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Effects of eco-innovation typology on its performance: Empirical evidence from Chinese enterprises

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A B S T R A C T

The reason for the lack of consensus on correlations between environmental performance and competitiveness may lie in scholars neglecting eco-innovation typology. To fill this gap, this study conducted regression analysis on 245 Chinese enterprises. The survey indicates the organizational eco-innovation is the most common with a ratio of 38.3%, then followed by process eco-innovation with 32.7%, product eco-innovation with 16.3% and end-of-pipe eco-innovation with 12.7%. The findings demonstrate that different types of eco-innovation do have significant influences on environmental performance and competitiveness. Firm size has differing impacts on environmental performance and competitiveness, being significantly positively associated with the former and not with the latter. Environmental regulation creates a positive effect on both firms' environmental performance and competitiveness, while the implementation of environmental regulation only significantly affects a firm's environmental performance and not its competitiveness.

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Introduction

Eco-innovation refers to "the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives" (Kemp and Foxon, 2007a, p. 4). In an effort to reduce or prevent negative environmental effects, eco-innovation has attracted significant attention among industrial practitioners, academic researchers, and government policy makers in the past several decades.

However, there is still a question mark over whether eco-innovation enhances the competitive advantage of a firm (Ambec, 2011; Wagner, 2005). In fact, there is no consensus regarding correlations between environmental performance and economic performance or competitiveness. That is to say, there is still no clear indication whether those correlations are positive, negative, or mixed, or even if these factors are correlated (Boons and Wagner, 2009). Perhaps this lack of clarity is a result of the dual nature of eco-innovation, as it can be viewed as both an innovation and an environmental measure (Rennings, 2000).

Underpinning the dual externality of eco-innovation are complex relationships between drivers, typologies and the performance of eco-innovation (Kemp and Foxon, 2007b). Researchers, such as Cleff and Rennings (1999), Rehfeld et al. (2007), Costantini and Mazzanti (2012), Rassier and Earnhart (2010) and Kesidou and Demirel (2012), have pointed out that eco-innovation features and types of environmental regulation have not been paid adequate attention, and thus the understanding of the effects these regulations have on a firm's eco-innovation performance is limited. Moreover, diverse regulatory measures add complexity to the issue (Wagner, 2006; Popp et al., 2011; Horbach et al., 2012).

Maintaining the balance between environmental and economic performance is more challenging in developing countries than in developed economies. In China, for example, eco-innovation practices are still embryonic, and most small and medium enterprises (SMEs) would perceive the costs of implementing eco-innovations to be prohibitive, and may not always have the resources to follow an optimal strategic eco-innovation strategy (Dong and Shi, 2013). Additionally, there has not been sufficient research in developing countries on eco-innovation measures and the sustainability performance of business practices (Dong and Shi, 2010).

This paper focuses on specific eco-innovation types, environmental regulations, and their impact on a firm's eco-innovation performance (including environmental performance and competitiveness). By scrutinizing empirical evidence from a sample of 245 Chinese enterprises, this paper identifies typologies of eco-innovation implemented in industrial enterprises, and then analyzes the mechanism of how those typologies affect a firm's eco-innovation performance, alongside environmental regulations and firm size.

Literature review

The typology of eco-innovation

Categorizing types of eco-innovation is a prerequisite of conducting eco-innovation research. Compared with research on general innovation, eco-innovation research acquires the new dimension of environmental management, which adds complexity. There are two ways to categorize eco-innovations.

The first way is to learn from categorization methods on general innovation (Huber, 2008). For example, Rennings (2000) assessed eco-innovation activity to categorize eco-innovations into technological, organizational, social, and institutional types. Laurentis and Cooke (2008) and Oltra and Saint (2009) differentiated eco-innovation by product innovation, process innovation, and organizational innovation types. The Measuring Eco-Innovation (MEI) project (2007) categorized eco-innovation into disruptive innovation, sustainable innovation, and system innovation according to innovation intensity. Another possibility is to categorize eco-innovation according to a firm's position in its supply chain and thus into initial product, process, end-product, and customer innovation (Huber, 2008).

The second way is to consider the features of environmental management. For example, Reid and Miedzinski (2008) classified eco-innovation into four types: life-cycle innovation, product and process innovation, organizational innovation, and marketing innovation by considering the environmental performance of eco-innovation. The OECD (2009) distinguished four types of eco-innovation: pollution management, clean technologies and products, natural resource management, and eco-friendly products based on their technical characteristics and environmental impacts.

Eco-innovation performance

Eco-innovation performance has been referred to in extant literature as a combined indicator of economic performance, sustainable competitiveness and environmental performance (Orlitzky et al., 2003; Margolis and Walsh, 2003; Boons and Wagner, 2009).

Economic performance indicators include the investment cycle, rate of return on investment (ROI) and net present value, and are usually measured through cost-benefit analysis, incorporating cash flow, and financial dynamic profitability (Kemp and Horbach, 2007). The MEI project (2007) recommended that the measurement of the economic performance of an eco-innovation system be expanded to consider a broader framework covering the market for the firm's products, factors of production, education and training systems, tangible infrastructures, and macro-economic policies.

Competitiveness is defined as high levels of international advantage and income flows (OECD, 2005), as well as profitability from a firm's process or product innovation. Fischer and Schornberg (2007) measured competitiveness by analyzing profits, production rates, and output increases, whereas Yu (2010) defined competitiveness as revolving around the familiarity with the relevant industry and competitors, price-based competition, and the follow-up speed of state-of-the-art technology. He et al. (2007) proposed short-term market profitability (e.g., ROI, net profit, profit increase, and net profit growth compared to competitors) and long-term growth potential (e.g., increased cash flow, sales, revenue growth, and market share) as indicators of competitiveness.

Environmental performance is central to eco-innovation. However, finding a suitable way to define environmental performance for eco-innovation is challenging (Wood and Jones, 1995). Generally, environmental performance is defined from a micro or a macro perspective.

From the micro perspective, environmental performance involves standards defined in existing environmental regulations as well as other directly measurable environmental indicators, such as water quality, air pollutant emissions, solid waste generation, and noise level (Boons and Wagner, 2009). These environmental indicators are usually quantitative and standardized, such as water and air pollution indices, and could be condensed into a single factor, or presented as a weighted-indicator that measures a variety of environmental influences (Belin et al., 2009). Micro-level eco-innovation performance is usually measured to evaluate the legality of a firm's operations and/or compare it to different firms (Lázaro et al., 2007).

From the macro perspective, environmental performance measures a firm's performance from systematic and dynamic viewpoints, indicating the accumulative efficiency and effectiveness of a firm's long-term efforts at pollution control, natural resource preservation, and ecological restoration (Ofezu, 2006). Environmental management performance systems and green innovation accounting systems (Chen and Xue, 2006) are examples of the tools utilized to measure a firm's macro-level eco-innovation performance. Macro-level eco-innovation performance considers not only the micro-level performance indicators but also the benefits achieved by continuous environmental improvements, among which economic performance and competitive advantages are particularly closely scrutinized (Boons and Wagner, 2009).

Owing to the diversity of environmental performance, some researchers have proposed an integrated indicator system to measure environmental performance. For example, Mazzanti and Zoboli (2006) stated that the measurement of eco-innovation performance should include the following four areas: (a) number of patents, number of environmental patents, and R&D expenses; (b) expenses on pollution control; (c) production efficiency of natural materials and pollution intensity; and (d) reduction of pollutant emissions. Similarly, the MEI project adopted a series of indicators in its final report on eco-innovation measurement that included firm image, market share, natural resource

Table 1
Eco-innovation performance indicators and their sources.

Variable	Measures (indicator)	Literature
Environmental performance (the improvement of the environment in the past 3 years)	Reducing the material utilization per unit product	MEI (2008), ZEW (2008), Mazzanti and Zoboli (2006), Seroa da Motta (2006), Doonan et al. (2005) and Cole et al. (2005)
	Reducing the energy consumption per unit product	
	Reducing the water consumption per unit product	
	Replacing the energy consumption by recycling energy	
	Replacing materials with safer or less harmful alternatives	
	Reducing the emission of liquid, gas or solid pollution or waste products	
	General environmental indicators	Nogareda (2007) and Cole et al. (2005)
Competitiveness (compared with the national average in the same industry)	Market share	MEI (2008), Oltra et al. (2008), Oltra and Saint (2009) and Park (2005)
	Firm's image	MEI (2008), Nogareda (2007) and ZEW (2003)
	Firm's general competitiveness	Brunnermeier and Cohen (2003)
	Patent application number	Brunnermeier and Cohen (2003), Arundel and Kemp (2009)
	Firm's R&D expenditure	Cooper and Kleinschmidt (1987), Tien et al. (2005) and Hamamoto (2006)

usage, energy usage, renewable and non-renewable energy, water usage, greenhouse gas emissions, and total waste (Kemp and Pearson, 2007).

Overall, eco-innovation performance can be evaluated by its environmental and economic benefits, as well as by any competitive advantage from eco-innovations. The measures of eco-innovation performance and the major research pieces on them are summarized in Table 1.

Environmental regulation and the type and performance of eco-innovation

One important issue in eco-innovation research is the relationship between environmental performance and economic or competitiveness performance. In fact, this puzzle has been addressed by the famous Porter Hypothesis (PH) which posits whether environmental regulation can stimulate firms to carry out eco-innovation and then build a competitive advantage (Porter, 1991; Porter and Van der Linde, 1995).

In the past 20 years, the PH has been extensively discussed from both empirical and theoretical perspectives in the literature, without any clear consensus emerging as a result. To test the theory and evidence more acutely, Ambec et al. (2010) pointed out that the Hypothesis actually comprises two component parts, a "weak" and a "strong" version. The former refers to properly designed environmental regulation having the capacity to spur innovation. The latter refers to the situation where environmental regulation often leads to an increased firm competitiveness by offsetting additional regulatory costs. It indicated that most empirical studies validated the weak PH, while no consensus has been reached on the strong PH (Dong and Shi, 2013).

Based on evidence collected from seven OECD countries, Frondel et al. (2007) concluded that regulatory measures and the stringency of environmental policy were positively correlated with end-of-pipe technologies, whereas cleaner production may be motivated by market forces, among other factors.

Nogareda (2007) conducted a series of face-to-face interviews with a sample stratified along firm size and in subsectors of the German and Swiss chemical industry. The research results showed that the determining factors of environmental innovation included policy style characteristics and the stringency of regulation, thus emphasizing the importance of corporate environmentalism. In the case of environmental process innovation, regulatory stringency and quantity had a positive impact, but the hypothesized importance of policy style variables was not supported.

Demirel and Kesidou (2010) proposed that regulatory stringency plays an important role in a firm's eco-innovation activities. Johnstone and Labonne (2006) identified several influential factors that significantly affected eco-innovations, including the stringency of environmental regulations, the flexibility of environmental regulations, environmental management systems, and a firm's organizational framework for environmental management. Rehfeld et al. (2007) concluded that environmental regulation not only influenced eco-innovation activities but also affected the firm's eco-innovation performance. Using a Mannheim innovation panel[1] and telephone surveys, Cleff and Rennings (1999) demonstrated that in the case of end-of-pipe (EOP) solutions and clean technologies, compliance with policy measures (e.g., environmental labels, laws and regulations, penalty fines, and soft tools) was a major determinant of the effect on a firm's eco-innovation performance. The authors also concluded that the influences on product and process eco-innovations could vary under different policies, among which the adoption of ecological labels and ecological accounting have a significant positive impact.

Khanna et al. (2009) performed a series of analyses on regulatory pressures on toxic releases, including the effects of penalty fines, frequency of environmental inspections, and pollution prevention regulations. Their findings suggested that regulatory pressure was the major incentive and a firm's complementary assets contributed to the internal competence for eco-innovation. Ashford et al. (1985) noted that, in addition to regulatory stringency, flexibility in ensuring regulatory compliance could also help stimulate eco-innovations and technology upgrades. In other words, the effect of environmental regulations is dependent on how they are implemented.

Pablo del Río González (2009) reviewed the literature on the empirical analysis of the determining factors for environmental technological change, pointing out the significance of exploring those factors related to different types of environmental technologies. Meanwhile, he also proposed including the impact of regulatory stringency, the *style of regulation*, and the design elements of environmental policy on environmental technological change in future research.

In summary, environmental regulation does play a role in eco-innovation, and that role might be either positive or negative. The direction and strength of the impact depends on the type of environmental regulations, the type of eco-innovation, the stages of eco-innovation, and on some characteristics of the regulated object itself (Frondel et al., 2008; Horbach et al., 2012; Wagner, 2008).

Hypotheses on the relationship between eco-innovation types and eco-innovation performance

Eco-innovation types and environmental performance

Every eco-innovation should lead to improvement of environmental performance according to its definition. Thus, there is no significant meaning if we just consider the relationship between eco-innovation type and environmental performance without considering what typology influences competitiveness and how to make the difference. Now, the key point lies in how to categorize types of eco-innovation.

Extant studies aimed to examine the effects of specific eco-innovation types as well as the factors affecting a firm's environmental performance. The reported findings suggest that eco-innovation type is an important factor that, when combined with a firm's inherent character and environmental regulations, could significantly affect a firm's environmental performance.

Sheppard (2007) analyzed 82 process and product eco-innovation cases in the U.S.A. and concluded that eco-innovation performance delivers external recognition through awards, memberships, and

[1] Mannheim Innovation Panel – the Annual German Innovation Survey. Every year since 1993, the Centre for European Economic Research (ZEW) has gathered data on innovation activity within the German Economy. The ZEW innovation survey provides a valuable basis for the assessment of the German economy's technological performance.

certificates. Moreover, product eco-innovation prompts improved market recognition, while the effects of process eco-innovation on eco-innovation performance are neither as significant nor adequately valued by the market.

Seroa da Motta (2006) performed an analysis on the factors affecting the environmental performance of 325 medium- and large-sized Brazilian industrial firms. The findings suggest that the characteristics of the firm (i.e., firm size, industrial sector, and external connections), community demands, and market value, as well as the incentives from cost savings and subsidized credits, were significant determinants of a firm's environmental performance. These factors were also significant in determining and characterizing eco-innovation types.

Based on literature interviews above, the approach taken in the current research is to classify eco-innovation types into EOP solutions, process eco-innovation (PcEI), product eco-innovation (PdEI) and organization eco-innovation (OEI). The first three types emphasize technical aspects while the last type focuses on organizational issues, such as environmental certification, environmental audit, organization development, and other measures.

The aim of adopting EOP solutions in a firm is directly to improve environmental performance, such as by reducing the emission of pollutants to meet national or local standards. Generally, EOP solutions are usually implemented in response to environmental regulations and public pressures (Dong and Shi, 2013).

The aim of PcEI is not limited to explicitly improving environmental performance. Aims might include reducing cleaner production costs, or pollutant emissions to comply with environmental requirements, but the PcEI option might also be selected to enhance tacit environmental performance, such as increasing resource utilization and pollution protection.

The PdEI type aims to achieve long-term environmental performance by responding to the environmental needs of the market and the government in order to improve resource effectiveness and achieve the optimal environmental benefits for a product's lifecycle.

The OEI type aims to sustain and improve ecological benefits and resource efficiency, while extending the firm's social responsibility. Its aim is thus to improve total environmental performance, based on the environmental vision of the firm.

Therefore, the authors hypothesize that the types of eco-innovation a firm chooses to adopt significantly influences its environmental performance.

Hypothesis 1. A firm's environmental performance is significantly influenced by the eco-innovation type it adopts.

Eco-innovation types and competitiveness

A majority of researchers to date have considered eco-innovation a source of competitive advantage. Teece et al. (1997) concluded that a firm's competitive advantage stems from a combination of factors such as economy of scale, cumulative learning effects, internal competencies, innovation processes, and complementary assets. In implementing eco-innovation practices, a firm's technical and knowledge-based expertise is enhanced, and the economic performance hypothetically improves. However, the effects on competitiveness may vary depending on the eco-innovation type selected.

Kemp and Horbach (2008) considered product and process eco-innovation to be measures with the potential to reduce production costs and provide firms with a cost advantage. Moreover, firms might obtain first-mover advantage for novel products through market establishment. Nogareda (2007) stated that, compared with process and organization innovation, product eco-innovation could positively affect a firm's competitiveness and market recognition. Process eco-innovation usually provides more opportunities to improve production efficiency. Arundel and Kemp (2009) confirmed that eco-innovation could benefit both economic and environmental performance, but their effects on competitiveness might be indirect. Those authors also suggested that the effect on competitiveness could vary depending on the types of eco-innovation and the conditions of environmental regulations.

Eco-innovation enhances a firm's competitive advantage through different mechanisms. Product eco-innovation helps firms achieve high ROI through developing "green" products and can deliver the advantages of product differentiation in the market (Hart, 1995; Sheppard, 2007; Kammerer, 2009). Process eco-innovation focuses on technology and process upgrades, which improve production efficiency and logistics competence, thereby generating cost savings. However, in some cases, the environmental-performance improvement obtained by investing in eco-innovation may come at the cost of financial losses. This situation is particularly significant for EOP solutions, where the high capital investment in pollution prevention and/or control technologies, for example, may prevent firms from enhancing their competitiveness in the market.

Hypothesis 2. A firm's competitiveness is significantly influenced by its eco-innovation type.

Firm size and performance

Although evidence shows that SMEs display very different environmental behavior than large firms (Andries and Stephan, 2013), there is differ with how firm size affects the firms' eco-innovation and environmental performance. Most existing research suggests that firm size has a positive effect on eco-innovation performance from the perspectives of resources, economies of scale, advantage of reputation, R&D cost, and risks. Small firms may not have the necessary resource configurations and organizational practices to deal with the multidimensional nature and broad scope of eco-innovation (Darnall et al., 2007). Research supporting this assertion includes that of Arora and Cason (1995) based on data from 302 firms, and Hettige et al. (1996) who revealed that firm size affected the eco-innovation performance of 26 paper mills in Bangladesh, India, Indonesia, and Thailand. Conceicao et al. (2006) also found a positive relationship between eco-innovation and firm size in research on eco-innovation in Portugal from 1995 to 1997.

Given the link of eco-innovation and environmental performance, this effect also spills over to the latter. In line with this, Cole et al. (2005) found that pollution intensity was negatively correlated with firm size based on an analysis of industrial pollution emissions from British firms between 1990 and 1998. Similarly, based on the 1997 research of 325 large- and medium-sized firms in Brazil, Seroa da Motta (2006) argued that firm size was one of the key variables determining of environmental performance.

Other researchers have argued that firm size has a negative impact on the competitive performance of eco-innovation, due to issues of complementary assets, resource constraints and the nature of technology. Such studies include that of Ofezu (2006) and Wagner (2008) also arrived at similar findings following the European Business Environment Barometer (EBEB) survey conducted in nine European countries (Belgium, France, Germany, Hungry, the Netherlands, Norway, Sweden, Switzerland, and the UK) in 2001. Therefore, we hypothesize that:

Hypothesis 3. Firm size has a positive effect on its environmental performance.

Hypothesis 4. Firm size has a positive effect on its competitiveness.

Environmental regulation and implementation

Most researches have confirmed the role of environmental regulations in inducing eco-innovation (Lanoie et al., 2011; Lee and Bae, 2011; Doran and Ryan, 2012), however, the impact of environmental regulations on firm performance (which is focused by the strong PH) is ambiguous.

Some empirical studies confirmed the positive effects of environmental regulations on firm performance (Testa et al., 2011; Blind, 2012; Rexhäuser and Rammer, 2014), while some did not (Stanwick and Stanwick, 1998; Ramanathan et al., 2010). That means there exist complex mechanisms between environmental regulations and firm performance. The impact, direction and strength of environmental regulations on firm performance depend on the type, stringency, flexibility and uncertainty of regulations (Oltra et al., 2008).

Different types of environmental regulations may have different effects on performance. Command-and-control regulations can have a push effect by benefiting eco-innovators from lower uncertainty due to regulatory risks and demand-generating effects of regulation (Rennings and Rammer, 2011) whilst economic regulations can have a pull effect. For example, tax incentives will stimulate a consumer's motivation to purchase and demand eco-innovative products. Taylor et al. (2006) also found that the demand-pull effect works mainly with regard to the adoption and diffusion processes of eco-innovations.

Despite of the difference in regulation types, Rennings (2000) argued that environmental regulations have a "regulatory push/pull" effect that could positively affect corporate eco-innovation initiatives. Hence, the following two hypotheses are proposed with regard to regulation.

Hypothesis 5. Environmental regulation has a positive effect on a firm's environmental performance.

Hypothesis 6. Environmental regulation has a positive effect on a firm's competitiveness.

Besides the style of regulations, the implementation and stringency of regulations (which is here referred to as the execution of regulations) also impact the effect environmental regulations on firm performance (Pablo del Río González, 2009). For example, estimating a simultaneous panel data model of environmental innovation and toxic air pollution of 127 manufacturing industries Carrión-Flores and Innes, 2010 found that tightened pollution targets induced environmental innovation but the proportionate contribution of induced innovation to long-run emission reduction was small. Kneller and Manderson (2012) observing UK manufacturing industry during 2000 to 2006 also found that abatement pressures stimulated environmental innovation but that environmental costs were not positively related to total innovation activity. Thus, we propose the following hypotheses pertaining to effects of the execution of regulation.

Hypothesis 7. The execution of environmental regulations has a positive effect on a firm's environmental performance.

Hypothesis 8. The execution of environmental regulations has a positive effect on a firm's competitiveness.

Thus, we present eight hypotheses, as illustrated in Fig. 1.

Methods and data

Identifying eco-innovation types

According to the methods and findings in previous research (OECD, 2005; Mazzanti and Zoboli, 2006; CIFP, 2009; Foxon and Pearson, 2008; Arundel and Kemp, 2009; ZEW, 2008; Laurentis and Cooke, 2008), the current research is informed by responses to a questionnaire featuring two distinct sections that aimed to reveal the types of eco-innovation applied by firms (Section 1 of the Appendix: the types of ecological innovation). The first section is to ask about activities of the enterprise over the past three years (2007–2009), comprising 29 objective, multiple-choice questions on eco-innovation strategies, comprising five questions for EOP, nine for PcEI, six for PdEI, seven for OEI, and two for other aspects. In the second part, the respondents were asked to subjectively rate the four eco-innovation types and indicate their perceived significance. To identify the type of eco-innovation, we set the following equation.

$$EIScore_i = \frac{X_i}{X_{total}} \times (5 - Y_i) \tag{1}$$

$EIScore_i$ is the score assigned to the ith type of eco-innovation; $i=1,\ldots,4$ is the indicator of an eco-innovation type; X_i is the number of actions/measures taken in support of the ith type of eco-innovation; X_{total} is the total number of actions/measures; Y_i is the order of significance of the ith type of eco-innovation rated by the interviewees.

Measuring eco-innovation performance

The measurement of eco-innovation performance in this paper is based on previous research findings, empirical evidence, expert opinion and a pre-test. Other than questions about the objective characteristics of the surveying firms and/or the interviewees, questions on features of a firm's eco-

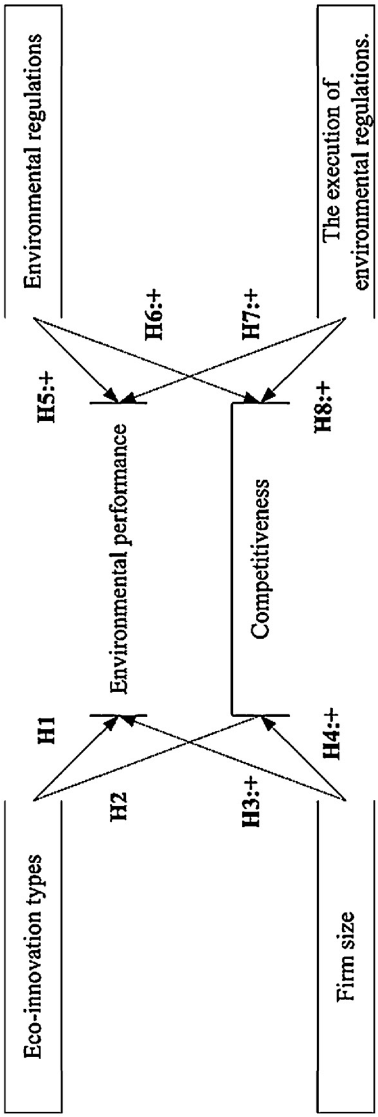

Fig. 1. The eight hypotheses in our model.

innovation activities, performance, and perception of regulations were assessed on a 7-point Likert scale.

The questionnaire included 12 questions to measure a firm's eco-innovation performance (Section 2 of the Appendix: performance of enterprise eco-innovation). The first 6 questions are to measure environmental performance by asking the enterprise what content was improved using the following indicators during the past three years: material consumption, energy consumption, water consumption, renewable energy replacement, safer or less harmful materials replacement, emissions of liquid, gaseous or solid wastes. The second set of 6 questions measure competitiveness according to expenses on pollution control, market share, firm image, general competitiveness, patents counts applied and R&D investment. The average score of these items of environmental performance and competitiveness is used to calculate the respective index.

Measuring the role of environmental regulations

Generally, environmental regulation tools include command and control policies, market orientation policies and information tools. Rehfeld et al. (2007) stated that environmental regulations not only affect a firm's eco-innovation performance but also the type of eco-innovation it adopts. Frondel et al. (2007) identified the environmental regulation types that influence firms' eco-innovations, citing market mechanism, management mechanism, information methods, voluntary agreement, subsidies, and stringency of policy. Cleff and Rennings (1999) demonstrated that actions taken to comply with environmental regulations influence the eco-innovation aspects of EOP solutions and clean technologies. In this study, the questionnaire sets six questions as follows. These questions aim to measure the role of environmental regulations as a whole on eco-innovation by averaging all the values of the six measures.

- Administrative control, such as administrative order and quotes.
- Restrictive policies, such as technical standards, effluent policy and admittance.
- Market policies, such as tariff adjustment, water adjustment, tax adjustments, the export tax rebate adjustment, resource tax adjustment and emissions trading.
- Subsidy policies, such as accelerated depreciation of fixed assets, the tax breaks of imported equipment, incentives and technical assistance.
- Voluntary initiatives, such as consultation with the government to determine emissions.
- Information policy, such as environment bulletin, publicity of inventory and publicity of pollution level.

In our research, we use the average score of the above items as the environmental regulation score.

Measuring the role of execution of environmental regulations

According to Johnstone and Labonne (2006) and Kammerer (2009), the execution of environmental regulations has also a significant effect on a firm's eco-innovation initiatives. To measure the role of execution of environmental regulations, this study set three questions as follows: law enforcement degree, the above policies need to be strengthened, policy implementation needs a reasonable time frame. Since a high score of the last two items means the enforcement of the regulation are not satisfactory at present, we reversed the score to make the direction of the measures consistent. In fact, for the last two items of our questionnaire, we used 8 minus the original reported score to get the new final score. The arithmetic mean of the above three items is used as the regulatory execution score.

Measuring other variables

In the current research, the annual turnover of the core business was used to classify firm size. The data on relevant companies for 2008 and 2009, provided by the Economic Census of the Statistics Department, were standardized, and the largest firm size was given the value of 1, and the remaining data was proportionally normalized in order to yield values between 0 and 1.

Survey

We designed the survey questionnaire to support face-to-face interviews in about 20 firms, and then pre-tested it on a group of academic researchers, professional eco-innovation practitioners, and R&D managers.

A sample of 393 manufacturing enterprises was randomly drawn from two industrial parks located in the Zhejiang and Jiangsu Provinces of eastern China. From June to September 2010, with the help of local governmental agencies, we sent the questionnaires to the firms by mail with complete instructions, a consent form, contact information, and a pre-paid postage response envelope.

We collected 256 responses with a response rate of around 65%. After excluding incomplete responses and/or those lacking clarity, we arrived at our final sample of 245 valid responses. Most of the respondents were from small- and medium-sized firms with fewer than 300 employees (79.6%), CNY 400 million ($ 65.1 million) of fixed assets (91.4%), and CNY 300 million ($ 48.8 million) of annual sales (91.4%). Around half of the respondents worked in technology-intensive sectors,[2] while the annual production value of newly developed products in most of the participating firms (79%) accounted for less than 5% of their total production value.

Results

Using Eq. (1) revealed that of 245 observations, 31 firms' eco-innovations were dominated by the EOP type, a ratio of 12.7%; 80 firms applied the PcEI type, a ratio of 32.7%; 40 firms applied the PdEI type, making up 16.3%; the remainder of the 94 firms applied the OEI type, making up 38.3% of the sample.

Variable reliability and validity

We tested the reliability and validity of our sample. From Table 2, we can see that the Cronbach's alpha coefficients of environmental performance, competitiveness, environmental regulation, and regulatory execution are respectively 0.9083, 0.9126, 0.9047 and 0.8215, all above the threshold of 0.7 (Hafiz and Shaari, 2013; DeVellis, 2003, p. 95). Besides, the factor loading within the items are all above 0.7, supporting the validity of the construct. The KMO scores of the factors are also reported.

To test for common method bias, we involve the Harman's single factor test. In our sample, the largest factor only explains 40.86% of the variance, and no single factor emerged from the factor analysis. Therefore, Harman's single factor test indicates that we need not to worry about the common method bias problem (Podsakoff et al., 2003).

Correlation analysis

In Table 3, descriptive statistics of the dependent variable and the explanatory variables were calculated, as was the correlation coefficient of these variables. The results indicate the relevance of the relationship between eco-innovation type and environmental performance, as well as eco-innovation type and competitiveness, both of which are at the 0.05 significance level. Hence, eco-innovation performance could be used as an explanatory variable. Those variables related to enterprise size, such as environmental performance, competitiveness, environmental regulation, and regulatory execution, show a strong correlation. In this context, the strong correlation between environmental performance and competitiveness suggests that these variables cannot be used as explanatory variables. For the same reason, environmental regulation and regulatory execution could not be used as explanatory variables either, owing to a potential issue with multi-collinearity. Thus,

[2] The technology-intensive sector refers to the sectors in which equipment and production process are based on science and technology, the technological characteristics of products are complex, and the resource consumption is low, such as the electronic and communication equipment manufacturing sector, biology pharmaceuticals and new materials sector, and the modern machinery manufacturing sector.

Table 2
Reliability and validity.

Factors	Items	Loading	Reliability and validity
Environmental performance	Reducing the material consumption per unit product	0.8361	Alpha = 0.9083 KMO = 0.8579
	Reducing the energy consumption per unit product	0.8649	
	Reducing the water consumption per unit product	0.8903	
	Replacing nonrenewable energy by renewable energy	0.7512	
	Replacing materials with safer or less harmful materials	0.7736	
	Reducing the emission of liquid, gas or solid pollution or waste products	0.8252	
Competitiveness	Expenses on pollution control	0.7679	Alpha = 0.9126 KMO = 0.8663
	Market share	0.8636	
	Enterprise image	0.8572	
	General competitiveness	0.8982	
	Patents counts applied	0.7952	
	R&D investment	0.8753	
Environmental regulation	Administrative control (administrative order, quotes, etc.)	0.8287	Alpha = 0.9047 KMO = 0.8149
	Restrictive policies (technical standards, effluent policy, admittance, etc.)	0.8481	
	Market policies (tariff adjustment, water adjustment, tax adjustments, the export tax rebate adjustment, resource tax adjustment, emissions trading, etc.)	0.8280	
	Subsidy policies (accelerated depreciation of fixed assets, the tax breaks of imported equipment, incentives, technical assistance, etc.)	0.8158	
	Voluntary initiatives (consultation with the government to determine emissions, etc.)	0.7811	
	Information policy (Environment Bulletin, publicity of inventory, publicity of pollution level)	0.8343	
Regulatory execution	Law enforcement degree	0.7636	Alpha = 0.8215 KMO = 0.6526
	The above policies need to be strengthened	0.9211	
	Policy implementation needs a reasonable time frame	0.9241	

the regression analysis was applied to verify the relationship between these variables. For further analysis, the following basic model was applied:

$$Per\,formance = const + \beta_1 \times EIScs + \beta_2 \times FirmSize + \beta_3 \times Environment$$

Here, *Performance* includes *Environmental Performance* and *Competitiveness*, *EIScs* contains four types of environmental innovation (EI) scores, and *FirmSize* is a control variable. Moreover, *Environment* includes *Environment Regulation* and *Regulatory Execution*.

Hypothesis results

In Model 1, the dependent variable is environmental performance, while the four types of eco-innovation serve as explanatory variables. The regression coefficients shown in Table 3 indicate that EOP, PdEI, and OEI are significantly positive at the 1% significance level. The coefficients are respectively 0.492, 0.344, and 0.253. Moreover, with the value of 0.186, PcEI is significantly positive at the 10% significance level. Based on these results, H1 is supported (Table 4).

In Model 2, the independent variable is the vector of a firm's eco-innovation type, and the dependent variable is the firm's competitiveness. The regression coefficients shown in Table 3 indicate that EOP and PdEI are significantly positive at the 1% significance level. The coefficients are respectively 0.452 and 0.228. In addition, OEI and PcEI are significantly positive at the 5% significance level, with the respective values of 0.206 and 0.152. As above, the results show that the four types of

Table 3
Basic statistics and correlation coefficients table (N=245).

	Variable	Average	Standard deviation	1	2	3	4	5	6	7	8	9
1	EOP	0.58612	0.746777	1								
2	PcEI	1.10386	0.889087	0.3495*	1							
3	PdEI	0.77347	0.912147	0.1634*	0.3418*	1						
4	OEI	1.09235	0.924579	0.3371*	0.3157*	0.4038*	1					
5	Enterprise size	0.02874	0.122767	0.2011*	0.1942*	0.0459	0.0988	1				
6	Environmental performance	4.22262	1.504225	0.3690*	0.3155*	0.3488*	0.3567*	0.1433*	1			
7	Competitiveness	4.58769	1.210372	0.3991*	0.3176*	0.3187*	0.3557*	0.1383*	0.5368*	1		
8	Environmental regulation	4.97973	1.219966	0.2168*	0.2033*	0.2584*	0.2469*	0.0853	0.3800*	0.2803*	1	
9	Regulatory execution	4.998634	1.357197	0.1871*	0.2196*	0.1013	0.1679*	0.0397	0.3050*	0.2059*	0.6832*	1

* Significance level $P < 0.05$ (two-tailed test).

Table 4
Regression analysis (N=245).

Variables	Model 1 Environmental performance	Model 2 Competitiveness	Model 3 Environmental performance	Model 4 Competitiveness	Model 5 Environmental performance	Model 6 Competitiveness	Model 7 Environmental performance	Model 8 Competitiveness
EOP score	0.492 (0.133)***	0.452 (0.097)***	0.476 (0.134)***	0.443 (0.0978)***	0.417 (0.133)***	0.417 (0.096)***	0.433 (0.131)***	0.427 (0.097)***
PcEI score	0.186 (0.102)*	0.152 (0.073)**	0.173 (0.102)*	0.144 (0.073)*	0.149 (0.101)	0.134 (0.073)*	0.118 (0.099)	0.124 (0.073)*
PdEI score	0.344 (0.080)***	0.228 (0.083)***	0.347 (0.081)***	0.229 (0.082)***	0.280 (0.085)***	0.201 (0.085)**	0.349 (0.082)***	0.230 (0.082)***
OEI score	0.253 (0.081)***	0.206 (0.081)**	0.252 (0.081)***	0.205 (0.081)**	0.207 (0.083)**	0.186 (0.079)**	0.224 (0.082)***	0.195 (0.079)**
Enterprise size			0.624 (0.317)**	0.388 (0.371)	0.538 (0.286)*	0.351 (0.373)	0.677 (0.273)**	0.407 (0.378)
Environmental regulation					0.294 (0.079)***	0.126 (0.064)**		
Regulatory execution							0.225 (0.071)***	0.0825 (0.052)
Constant term	3.187 (0.170)***	3.754 (0.133)***	3.191 (0.170)***	3.757 (0.133)***	1.893 (0.357)***	3.198 (0.324)***	2.182 (0.351)***	3.386 (0.286)***
Maximum VIF	1.32	1.32	1.32	1.32	1.33	1.33	1.33	1.33
F value	22.45***	24.19***	21.41***	19.99***	24.27***	17.87***	21.94***	17.33***
R^2	0.253	0.257	0.255	0.259	0.306	0.273	0.294	0.267

Notes: Robust standard errors are given in parentheses.
* $P<0.1$.
** $P<0.05$
*** $P<0.01$

eco-innovation exert different influences on a firm's environmental performance. Those importance rankings are EOP, PdEI, OEI, and PcEI, in descending order. The results offer support for H2.

We also have done seemingly unrelated regressions to test the significant difference of coefficients between environmental performance and competitiveness for each of the four eco-innovation types. The p values are 0.7517, 0.7551, 0.2651 and 0.6534, respectively. All of the p values are above 0.1, hence we cannot reject that there are no significant differences between the coefficients.

In Models 3 and 4, the independent variable is firm size, and the dependent variables are the firm's environmental performance and competitiveness. The results show that firm size is significantly positive at the 5% significance level with environmental performance, while it is not significant (P-value > 0.1) with its competitiveness (Fig. 4). Hence, H3 is supported and H4 is not.

In Models 5 and 6, the independent variables are environmental regulation, and the dependent variables are the firm's environmental performance and competitiveness. The results suggest that environmental regulation correlate positively with both environmental performance (P value < 0.1) and competitiveness. Thus, both H5 and H6 are supported.

In Models 7 and 8, the independent variables are regulatory execution, and the dependent variables are the firm's environmental performance and competitiveness. The results suggest that regulatory execution correlates positively with environmental performance (P value < 0.05), but regulatory execution is not significant (P value > 0.1) with competitiveness. Thus, H7 is supported while H8 is not.

Discussion

The findings show that eco-innovation has a positive effect on both a firm's environmental performance and competitiveness, while the magnitude varies with the eco-innovation types. Currently, the EOP type plays the most important role in improving environmental performance. The PdEI type is the second most important factor in terms of direct market impact, followed by OEI, while PcEI has less obvious direct effects. These findings reveal that eco-innovation initiatives remain embryonic in Chinese enterprises.

Though EOP initiatives can significantly improve environmental performance, most of them are difficult to deliver economic benefits. Thus, they are often regarded as a burden for an enterprise as well as a barrier to industry penetration for most of the less competitive enterprises. On the contrary, strongly competitive enterprises will adopt EOP measures due to its role enhancing market threshold to entry. The survey was conducted in the 2007–2009 period when pollution control was suddenly strengthened in China. In fact, China formulated reduction targets in its 11th Five-Year Plan, which dictated that sulfur dioxide, chemical oxygen demand and solid waste levels were to be reduced by 10% by 2010 compared to 2005 levels.

Furthermore, product eco-innovation registers a significant impact because investing in an improved product range and quality is a key strategy for companies seeking competitive advantage (Porter and Van der Linde, 1995). Process and organization management were not significant in this study because the majority of Chinese firms are still in the early stages of developing a management strategy. Consequently, process and management have not yet become aspects of the core competitiveness of enterprises (Yu, 2010).

Firm size significantly influences environmental performance but not competitiveness. One of the possible reasons for this outcome is that the firms included in the study were industrial enterprises above a designated size. Alternatively, as the variable of competitiveness is relative, it has absorbed a significant portion of the scale effect, even though there is no multi-collinearity.

Environmental regulations and their execution significantly influence environmental performance, indicating that under the same conditions—with stricter environmental regulation and more stringent regulatory implementation—environmental performance will be better. In both cases, the effect of firm size decreased in relation to environmental performance. These study findings are in line with the research by Cleff and Rennings (1999) and Rehfeld et al. (2007), indicating that the environmental performance of Chinese enterprises is positively correlated with environmental control. Moreover, as the spontaneous emergence of ecological consciousness is stronger in larger enterprises, the influence of environmental control is weaker. The current research thus shows the execution of environmental regulations does not have a significant positive impact on a firm's competitiveness, but does not risk competitiveness. In line with the Porter Hypothesis, environmental regulation per se has just such a statistically significant impact.

These results suggest that, under the same conditions and stricter environmental regulation, competitiveness will be greater, even though regulatory execution does not correlate significantly with competitiveness. The study confirms the findings reported by Porter and Van der Linde (1995) reporting how appropriate environmental standards could trigger eco-innovations within firms that might lower the costs of compliance or even eliminate them. Therefore, it seems there can be a win–win situation in terms of economic and environmental benefits. This finding offers a different perspective to that often presented by researchers in the traditional environmental management field, many of whom consider EOP merely as a measure to improve environmental performance, but one lacking any positive effect on competitiveness (Walley and Whitehead, 1994; Stanwick and Stanwick, 1998).

Conclusions

The survey of 245 Chinese enterprises indicates that the most common eco-innovation types in China are the organizational and process improvement types, which registered proportions of 38.3% and 32.7% respectively. The EOP treatment contributed 12.7% and the product eco-design 16.3%.

All the hypotheses except for H4 and H8 were supported. This demonstrates that different types of eco-innovation do have significant influences on environmental performance and competitiveness. The finding implies that typology is an important issue for eco-innovation studies. The size of a firm affects environmental performance and competitiveness.

The research illustrates that environmental regulation has a significant influence on a firm's environmental performance and competitiveness while the implementation of environmental regulation only has significant effect on a firm's environmental performance but not its competitiveness. That means China has established effective environmental regulations and spurred improvements in the environmental performance of its enterprises. At the same time, the failure of H8 to gain support may imply that the execution of environmental regulations does not hinder the competitiveness of firms.

One limitation of our study relates to the identification of the eco-innovation typology. We only attach one leading eco-innovation type to a firm based on the frequency of different types of eco-innovation activities, rather than their intensity. We are aware, however, that firms might adopt two or three types of eco-innovation. Future research should consider multiple types of eco-innovation in a firm and the associated strategic optimization.

Another limitation is the neglect of industrial sector features that some eco-innovation research has stressed (Oltra and Saint, 2009; Wagner and Llerena, 2011), despite the fact that different enterprises usually have different levels of environmental performance and competitiveness. For instance, the iron and steel, petroleum refining and other energy-intensive industries usually have greater negative impacts on the natural environment and are more responsive to environmental regulations. Besides the diversity of eco-innovation, both environmental policy and sector-specific aspects also have complex typologies and can complicate the understanding of the eco-innovation typology focus of this study. Further research should incorporate examination of the portfolio of industry- and sector-specific features.

In short, our study aids the understanding of eco-innovation in Chinese firms, the further understanding of the relationship between eco-innovation types and performance, and the direct impacts of regulatory measures and regulatory stringency on eco-innovation performance. Future studies examining the relationships between eco-innovation, technological change, and environmental governance in the Chinese context, and involving more Chinese firms would be welcome and indeed warranted.

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Appendix A. Firm eco-innovation survey

A.1. The types of eco-innovation

1. Activities of the enterprise over the past three years (2007–2009)

Objects	Activity	If yes, please tick
A Pollutants/wastes (end-treatment)	Water treatment works or facilities are available, such as biological treatment, and physical and chemical treatment equipment	
	Air pollution control projects or facilities are available, such as precipitators, desulfurization, denitrification or incinerator equipment	
	Solid waste or hazardous waste treatment projects or facilities are available, such as incinerator, landfill	
	Degraded, damaged or destroyed ecosystems in plants were restored	
	Detection instruments were applied to environmental monitoring in plants	
B Manufacturing technique (cleaner production)	Cleaner production was assessed	
	Novel production line or key equipment was applied	
	Main equipment was technically modernized with capacity expansion	
	Process routes were improved or replaced	
	Raw materials were replaced	
	Energy system was improved or replaced, such as oil replaced by gas	
	Toxic raw materials were replaced or abandoned	
	Main waste was recycled in plants	
	Main waste was recycled through other company	
C Products or services	Environmental performance of products was evaluated	
	Products were marketed as environmental or green	
	Products were authenticated to be environmental, energy-saving or water-saving	
	Specific labels, such as Energy Efficiency Grade, recyclable, energy-saving, were attached on the products	
	Specific environmental performance was addressed in the R&D of novel products	
	Specific environmental performance was indicated in the product packaging	
D Management	ISO14001 or other environmental authentication was conducted	
	ISO9001was authenticated	
	Provider of raw materials is required to be authenticated by ISO14001	
	Provider of raw materials is required to have good environmental performance	
	Customers with good environmental performance were prioritized in the product sales	
	Demonstrated care pertaining to the waste treatment route when designated to another company	
	Independent department for environmental protection or security was established	
E Others	Identified as a pilot enterprise for cleaner production	
	Identified as a pilot enterprise for circular economy	

2. Importance of improvement of environmental performance using the following measures during the past three years (2007–2009).

A End-of-pipe treatment	B Cleaner production	C Products or services innovations	D Management improvement

1: Very important, 2: important, 3: slightly important, 4: not important.

A.2. *Performance of enterprise eco-innovation*

3. Environmental performance of your enterprise to be improved during the past three years.

Type	No change → significantly						
Reducing the material consumption per unit product	1	2	3	4	5	6	7
Reducing the energy consumption per unit product	1	2	3	4	5	6	7
Reducing the water consumption per unit product	1	2	3	4	5	6	7
Replacing nonrenewable energy by renewable energy	1	2	3	4	5	6	7
Replacing materials with safer or less harmful materials	1	2	3	4	5	6	7
Reducing the emission of liquid, gas or solid pollution or waste products	1	2	3	4	5	6	7

4. In comparison with the domestic industrial level, how does your enterprise rate on the following measures?

	Lowest	Lower	Low	Average level	High	Higher	Highest
Expenses on pollution control	1	2	3	4	5	6	7
Market share	1	2	3	4	5	6	7
Enterprise image	1	2	3	4	5	6	7
General competitiveness	1	2	3	4	5	6	7
Patents counts applied	1	2	3	4	5	6	7
R&D investment	1	2	3	4	5	6	7

A.3. *Environmental regulations and their execution*

5. Environmental regulations relating to your enterprise during the past three years (2007–2009).

	Not important → important						
Administrative control (administrative order, quotes, etc.)	1	2	3	4	5	6	7
Restrictive policies (technical standards, effluent policy, admittance, etc.)	1	2	3	4	5	6	7
Market policies (tariff adjustment, water adjustment, tax adjustments, the export tax rebate adjustment, resource tax adjustment, emissions trading, etc.)	1	2	3	4	5	6	7
Subsidy policies (accelerated depreciation of fixed assets, the tax breaks of imported equipment, incentives, technical assistance, etc.)	1	2	3	4	5	6	7
Voluntary initiatives (consultation with the government to determine emissions, etc.)	1	2	3	4	5	6	7
Information policy (Environment Bulletin, publicity of inventory, publicity of pollution level)	1	2	3	4	5	6	7

6. The execution of environmental regulations relating to your enterprise during the past three years (2007–2009)

	Not important → important						
Law enforcement degree	1	2	3	4	5	6	7

	Do not agree → agree						
The above policies need to be strengthened	1	2	3	4	5	6	7
Policy implementation needs a reasonable time frame	1	2	3	4	5	6	7

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