicated that manufacturers characterized with more efforts in GO are also more knowledgeable about what their suppliers have done in the same area. The degree of interaction between manufacturers and their suppliers could influence how the former perceive the capabilities of the latter. Bearing this mind, this study specifically focuses on the assessment of suppliers' EMC from electronics manufacturers' perspective. While 63.9% of the respondent firms possess 500 or less number of employees, the key informants in these executive positions are likely to be involved in and have knowledge about GO and its related aspects in the companies. The annual revenue of 27% of respondent firms is less than NT$1.1 billion (US$1 = NT$33 approximately), while 36% of respondent firms have annual revenue between NT$1.1 billion and NT$4.0 billion, and 37% have annual revenue over NT$4.0 billion. Hence, potential method bias by using the key informant approach does not seem to be a major issue in this study.

Tests were conducted to verify if non-response bias is a problem in this study. Following Armstrong and Overton (1977) and Lambert and Harrington (1990), the second wave of respondents' returns is assumed to be most similar to those of non-respondents. A t-test analysis showed that there were no significant differences (at $p < 0.05$) as regards to all variables analyzed. Although the results did not rule out the possibility of non-response bias, they suggest that non-response bias was not a concern in this study.

Table 1
Common method bias analysis.

	PD	PS	EMC	PR
PS	0.82			
	0.81			
EMC	0.52	0.58		
	0.52	0.57		
PR	0.62	0.71	0.53	
	0.63	0.71	0.54	
Type of ownership (marker variable)	*−0.04*	*0.04*	*−0.01*	*0.17*

PD=product stewardship, PS=process stewardship, PR=pollution reduction, EMC=environmental management capability of suppliers. The first value in each cell is the correlation between the constructs, and the second value is the correlation corrected for method bias.All correlations are significant at $p<0.01$, except for values in italics.

Two steps were undertaken to determine whether common method variance posed a serious threat to this study. First, Harmon's one-factor test was applied to assess whether a single latent factor would account for all the theoretical constructs. The single-factor model yielded a χ^2 value of 624.69 (df=151). We conducted a χ^2 difference test against the hypothesized four-factor model to assess the common method variance. A significant difference between the χ^2 values of the two models ($\Delta\chi^2=295.43$; Δdf=6, $p<0.001$) suggested that the fit in the measurement model was significantly better than the single-factor model, providing preliminary evidence that common method variance was not a problem in this study. Second, we followed the guidelines recommended by Lindell and Whitney (2001) and Malhotra et al. (2006) to test for potential common method variance by using the type of ownership of the firm (e.g., joint-venture, state-owned, privately owned, etc.) as the marker variable. This marker variable is used for common method variance analysis because it is theoretically unrelated to all the dependent variables of this study (i.e., pollution reduction and objective financial performance measures). The correlations between the type of ownership of the firm and the constructs in the measurement model are insignificant. The partial correlations between the constructs are significant after controlling the effect of common method bias. These results are summarized in Table 1 and provided evidence that the common method bias did not pose a serious threat to the interpretation of the study results.

4.3. Measurement development

We conducted extensive literature review in the development of the research instrument in the form of survey questionnaire. In addition to adopting measurement scales from the literature, we improved content validity of the measurement by conducting interviews with 30 executives of electronics manufacturers, who are in charge of the production and distribution processes, and consultants in operations and supply chain management to ensure the questions are relevant to their operations, well-understood, and interpreted consistently. Based on their feedback, we refined the measurement scales and administrated the measurement items in the form of questionnaire to another 30 executives for pilot test. We conducted exploratory factor analysis to purify our scales. The results led us to delete two items because their corrected item-to-total correlation were lower than the threshold value of 0.30, suggesting that these items are not measuring what the rest of the items are measuring. After eliminating the items, we had a more parsimonious scale (Henrysson, 1963) with 17 items for further analysis. The final measurement scales are attached in Appendix A.

4.3.1. Independent variables

Product stewardship is conceptualized as the product-oriented environmental practices of firms where environmental issues are taken into account in such product-related aspects as product design, materials used, and product packing. A four-item scale is adopted from Gonzalez-Benito and Gonzalez-Benito, 2005 and Zhu and Sarkis (2004). Process stewardship is concerned with the reduction of natural resources consumption and pollution in the SC processes. A six-item measurement scale is adopted from Gonzalez-Benito and Gonzalez-Benito, 2005 and Aragon-Correa et al. (2008). We asked respondents to assess their firms on these items using a seven-point Likert scale with 1=strongly disagree and 7=strongly agree.

4.3.2. Moderating variable

The EMC of suppliers reflects their ability to manage their environmental impacts through provision of environmentally conscious products, adopting cleaner production processes, integrating environmental issues into business routines, sourcing from environmentally responsible upper-tier suppliers, and communicating their environmental policy with partners (Lee and Klassen, 2008). We adopted the measurement scales developed by Zhu et al. (2005). Respondents were asked to assess these attributes of EMC in their suppliers with regard to obtainment of ISO 14000 certificate, environmental evaluations of second-tier suppliers, provision of ecological proof of their products and environmental management guidelines, and cooperation with manufacturers to reduce environmental impact on a seven-point Likert-scale with 1=strongly disagree and 7=strongly agree.

4.3.3. Dependent variables

Performance outcomes of GO are measured in terms of environmental and financial performance. Pollution reduction is operationalized as the decrease of waste and consumption of natural resources (e.g., fossil fuel). A four-item scale from Zhu and Sarkis (2004) and Rao and Holt (2005) was adopted, and asked respondents to assess their pollution reduction improvement relative to their previous year performance on a seven-point Likert-scale with 1=strongly disagree and 7=strongly agree.

To complement the perceptual measurement of pollution reduction and to evaluate more accurately the financial performance of responding firms (Devaraj and Kohli, 2003; Kim and Malhotra, 2005), objective measures obtained from the Taiwan Stock Exchange Corporation were used to assess the financial outcomes of GO in terms of return on asset (ROA), return on equity (ROE), net profit, and earnings per share (EPS).

Before testing the hypotheses, we evaluated the psychometric properties of the factor structures. We began with confirmatory factor analysis (CFA) using AMOS 7.0. The measurement items load significantly (i.e., $p<0.001$) onto their respective constructs with loadings ranging between 0.58 and 0.98, suggesting convergent validity of the theoretical constructs according to the guidelines by Anderson and Gerbing (1988) and other studies utilizing organizational-level latent constructs (Lindell and Whitney, 2001; Novak and Eppinger, 2001). We proceeded to fit CFA on all the four constructs for path coefficients of the hypothesized structural model. Table 1 summarizes the composite reliability, Cronbach's α, and average variance extracted. Cronbach's α is used to assess unidimenstionality of constructs, and all the Cronbach's α values were well above the threshold value of 0.70 (Nunnally, 1984), ranging from 0.84 to 0.93. Composite reliability for the constructs fell in the range of 0.84–0.92, and well above the recommended value of 0.70, suggesting internal consistency of each set of observed variables in its respective construct (Fornell and Larcker, 1981). Discriminant validity was assessed following the guidelines of Fornell and Larcker (1981). The average variance extracted (AVE) estimate of each construct was

Table 2
Measurement model.

Panel A: scale properties of the latent factors

Construct	Cronbach's α	Composite reliability	Average variance extracted	Highest shared variance
PD	0.84	0.84	0.57	0.41
PS	0.87	0.86	0.53	0.49
PR	0.93	0.92	0.56	0.50
EMC	0.88	0.86	0.80	0.52

Panel B: CFA results of the latent factors

Indicator	Direction	Construct	Estimate	Standardized estimate	S.E.	*t*-value	*p*
PD1	←	PD	1.00	0.72			
PD2	←	PD	1.14	0.77	0.14	7.93	0.00
PD3	←	PD	1.05	0.83	0.12	8.70	0.00
PD4	←	PD	1.12	0.68	0.15	7.17	0.00
PD5	←	PD	0.94	0.61	0.15	6.36	0.00
PS1	←	PS	1.00	0.64			
PS2	←	PS	1.13	0.82	0.15	7.64	0.00
PS3	←	PS	1.13	0.81	0.15	7.45	0.00
PS4	←	PS	0.84	0.73	0.12	6.86	0.00
PS5	←	PS	0.95	0.74	0.14	6.96	0.00
PR1	←	PR	1.00	0.97			
PR2	←	PR	0.99	0.97	0.04	27.57	0.00
PR3	←	PR	0.64	0.73	0.06	11.05	0.00
EMC1	←	EMC	1.00	0.65			
EMC2	←	EMC	0.98	0.66	0.12	7.91	0.00
EMC3	←	EMC	1.01	0.71	0.15	6.68	0.00
EMC4	←	EMC	1.20	0.78	0.17	7.05	0.00
EMC5	←	EMC	1.23	0.86	0.17	7.17	0.00

found to be higher than the highest variance that each construct shared with the other constructs in the model. Such result suggests that all our study constructs exhibited discriminant validity. In addition, the AVE estimates of the constructs were also above the recommended threshold value of 0.50 in the range between 0.53 and 0.80. This result suggests the variance due to measurement error is smaller than the variance due to the construct, indicating convergent validity of the constructs. The four-factor measurement model exhibited a good fit with the data ($\chi^2=247.54$, df=125, IFI=0.92, TLI=0.91, and CFI=0.92). The standardized factor loads were in the range from 0.61 to 0.97, and were statistically significant at $p<0.01$ level. This result provides evidence that the constructs exhibited convergent validity (Table 2).

4.4. Hypotheses testing

After verification of the validity and reliability of the constructs in the form of measurement scales, we tested the hypotheses using the maximum likelihood estimation with the sample covariance matrix as input in AMOS 7.0. The research model provided reasonable fit to the survey data with fit indices $\chi^2=245.16$, df=122, IFI=0.93, TLI=0.92, and CFI=0.93. The results supported Hypothesis 1, which predicts positive association of product stewardship with process stewardship ($r=0.98$, $p<0.05$) as shown in Fig. 1. The findings also provide support for Hypothesis 4 that implementation of process stewardship can help reduce waste and pollution ($r=3.50$, $p<0.05$). Moreover, the findings show that process stewardship has significant positive influence on financial performance in terms of ROA ($r=8.72$, $p<0.05$), ROE ($r=8.12$, $p<0.05$), net profit ($r=7.28$, $p<0.05$), and EPS ($r=6.81$, $p<0.05$), lending support for Hypothesis 3. Contrary to our theorization, product stewardship has negative impact on both pollution reduction and financial performance at $p<0.05$, thus providing no support for Hypotheses 2 and 5. The findings also reveal that pollution reduction has no impact on financial performance, failing to support Hypothesis 6. Fig. 2 depicts the summary of path estimates of the structural model.

4.5. Moderating role of EMC of supplier

To determine whether suppliers with higher EMC are helpful for firms to improve environmental and financial performance, we tested the moderating role of supplier EMC by conducting multi-group analysis with AMOS 7.0. Following the guidelines suggested by Marsh and Hocevar (1985), Byrne (2004), and Koufteros and Marcoulides (2006) on multi-group analysis, we first created a two-group model by dividing the total 122 sample firms according to the level of EMC of their suppliers into a high EMC group ($n=52$) and low EMC group ($n=70$). The multi-group analysis was conducted in three steps to test if a change in the χ^2 between the two groups is statistically significant, which indicates a moderating effect of EMC. First, we allowed the structural parameters to vary freely across the two groups to form a baseline model (M1) with $\chi^2_{(df=276)}=454.05$, IFI=0.91, TLI=0.90, and CFI=0.90. We then constrained the structural parameters between the two groups to form a constrained model (M2) with $\chi^2_{(df=328)}=646.24$, IFI=0.82, TLI=0.81, and CFI=0.82. Lastly, we compared the equality of the paths between the two groups using the χ^2 difference between M1 and M2. We found significant differences in the χ^2 statistics of all the paths between the high and low EMC groups $\Delta\chi^2_{(\Delta df=52)}=192.19$, $p<0.05$. These results of multi-group analysis provided support for the moderating role of supplier EMC on the relationships of GO of firms and its performance outcomes.

To test the moderating effect on the performance outcomes of product stewardship and process stewardship, we constrained the structural paths one-by-one and compared the χ^2 change with the baseline model, i.e., M1. Significant difference was found in χ^2 values

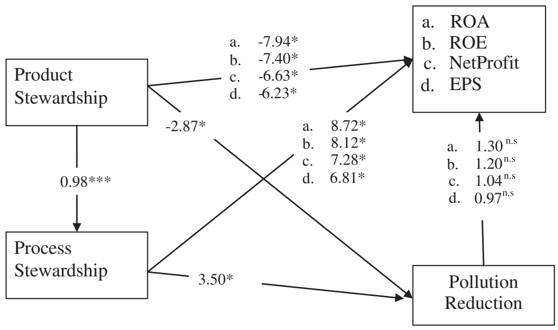

Fig. 2. Summary of path estimates without moderating effect. $^{**}p<0.01$; $^{*}p<0.05$; n.s., not significant.

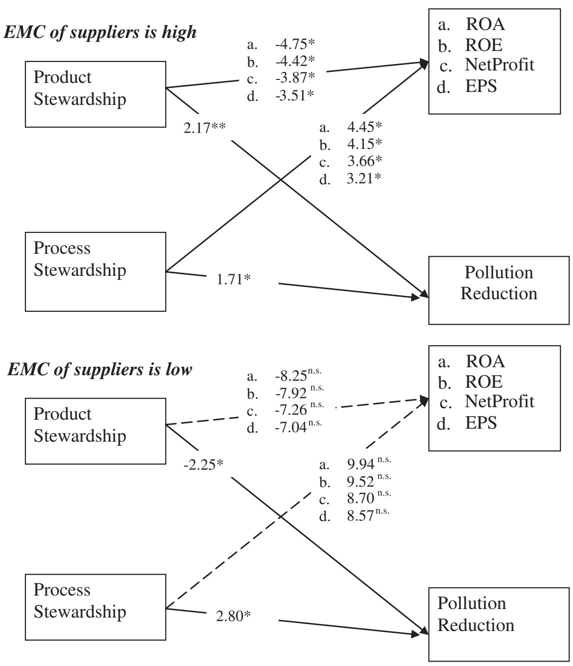

Fig. 3. Summary of path estimates from results of multi-group analysis. $^{**}p<0.01$; $^{*}p<0.05$; n.s., not significant.

between the high and low supplier EMC groups for the following paths: product stewardship→pollution reduction ($\Delta\chi^2_{(\Delta df=1)}=17.10$, $p<0.001$), product stewardship→ROA ($\Delta\chi^2_{(\Delta df=1)}=4.00$, $p<0.05$), product stewardship→ROE ($\Delta\chi^2_{(\Delta df=1)}=4.01$, $p<0.05$), product stewardship→net profit ($\Delta\chi^2_{(\Delta df=1)}=4.00$, $p<0.05$), and product stewardship→EPS ($\Delta\chi^2_{(\Delta df=1)}=4.00$, $p<0.05$). The path estimates of the high and low supplier EMC groups are summarized in Fig. 3. The findings lend support for Hypothesis 7a that suggests the positive association between the product stewardship of electronics manufacturers and pollution reduction is strengthened when their upstream suppliers have a high level of EMC. However, Hypothesis 7b is not supported. Product stewardship is found to be negatively associated with the financial performance measures with or without the moderation of supplier EMC.

We found significant difference in χ^2 values between the high and low supplier EMC groups for the paths on process stewardship→pollution reduction ($\Delta\chi^2_{(\Delta df=1)}=17.08$, $p<0.001$), process stewardship→ROA ($\Delta\chi^2_{(\Delta df=1)}=4.10$, $p<0.05$), process stewardship→ROE ($\Delta\chi^2_{(\Delta df=1)}=4.00$, $p<0.05$), process stewardship→net profit ($\Delta\chi^2_{(\Delta df=1)}=4.01$, $p<0.05$), and process stewardship→EPS ($\Delta\chi^2_{(\Delta df=1)}=4.00$, $p<0.05$). These findings support Hypothesis 8b that suggests the positive associations between process stewardship and various financial measures are strengthened when their suppliers have a high level of EMC. However, the positive association between process stewardship and pollution reduction is not strengthened when working with high EMC suppliers, but is relatively weaker than working with low EMC suppliers. Thus, the multi-group analysis results failed to support Hypothesis 8a. Fig. 3 summarizes the path estimates from the multi-group analysis.

5. Discussions

Due to growing concern on electronics waste, GO is helpful for electronics manufacturers to control pollution in their operations processes. The research question here relates to the impact of GO for electronics manufacturers to reap environmental and financial performance, and how these GO-performance linkages are influenced by the EMC of their suppliers. According to the NRBV, process stewardship can reduce waste and pollution (Konar and Cohen, 2001; Zhu et al. 2008) as reflected by its financial impact in terms of ROA, ROE, net profit, and EPS.

Contrary to our hypotheses, product stewardship is found to bring a negative impact on both the environmental and financial performance of electronics manufacturers. This counterintuitive finding indicates that product stewardship is desirable but insufficient to lessen environmental damage, reduce costs in product development, and improve financial performance. New product design, use of recyclable containers for transportation, redesign of packing, and sourcing of ecological materials may incur costs and irrecoverable financial investments as well as materials use in the early implementation stage before firms are able to reap the benefits of scale economy and waste reduction (Russo and Fouts, 1997). Similarly, the development of environmentally friendly product and packing may generate waste and pollution that cannot be avoided and justified in product introduction. Such environmental practices as using ecological materials, product design for easy disassembly, and recyclable containers are far from being readily visible to stimulate customer purchase, and lack the immediate bottom-line effect desired by electronics manufacturers. Although we found no impact of product stewardship on environmental and financial performance, it has a positive association with process stewardship, which in turn improves these performance outcomes.

In addition, we found that pollution reduction has no significant impact on financial performance. Although this finding is inconsistent with our theorization, it can be explained that the reduction of air emission and waste water, and so forth, cannot be easily detected by the market. This result suggests that the gains on financial performance should not be confined to pollution reduction. Efforts should be spent on promoting the pollution reduction efforts and results of electronics manufacturers to generate sales revenue and financial performance gains (Chan, 2000).

We found further that GO in terms of product stewardship and process stewardship has significant positive influence on pollution reduction particularly when the EMC of suppliers is high, suggesting the role of EMC of suppliers on the GO-performance link is noteworthy. Working with suppliers of high EMC, process stewardship can bring positive impact on ROA, ROE, net profit, and EPS, while such positive association is not found when the EMC of suppliers is low. However, the negative influence of product stewardship on these financial performance measures should be noted even though the EMC of suppliers is high. This result is consistent with the model that goes without moderation by the EMC of suppliers. By focusing only on environmentally conscious product design and packing, electronics manufacturers are less likely to achieve financial gains. Regardless of the EMC of suppliers, product stewardship lacks the attraction to stimulate customer purchase and the resultant financial performance.

6. Theoretical implications

This study advances the knowledge of GO for environmental protection by examining the performance impacts of product- and process-oriented environmental practices. Process-oriented environmental practices are important for both financial performance and pollution reduction. This finding enriches the literature on the financial value of preventing pollution in the logistics processes with the adoption of environmental technology, control of carbon emission, deployment of cleaner transportation methods, and implementation of a recycling system to mitigate environmental pollution. These process stewardship practices can be visible to environmentally conscious customers in disposing of electronics products, such that these customers can return their end-of-life electronics products for recycling. In addition, process stewardship is helpful for cost reduction by lessening resources consumption (e.g., fuel and energy usage in operations) and capturing residual values (e.g., reusable components and materials) to lower the costs of purchasing materials and components. This way is congruent with the NRBV, where processes are less likely to be imitated due to their complexity and lack of visibility to competitors, thus contributing to performance.

The negative financial impact of product stewardship is counterintuitive. Although product stewardship is believed to provide opportunities to minimize waste, and improve efficient use of resources through product design, packing, and material uses, there are restraints for cost savings and pollution control (Lewis and Gertsakis, 2001). For example, costs are likely to be incurred when returning the reusable packaging to manufacturers. It is difficult to achieve scale economy in developing eco-friendly electronics products with environmentally friendly parts and components in the product introduction stage (Russo and Fouts, 1997). Moreover, the applications of ecological materials in electronics products development may not be observable to stimulate purchase by consumers. However, our finding reveals that product stewardship has positive influence on process stewardship, which has positive impact on financial performance and pollution reduction. This advances knowledge on the positive association between product and process stewardship, where the environmentally conscious design of electronics products and packing can facilitate the process-oriented environmental practices in capturing the residual value of products through recuperation and recycling for performance gains.

There is also a lack of positive association between pollution reduction with financial performance in terms of ROA, ROE, net profit, and EPS. This can be explained by the insufficient knowledge of consumers on the pollution reduction and environmental conservation efforts contributed by electronics manufacturers. The finding implies that electronics manufacturers need to show or even involve customers in their GO, encouraging customer participation in the SC processes to return used products for recycling, in order to achieve financial performance.

Consistent with the complementary perspective of NRBV, process stewardship has positive impact on both financial performance and pollution reduction when the EMC of suppliers is high. Such supplier capability is reflected in their products, production processes, business routines, sourcing, and communication, which are found supporting the process-oriented GO of electronics manufacturers.

Prior research points out that little is known about the link of product stewardship to product development in contributing to environmental conservation (Gottberg et al., 2006). We add to the literature by examining how supplier EMC influences the performance impact of product stewardship. We found that product stewardship has a positive impact on pollution reduction when electronics manufacturers source from suppliers with a high level of EMC. Our findings suggest the performance impact of GO is not universal, but contingent on the EMC of suppliers. We contribute to the NRBV by providing empirical evidence on how the EMC of suppliers complements as an external asset for buying firms to facilitate both product- and process-oriented environmental practices towards achieving financial gains and pollution prevention.

7. Managerial implications

This study offers a number of insights into the GO of electronics manufacturers. Process stewardship is valuable for firms to reduce pollution and achieve financial performance. Electronics manufacturers can benefit from implementing such GO practices as collecting and recycling returned products, using clean transportation methods, and so forth, to mitigate environmental pollution as well as to attract and retain environmentally conscious customers. To ensure that SC processes are not damaging the environment, customer involvement in environmental protection is needed for financial performance. Electronics manufacturers should therefore consider implementing GO that require inputs from customers to help them realize the electronics products they purchase are produced and distributed in an environmentally friendly manner. The process-oriented environmental practices not only are crucial for financial gains and pollution reduction, but also help electronics manufacturers to realize the benefits of product stewardship that was found to be insufficient to directly generate desirable performance. Related practices such as eco-design, recycling packaging, and use of nonhazardous materials for product development are useful enablers for process stewardship to bring both financial and environmental performance.

This study also sheds light on the contingency effect of supplier EMC on the associations between GO and its performance outcomes. Electronics manufacturers seeking performance improvement in their implementation of product stewardship require the support of their suppliers who possess EMC that reflects suppliers' ability to produce components or parts that are composed of environmentally friendly materials, and distributed in an environmentally conscious manner. Our study findings recommend managers to source from suppliers who are ISO 14000 certified, conduct environmental evaluation on the second-tier suppliers, reduce environmental impact in their manufacturing processes, provide ecological proof of their outputs, and communicate about their environmental management with trading partners. In particular, it is desirable for electronics manufacturers to work with suppliers having a high level of EMC in order to reduce pollution from their effort in developing environmentally conscious products and packing, which is found to be insufficient to reduce pollution when EMC of suppliers is low.

8. Limitations and directions for future research

We acknowledge that this study has a number of limitations, which are left for future research. First, our study takes account of one external complementary asset that is found to influence the performance outcomes of GO of electronics manufacturers. Although EMC of suppliers is found to be essential to facilitate the performance of GO, there are other pertinent factors that can influence the associations between GO and its performance outcomes of electronics manufactures. Future studies may investigate the moderating effect of such factors as business environment conditions and government regulations on the performance impacts of GO, particularly on the contingency under which the implementation of product stewardship would contribute to positive financial performance.

Second, this study only examines the moderating effect of EMC of suppliers on the relationship between GO and performance. It is also possible for the EMC of customers to assume equal importance in GO as those contributed by suppliers. Customers may have high EMC and are willing to pay a premium price for or even patronage a product considered by them as environmentally friendly. It is worthwhile to examine the influence of EMC of customers on the GO-performance link in future research.

Third, this research study is a cross-sectional design. A longitudinal study is worth pursuing as it can shed light on the casual relationships amongst product stewardship, process stewardship, financial performance, and pollution reduction. Such study can advance understanding on the changes of GO of firms to bring performance outcomes over time.

Lastly, this study is conducted in the context of electronics manufacturing. Although this industry is known for polluting the environment due to the use of toxic substances in the production of electronics products, there are other highly polluting and resource consuming industries, such as textiles and garment manufacturing, and shoemaking. Future studies on GO of other industries can gain understanding and compare the GO of different industries to explore if there are different ESO practices that can be learnt from one another.

9. Conclusions

This study advances the knowledge of environmental management in green operations and the supplier role to improve performance. We adopt the NRBV to examine the performance outcomes of GO in terms of product and process stewardship that work with suppliers characterized with high and low levels of EMC. We provide empirical evidence to account for the EMC of suppliers that influence the organizational success of implementing GO to achieve business as well as environmental goals. The study findings provide evidence to show the performance impacts of product and process stewardship with high and low variations of the supplier EMC. We provide managerial insights into the value of supplier EMC and the level of supplier EMC conducive to the performance of product and process stewardship. This research lays foundation for this line of environmental management research with topics on other complementary capabilities of suppliers such as information processing (Wong et al., 2009) and supplier cooperation and commitment (Lai, 2009) affecting performance outcomes of GO and how manufacturing firms may leverage the EMC of their suppliers to compete and in other industrial contexts such as shipping and transport logistics (Lun et al., 2011).

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Appendix

See Table A1 for more details.

Table A1
Measurement scales.

Constructs	Item codes	Measurement items
Product stewardship	PD1	Design of products are for easy disassembly for reuse or recycle
	PD2	Recyclable or reusable packaging of products are used for transportation
	PD3	Ecological materials are used for packaging of our products
	PD4	Packing of products are designed to reduce consumption of materials
Process stewardship	PS1	Production processes are designed to reduce consumption of resources in operations
	PS2	Environmental technologies are used to preserve the environment
	PS3	Control carbon emission
	PS4	Use cleaner transportation methods
	PS5	A recuperation and recycling system is in place to collect products from the market
Pollution reduction	PR1	Reduction of carbon emission
	PR2	Reduction of waste water
	PR3	Reduction of solid wastes
Environmental management capability of supplier	EMC1	Our suppliers are ISO 14000 certified
	EMC2	Second-tier supplier environmental evaluations are conducted by our suppliers
	EMC3	Our suppliers are able to provide ecological proof of their products
	EMC4	Specific environmental management guidelines are provided to our upstream suppliers
	EMC5	Our suppliers cooperate with us to reduce environmental impact in the manufacturing processes

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