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Article

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MANAGEMENT | RESEARCH ARTICLE

Towards the open eco-innovation mode: A model of open innovation and green management practices

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Abstract: Small- and medium-sized enterprises (SMEs) have played an income-generating role in economic notions of prosperity in many developed countries, especially Thailand. Inside green economy, fostering eco-innovation by open innovation has become an increasingly new normal issue in Thailand. The ability to identify and collaborate with external knowledge sources and eco-innovative characteristics of SMEs is of essence to policy-makers and firm practitioners. This paper aims to shed the new light on the adoption of open innovation into eco-innovation which leads to the open innovation mode. Simultaneously, eco-innovation requires green management practices to interact with the concept of open innovation. Through structural equation modelling, 636 firms were collected and employed to estimate the proposed model. The prominent results verify: (1) open innovation

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PUBLIC INTEREST STATEMENT

In this article, researchers find that SMEs whose innovation activities have Open Eco-Innovation Model are more likely to entail product, process, and managerial innovation. However, seeking external partners can provide the eco-innovators with an environmental safeguard against the potential discharge of inputs (i.e., raw materials etc.) sourcing from outside. The influence of breadth and depth of knowledge sources on eco-innovations is important to identify extensive and intensive collaboration with external partners, such as academic institutions, customers, competitors, research institutes, consultants, suppliers, or government. Based on the evidence, policy-makers and firm practitioners can improve the open eco-innovation model by integrating open innovation and eco-innovation with green management practices in their strategic planning and decisions.

significantly affects eco-innovation, which allows to obtain the open eco-innovation mode, and (2) open innovation through green management practices contributes significant benefits to eco-innovation. Based on the evidence, policy-makers and firm practitioners can improve the open eco-innovation model by integrating open innovation and eco-innovation with green management practices in their strategic planning and decisions.

Subjects: Business, Management and Accounting; Production, Operations & Information Management; Strategic Management; Management of Technology & Innovation; Entrepreneurship and Small Business Management

Keywords: open innovation; eco-innovation; the open eco-innovation; green management practices; Thailand; SMEs

1. Introduction

Recently, open innovation has been recognized as a robust mechanism for the sustainable business innovation model development of small firms and as a lever of environmental, social and economic benefits across inter-firm boundaries (Srisathan et al., 2020). Open innovation strategy brings small firms to innovative solution through business innovation collaboration (Naruetharadhol et al., 2020). The main idea to open innovation is the integration of the consumers' pain points into the innovation process (Belz & Peattie, 2012). In recent year, economic performance needs to go hand in hand with environmental and social performances. Inside the input process of innovation generation, the activities that relate to demonstrating the resources on a country's requirement to produce goods and services and increasing unwanted products in the form of waste and pollution also need to be well managed. Such economic activities and growth have altered the natural environment (Bergsman et al., 1975; Roberts et al., 2015). Thailand has become a destination for international migrant workers (Ketkaew & Naruetharadhol, 2016) and foreign investments. As a result, the increasing need has created to move towards the green economy for eco-friendlier driven innovation or eco-innovation. This means new products, processes, and management solutions that reduce the impact on the environment.

The economic essence of eco-innovation is today's choice concerning the green-oriented scope of firms, people, policy-makers and countries. Besides, the way to gain a competitive advantage of open innovation and eco-innovation lies in part with the firms' capacity to innovate, evaluate, and exploit inside and outside green knowledge (Albort-Morant et al., 2016). The openness to eco-innovation has a prominent "win-win" effect whereby firms retain competitiveness and environmental sustainability (Ambec et al., 2013; Ghisetti et al., 2015). The twofold relationship of open innovation and eco-innovation shifts to the new mode—the open eco-innovation. This indicates a need to take advantage of (1) heterogeneous sources of green knowledge inputs and (2) SMEs' core competencies and eco-image improvement (Albort-Morant et al., 2016). The heterogeneity of knowledge is not just a diverse set of complexities between technical knowledge belonging to innovation partners but also includes the cultural distance between an enterprise and its innovation partners (Santoro et al., 2018).

Although The Thai national strategy has focused on promoting green growth and sustainable development, it has been reached at a certain level of success due to lack of implementation. This is because there are neither good governance nor integrated partnerships to target mutual growth in terms of the economy, environment, and quality of life. Furthermore, there is also an ineffectiveness of Thai public policy intervention, unable to extend the socio-economic benefits of eco-innovation due to no collaboration. Consequently, it causes the extreme constraint of SMEs and policy-makers towards eco-innovation policy and strategy. Without the implementation of green management practices, Thai SMEs cannot report and update information on the performance and compliance of their activities impacting the environment. Not every SME is in the position to pursue

external partners to implement ISO 14,001 (Heras-Saizarbitoria, 2018). Instead, green management for small firms may be in other practices, such as the 3 R concept (Reduce-Reuse-Recycle), less energy usage, and waste minimization. This, therefore, leads to the idea that green initiatives and management can stimulate innovation and reveal new sources of new products and revenue. This research undertakes an evaluation of open innovation and eco-innovation to gain more insight into a new concept, the *Open Eco-Innovation Mode (OEIM)*. In turn, it investigates the concept's impact on small and medium-sized enterprises (SMEs) and evaluates the resulting implications for practices and management. In this context, this research poses two central research questions. **RQ1:** do open innovation relates to eco-innovation? **RQ2:** how does green management practices mediate the relationship between open innovation and eco-innovation in SMEs?

There is an abundance of literature (see, e.g., Cherrafi et al. (2018), Liu et al. (2017), and Ma et al. (2018)), which points out the importance of green management practices. Green management practices consist of three key elements such as cooperation with supply chain partners (Cherrafi et al., 2018); environmentally friendly operations (Liu et al., 2017); and internal management and support (e.g., internal efficiency demand) (Ma et al., 2018). However, green management practices in small firms do not engage enough in a formal eco-friendly activity (standards relevant to green management system), which is crucial to find alternative ways to eco-innovate. Environmental policy initiatives have concentrated on banning single-use plastic bags (Xanthos & Walker, 2017) and promoting the waste-to-energy (Shimbar & Ebrahimi, 2017). Thus, a focus on the extension of open innovation to eco-innovation is timely to address. In addition, firms also need to take green management into account.

The current research explores the open eco-innovation in SMEs. The importance of open innovation in SMEs stems from firm-level innovation activities. Open innovation is associated with technology exploration and exploitation (Lichtenthaler, 2009). It is, therefore, as a driver of eco-innovations is essential to small firms. In this current research, eco-innovation is the possible performance indicators which require a holistic view to implement eco-innovation policy in the small firm level. A few studies (e.g., Ghisetti et al. (2015), Triguero et al. (2018), and Yang and Roh (2019)) have focused on efforts to identify the search-breadth and -depth strategies of external knowledge sourcing and customer demands through eco-innovation adoption. This is possible to form the concept of the open eco-innovation mode. Therefore, from the holistic view, SMEs' capabilities are probably to engage in open innovation and eco-innovation, which allow eco-innovation typology and novelty degree to emerge in the context of small businesses. Ghisetti et al. (2015) consider the non-linear impact of absorptive capacity and knowledge sourcing on the firms' eco-innovation in the European context, finding that broad and deep sourcing strategies are important to increase their eco-innovation. But they measure eco-innovation as the number of environmental-innovation typologies introduced and adopted by firms. Triguero et al. (2018) find similar results that there is a relationship between open innovative strategies and eco-innovations (i.e., material-efficiency innovation, energy-efficiency innovation, and environmental responsiveness) in the Spanish food and beverage industry. In case of South Korea, Yang and Roh (2019) find open innovation collaborated with large organizations is more substantial than with small firms, suggesting that small firms should consider co-prosperity to eco-innovate with other companies. However, firms with an environmental management system tend to become more relevant to eco-innovation, they need to work on innovation and environmental performance (Khan et al., 2019). To distinguish from prior studies, this current research on the relationship between open innovation and eco-innovation takes the mediation effect of green management practices into account.

To date, there is limited empirical research on the combined characteristics of open innovation and eco-innovation in small firms and whether these characteristics contribute to small-firm-level open innovation which differs from large organizations. Besides, the current research is motivated by the Thailand 4.0 policy to drive the value-based economy. Since 2018, Thailand has attempted to encourage enterprises to employ technology and innovation throughout marketing,

management, and production chain (NESDB, 2018). The government aims to support the administration of SMEs' business and service by effectively developing related skills and knowledge (World Bank, 2018a). In Thailand, the proportion of research and development (R&D) expenditure in the public sector increased from 54% in 2014 to 73% in 2016 while in the private sector decreased from 46% in 2014 to 27% in 2016.¹ The private sector tends to continuously drive its internal capabilities and outsources to create better differentiation by offering high-value products than the public sector, although the private R&D spending grew by 50% in 2017 (World Bank, 2018b). What's more, there is a growing consensus that Thailand needs the improvement of labour skills in more productive and innovative ways (Suttawet & Bamber, 2018). Meanwhile, the promotion of innovations for sustainable growth is evident in the National strategy Thailand 4.0 for green growth industries (NESDB, 2018), which aim to reach the greenhouse gas reduction target by 20 to 25% by 2030. The plan also states that the communication of value creation for eco-innovation leads to diverse supply chain collaboration. As a consequence, Thailand serves as the place for the current research to investigate the open eco-innovation mode.

Against this backdrop, this research aims (1) to extend the open innovation paradigm to eco-innovation by developing this relationship as the new concept of the open eco-innovation mode, and (2) to test the effect of green management practices in that relationship. Because the relationship is built on the theoretical background of open innovation and eco-innovation, it needs more analysis on the issue to establish the idea of the open eco-innovation mode. It is also substantial to propose the practical value to policy-makers and firms looking to enhance their eco-innovation activities with external actors.

Our key findings contribute to advancing the insight of how open innovation is managed and adopted in practice within SMEs. This insight provides the need to differentiate between openness to external ideas, knowledge, and technology. Furthermore, we show open innovation as a holistic view consisting of inbound, outbound, and coupled innovation activities and create dimensionality of the open eco-innovation mode. Then, empirical contribution builds on extant literature to overcome existing limitations, proposing the measurement of eco-innovation through the use of objective indicators (product, process, and management). The concern about environmental problems due to the economic processes will be advanced to the practices of green management. Such variables provide more useful scale measures of firm propensity to openness.

The remainder of this paper is organized as follows: Section 2 develops the theoretical background and hypotheses; Section 3 presents the methods used to test the hypotheses; Section 4 discusses the empirical results and the critical theoretical and policy contributions; Section 5 concludes, states limitations and suggests opportunities for further research.

2. Theoretical background and hypotheses

Since the research topic being studied in our paper relates to the field of open innovation, green management practices, as well as eco-innovation. We will make a critical evaluation of the literature on these subjects in the following sub-sections. To demonstrate the comprehensive knowledge in this current research, the theoretical framework will be made on four major streams of literature review: (1) theory of open innovation; (2) theory of eco-innovation; (3) open innovation and eco-innovation; and (4) the mediation effect of green management practices.

2.1. Theory of open innovation

The importance of open innovation for economic growth is the exploration and exploitation of substantial knowledge and technology to enhance the firms' innovation process, beginning from Chesbrough's work in 2003. A number of contemporary open innovation studies such as Dahlander and Gann (2010) and Lopes et al. (2017) have still applied the Chesbrough' definition of open innovation until now. Chesbrough defines open innovation as a paradigm necessary to combine knowledge inflows with knowledge outflows into systems and architectures. This is to accelerate internal innovation creation and expand the market for outside exploitation of innovation.

Chesbrough and Crowther (2006) pinpointed that open innovation could be viewed as a paradigm that utilized for industrial innovation beyond high tech industries. This means the industry can seek innovation “ready” research from university-industry research collaboration when internal research and development can not generate spillovers and commercialize innovation to the market. Therefore, this results in open innovation through collaboration. Bogers et al. (2018) redefine open innovation as a distributed innovation process on the basis of purposive knowledge-flow management across firm boundaries, utilizing pecuniary and non-pecuniary mechanisms in line with the firm’s business model. This is how the business model puts the innovation process into the firm realm. Against this background, it is more recently argued that only inter-firms are not sufficient due to the awareness of a large society (Chesbrough, 2017). Thus, innovation communities are going to become increasingly important in general, which results in the new concept of “open innovation 2.0”. Inside the European Commission, open innovation 2.0 is a new paradigm based on the ideas of integrated collaboration, co-created shared value, cultivated innovation ecosystems, unleashed exponential technologies, and rapid adoption due to network effects (Curley & Salmelin, 2018). The key is to bring two critical factors to play in the innovation synthesis process, which are *customers* and *innovation ecosystem*. It brings firm-level innovation-related activities both from process and environment views to sustainable growth and societal development (European Commission, 2013). The development of open innovation as business model innovation or shift to service can result in crucial strategic innovations, demonstrating small firms with a competitive advantage of sustainable innovation (Chesbrough, 2017). It also implies open innovation can boost the efforts of small firms on eco-innovation (Lopes et al., 2017). In the open innovation model, firm boundaries become absorptive when there is more interaction between collaborative firms, which leads them to incorporate in more significant technology acquisition and exploitation (Naqshbandi et al., 2016). To do so, De Silva et al. (2018) explain that knowledge capitalization could help identify the causes for failure and, thus, generate internal value from their interaction with clients in the project-based collaboration by reducing uncertainty and cost, but increase the chance of knowledge loss to intermediaries because these individuals could always join competitors or change their association. On the contrary, Burcharth et al. (2014) explain that the internal resistance due to the Not-Invented-Here Syndrome (NIHS) is likely to take place within the firm. When small firm members with bias against external knowledge detract from absorbing it, especially in collaborative R&D practice, there may thus cause a negative impact on adopting open innovation practices because openness to innovation is retained to firm members’ attitudes to knowledge (Hannen et al., 2019). Furthermore, open innovation practices are contingent on firm-environmental factors. Popa et al. (2017) find that ecological dynamics increases the positive impact of innovation climate on outbound open innovation, indicating that innovation climate improves the innovativeness of SMEs. Rather, the innovation climate has a positive effect on both inbound and outbound open innovation. Hung and Chou (2013) consider internal R&D, technological turbulence, and market turbulence will moderate the extent of the open innovation processes, to which firms will decide to go for external technology acquisition (ETA) and/or external technology exploitation (ETE).

In support of the early studies, this current research considers open innovation as an innovation strategy for sustainable innovation, whereby we are mainly focusing on the outcome of open innovation processes with regard to products, processes, and organizations which the key actors can support. For instance, when the sustainability perspective is taken, this consideration plays in the foreground to ascertain the firm outcomes on social, economic and ecological collaboration mechanisms (Reficco et al., 2018). There is considerable attention to the business model innovation emphasizes a holistic approach to define business policy interventions when firms operate in a knowledge-based economy (McGuirk et al., 2015).

Saebi and Foss (2015) encompass the business models for open innovation strategy as follows: firstly, small firms the search processes to identify external knowledge sources; secondly, small firms must offer incentives for outside sources to serve up knowledge input; thirdly, small firms must provide incentives to own employees to interact with external collaborators; and fourthly, small firms must embrace sufficient absorptive capacity to combine external knowledge input. Nevertheless, Foss and Saebi (2018) pinpoint that different types of business models can give different results on open

innovation outcomes. For example, firms may take form on crowdsourcing as open innovation practices to foster existing product innovation performance. Based on this, it is likely to assume that the existing product performance can be developed into product eco-innovation.

Building on these arguments above, there is cue given open innovation plays a fostering role in firm-level sustainability. Such innovation that brings about sustainable development is called eco-innovations, for example. It is essential to seek more insight into the theory of eco-innovation before drawing the hypothesis.

2.2. Theory of eco-innovation

The term eco-innovation has been used synonymously with green innovation and environmental innovation (Kunapatarawong & Martínez-Ros, 2016). Eco-innovation is the process of developing new products, processes or services which provide customer and business value but significantly decrease environmental impact. When firms produce, assimilate, exploit a product, production process, service or management or business method is novel to the firms. This novel is to think based on a life cycle, environmental-risk reduction, pollution and other negative impacts of resources use compared to relevant alternatives (Kemp & Pearson, 2008). Foxon and Andersen (2009) point out that eco-innovation practices go much beyond the adoption of low carbon technologies; they require learning new things, creating new knowledge and values and searching for rules and capabilities, besides the creative destruction of old practices and capabilities.

According to García-Granero et al. (2018), Pacheco et al. (2018), and Pacheco et al. (2017), the typology of eco-innovation categories often adopted in theoretical and empirical studies are classified in six categories: product, process, organizational, marketing, social, and system eco-innovations. Although eco-innovations offer great opportunities, implementation of such eco-innovative initiatives brings about various difficulties at the firm level. Eco-innovation first happened in the concept of intermediate technology, also known as appropriate technology (Schumacher, 1973). Inside the Intermediate Technology Development Group (ITDG) in 1966, this concept emphasized on attempting to meet the following bottom lines: how to minimize resource consumption and how to reduce the degradation of the environment due to poverty considered as the non-application of appropriate technology in many developing countries (Bowonder, 1979). Now the Intermediate Technology Development Group (ITDG) changed its working name to Practical Action since 2008 (Toye, 2012). Over the years, the transition of technology was developed on the environmental discourse of O’Riordan, i.e., from technocentrism to eco-centrism (Hazarika & Zhang, 2019). O’Riordan (1989) mentioned the need for improving resilience could be derived from understanding durability and sustainability. This is how to explicitly demonstrate the present form of eco-innovation in order to match the current environmental situation firms (Hazarika & Zhang, 2019; Yurdakul & Kazan, 2020). Therefore, the evolution of theoretical background has been interesting in moving from rigid neoclassical cost-benefit analysis to an evolutionary approach; this is suitable for understanding eco-innovation as an instrumental entity to a social entity (Rosenberg, 1982). However, Rennings (2000) points out that the effects of market pull, technology push, and regulatory push/pull contributed to denoting and sustaining the various aspects of eco-innovation for greater adoption and diffusion. This, therefore, leads to the creation of technological alliances. Technology push helps identify key stakeholders, including producers, suppliers, collaborators, and research organizations (Costantini et al., 2015). The alliances will reflect on the openness of R&D which leads firms to actively utilizing and exploiting knowledge sharing and technology transfer (Faems et al., 2010; Terjesen et al., 2011).

Accordingly, we conceptualize the open eco-innovation mode originated from open innovation and eco-innovation theories in the next section.

2.3. The open eco-innovation mode: open innovation and eco-innovation

The use of theoretical lenses of open innovation and eco-innovation is supported to remain clear on how they contribute to the literature. The literature reveals that the linkage between open innovation and eco-innovation is far from simple since it may be influenced by internal and external factors of eco-innovation (Kesidou & Demirel, 2012) and enablers of open innovation (Lopes & de Carvalho, 2018). For example, the supply-side factors (e.g., firms' internal capabilities) and demand-side mechanisms (e.g., customer requirements and societal requirements on corporate social responsibility) play essential roles in the adoption and diffusion of eco-innovation.

The terms “the open green innovation mode,” “the open eco-innovation mode,” and “the open environmental innovation mode” are interchangeable in use. Ghisetti et al. (2015) define open eco-innovation as the firm's green capabilities exposed to green technology diffusion. External knowledge sources help firms attenuate the internal constraints (e.g., the lack of capabilities and intangible inputs to the generation/adoption of green-knowledge). To distinguish from Ghisetti's definition, we add commercialization into the definition and develop on the basis of Chesbrough's definition. Therefore, this research defines open eco-innovation as the extent to which firms: (1) utilize ideas, knowledge and technology from outside to accelerate internal innovation; and (2) expand the markets for commercialization of internal innovation, but importantly decrease environmental risks, pollution, and any other adverse effect of natural use. For example, the introduction of a new product using different low-environmental-impact raw materials can meet customer response to environmental concern (Huang et al., 2016). Therefore, open innovation can become a repeatable and scalable strategy for the growth of both SMEs and large firms. At the same time, participation in networks as collaboration gives access to a wide range of (green) knowledge that can lead to a sustainability innovation process (Arcese et al., 2015).

Ghisetti et al. (2015) tested the open eco-innovation mode with a set of hierarchical econometric models, which tried to understand the effect of the internal and external knowledge search patterns on eco-innovation in the context of European countries. It is assumed that a few external knowledge providers can satisfy the firms' internal capabilities. Their results show that external search breadth positively links with the propensity for eco-innovation, but various-partner coordination also diminishes eco-innovation propensity because of mismatched knowledge providers. Existing evidence demonstrated that both internal and external knowledge search had incentives to advocate eco-innovation, which could potentially promote EI-friendly model of absorptive capacity and knowledge sourcing. This provides the empirical evidence of open eco-innovation mode. Unlike the study of Ghisetti et al. (2015), our paper considers the core-based processes of open innovation into our analysis since the innovation process is not only about outsourcing all internal innovation activities but also exploiting innovations to the market.

Hou et al. (2017) analyze the adverse effect of external knowledge sourcing on green innovation growth in Chinese manufacturing, which considers external knowledge sourcing as external R&D costs. It is suggested that the manufacturing industry adequately control the input costs of external sourcing. Also, the establishment of new opportunities between internal R&D and external sourcing suppliers is essential to promoting cooperation on eco-innovation. Simultaneously, the government needs to come up with the supportive policies relevant to open and eco-innovations. Firms can improve the industrial eco-innovation system to absorb external knowledge of green technology and idea, and optimize green production and technical conditions. Therefore, the open model of eco-innovation can expand R&D for manufacturing and production efficiency to improve external eco-innovation. In our analysis, we consider internal knowledge sourcing (e.g., innovative human capital (McGuirk et al., 2015)) and non-R&D to diversify the innovation path, in addition to external knowledge sourcing and R&D.

There are key notions that are still discussed in the literature that when firms cooperate with other outside firms for eco-innovation, they need to consider the mechanism to obtain eco-innovation not only in supplier but also in customer perspectives (Jansson et al., 2010). Yang

and Roh (2019) investigated the relationship of open innovation with the process and consumer eco-innovations, finding that consumers would give the values to achieving environmental performance while using products. Therefore, it is more critical for management to take various consumer positions into account. For example, firms may design products possible to be returned to other raw materials after use, to recycle, to reduce their energy during manufacturing, and to reduce waste disposal cost (García-Granero et al., 2018). To fill this literature gap, this paper identifies and incorporates the firm's capacity and competence for (managerial) eco-innovation, which cooperation with external partners are likely to have a critical impact on the formulation of eco-innovation into our model.

Depending on all the above, we can state that there is a relationship between open innovation and eco-innovation, which formulate as the new mode, "open eco-innovation." Therefore, it can be assumed in the following hypothesis:

Hypothesis 1: *There is a positive relationship between open innovation between eco-innovation.*

Based on the argument, to understand how green or environmental management practices mediate the relationship between open innovation and eco-innovation, we explore the stream of the literature on the mediating effect of green management practices in the next section.

2.4. The mediation effect of green management practices

Green management practice is considered as a potential economic and strategic leverage to gain environmental and financial benefits (Escoubès, 1996). Notably, open innovation has been highlighted as a pivotal contributor to eco-innovation because the open innovation paradigm as the business model innovation can aid in reacting to environmental regulations and threats of fines and lawsuits and undercut more existing and efficient competitors (Cheremisinoff & Bendavid-Val, 2001; Guo et al., 2017).

We use the term "green management" and "environmental management" practices interchangeably. Green management refers to the managerial processes and methods of how firms organize the effects of their activities on environmental aspects (Lun et al., 2016). Such aspects include using innovation to obtain sustainability, waste reduction, and environmental responsibility. When firms become aware of environmental management to minimize environmental impact through making green production, conducting green research, and organizing green marketing, they can integrate effectiveness-enhancing outcomes and organizational inputs of eco-friendly development strategies (Katsikeas et al., 2016). However, we define green management as methods and practices that impact the environment as less as possible, by minimizing non-environmental processes and footprint, to make the business more sustainable. Besides, the effects of green management practices bring firm to gain competitive advantages via (1) continuous learning capability and development, (2) costs and differentiation, and (3) the embrace of green goals, objectives, and strategies (King, 2000; Peng & Lin, 2008), fully formed into a firm's corporate strategy.

Being green is no longer a cost of doing business; it is a catalyst for innovation, new market opportunity, and wealth creation (Clark et al., 1994). The practices of green management demonstrate a standardized mechanical guideline for managers to use eco-friendly information, knowledge and ideas to improve their internal capacity and competitiveness such as cost, quality, and delivery (Yang et al., 2010). Since SMEs rely heavily on opportunities for survival and success that include the maintenance of product standards and quality (Guo et al., 2017). Hence, it is likely to examine how green management practices influence innovation. Zhu and Sarkis (2004) show that environmental management systems (e.g., ISO 14,000 implementations) moderate internal and external practices that provide diverging environmental consequences. Molina-Azorín et al. (2015)

consider environmental management systems through technical, operational, information, and strategic systems. Their result reveals that strategic practices play the most relevant roles in defining and communicating the policies and objectives. Also, customer focusing on quality practices tends to reinforce these positive effects to innovate in the firms' services. Hamdoun et al. (2018) describe that environmental management systems or ISO 14,001 as a form of environmental management to increase firms' innovation performance. They also suggest that the uptake of and the adoption of their particular elements (e.g., clear green managerial policy, 3Rs, less-polluting product development, green supplier selection, and knowledge promotion on environmental performance) represent innovations to generate and transfer new environmental knowledge among firm members.

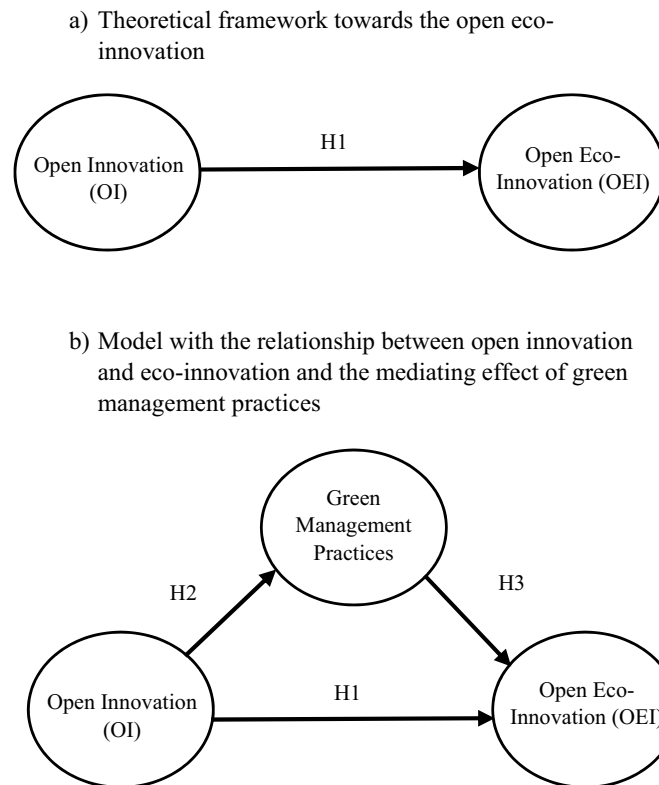
There is an argument on the linkage between eco-innovation and business performance (i.e., introducing sustainable development goals), which environmental management system (ISO 14,001) moderates its nexus in its context when the firms' environmental performance can be measured in the certain level (Khan et al., 2019). Indeed, not every small firm gets ISO 14,001 certified. This current research attempts to understand the context of mediation rather than moderation, different from the previous study of Khan et al. (2019). Therefore, the environmental management system can simply moderate the effect of open innovation on eco-innovation, especially in green (industrial) firms. Non-green (industrial) firms' innovation is likely to be mediated or intervened to enhance their environmental performance, which causes these non-green firms to identify their eco-innovation portfolio indirectly. Not all SMEs can have enough knowledge and capacities to foster eco-innovation and to implement ISO 14,001, the outcome of traditionally non-green industries or with a product portfolio filled with outsourcing products cannot be green (Calza et al., 2017).

Jabbour et al. (2013) consider the relationship of lean manufacturing practices and human resource management practices with the environmental management which provides the environmental efficiency of the final product. Pinto et al. (2018) consider and address CO₂ emission and water quality in environmental management practices implemented in Brazil, Russia, India, China and South Africa (BRICS), finding the public policies affect the promotion of sustainable development in industries.

There is empirical evidence that the positive relationship between environmental management implementation and eco-innovation could be partially confirmed in the case of self-reported process eco-innovation (Wagner, 2007). Another empirical proof from Ziegler and Seijas Nogareda (2009) revealed that environmental management systems could positively promote both product and process eco-innovations. Still, they also concluded that the relationship between EMS and technological eco-innovations was quite ambiguous. Consequently, this leaves a gap for our analysis to confirm this relationship. Despite the environmental and stakeholder pressures, it is not straightforward for small firms to have good environmental governance because only internal R&D activities tend to be risky and time-consuming (Bönte & Dienes, 2013; Mina et al., 2014). With a strategy of open innovation, small firms can use external technology resources to enhance their innovation capabilities to discuss the problems of environmental management productivity (i.e., energy inputs and environmental pollution) (Hu et al., 2017). Therefore, open innovation promotes them to conduct and implement basic research on their own for new technology to generate less polluted products and reduce environmental pollution. Foreign technology acquisition is more likely to be more costly than domestic technology but transferred with higher quality and more maturity than domestic technologies, so domestic firms have greater motivation to exploit their potential value (Li-Ying & Wang, 2015). As a result, we assume that there will have the effect of open innovation on environmental management.

However, open innovation allows them to access relationship learning and cooperate with supply chain partners (Albort-Morant et al., 2016). As a result, internal green management support plays an intermediary role in interfacing between open innovation and eco-innovation since green

Figure 1. Research model.



management practices are implemented to maximize stakeholder's benefits and involve not only green initiatives but also technology and commercial endeavours. Triguero et al. (2017) indicate that the influence of R&D alliance on eco-innovation is not always positively confirmed in the literature. For instance, the role of (green) R&D intensity is found to be influenced lower in eco-innovators than in non-eco-innovators, or R&D resources do not affect the degree of eco-innovation. Lee and Min (2015) suggest that firms' proactive green strategy works when unique resources and capabilities are well organized to manage environmental, financial, and firm performance then may improve the ability to nourish eco-innovation. Likewise, Bocken et al. (2011) point out that green consumer awareness, environmental regulation and government pressure drive to reduce environmental impact. Firms will be required to innovate to exploit technological opportunities and market dynamics for the adoption of eco-innovation. In doing so, Darnall et al. (2010) find that small firms tend to respond to value-chain, internal efficiency and external legitimacy, and regulatory stakeholder pressures positively, suggesting that green management practices help identify customer needs, get feedback on customer satisfaction, and decide on the improvement of product and process innovation propensities. Therefore, we conclude that green management practices can contribute to eco-innovation efforts. Because of firms' scarcer resources, the open eco-innovation model requires collaboration and environmental knowledge exchange with external stakeholders. This current research presents a research framework with the relationship between open innovation, green management practices, and eco-innovation are related (Figure 1). Taking all the above into consideration, we, therefore, propose the following hypotheses:

Hypothesis 2: Open innovation relates positively to the firm's green management practices.

Hypothesis 3: Green management practices have a positive effect on eco-innovation.

Hypothesis 4: Green management practices positively mediate the relationship between open innovation between eco-innovation.

3. Research methodology

3.1. Data collection and sampling

This research was conducted in the SME industries because the government aims to upgrade Thai SMEs to be involved in the innovation adoption and solution for the circular economy. Furthermore, Thai SMEs are the family-business unit that creates significant profit margins for the country compared to the large companies, where a considerable portion of revenue is used for imported machinery, technologies and materials. Besides, SMEs also develop wealth and prosperity in the rural areas of the country. As a result, such industries provide a high level of innovativeness, knowledge intensity, and product and process orientations (e.g., biodegradable products) (TIR, 2017). More supports from industries sector and government agency are needed to collaborate (Phaninee Naruetharadhol et al., 2020) and invest. Therefore, Thai SMEs are suitable to investigate in the field of innovation.

The data source was merged from the Department of Business Development (DBD) Data Warehouse to elicit a list of Thai-registered SMEs. This source was used to check for SME information before conducting a field survey study to test the proposed hypotheses. This study's population size was 680,269 firms that have continued in existence.² To ensure that those firms were in the SME industries literally, we followed the OECD criteria to classify them according to the business size (i.e., number of employees as seen in Table 1). In case that firms employ over 250 people, they will be considered as large enterprises. Data collection was carried out over six months (September 2018—April 2019). To prevent a complacency effect, the respondents were focused on top positions involving the strategic orientation of their firms (e.g., junior, middle, senior managers or CEO or any firm representatives who are mainly and relatively responsible for the firms' innovation activities). This allows us to ensure that the respondents are the business personnel but not from external sources of the answer. In addition, the firms were also scanned and asked them on the phone before mailing and e-mailing them a questionnaire. Based on a population of 680,269 firms, the recommended sample size of at least 384 firms would be necessary if a margin of error falls 5% at the 95% confidence level (Daniel & Cross, 2018). We distributed 800 questionnaires via both postal and electronic mail attached an official cover letter explaining the purpose of the study. Inside the letter, the QR code was implemented to access Google Form as the survey administration platform. This number of 800 was to prevent errors such as extreme answer, no reply, no surveyed return, wrong address and other causes. Also, this figure was distributed to obtain the final sample as accurate as possible. We received 636 usable questionnaires participated in our study from all contacted firms of 800, but another 164 firms refused to participate and gave no reply. Therefore, 636 samples provided a response rate of $636/800 \times 100 = 79.5\%$ and were used for further statistical analysis.

A sample was applied and selected based on a two-stage sampling design: cluster sampling and purposive sampling techniques (McClave & Sincich, 2016). In the first stage, we used cluster sampling involved the division of a population into separated clusters based on geographical regions – namely, the Northern, Northeastern, Central, Eastern, Western, and Southern of Thailand. The second stage involved purposive random sampling in selecting firms from the SME industry identified in the first stage.

3.2. Measures and variables

We applied a 7-point Likert-type scale which is a psychometric scale development of Likert (1932), ranging from 1 (strongly disagree) to 7 (strongly agree). Since the 7-point scale is the most accurate of a better reflection of a participant's evaluation (Finstad, 2010), it tends to demonstrate more varieties of answer options, increasing the chance of meeting participants'

Table 1. The characteristics of the sample

Demographic of SMEs	Number of firms (n = 636)	Percent (%)
(a) Firm size		
1-10 employees	146	23.0
11-50 employees	233	36.6
51-250 employees	257	40.4
(b) Firm age		
0-10 years	200	31.4
11-20 years	205	32.2
21-30 years	83	13.1
31-40 years	44	6.9
Above 40 years	104	16.4
(c) Respondents' position		
CEO, Entrepreneurs, Business owners, managers, or other top or middle positions	518	81.4
Lower than positions mentioned above	118	18.6
(d) The geographical region of Thailand		
the North Region	49	7.7
the Northeast Region	61	9.6
the Central Region	385	60.5
the East Region	20	3.1
the West Region	67	10.5
the South Region	54	8.5
(e) Type of industry		
Food & beverage/Agriculture	110	17.3
Plastic	36	5.7
Medical devices & pharmaceutical	36	5.7
Auto parts and Machinery	31	4.9
Material science & Chemicals	28	4.4
Retail/wholesale	16	2.5
Steel	24	3.8
Rubber	24	3.8
Transportation	20	3.1
Electronics	25	3.9
Electronics/Automation/Robotics	23	3.6
Others	263	41.4
(f) Seniority		
0-5 years	204	32.1
6-10 years	169	26.6
11-15 years	102	16.0
Above 15 years	161	25.3

objective reality (Cox, 1980). What's more, the item-response-theory evidence from Wakita et al. (2012) indicated that the number of options affected the response for the most part of the 7-point-scale adoption. All key constructs were adapted with the minor change from previous studies (see Appendix 1).

The independent variable, open innovation practices, was a composite of six items, which measure: (1) inbound activities that are related to the involvement of external partnership (Hung & Chou, 2013) and an internet search for new trends or technology (Burcharth et al., 2014); (2) outbound activities that are related to licenses and the establishment of product lines, divisions, or the dedicated business unit to commercialize knowledge assets (Hung & Chou, 2013); and (3) coupled activities that capture R&D alliance/joint venture (Mazzola et al., 2012) and coordination of information exchange among partners (Cheng & Huizingh, 2014).

The dependent variable, open eco-innovation, refers to the extent to which firms' activities are associated with the inflow and outflow of environmental knowledge in terms of product, process, and management. Product eco-innovation is designed to capture the activities of developing new products/services with low environmental impacts and reducing the use of raw materials (Chiou et al., 2011; García-Granero et al., 2018). Process eco-innovation included the activities that are involved with reusing the components and reducing chemical waste and using the innovative environmental-friendly technologies to save energy (Chiou et al., 2011; García-Granero et al., 2018). Managerial eco-innovation included cooperating with customers/clients for green innovation management and collaborating with stakeholders to implement strategic eco-innovation development (Chiou et al., 2011; García-Granero et al., 2018).

The mediator variable, green management practices, refers to the extent to which firms incorporate environmentally conscious strategy, which measures activities of defining clear objectives and long-term environmental plans, the requirement for suppliers and distributors based on environmental criteria, green-knowledge application, 3Rs concept (e.g., Reduction, Reuse, and Recycling), and environmental management systems (e.g., ISO 14,000/14,001 or others) (Jabbour et al., 2013; Pinto et al., 2018).

4. Data analysis and results

4.1. Descriptive statistics

Sample demographics are given in Table 1 which describes the characteristics of SMEs and their distribution. These demographics were used as control variables. Understanding the effect of firm size could justify the enhancement in eco-innovation (Lin et al., 2019). Most respondents by firm size which was described in the number of employees were between 51 and 250 employees (medium-sized enterprises) account for 40.4%, followed by 11–50 employees (small enterprises) with 36.6%, and finally 1–10 employees (micro-enterprises) 21.6%. Next, the number of years the firm had been in business affected how knowledge would be spread and interpreted within the firm (Sirén et al., 2017). 32.2% of firm age was between 11 and 20 years as firms. The next two places of lengths of business running have been operated for less than 10 years (31.4%) and above 40 years (16.4%). The remaining firm age comprised 21 to 30 years and 31 to 40 years has followed distributions of 13.1% and 6.9%, respectively. The respondents' attitudes towards surveys can substantially affect the quality of data collected; their positions and experience are important to the willingness to participate in surveys (Stocké, 2006). The positions of respondents were found that 81.4% of them were in the top positions (e.g., CEO, Entrepreneurs, Business owners, managers, or other top or middle positions), indicating that this percentage shows the study's criteria follow a majority of respondents. While 18.6% of respondents are in lower than the positions mentioned above. Being an important character of enterprises, the firm location contributes to the differences in resource endowment (Yao & Liang, 2017). Based on the firm's location, almost half (40.7%) of the firms are located in the Northeast region, followed by the Central Region (33.5%). The other four regions are the North Region (8.8%), the East Region (6.9%), the South Region (7.2%), and the West Region (2.8%). Motivated by choice of innovations, different industries play an essential role in various-industry and cross-sector collaboration to redress environmental impacts (McDonald & Young, 2012). The most significant portions of firms are classified in "others" type (e.g., software, ceramic, waste segregation, cosmetic products, paper-making, university and others) account for 41.4%. The next five largest industrial types were food & beverage/agriculture

(17.3%), plastic and textile/fibre both on (5.7%), medical devices & pharmaceutical (4.9%). The remaining was dominated by auto parts and Machinery (4.4%), material science & Chemicals (2.5%), retail/wholesale and steel both on (3.8%), transportation (3.9%), and electronics/automation/robotics (3.6%). The last aspect, seniority, provides information on the majority of top management respondents who have time on their specific job on 0 to 5 years (32.1%), 6 to 10 years (26.6%), more than 15 years (25.3%), and 11 to 15 years (16.0%). The seniority in terms of their involvement in the business can help increase the speed and volume of innovations (Brown, 1998).

4.2. Reliability and validity

Data were initially estimated to ensure instrument quality by convergent and discriminant validity. Using SPSS Statistics v26³ (IMB Corp., 2019), the principal components analysis (PCA) was carried out measuring the underlying dimension associated with 18 items. The result of Harman’s one-factor test showed that the total variance of 39.398% extracted by one factor and it was less than the recommended threshold of 50% (Harman, 1976), there was no issue with common method bias in this study. This result indicated the sampling was, 0.974, adequate for factor analysis since its value exceeded the acceptable threshold of 0.6 (Kaiser, 1974), while Bartlett’s Test of Sphericity (see Table 2) was found to be significant ($\chi^2 = 10,027.253$; $P < 0.001$), indicating that factor analysis could be useful with our data. To ensure of this, variance inflation factor (VIF) was performed (see Table 3). The issue of multi-collinearity could also be detected when the values of tolerance were more than 0.2 (Hair et al., 2010), which ranged from 0.392 to 0.512 and, simultaneously, the values of variance inflation factor were less than 5 (Hair et al., 2010), which ranged from 1.953 to 2.551. Overall, the exploratory factor analysis provides a satisfactory identification of how variables relate, and then confirmatory factor analysis will be performed to determine the factor structure of our dataset in the next step.

Table 3 shows convergent validity and reliability. The values of Cronbach’s alpha were from 0.863 to 0.895, which passed a threshold of 0.7. Also, composite reliability values were from 0.842 to 0.926, which need to be higher than the benchmark of 0.6 or above (Fornell & Larcker, 1981). Thus, these results assured a desirable level of reliability. Meanwhile, all items’ factor loading was higher than the threshold of 0.7 (Bryant & Yarnold, 1995), indicating that variables well belonged to each construct. Consequently, average variances extracted (AVE) were between 0.547 and 0.587, and they were more than the threshold of 0.5 (Hair et al., 2010).

Because of the non-parametric test, Spearman rank correlation was conducted to measure the ordinal degree of association between two variables (Spearman, 1904). Hence, we had the Spearman correlation coefficient (r_s) ranging from 0.327 to 0.592, indicating a positive relationship between the ranks observed variables obtained in each construct. Table 4 shows a discriminant validity. The results of the Fornell-Lacker criterion revealed that the square root of the AVEs (in bold diagonal elements) for each construct surpassed its correlation with any other latent construct (Fornell & Larcker, 1981). The results of the heterotrait-monotrait ratio of correlations (HTMT) also confirmed that there was no discriminant validity problem according to HTMT_{0.85} (Henseler et al., 2014). Therefore, it could be concluded that the discriminant validity provided that the items of constructs were measuring the different things.

Table 2. Results of Kaiser-Meyer-Olkin (KMO) and Bartlett’s Test

KMO and Bartlett’s Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.974
Bartlett’s Test of Sphericity	Approx. Chi-Square	10,027.253
	df	276
	Sig.	0.000

Table 3. CFA, loadings, construct reliability, and convergent validity

Constructs	Items	Factor Loadings	AVE	CR	Cronbach's alpha	VIF	Tolerance
Open innovation (OI)	COI2	0.70				1.953	0.512
	COI1	0.736				2.179	0.459
	OOI2	0.766				2.421	0.413
	OOI1	0.725				2.105	0.475
	IOI2	0.722				2.092	0.478
	IOI1	0.73	0.532	0.872	0.872	2.141	0.467
Green management practices (GMP)	GMP1	0.733				2.160	0.463
	GMP2	0.778				2.532	0.395
	GMP3	0.75				2.283	0.438
	GMP4	0.774				2.494	0.401
	GMP5	0.771				2.463	0.406
	GMP6	0.726	0.57	0.889	0.888	2.114	0.473
Open Eco-innovation mode (OEIM)	MEI1	0.759				1.976	0.506
	MEI2	0.797				2.551	0.392
	PCEI1	0.736				2.532	0.395
	PCEI2	0.765				2.217	0.451
	PDEI1	0.783				2.326	0.43
	PDEI2	0.757	0.559	0.883	0.883	2.101	0.476

Table 4. Discriminant validity				Fornell-Larcker Criterion				Heterotrait–Monotrait Ratio (HTMT) ⁴			
	GMP	OEIM	OI		GMP	OEIM	OI		GMP	OEIM	OI
GMP	0.756			GMP				OEIM	0.542		
OEIM	0.542	0.747		OEIM	0.542			OI	0.44	0.506	
OI	0.44	0.506	0.73	OI	0.44	0.506					

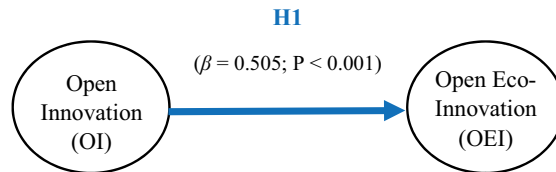
We conducted the confirmatory factor analysis (CFA) with SPSS Amos v26³ (Arbuckle, 2019) to determine how well the model fits to the data. The model fit index fitted fairly well to the data: *CMIN/DF* = 2.078; *GFI* = 0.954; *AGFI* = 0.94; *NFI* = 0.953; *CFI* = 0.975; *TLI* = 0.971; *RMSEA* = 0.041; *RMR* = 0.043 (see Table 5).

4.3. Hypothesis testing and structural model

Figure 2 exhibits the testing results of the structural model. The results show the coefficient of determination (*R*²) for the two models' path coefficients, which all the path coefficients are statistically significant to support the hypotheses as follows. This study aimed at estimating the mediation effect of green management practice on the relationship between open innovation and eco-innovation. Thus, before hypothesising the mediating effect of green management practice, we test the first model describing a reciprocal relationship between open innovation and eco-innovation (*R*²_{OEIM} = 0.255; *β* = 0.505; *t-value* = 10.075; *P* < 0.001), which supported **H1**. Fit indices

Figure 2. Structural model.

Model 1



Model 2

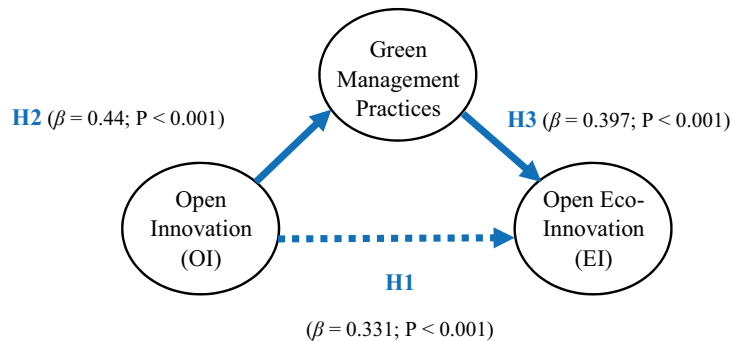


Table 5. Testing for measurement models

	χ^2/df	GFI	AGFI	NFI	CFI	TLI	RMSEA	RMR
CFA	2.078	0.954	0.94	0.953	0.975	0.971	0.041	0.043
Model 1	2.374	0.967	0.952	0.965	0.979	0.974	0.047	0.038
Model 2	2.078	0.954	0.94	0.953	0.975	0.971	0.041	0.043
Thresholds	< 3.00	> 0.90	> 0.90	> 0.90	> 0.90	> 0.90	< 0.08	< 0.08

Note: Chi-Square (χ^2); Degrees of Freedom (df); Goodness of Fit (GFI); Adjusted Goodness of Fit (AGFI); Normed-Fit Index (NFI); Comparative Fit Index (CFI); Tucker Lewis Index (TLI); Root Mean Square Error of Approximation (RMSEA); Root Mean Square Residual (RMR)

Table 6. Structural model results

Path Relationships	Model 1			Model 2		
	Path coefficient	T-value	Results	Path coefficient	T-value	Results
H1: OI → EI	0.505***	10.075	Yes	0.331***	7.048	Yes
H2: OI → GMP				0.44***	9.128	Yes
H3: GMP → EI				0.397***	8.208	Yes

Note: * P < 0.05; ** P < 0.01; *** P < 0.001

for the model 1 were adequate: CMIN/DF = 2.374; RMR = 0.038; GFI = 0.967; AGFI = 0.952; NFI = 0.965; TLI = 0.974; CFI = 0.979; RMSEA = 0.047. This lends support to the open eco-innovation theory (Ghisetti et al., 2015; Montresor et al., 2013), indicating that open innovation could result in eco-innovation which this current investigation can also reach the new mode to implement the strategies and policies in the next section. Still, **H2** was confirmed to investigate how open innovation relates to the small firm's green management practices. Findings indicate open innovation was a significant determinant of the small firm's green management practices ($R^2_{GMP} = 0.193$; $\beta = 0.44$; $t\text{-value} = 9.128$; $P < 0.001$). **H3** was also supported to test the effect of green management practices on eco-innovation, unfolding ($R^2_{OEIM} = 0.382$; $\beta = 0.397$; $t\text{-value} = 8.208$; $P < 0.001$). As a result, the strength of the effect of **H1**, **H2** and **H3** provided evidence for **H4**. The empirical results of **H4** ($R^2_{GMP} = 0.193$; $R^2_{OEIM} = 0.382$; $P < 0.001$) suggested that green management practices positively mediated the relationship between open innovation between eco-innovation, as shown in Table 6. However, the OI-EI relationship's coefficient diminishes due to the presence of green management practice as a mediator variable (**H4**). Thus, the second model reveals how the direct relationship between open innovation and eco-innovation, although significant, is lower than the relationship in the first model. These results support the mediation test of hypothesis 4 (i.e., model 1 with a direct relationship and model 2 with indirect or mediating effect). After confirming the overall measurement model was valid and acceptable, the structural model for the model 2 was evaluated. The fit indices for the model 2 (see Table 5) were explained as follows: CMIN/DF = 2.078; RMR = 0.043; GFI = 0.954; AGFI = 0.94; NFI = 0.953; TLI = 0.971; CFI = 0.975; RMSEA = 0.041. All indices indicate a good fit (Hair et al., 2010).

4.4. Discussion

The results of this current research contribute to the new integrative model of innovation theories, namely, the open eco-innovation mode, and also provide potentially necessary policy implications. Firstly, the current study adds to open innovation and eco-innovation theories by introducing the concept of open eco-innovation mode (OEIM) as a competitive environmental advantage for SMEs. This is critical as the value of small firms' innovation levels as a competitive environmental advantage is likely to arise in the future, as the proportion of stakeholders with green awareness increases, particularly across developing industrial economies like Thailand. The idea of moving beyond an econometric measure as a measure of human capital is beginning to disclose in the literature (Ghisetti et al., 2015; Lopes et al., 2017; Triguero et al., 2018; Yang & Roh, 2019); our research's results proffer additional insights to this debate.

Addressing **H1**, we find that the firm's open innovation affects the adoption of eco-innovation among Thai SMEs. Those small firms that have academically high-educated employees applied the open innovation strategies more often. We find that open innovation with small firms can boost eco-innovation, which allows us to obtain the open eco-innovation mode. This finding contrasts against Yang and Roh (2019), recommending that the influence of open innovation by larger firms goes well on process eco-innovation, especially reducing the waste of products by consumers. Our finding is also supported by Ghisetti et al. (2015), suggesting that external knowledge sourcing may improve the firm's coverage of the multiple knowledge needs involved by the multi-dimensionality of eco-innovation. In addition, open R&D can increase the firm's propensity to scan external knowledge and decrease the cognitive dissonance from the external sources. For example, employees may prevent training for innovation and creativity, causing the NIH syndrome (Burcharth et al., 2014). At the same time, Thailand's economic-recessive climate can be argued that financial resources and accessibility may be increasingly limited. The market power of the latter with the exception of incremental and radical environmental friendly eco-innovations shows larger firms eco-innovate more than SMEs (Triguero et al., 2018). However, most SMEs do not carry out R&D, and the possibility to survive in business relies on the knowledge-asset exploitation such as patent and as a tool to increase firms' innovative activities (McGuirk et al., 2015), particularly idea search and generation (Gama et al., 2019). As supported by Lopes et al. (2017), the review of the product issues is important to talk sufficiently about, and research on the product impact may have on people and the world. We find the mechanisms of

open innovation for sustainability reflected the process, management and product orientation with firms to guarantee that the raw materials link the bottom line of sustainability (i.e., connecting ecology with social and economic awareness). The critical point is to communicate about environmental criteria throughout the whole supply chain. Our evaluation results concerning **H2**, **H3** and **H4** indicate that the mediating role of green management practices on the relationship between open innovation and eco-innovation; smaller and younger firm tend to apply the open eco-innovation strategies more often than larger and older ones. We find that green management can stimulate a different type of eco-innovation, particularly internally-oriented process eco-innovation. This can bring the firm the cost efficiency and product quality. If the differentiation benefit is present, SMEs should develop product eco-innovation, that is, a firm's eco-innovation can develop the eco-friendly product with various market-based collaboration (e.g., green customers and green suppliers) and university. Particularly in non-specific green firms, our finding suggests that the engagement of external actors (supply chain partners) rather than the internal environmental management to activate eco-innovation efforts. Consequently, the current research on the open eco-innovation model also suggests green management practice can connect indirectly through the relationship between different types of open innovation whether firm's internal innovation capabilities or support routines for stable interactions with external knowledge sources. We may observe a definite effect of open innovation on eco-innovation when firms' opportunities are open for venture capital, highly qualified specialists, and competent customers and specialized green suppliers. But open innovation itself does not have the power to affect large sums in internal (green) research and development (R&D) to establish it as a know-how centre or even innovative products and solutions. Green management practices without which there would be no connection to implement simple and inexpensive changes that lead to significant reductions of environmental impact. Therefore, only affecting green management practices as an intermediary can it make an actual difference in small firms' environmental impact diminished. For instance, open innovation as a new business unit *does not need* to implement ISO 14,001 or other environmental management systems. As a result, this can be achieved by external-involved selection from the views of manufacturers and suppliers provides the environmental standard and evaluate them on both conventional criteria: and environmental criteria (Gupta et al., 2019). Interestingly, Khan et al. (2019) argue differently from our finding that the environmental management system ISO 14,001 will help modify the inefficient use of resources, non-clean energy, non-green technologies. It also guides top-level managers to meet stakeholder's expectation without the future generation needs and wants. This role of green management practice acts as a moderator variable. However, Hamdoun et al. (2018) support our finding that green management practices encourage innovation with many features. The practices provide a robust mechanism to develop their management practices, seek and use the information and enhance their capacity to exploit innovation to cope with changing circumstances and this, in turn, increases the capability for eco-innovation. What's more, continuous improvement of the firm's eco-innovation performance gets incorporated into organizational and operational structures in which staff are getting involved in the reduction of environmental impact (Yang et al., 2010).

5. Implications for strategy and policy

The results of this study suggest that open innovation and green management practices promote eco-innovation. These results can help practitioners (such as managers, academic researchers and policy-makers) reap advantages in the open eco-innovation mode, which represents open innovation and eco-innovation to reduce or prevent negative environmental effects with various stakeholders. This paper develops the novel and multi-dimensional OEIM concept and offers insights to understand the eco-innovation benefits, which can be derived from open innovation by enhancing green management practices. Based on evidence-based implications, we use the item measures from factor loadings to recommend some of the following strategy and policy initiatives to promote the open eco-innovation mode:

- (1) **Clear objectives and long-term environmental plans:** firms must set feasible, appropriate goals for their environmental position. This is to provide a clear target for all staff to work toward the environmental goals in the organization. Long-term environmental plans are more likely to cause harmful change in stakeholder traits because of the long-term negative effects. Therefore, planning for the reduction of hazardous substances (e.g., chemical waste) can make continuous efforts toward diminishing the environmental impact through comprehensive voluntary controls and strategic eco-innovation development.
- (2) **Be actively involved with external partners:** External engagement is collaborating for mutual benefit with the university, customers, competitors, research institutes, consultants, suppliers, or government). It is crucial to identify external partners who can influence or could be affected by the project. This is to meet what they anticipate from you as firms and disclose what you as firms cannot control. Communicating with or directly involving stakeholders is vital for an open innovation project.
- (3) **Coordinate the activities of information exchange among partners:** Coupled Open innovation facilitate transparency and growth in knowledge transfer and start-up and business development. This allows SMEs to exchange information directly, promoting informal contacts and better understanding among partners. Support a learning culture among staff.
- (4) **Use innovative, environmental-friendly technologies to save energy:** If SMEs can take action plan for each industry sector (e.g., food & beverage, agriculture, plastic, auto parts and machinery etc.), they can save energy and reduce CO₂ emissions. Thus, promoting innovation to use in any economic activities can help minimize CO₂ emissions from routine operations.

6. Conclusion, limitations, and future research

Using data on Thai SMEs, this paper studies the adoption of open innovation to extend the efforts of eco-innovation by firms belonging to traditional (close) and open industries. Also the intermediary role of green management practices which represents state of the art in the new concept of the open eco-innovation mode is considered. For both models, the results show awareness in SMEs; there is evidence from the distribution results that the open eco-innovation may be more valuable to medium-sized enterprises (i.e., 51–250 employees). Our findings overall demonstrate a clear relationship between open innovation and eco-innovation. The relationship between open innovation and eco-innovation is found to be positive and significant, and this confirms our hypothesis that having both open innovation and eco-innovation and utilizing both aspects simultaneously can lead to the open eco-innovation mode. This finding is consistent with early empirical studies (Ghisetti et al., 2015; Lopes et al., 2017; Triguero et al., 2018; Yang & Roh, 2019) while we explain the lack of statistical evidence of green management practices as a mediator to intervene in the relationship between open innovation and eco-innovation in order to reduce environmental impacts. It also answers the two key questions posed, namely: do open innovation activities respond to eco-innovation? and how does green management practices mediate the relationship between open innovation and eco-innovation to extend towards the open eco-innovation mode in SMEs? We find that SMEs whose innovation activities have OEIM are more likely to entail product, process, and managerial innovation. However, seeking external partners can provide the eco-innovators with an environmental safeguard against the potential discharge of inputs (i.e., raw materials etc.) sourcing from outside. The influence of breadth and depth of knowledge sources on eco-innovations is important to identify extensive and intensive collaboration with external partners such as academic institutions, customers, competitors, research institutes, consultants, suppliers, or government. At the same time, the implementation of eco-innovation requires inward-oriented green management. However, if SMEs wish to obtain the win-win Porter effects, they need to connect closely with the novel degree of eco-innovators (Ambec et al., 2013).

Although our study proffers the valuable new insights into the open eco-innovation mode, it does inevitably have limitations which need to be considered for further investigations. First, our analyzed findings surveyed and restricted to only SMEs in Thailand. Thailand context is an

important one with vital significance to the ASEAN community; however, it is rather specific and can limit the generalizability of our results, particularly in large organizations. Thus, future researchers should explore the mediating effects of green management practices on the open eco-innovation mode comparing the influential innovation activities between SMEs and large corporations to be able to estimate the generalizability of the current research's findings. Accordingly, time limitation allows us to use cross-sectional data. We encourage the next further investigation to develop multilevel time series models with applications to repeated measures data. This to reach pre- and post-behavioural interpretation to specify causality. Thirdly, and motivated by (Triguero et al., 2018; Yang & Roh, 2019), it is encouraged to consider the different types of eco-innovation; consumer eco-innovation and supplier eco-innovation. If environmental impacts on both innovation adoptions are considered, the balance between production and customer demand probably interact with time requirements, costs, and energy consumption to produce goods. Finally, we cannot test green management practices in the non-linear relationship because of their nature. Future research may develop the curvilinear function to see the performance of green management practices.

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Notes

1. Data taken and calculated from *Thailand Board of Investment (BOI) and the National Science Technology and Innovation Policy Office (STI)*.
2. The population size is based on this report of DBD: https://www.dbd.go.th/download/document_file/Statistic/2560/H26/H26_2017.pdf
3. Licensed by Khon Kaen University (KKU).
4. In our analysis, we interestingly found that the off-diagonal correlations in Fornell-Larcker Criterion were the same as correlations in Heterotrait-Monotrait Ratio (HTMT).

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Appendix

Table 1. Measures and survey questions		
Bibliographic references	Constructs	Statements
Jabbour et al. (2013) Pinto et al. (2018)	Green Management Practices (GMP)	I believe that our firm prioritizes to promote ...
		GMP1: ... clear objectives and long-term environmental plans
		GMP2: ... requirement for suppliers and distributors based on environmental criteria
		GMP3: ... green knowledge infusion among employees
		GMP4: ... 3Rs concept (e.g., Reduction, Reuse, and Recycling)
		GMP5: ... environmental management systems (e.g., ISO 14,000/14,001 and/or others)
Hung and Chou (2013) Burcharth et al. (2014)	Inbound Open Innovation (IOI)	I believe that our company prioritizes to ...
		IOI1: ... involve with external partners (e.g., university, customers, competitors, research institutes, consultants, suppliers, or government) in all our innovation projects
		IOI2: ... use the internet to search for new trends or technology
Hung and Chou (2013)	Outbound Open Innovation (OOI)	I believe that our company prioritizes to ...
		OOI1: ... often sells licenses, such as patents, copyrights, or trademarks, or know-how to other firms in the market
		OOI2: ... have product lines, divisions, and/or the dedicated business unit (i.e., gatekeepers, promoters) to commercialize knowledge assets (e.g., selling, cross-licensing patents, or spin-off)
Mazzola et al. (2012) Cheng and Huizingh (2014)	Coupled Open Innovation (COI)	I believe that our company prioritizes to ...
		COI1: ... engage in R&D alliance and/or R&D joint venture
		COI2: ... coordinate the activities of exchange of information among partners

(Continued)

Table 1. (Continued)

Bibliographic references	Constructs	Statements
Chiou et al. (2011) García-Granero et al. (2018)	Product eco-innovation (PDEI)	Relative to the firm's environmental objective, I believe that our firm searches for ...
		GPI1: ... developing new products/ services with low environmental impacts
		GPI2: ... reducing the use of raw materials
Chiou et al. (2011) García-Granero et al. (2018)	Process eco-innovation (PCEI)	Relative to the firm's environmental objective, I believe that our firm searches for ...
		GPCI1: ... reusing the components and reducing chemical waste
		GPCI2: ... using the innovative, environmental-friendly technologies to save energy
Chiou et al. (2011) García-Granero et al. (2018)	Managerial eco-innovation (MEI)	Relative to the firm's environmental objective, I believe that our firm searches for ...
		GMI1: ... cooperating with customers and/or clients for green innovation management
		GMI2: ... cooperating with stakeholders to support strategic eco-innovation development



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