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Revisiting the Porter hypothesis: a multi-country meta-analysis of the relationship between environmental regulation and green innovation

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Although large numbers of studies have examined the Porter hypothesis, one important issue that remains to be addressed is that why past studies give rise to mixed results. By filling this knowledge gap, our research aimed to provide a fuller picture of the Porter hypothesis. By using the method of meta-analysis, including a total of 58 papers across the world, the findings showed that (1) the overall Porter hypothesis was confirmed—that, in general, environmental regulation had a positive effect on green innovation; (2) by decomposing environmental regulatory types and measures of green innovation, it validated the ‘narrow’ version of the Porter hypothesis—that flexible environmental regulation could foster innovation. Especially, we found the command and control regulation had shown its highest consistency and effectiveness in driving green innovation, whereas voluntary regulation had the highest level of flexibility among all regulatory measures; (3) we also found that heterogeneities of the results were attributed to country type and level of analysis. Overall, by integrating studies with large sample sizes and identifying variations among studies, we offered a comprehensive understanding of the mixed results of the Porter hypothesis and generated more precise and generalizable conclusions than the past studies.

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Introduction

Since the early 1990s, researchers and policy makers have provided increasing insights into the Porter hypothesis, suggesting that environmental regulations can actually stimulate firms' innovation and competitiveness, rather than hinder their sustainable development. The value of this topic is partly attributed to both concepts of environmental regulation and innovation having received great attention in the current society. Specifically, the urgency of environmental regulation to ensure environmental protection has been widely recognized (Li et al., 2022; Ren et al., 2023; Wang et al., 2023), and innovation has been proven to play a crucial role in the success of an organization (Ren et al., 2023; Tang et al., 2020; Wang et al., 2021), where "there is greater competition and enhanced pressure for innovation" (Parker and Collins, 2010, p. 633). It is also attributed to the Porter hypothesis opposing to the conventional wisdom that environmental regulations may hinder innovation that is costly to firms (Palmer et al., 1995; Petitjean, 2019). The Porter hypothesis states that regulations stimulate firms to enhance competitiveness through 'innovation offset' (Takalo et al., 2021). That is to say, the benefits of innovations triggered by properly designed environmental regulations "may partially or more than fully offset the cost of complying with them" (Porter and van der Linde, 1995, p. 98).

However, it reaches no consensus in terms of the association between environmental regulation and innovation. In the past quantitative reviews, Ambec and Lanoie (2008) reported no clear relationship between environmental regulation and innovation on the basis of papers published between 1983 and 2007. Cohen and Tubb (2017) found varying relationships over 2000 estimated 'effect sizes' within 103 published studies, but the relationships were still broadly insignificant. However, Dechezleprêtre and Sato (2017) found evidence to support the weak version of the Porter hypothesis, finding a strong and positive relationship between environmental regulation and innovation in relation to cleaner technology.

Thus, considering the lack of clarity over the validity of the Porter hypothesis (Li et al., 2022), this paper aims to test the 'overall' and 'narrow' versions of the Porter hypothesis¹ (other versions have not been tested due to data availability). In particular, we used the approach of meta-analysis to address the mixed results of the environmental regulation–green innovation relationship, and heterogeneities across contexts were also assessed. The main findings showed that: (1) the "overall" version of the Porter hypothesis was confirmed; (2) we supported the "narrow" version of the Porter hypothesis. Particularly, command and control regulation had shown its highest consistency and effectiveness in driving green innovation, whereas voluntary regulation had the highest level of flexibility among all regulatory measures; and (3) country type (i.e. developing or developed country) and level of analysis (i.e. firm-level, city-level, province-level or country-level) moderated the relationship between environmental regulation and green innovation.

We have made marginal contributions in the field of the Porter hypothesis assessment that are different from the previous studies. First, unlike past quantitative reviews considering the relationship between types of regulation and general innovation or overall competitiveness (e.g. Cohen and Tubb, 2017), our focal point is green innovation, which is directly driven by environmental regulation. One potential problem with past quantitative reviews is that some of the innovations or competitiveness advantages included in these reviews might not be induced by environmental regulations, thereby distorting their effects. For example, Popp (2019) noted that while patent data is an excellent indicator of innovation, some irrelevant patents should be filtered out since they are not driven by environmental regulations. Therefore, the usage of the term 'green innovation' should be

more closely evaluated to give a more precise understanding of its relationship with environmental regulations. Furthermore, we distinguished the measures of green innovation, therefore largely minimizing the bias caused by varying measures.

Second, despite the interest in the Porter hypothesis, no quantitative synthesis is found to address the relationship between environmental regulation and green innovation, a gap filled by our study. Existing research has shown mixed results, with some studies suggesting positive effects (Liao and Liu, 2022; Zhao et al., 2022), some reporting negative effects (Feng et al., 2018; Guo et al., 2017), and some finding insignificant effects (Arimura et al., 2007; Long and Wan, 2017). The number of observations, measurements, and environmental interventions may be the causes of conflicting findings (Creswell and Creswell, 2017). For example, Ambec et al. (2012) have called for light to be shed on the comparison between different types and measurements of regulation and innovation, and for factors moderating the relationship to be examined due to the result inconsistencies. These aims can be accomplished by using meta-analysis, which is a useful approach for integrating results that can lead to more accurate and generalizable conclusions than those shown in any single study (Ryan et al., 2022).

Third, this paper chose the level of analysis and country type as moderators in the environmental regulation–green innovation relationship with high heterogeneities. Since past studies only empirically assessed this relationship at a given level such as individual-, firm-, industry- or regional-level, no study has shown whether the level of analysis has a moderating effect. Given that each level of study provides a different perspective and understanding of phenomena, contributing to broader insights and knowledge in their respective domains, it is valuable to examine whether this variable has a moderating effect. In terms of country type, as countries differ in various aspects such as available resources, maturity of the market, and public environmental awareness, all of which may affect the validity of the Porter hypothesis, we, therefore, included the country as the second moderator, the moderator of which has been suggested, but surprisingly, yet to be examined. In fact, the majority of past research focuses on one country and lacks comparisons between countries (Cui et al., 2022; Wang et al., 2022). In this case, we divided countries into two groups: developed countries and developing countries (which are representative), in order to determine whether disparities in these areas impact the relationship.

Fourth, our research also provides significant practical values. In comparison with previous research, we provide a more nuanced and comprehensive view of the issue of the Porter hypothesis by distinguishing types and measures of environmental regulation and green innovation, as well as heterogeneity analysis between studies, which provides a theoretical basis for relevant authorities to formulate a more targeted strategy of the execution of green innovation. In addition, since our research exploits a large sample size over the world, the generalization and representation of this study may strengthen the confidence of governments from different countries to enact appropriate regulatory policies to enhance green innovations while some studies hold the opposite position.

In sum, we addressed four research questions in this paper: (1) What is the overall relationship between environmental regulation and green innovation? (2) What is the relationship between different types of environmental regulation and green innovation? (3) Does the relationship between different types of environmental regulation and green innovation vary across measures of green innovation? (4) Do the level of analysis and country type moderate the relationship between environmental regulation and green innovation?

Theoretical background

Concepts of Porter hypothesis

Porter hypothesis. The Porter hypothesis is defined as “regulation could potentially enhance productivity and/or competitiveness by generating substantial innovation offsets” (Cohen and Tubb, 2017, p.3), indicating that environmental regulation could stimulate firms’ innovation, which in turn promotes their productivity and/or competitiveness. It can be seen as the “overall” version of the Porter hypothesis.

Specifically, Porter’s hypothesis can be divided into three forms including “narrow”, “weak” and “strong” versions, and in line with most studies, we used Jaffe and Palmer’s (1997) definitions: the “narrow” version refers to flexible regulation increasing firms’ incentives for innovation; the “weak” version indicates that environmental regulations will trigger certain kinds of innovation; the “strong” version describes that the benefits of innovation driven by conforming to environmental regulations will exceed the costs of regulatory compliance.

Environmental regulation. Environmental regulation is conceptualized as environmental policies implemented by public agencies in order to solve environmental problems through changing the behaviors of individuals and organizations (Lin and Wu, 2020; Sanni, 2018). Current literature identifies three key sub-dimensions: command and control regulation, market-incentive regulation, and voluntary regulation (Huang et al., 2014; Ren et al., 2018). Command and control regulation uses laws and regulations to control pollution—for example, sewerage and drainage regulations and carbon dioxide emission standards (Ouyang et al., 2020). Market-incentive regulation uses market-based approaches to reduce pollution, such as pollution charges, emission taxes, and emission subsidies (Wang et al., 2022). Voluntary regulation refers to organizations’ and individuals’ voluntary commitments—rather than mandatory requirements—to control pollution, and includes using environmental labeling and certificates, and signing voluntary agreements (Bu et al., 2020).

The underlying logic behind adopting environmental regulations is to help address ‘market failures’, such as pollution externalities, specific investments with contractual incompleteness, asymmetric information within firms, and spillovers in knowledge. For example, it is difficult to force polluters to consider the costs to those harmed by their pollution without proper environmental regulations. Previous research suggests that environmental regulation is a crucial predictor of innovation (e.g., Ahmed et al., 2023; Fang et al., 2020; Jaffe and Palmer, 1997).

Green innovation. Green innovation is defined as innovations in processes, technologies, practices, systems, or products intended to minimize energy consumption or pollution emissions (Ashford and Hall, 2011; Bai et al., 2021). Green innovation takes two forms: either firms optimize pollution handling after it happens—e.g. reducing emissions of wastewater and toxic gas—or they address “environmental impacts while simultaneously improving the affected product itself and/or related processes” (Porter and van der Linde, 1995, p. 101). Referring to Sanni’s categorization (2018), the determinants of green innovation are regulation (Adelegan et al., 2010; del Rio Gonzalez, 2005), demand-pull factors (Horbach, 2008), technology-push factors (Sáez-Martínez et al., 2014; Triguero et al., 2013) and firm-specific factors (Chassagnon and Haned, 2015; Frenz and Ietto-Gillies, 2007).

The environmental regulation–green innovation relationship:

Mixed results. Similar to the results of the relationship between environment regulation and general innovation or overall competitiveness, previous empirical research on the environmental

regulation–green innovation relationship also shows mixed results, including positive (e.g. Popp, 2002; Xiang et al., 2020; Zhu et al., 2019; Wang et al., 2022), insignificant (e.g. Brunel, 2019; Tian et al., 2021; Zhu et al., 2021) and negative associations (e.g. Cerin, 2006; Desrochers, 2008; Li and Zeng, 2020).

Studies supporting a positive relationship between environmental regulation and green innovation include Dangelico (2016), Doran and Ryan (2012, 2016), Li and Hamblin (2016), Liao and Liu (2022), and Zhao et al. (2022). For example, from 24 studies, with a total sample size of 47,704, Liao and Liu (2022) reported a significant and positive relationship ($\beta = 0.354$, $p < 0.001$).

Insignificant associations between environmental regulation and green innovation have also been found by studies other than those mentioned above. Long and Wan (2017) reported an insignificant association between environmental regulation and firms’ innovation. Arimura et al. (2007) found environmental standards and taxation have no significant relationship with environmental innovation, based on a survey of 4000 facilities in seven OECD countries. Brunnermeier and Cohen (2003) used a panel of 146 USA manufacturing companies between 1983 and 1992 and reported that water pollution control inspections have no impact on a number of environment-related patents.

Negative relationships between environmental regulation and green innovation are also found in several other studies (Feng et al., 2018; Guo et al., 2017). Based on panel data from 27 Chinese manufacturing companies between 2009 and 2015, Feng et al. (2018) found environmental regulations have significant negative effects on green innovation.

The inconsistent relationships should be attributed to three potential reasons. First, previous studies do not distinguish between different types of environmental regulation, therefore offering a rather vague picture. Indeed, past researchers have stressed that differentiating between types of regulation is important in exploring the relationship (Fu et al., 2018; Zhao et al., 2023). Zhao et al. (2023) noted that specific forms of environmental regulations including formal (e.g. command and control regulation) and informal (e.g. voluntary regulation) ones should be further studied, which are potential to cause more significant results. Fu et al. (2018) found, in the USA, that while renewable portfolio standards (a requirement to produce a specified proportion of energy from renewable sources) induce innovation, financial incentives such as tax breaks and subsidies have no impact at the national level, indicating the necessity of decomposing kinds of regulatory types.

Second, the diversity of innovation measures also influences the consistency of results (Lankoski, 2010). Wang et al. (2022) noted that in order to induce a more accurate result, they used the measure of the application number of green invention patents rather than the measure of authorized green patents which is widely applied in innovation research. They criticized the measure of authorized green patents for their vulnerability to human factors and having a time of lagging issue, therefore leading to imprecise results. Cui et al. (2022) mentioned one of their research limitations is that they only counted the number of patents but neglected other measures of innovations. Therefore, the generalization of their study should be considered with caution. Jaffe and Palmer (1997) estimated the relationship between total research and development (R&D) expenditure and the number of successful patent applications and pollution abatement costs (R&D expenditure and successful patent applications are two popular indicators of green innovation, and pollution abatement cost is a proxy for the stringency of environmental regulation). They found a positive link between R&D expenditure and pollution abatement cost (an increase of 0.15% in R&D for a cost increase of 1%), but no statistically significant link to the number of patents.

Third, the inconsistent results may be attributed to issues such as location, ownership, and areas of technology (Chen et al., 2021; Wang et al., 2022). Through categorizing the sample enterprises into different groups, Wang et al. (2022) found that the impact of environmental regulation on green technology innovation is more prominent in the eastern region of China than the other areas, and they also found that command and control regulation is positively associated with green technology innovation among state-owned enterprises but no impact on non-state-owned enterprises. By using panel data relating to patent numbers for seven different renewable energy technologies in Germany, Böhringer et al. (2017) explored how technology areas moderate the association between environmental regulation and green innovation. They found that, among seven renewable energy technologies, the area where feed-in tariffs result in the greatest increase in innovation was wind power. Conversely, the impact of the tariffs on innovation in the area of biomass technology is insignificant. Nicolli and Vona (2016), and Johnstone et al. (2010) also showed that the type of technology plays a crucial role in moderating the environmental regulation–innovation relationship.

Research method

We followed the meta-analysis procedure to address research questions. The advantage of this method lies in that since some primary studies lack sufficient sample sizes to induce statistically significant findings and most studies are unable to generate a precise estimate of effect size (Geyskens et al., 2009), meta-analysis, which integrates regression coefficients and recognizes heterogeneities of multiple independent studies that bear on the same relationship, can lead to more accurate conclusions than those shown in any single study. In this section, we first explained the search strategy including the applied search engine, search field, and search terms. Then we provided criteria for studies that should be included or excluded in the meta-analysis. Next, the study-selection process was described which was followed by measurements of environmental regulation and green innovation. In the last part, estimation techniques were explained in detail.

Search strategy. We used the electronic search engine Scopus to perform the search, using the search field ‘Title, Keywords and Abstract’. Scopus was selected due to its interdisciplinary coverage and popularity among literature reviews relating to environmental research in recent years (Bourcet, 2020; Menegaki et al., 2021). The search terms used were: (“environmental regulation” OR “environmental polic” OR “environmental governance” OR “environmental legislation”) AND (“green innovation” OR “green technological innovation” OR “green production innovation” OR “environmental innovation” OR “eco-innovation”).

Inclusion and exclusion criteria. First, we included only quantitative studies that have reported the relationship between environmental regulation and green innovation, because these studies have produced relevant coefficients such as Pearson correlations, *t*-statistics, and regression coefficients. Second, all papers should be published, full-length and peer-reviewed—incomplete or unpublished articles, or those where only an abstract was available, were not considered. Third, we only reviewed journal articles written in English, or translated into English. Fourth, to guarantee the quality of selected articles, we only used papers falling into the top two quartiles (Q1 or Q2) in journal citation reports (JCR), which aimed to identify journals of high quality in a particular subject area. Three authors decided which papers should be included, and only those papers meeting

the inclusion criteria were selected. Last, we only included papers published since 2016, as we wanted to verify whether the findings were in accordance with Ambec et al.’s (2012) and Cohen and Tubb’s (2017) suggestion that calls for studies if recent studies tend to elicit more positive results than those from longer ago, which remains to be evaluated. Also, the Paris Agreement came into force in 2016—the first binding agreement that brings all nations together in a common cause to fight against climate change. Under such pressure, we believe all nations will formulate more intensive regulatory policies to promote green innovation, an issue that has not received much attention.

Study-selection procedure. Our research followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to demonstrate the study-selection process, with the purpose of improving the transparency and accuracy of literature selection. It consists of a checklist and a flow diagram that provide a standard framework for reporting systematic reviews and meta-analyses. The checklist covers multiple aspects of the review process, such as the title, abstract, introduction, methods, results, discussion, and funding. The flow diagram outlines the study selection process, including the number of studies identified, screened, included, and excluded, along with the reasons for exclusion.

Using the search strategy and inclusion/exclusion criteria already defined, 594 papers were identified from Scopus. Of these, 292 were discarded after examining titles and abstracts because the contents were not relevant, and 78 were removed as they were published before 2015 and therefore predated the Paris Agreement (adopted 2015, entered into force 2016). Of the remaining 224 papers, 75 did not fall into Q1 or Q2 in JCR, and 91 did not include the necessary data for effect size calculation. This left 58 studies that assessed the relationship between environmental regulation and green innovation and met our criteria. The PRISMA flow diagram is shown in Fig. 1 to demonstrate the study-selection process.

Measurements of environmental regulation and green innovation. After reviewing the included studies, we grouped environmental regulations into five categories: overall regulation (OVR), command and control regulation (CACR), market incentive regulation (MIR), voluntary regulation (VR), and other regulations (ORS). Overall regulation indicates a measurement that includes two or more dimensions of environmental regulation. Command and control regulation, market incentive regulation, and voluntary regulation have previously been explained. Other regulations are the environmental regulations that do not fall into the other categories, comprising environmental disclosure (Xiang et al., 2020), information-based instruments (Liao, 2018), and formal and informal regulation pressure (Wu et al., 2022).

We categorized green innovation measures into eight groups: number of patents (NOPS), frequency of terms mentioned in the annual report (FOT), new-product sales revenue (NPSR), R&D expenditure/revenue (RDER), questionnaire measures regarding green innovation (QGI), energy-based indices (EBI), pollution-based indices (PBI) and other measures (OMS). Number of patents indicates the number of green patent authorizations; frequency of terms mentioned in the annual report refers to the frequency with which terms relating to green innovation are used in companies’ annual reports; new-product sales revenue gives sales revenue generated new products or services driven by green innovation; R&D expenditure/revenue shows the amount spent by a company on green research and development; questionnaire measures regarding green innovation relate to questionnaire

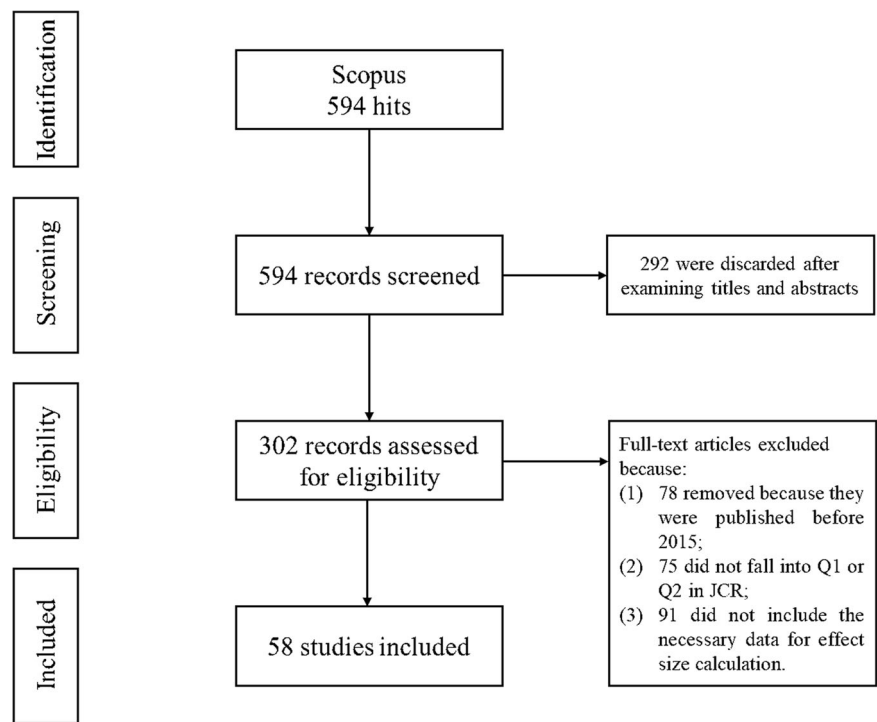


Fig. 1 The PRISMA flow diagram. The figure describes the process of paper selection, following the guidelines of PRISMA used for reporting meta-analyses.

Table 1 Variables in the study.	
Variable	Definition
OVR	Overall regulation
CACR	Command and control regulation
MIR	Market incentive regulation
VR	Voluntary regulation
ORS	Other regulations
NOPS	Number of patents
FOT	Frequency of terms mentioned in the annual report
NPSR	New product sales revenue
RDER	R&D expenditure/revenue
QGI	Questionnaire measures regarding green innovation
EBI	Energy-based indices
PBI	Pollution-based indices
OMS	Other measures

items on green innovation—for example, ‘Our company often places emphasis on developing new eco-products through new technologies to simplify their package’ (Liao, 2018); energy-based indices are measures of energy consumption, such as reduced energy use and changes in plants’ energy intensity; pollution-based indices consider wastewater treatment capacity, discharge of wastewater, sulfur dioxide emissions and fixed waste emissions; other measures consist of passing ISO 14001 certification (Li et al., 2017) and changes in efficiency and progress relating to green technology (Peng, 2020). A summary of mentioned variables is shown in Table 1.

Estimation techniques. First, we calculated quantitative effect sizes using Fisher’s Z as our effect size metric. Because most of the included studies used regression analysis, we followed Ringquist’s (2013) recommendation by first converting each paper’s parameter estimate into a correlation coefficient, *r*. The approach for

converting from regression coefficients to correlation coefficients *r* is referred to by Ringquist (2013). Once the correlation coefficient *r* is estimated for study *i*, Fisher’s Z for each study is calculated (*y_i*). To convert *r* to Fisher’s Z, we used the following equation:

$$y_i = 0.5 \ln \frac{1 + r_i}{1 - r_i} \tag{1}$$

The second step is to count the weight of each study (*w_i*). We used a random effects model by maximum likelihood (ML) method, rather than a fixed effects model because there are factors that might change the relationship between environmental regulation and green innovation between studies, such as country type, type of regulation, measure of innovation, and level of regulation. Results are therefore likely to be heterogeneous between studies, meaning a random effects model was suitable. Based on the marginal distribution *y_i* ~ *N*(*μ*, *v_i* + *τ*²) The estimate *w_i* is calculated by the following equations:

$$\ln L(\mu, \tau^2) = -\frac{k}{2} \ln(2\pi) - \frac{1}{2} \sum \ln(v_i + \tau^2) - \frac{1}{2} \sum \frac{(y_i - \mu)^2}{v_i + \tau^2} \tag{2}$$

$$\hat{\tau}_{ML}^2 = \max \left\{ 0, \frac{\sum w_i^2 \left((y_i - \hat{\mu}_{RE}(\hat{\tau}_{ML}^2))^2 - v_i \right)}{\sum w_i^2} \right\} \tag{3}$$

$$w_i = \frac{1}{v_i + \hat{\tau}_{ML}^2} \tag{4}$$

The last step is to aggregate effect sizes by

$$\bar{y} = \frac{\sum w_i y_i}{\sum w_i} \tag{5}$$

Results
Characteristics of included studies. Our analysis of the characteristics of the included studies provides an overview of their

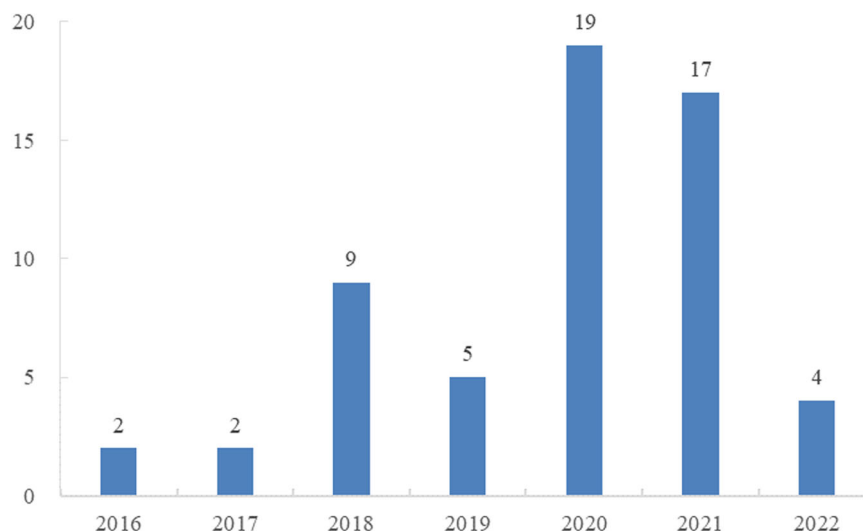


Fig. 2 Studies by year of publication. The figure describes the number of papers selected between 2016 and 2022.

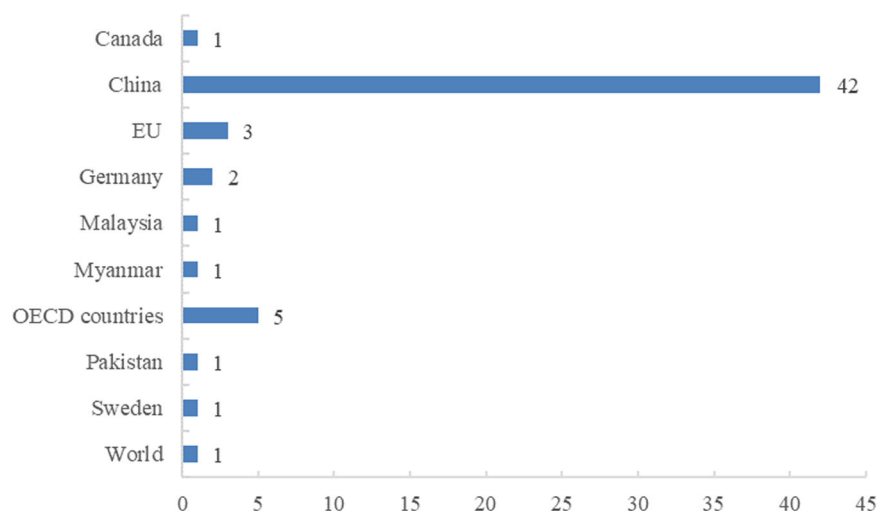


Fig. 3 Country of source data for included studies. The figure illustrates the country distributions of the papers included.

nature and considers publication year, journal, and the country from which source data was taken. Figure 2 shows the studies by year of publication, and reveals that the highest number of papers was published in 2020 (19), with 2021 second (17). Few papers from 2022, were included, but this is due to our search period, which ended in January 2022. These figures suggest the popularity of research into the environmental regulation-green innovation relationship is growing. Figure 3 shows the country from which data is used for each study, and shows that China is the most popular country to be analyzed (42), followed by OECD (Organization for Economic Co-operation and Development) countries (5). This indicates that the topic receives considerable attention among Chinese scholars, possibly due to severe environmental problems in China which the Chinese government has committed to addressing. Table 2 shows the studies distributed by publication journal and year of publication. 26 journals published papers on the issue during the study period; notably, the *Journal of Cleaner Production* published 9 relevant papers, between 2017 and 2021.

Co-occurrence network analysis. A co-occurrence network analysis of keywords for the included studies, executed in VOSviewer, is shown in Fig. 4. This suggests that the terms ‘China’, ‘environmental policy’, ‘government regulation’, and ‘green innovation’

are strongly correlated. They are clustered into separate groups. In particular, ‘China’ emerges as the most frequently used keyword, emphasizing the attention the topic has attracted in China, as it strives to implement government regulations promoting green innovation in order to address its environmental problems.

Relationships between environmental regulation and green innovation

Overall relationship between environmental regulation and green innovation (the Porter hypothesis taken as a whole). The meta-analysis results for each paper’s effect size, and the aggregate effect size for all studies, are presented graphically as a forest plot in Fig. 5. A total of 70 effect sizes were calculated for the 58 included studies because 9 studies included two or more effect sizes. The results show that although most effect sizes are positive (39), insignificant and negative effect sizes are not uncommon (24 and 7, respectively). The aggregate effect size of the overall relationship is positive (0.10; $p \leq 0.001$, 95% CI = [0.08, 0.13]), suggesting that the Porter hypothesis as a whole is confirmed. However, the variations in effect sizes between studies show that the relationship varies depending on the specific types of environmental regulation and measures of green innovation considered.

Table 2 Publication journal and year.							
	2016	2017	2018	2019	2020	2021	2022
Clean Technologies and Environmental Policy				1		1	
Complexity						1	
Corporate Social Responsibility and Environmental Management			1	1	1		
Economic Analysis and Policy						1	
Economic Modeling					1		
Economic Systems						1	
Emerging Markets Review							1
Empirical Economics					1		
Energy Economics						1	
Environmental Science and Pollution Research					2	2	
Expert Systems			1				
Industry and Innovation	1		1				
International Journal of Environmental Research and Public Health			1		2	5	
Journal of Business Research							1
Journal of Cleaner Production		1	3	1	3	1	
Journal of Corporate Finance						1	
Journal of Environmental Management				1	1		
Journal of Environmental Planning and Management	1						
Natural Hazards					1		
Research Policy					2		
Science of the Total Environment					2		
Sustainability		1	2			1	
Sustainable Production and Consumption						1	
Technological Forecasting and Social Change					2	1	2
Technovation					1		
The World Economy				1			

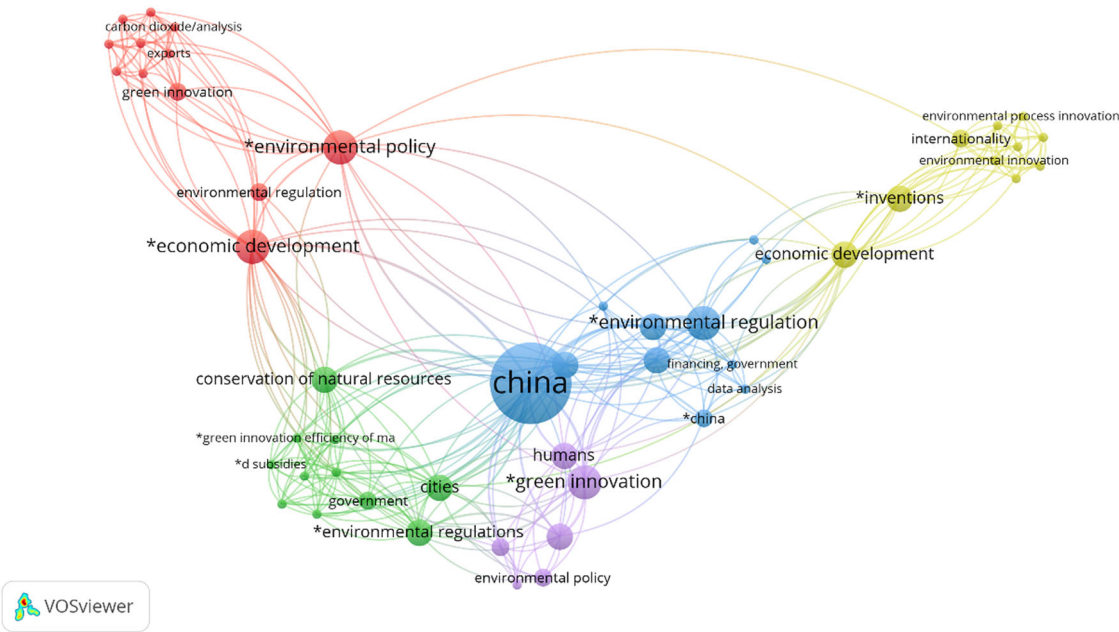


Fig. 4 Co-occurrence network analysis of keywords in included studies. The figure shows a graphic visualization of potential relationships between keywords in the included papers.

Relationships between each type of environmental regulation and green innovation (the ‘narrow’ version of the Porter hypothesis). The analysis is performed for each different dimension of environmental regulation identified, to assess how they foster green innovation individually. The results are presented in Table 3 and show that, while green innovation is positively associated with overall regulation (0.10, $p \leq 0.05$, 95% CI = [[0.02, 0.19]], command and control regulation (0.12, $p \leq 0.001$, 95% CI = [[0.09, 0.16]]) and other regulations (0.24, $p \leq 0.01$, 95% CI = [[0.08, 0.40]]), it has no significant relationship with market

incentive regulation (0.12, $p > 0.05$, 95% CI = [[−0.01, 0.25]]) or voluntary regulation (0.02, $p > 0.05$, 95% CI = [[−0.08, 0.13]]), suggesting that only certain types of environmental regulation stimulate green innovation, and supporting the ‘narrow’ version of the Porter hypothesis.

Relationships between each type of environmental regulation and each measure of green innovation. Effect sizes for the relationships between the different dimensions of environmental regulation and the identified measures of green innovation are presented in Table 4.

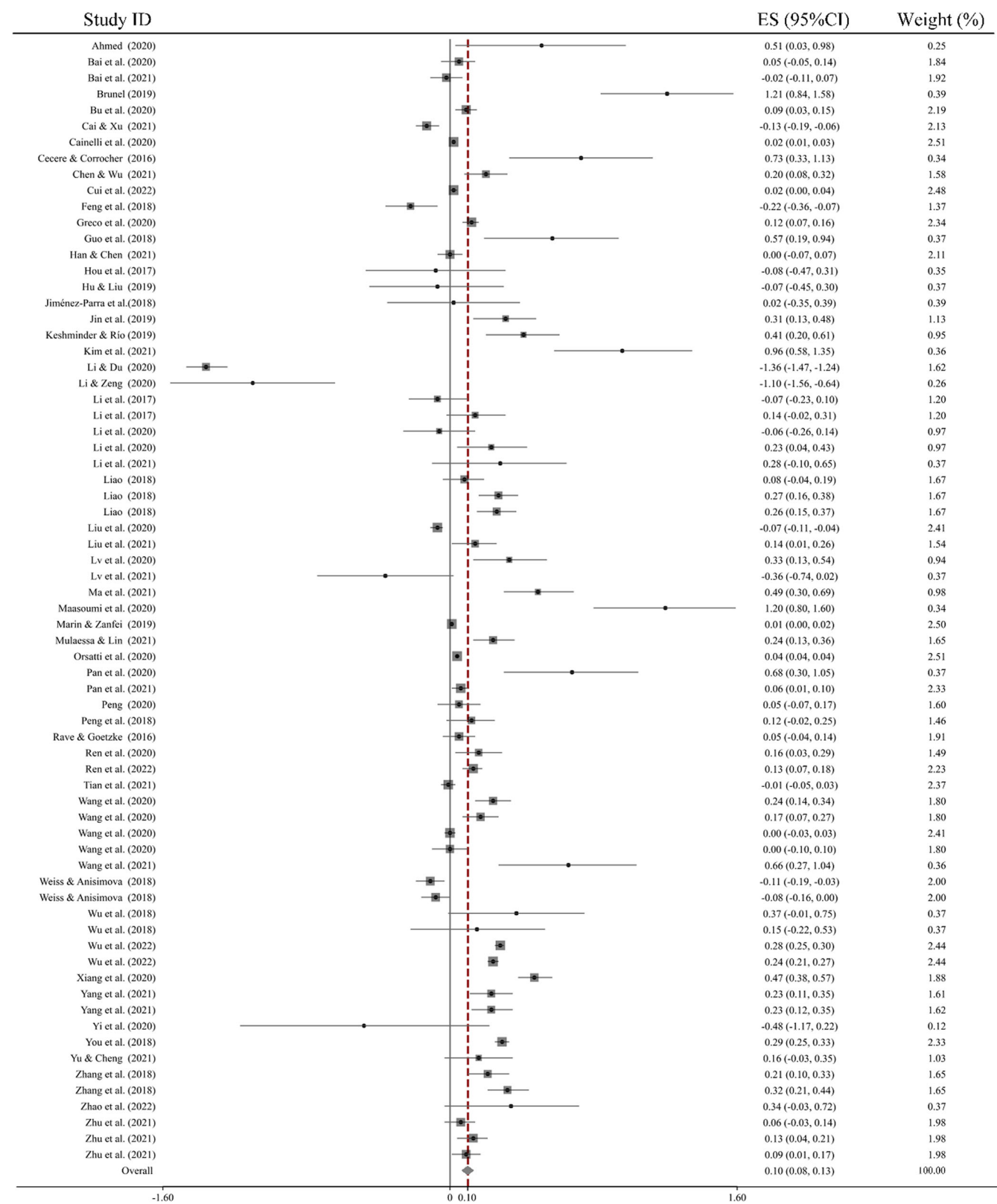


Fig. 5 The forest plot of all included studies. The figure summarizes the effect sizes with the 95% confidence intervals of the relationship between environmental regulation and green innovation in the included studies.

Relationships are assessed for all combinations of regulation type and innovation measures for which sufficient data is available to do so. Overall regulation is positively associated with new-product sales revenue (0.66, $p \leq 0.001$, 95% CI = [0.27, 1.04]), questionnaire measures regarding green innovation (0.35, $p \leq 0.001$, 95% CI = [[0.22, 0.48]]) and energy-based indices (0.12, $p \leq 0.001$, 95% CI = [[0.07, 0.16]]); command and control regulation is positively related to number of patents (0.16, $p \leq 0.001$, 95% CI = [[0.10, 0.22]]) and

Table 3 Effects of each type of environmental regulation on green innovation.

Type of regulation	Number of studies	Sample size	Effect size	95% CI
p-value				
Overall regulation	25	717,500	0.10*	[0.02, 0.19]
0.02				
Command and control regulation	28	124,193	0.12***	[0.09, 0.16]
<0.001				
Market incentive regulation	7	5762	0.12	[−0.01, 0.25]
>0.05				
Voluntary regulation	6	2298	0.02	[−0.08, 0.13]
>0.05				
Other regulations	4	6463	0.24**	[0.08, 0.40]
0.003				

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$ (significance levels based on two-tailed tests).**Table 4 Effects of different dimensions of environmental regulation on each identified measure of green innovation.**

Type of regulation	Measures of green innovation	No. of studies	Sample size	Effect size	95% CI	p-value
Overall regulation	Number of patents	15	711,134	0.13	[−0.02, 0.29]	>0.05
	New-product sales revenue	1	29	0.66***	[0.27, 1.04]	0.001
	R&D expenditure/revenue	1	3557	0.00	[−0.03, 0.03]	>0.05
	Questionnaire measures regarding green innovation	2	227	0.35***	[0.22, 0.48]	<0.001
	Energy-based indices	1	2053	0.12***	[0.07, 0.16]	<0.001
	Pollution-based indices	2	51	−0.26	[−1.90, 1.37]	>0.05
	Other measures	3	449	0.01	[−0.17, 0.20]	>0.05
Command and control regulation	Number of patents	21	58,816	0.16***	[0.10, 0.22]	<0.001
	Frequency of terms mentioned in the annual report	2	3947	0.17	[−0.05, 0.40]	>0.05
	Questionnaire measures regarding green innovation	3	822	0.14***	[0.05, 0.22]	0.001
Market incentive regulation	Energy-based indices	2	60,608	−0.04	[−0.17, 0.09]	>0.05
	Number of patents	4	4550	0.08	[−0.08, 0.24]	>0.05
	Questionnaire measures regarding green innovation	2	604	0.30***	[0.22, 0.38]	<0.001
Voluntary regulation	Energy-based indices	1	608	−0.08*	[−0.16, −0.00]	0.04
	Number of patents	5	2109	0.08*	[0.00, 0.15]	0.04
Other regulations	New-product sales revenue	1	189	−0.22**	[−0.36, −0.07]	0.003
	Number of patents	1	464	0.47***	[0.38, 0.57]	<0.001
	Questionnaire measures regarding green innovation	3	5999	0.17	[−0.00, 0.33]	>0.05

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$ (significance levels based on two-tailed tests).

questionnaire measures regarding green innovation (0.14, $p \leq 0.001$, 95% CI = [[0.05, 0.22]]); market incentive regulation is positively related to questionnaire measures regarding green innovation (0.30, $p \leq 0.001$, 95% CI = [[0.22, 0.38]]), but has a negative relationship with energy-based indices (−0.08, $p \leq 0.05$, 95% CI = [[−0.16, −0.00]]); voluntary regulation has positive and negative relationships respectively with number of patents (0.08, $p \leq 0.05$, 95% CI = [[0.00, 0.15]]) and new-product sales revenue (−0.22, $p \leq 0.01$, 95% CI = [[−0.36, −0.07]]); and other regulations have a strong and positive relationship with number of patents (0.47, $p \leq 0.001$, 95% CI = [[0.38, 0.57]]). All other relationships assessed are insignificant (see Table 4). These results suggest that distinctions between measures of green innovation have a significant impact on the apparent validity of the Porter hypothesis.

Publication bias. One important test of a meta-analysis is to assess whether the results are subject to publication bias, where the

outcome of a study plays a part in deciding whether or not it is published—something which has been revealed in past research (Franco et al., 2014; Rothstein et al., 2005). Visual inspection of the funnel plot in Fig. 6 shows that the selected publications can largely be considered unbiased. Statistically, the result of the fail-safe N test further suggests there is no publication bias (8989 more unpublished studies are required to make the results insignificant).

Moderator analyses. Table 5 reveals the result of a heterogeneity test on effect sizes. It shows that the effect-size heterogeneity of the relationships between certain types of environmental regulation and certain measures of green innovation is caused by moderations, including the relationships between overall regulation and the number of patents (I^2 : 97.84, $p \leq 0.001$), between overall regulation and pollution-based indices (I^2 : 96.67, $p \leq 0.001$), between command and control regulation and number

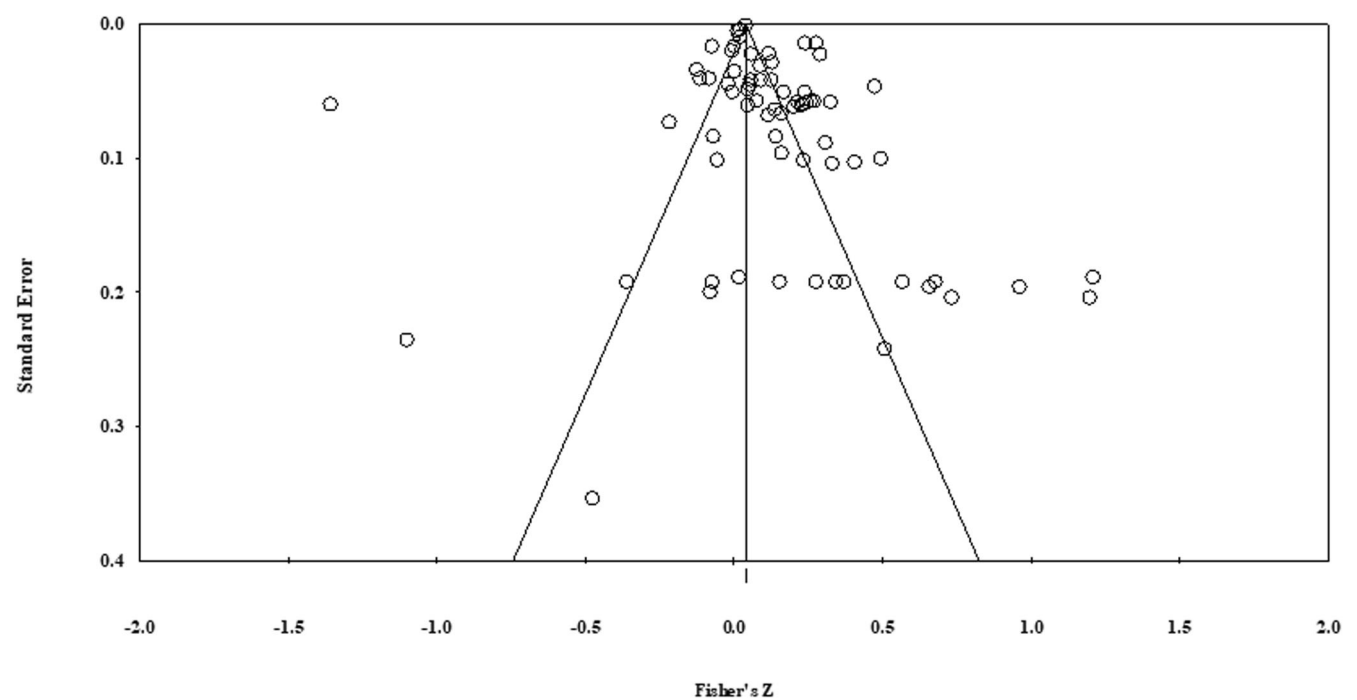


Fig. 6 Funnel plot. The figure is used as a visual aid for detecting bias in the relationship between environmental regulation and green innovation.

Table 5 Results of heterogeneity test on effect sizes.				
Group	Number of studies	Heterogeneity		
		Q-value	P-value	I-squared
OVR to NOPS	15	647.02	0.000	97.84***
OVR to NPSR	1	0.00	1.000	0.00
OVR to RDER	1	0.00	1.000	0.00
OVR to QGI	2	0.53	0.470	0.00
OVR to EBI	1	0.00	1.000	0.00
OVR to PBI	2	30.02	0.000	96.67***
OVR to OMS	3	5.73	0.057	65.07
CACR to NOPS	21	462.41	0.000	95.68***
CACR to FOT	2	53.07	0.000	98.12***
CACR to QGI	3	2.96	0.228	32.42
CACR to EBI	2	10.90	0.001	90.83***
MIR to NOPS	4	36.50	0.000	91.78***
MIR to QGI	2	0.46	0.499	0.00
MIR to EBI	1	0.00	1.000	0.00
VR to NOPS	5	7.63	0.106	47.60
VR to NPSR	1	0.00	1.000	0.00
ORS to NOPS	1	0.00	1.000	0.00
ORS to QGI	3	39.45	0.000	94.93***

****p* ≤ 0.001 (significance levels based on two-tailed tests).

of patents (I^2 : 95.68, $p \leq 0.001$), between command and control regulation and frequency of terms mentioned in the annual report (I^2 : 98.12, $p \leq 0.001$), between command and control regulation and energy-based indices (I^2 : 90.83, $p \leq 0.001$), between market incentive regulation and number of patents (I^2 : 91.78, $p \leq 0.001$) and between other regulations and questionnaires regarding green innovation (I^2 : 94.93, $p \leq 0.001$).

Based on these results, we tested our identified potential moderators—country type and level of analysis—on the relationships with significant heterogeneities. The results of this analysis are presented in Table 6. We did not examine the moderating effects of country type and level of analysis on the relationships between other regulations and questionnaire measures regarding

green innovation, and between command and control regulation and frequency of terms mentioned in the annual report, because the data for both relationships is only available for a single country type and level of analysis.

The results show that command and control regulation is significantly correlated with number of patents in both developing countries (0.14, 95% CI = [[0.06, 0.22]]) and developed countries (0.39, 95% CI = [[0.16, 0.58]]), while the heterogeneity test reveals that the result differs between the two types of country ($p = 0.04$)—hence country type acts as a moderator in the relationship between command and control regulation and number of patents. However, country type does not moderate the relationship between overall regulation and number of patents ($p > 0.05$). Country type was not used to moderate the relationship between overall regulation and pollution-based indices, or between market incentive regulation and number of patents because these two relationships were only investigated using data from developing countries.

All the relationships listed in Table 6 are significantly moderated by the level of analysis. The relationship between overall regulation and number of patents only becomes positive at the country level (0.68, 95% CI = [[0.40, 0.85]]). Relationships at the level of firm (0.09, 95% CI = [[−0.00, 0.19]]), city (−0.36, 95% CI = [[−0.83, 0.41]]) and province (0.29, 95% CI = [[−0.13, 0.62]]) are all insignificant. The heterogeneity test shows that the relationship varies by level of analysis ($p = 0.003$). The association between overall regulation and pollution-based indices is positive at the province level (0.51, 95% CI = [[0.19, 0.74]]) but negative at the firm level (−0.80, 95% CI = [[−0.92, −0.56]]). The heterogeneity test again indicates that the relationship is significantly different between levels of analysis ($p = 0.000$). Although effect sizes at all levels of analysis for the relationship between command and control regulation and number of patents are positive, the level of analysis still moderates the relationship—the P -value of the heterogeneity test is significant ($p = 0.02$), and the correlations become increasingly strong from firm to city level (0.10–0.62). Finally, the relationship between market incentive regulation and the number of patents is negative at the city level

Table 6 Results of the test of potential moderators.

Group	Effect size and 95% confidence interval				Heterogeneity	
	Number of studies	Point estimate	Sample size	95% CI	Q-value	p-value
Overall regulation and number of patents						
Country type						
Developing country	12	0.10	4144	[−0.18, 0.37]	0.98	0.32
Developed country	3	0.37	706,990	[−0.10, 0.71]		
Level of analysis						
Firm	6	0.09	707,931	[−0.00, 0.19]	13.96	0.003**
City	3	−0.36	3035	[−0.83, 0.41]		
Province	3	0.29	90	[−0.13, 0.62]		
Country	3	0.68	78	[0.40, 0.85]		
Overall regulation and pollution-based indices						
Level of analysis						
Firm	1	−0.80	21	[−0.92, −0.56]	30.02	0.000***
Province	1	0.51	30	[0.19, 0.74]		
Command and control regulation and number of patents						
Country type						
Developing country	17	0.14	20,369	[0.06, 0.22]	4.08	0.04*
Developed country	4	0.39	38,447	[0.16, 0.58]		
Level of analysis						
Firm	14	0.10	58,013	[0.04, 0.16]	10.18	0.02*
City	1	0.20	266	[0.08, 0.31]		
Province	3	0.25	450	[0.16, 0.33]		
Country	3	0.62	87	[0.01, 0.89]		
Market incentive regulation and number of patents						
Level of analysis						
Firm	1	0.13	573	[0.04, 0.21]	36.49	0.000***
City	1	−0.07	3557	[−0.11, −0.04]		
Province	2	0.17	420	[0.07, 0.26]		

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$ (significance levels based on two-tailed tests).

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$ (significance levels based on two-tailed tests).

(−0.07, 95% CI = [−0.11, −0.04]), but positive at the firm and province levels. Again, the relationship between market incentive regulation and number of patents is heterogeneous by level of analysis ($p = 0.000$).

Discussion

Our results largely add support to the overall Porter hypothesis, as well as its ‘narrow’ version. By distinguishing between different types of environmental regulation and measures of green innovation, and by assessing country type and level of analysis as moderators, our study extends our understanding of the Porter hypothesis and resolves the ambiguity issue raised previously (Ambec et al., 2012; Zhao et al., 2022).

The overall Porter hypothesis. The positive aggregate effect size (0.10; $p \leq 0.001$) for the overall Porter hypothesis adds support to its conclusions. In line with Jaffe and Palmer’s (1997) view, it is possible that environmental regulations remind firms of available or potential technology improvements and likely resource inefficiencies, as well as encouraging investment in green innovation. Environmental regulations may also pressure firms to foster eco-innovations, and raise their awareness of environmental promotion. All these factors help to explain the positive effect of environmental regulation on green innovation. Nonetheless, the result differs from a previous meta-analysis testing the Porter hypothesis, where aggregate effect size turned out to be insignificant (Cohen and Tubb, 2017). The divergent results may be due to the wider time span of Cohen and Trubb’s analysis (1990–2015, rather than 2016–2022), and the broader outcomes on which they focused (competitiveness and financial and economic performance as well as all types of innovation).

One potential reason that a different timespan produces different results may be that enactments of environmental regulations have lagged effects. Regulatory compliance often leads to short-term costs, but it takes time for firms to adjust their procedures and culture to embrace long-term innovation and experience its benefits. Through years—even decades—of such adjustments, firms tend to shift from a position of denial to one of voluntary innovation and become more capable of taking advantage of regulatory policies to become more competitive. The Paris Agreement provides further opportunities for them to take greater steps to enhance their competitiveness through green innovation. Indeed, previous research has found that studies using lagged variables are more likely to demonstrate a positive relationship (Brunnermeier and Cohen, 2003). The broader focus of Cohen and Tubb’s (2017) study may also lead to a discrepancy in results due to the inclusion of types of competitiveness, performance, and innovation which are unaffected by environmental regulation.

The ‘narrow’ version of the Porter hypothesis. Our results give support to the ‘narrow’ version of the Porter hypothesis—that only certain types of environmental regulation will foster green innovation. There are a number of reasons for this. First, command and control regulation, a traditional regulatory approach, is an ‘end-of-pipe’ regulation. It provides a clear-cut incentive for eco-innovations. It is therefore not surprising to see the positive effect of command and control regulation on green innovation. We believe this approach is particularly useful among developing countries in comparison with other regulatory types. Firms in developing countries rely more on information gathered by government and are often inexperienced in dealing with potential negative environmental impacts. Additionally, organizational inertia can be overcome through pressure from environmental

regulation. Parsad and Mittal (2022) demonstrated that the regulatory mechanism dominates firms' environmental activities in developing nations, while market and institutional forces are expected to be stronger among developed countries. Second, the insignificant relationship between market incentive regulation and green innovation may be attributable to the sample characteristic that only one study explored this relationship in developed countries (Weiss and Anisimova, 2018). We expect that this relationship would become positive if more samples could be acquired from developed countries, as they have a more complete market mechanism. Third, voluntary regulation is the type of regulation with the highest level of flexibility among all regulatory measures (Christmann and Taylor, 2006). While there is an insignificant association with green innovation in general, the relationship varies after dividing the measures of green innovation. Specifically, we found a positive relationship between voluntary regulation and number of patents, but a negative relationship between voluntary regulation and new-product sales revenue. This distinction confirms that it is significant to assess the Porter hypothesis by measures of green innovation or confusion is likely to be raised. Fourth, the significant and positive relationship between other regulations and green innovation indicates that a variety of regulations other than the three common types considered can also be used to achieve the objective of green innovation. Further analysis of the results, by distinguishing between measures of green innovation within each type of environmental regulation, indicates that the specific measure of green innovation does indeed influence the apparent validity of the Porter hypothesis, consistent with Lankoski (2010) and Ambec et al.'s (2012) contention. Table 4 shows that the number of patents is the most frequently used measure, possibly because it is easy to access, but also because it is indeed a good indicator of green innovation.

Moderating effects. Table 6 demonstrates that there is considerable variation in the moderating effects of country type and level of analysis on the Porter hypothesis. While we found no difference in the relationship between overall regulation and the number of patents between developed and developing countries, the association between command and control regulation and the number of patents does show a distinction based on country type. Given that firms in developed countries have better research and development capabilities than those in developing countries, they are more capable of dealing with mandatory regulations by finding new solutions and therefore increasing the number of patents. This makes the positive relationship between command and control regulation and the number of patents stronger in developed countries than in developing ones. The results are also heterogeneous by level of analysis. In general, a higher level of study (for example considering countries as opposed to firms) shows a stronger association between environmental regulation and green innovation. One explanation for this may be that when a relationship is investigated from a more global perspective, micro-level differences, such as different attitudes towards environmental regulation and limitations on firms' actions that are designed to enhance innovation, are minimized, leading to a more consistent outcome at lower levels of analysis.

Conclusions and policy implications

The mixed results shown by studies of the Porter hypothesis have raised considerable debate in the past three decades. Our study, based on the relevant literature published between 2016 and 2022, is the first meta-analysis exploring the association between environmental regulation and green innovation. We found that environmental regulation has a positive association with green

innovation, providing support for the overall version of the Porter hypothesis. Additionally, our results provided evidence supporting the 'narrow' version of the Porter hypothesis by distinguishing between different types of regulation. More importantly, we have provided reasons why divergent results are shown in past studies, not only including the failure to consider different environmental regulation types, green innovation measures, country types, or levels of analysis, but also the lagged effects of regulations and the scopes of innovation considered. All these factors, which have not previously been fully tested, have influenced the relationship, causing results to be inconclusive.

Our study also has important practical implications. First, since the overall Porter hypothesis is supported, governments should insist on using environmental regulation to foster green innovation, therefore improving their countries' overall competitiveness. In developing countries, where markets are less complete and firms have lower research and development capabilities than those in developed nations, command and control regulation should be used as the main type of regulation. In developed countries, while market-based instruments are often seen as a stronger incentive for innovation than mandatory regulations, our results suggested that command and control regulation increased the number of patents to a greater extent than in developing ones, indicating that this traditional form of regulation still has an important part to play. This finding is in line with that of Popp (2002) and Taylor (2012) that command and control regulation still has a crucial role to play in developed countries.

Second, a variety of environmental regulations should be combined to improve green innovation, since most types of regulation have positive impacts in some forms. Our results show that environmental regulation exerts varying effects at the firm, city, province, and national levels, and policymakers should determine the best combinations of regulations to use in each circumstance, thus engendering the highest possible level of innovation.

Finally, although our meta-analysis extends our understanding of the Porter hypothesis by addressing the issue of mixed results in relation to it, some limitations and further opportunities remain. First, since the data comes largely from China, it is likely to give rise to a generalization issue. One possible reason is that China has faced significant environmental challenges due to its rapid industrialization and economic growth. The Chinese government has recognized the importance of addressing these challenges and has implemented stringent environmental regulations in the last several years. This emphasis on environmental policy has led to a growing interest among Chinese scholars in studying the potential economic benefits of these regulations, as proposed by the Porter Hypothesis. To address the potential bias issue, more studies deriving data from other nations are required to further investigate the nature of Porter's hypothesis. Second, although we categorize measures of green innovation into eight groups, we do not know the underlying mechanisms behind the relationships between each regulatory type and the various measures of green innovation. Future research in this field would be beneficial in improving the effectiveness of environmental regulation in increasing green innovation. Third, due to data limitations, we are unable to test the 'weak' and 'strong' versions of the Porter hypothesis. More evidence is required so that these versions of Porter's hypothesis can be fully tested, providing a fuller picture of the environmental regulation-green innovation relationship.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Note

1 The definitions of ‘overall’ and ‘narrow’ versions of the Porter hypothesis are provided in the section “Porter hypothesis”.

References

- Adelegan JA, Carlsson B, Perelli S (2010) Eco-innovation and corporate performance: the African experience. Paper Presented at the Berlin Conference on the Human Dimensions of Global Environmental Change, Berlin, 8–9 October 2010
- Ahmed K (2020) Environmental policy stringency, related technological change and emissions inventory in 20 OECD countries. *J Environ Manag* 274:111209–111215. <https://doi.org/10.1016/j.jenvman.2020.111209>
- Ahmed RR, Akbar W, Aijaz M, Channar ZA, Ahmed F, Parmar V (2023) The role of green innovation on environmental and organizational performance: moderation of human resource practices and management commitment. *Heliyon* 9:e12679. <https://doi.org/10.1016/j.heliyon.2022.e12679>
- Ambec S, Cohen MA, Elgie S, Lanoie P (2012) The Porter hypothesis at 20: can environmental regulation enhance innovation and competitiveness? *Rev Environ Econ Policy* 7(1):2–22. <https://doi.org/10.1093/reep/res016>
- Ambec S, Lanoie P (2008) Does it pay to be green? A systematic overview. *Acad Manag Perspect* 22(4):45–62. <https://doi.org/10.5465/amp.2008.35590353>
- Arimura TH, Hibiki A, Johnstone N (2007) An empirical study of environmental R&D: What encourages facilities to be environmentally innovative. In Johnstone N (ed), *Environmental Policy and Corporate Behaviour*. Edward Elgar Publishing Ltd., p 142–173. <https://doi.org/10.4337/9781781953020.00009>
- Ashford NA, Hall RP (2011) The importance of regulation-induced innovation for sustainable development. *Sustainability (Basel, Switz)* 3:270–292. <https://doi.org/10.3390/su3010270>
- Bai Y, Qian Q, Jiao J, Li L, Li F, Yang R (2020) Can environmental innovation benefit from outward foreign direct investment to developed countries? Evidence from Chinese manufacturing enterprises. *Environ Sci Pollut Res* 27(12):13790–13808. <https://doi.org/10.1007/s11356-020-07819-z>
- Bai Y, Wang JY, Jiao JL (2021) A framework for determining the impacts of a multiple relationship network on green innovation. *Sustain Prod Consum* 27:471–484. <https://doi.org/10.1016/j.spc.2021.01.014>
- Böhringer C, Cuntz A, Harhoff D, Asane-Otoo E (2017) The impact of the German feed-in tariff scheme on innovation: evidence based on patent filings in renewable energy technologies. *Energy Econ* 67:545–553. <https://doi.org/10.1016/j.eneco.2017.09.001>
- Bourcet C (2020) Empirical determinants of renewable energy deployment: a systematic literature review. *Energy Econ* 85:104563–104581. <https://doi.org/10.1016/j.eneco.2019.104563>
- Brunel C (2019) Green innovation and green Imports: links between environmental policies, innovation, and production. *J Environ Manag* 248:109290–109305. <https://doi.org/10.1016/j.jenvman.2019.109290>
- Brunnermeier SB, Cohen MA (2003) Determinants of environmental innovation in US manufacturing industries. *J Environ Econ Manag* 45:278–293. [https://doi.org/10.1016/S0095-0696\(02\)00058-X](https://doi.org/10.1016/S0095-0696(02)00058-X)
- Bu M, Qiao Z, Liu B (2020) Voluntary environmental regulation and firm innovation in China. *Econ Model* 89:10–18. <https://doi.org/10.1016/j.econmod.2019.12.020>
- Cai W, Xu F (2021) The impact of the new environmental protection law on eco-innovation: evidence from green patent data of Chinese listed companies. *Environ Sci Pollut Res* 29(7):10047–10062. <https://doi.org/10.1007/s11356-021-16365-1>
- Cainelli G, D’Amato A, Mazzanti M (2020) Resource efficient eco-innovations for a circular economy: Evidence from EU firms. *Research Policy* 49(1):103827–103837. <https://doi.org/10.1016/j.respol.2019.103827>
- Cecere G, Corrocher N (2016) Stringency of regulation and innovation in waste management: an empirical analysis on EU countries. *Ind Innov* 23(7):625–646. <https://doi.org/10.1080/13662716.2016.1195253>
- Cerin P (2006) Bringing economic opportunity into line with environmental influence: a discussion on the Coase theorem and the Porter and van der Linde Hypothesis. *Ecol Econ* 56:209–225. <https://doi.org/10.1016/j.ecolecon.2005.01.016>
- Chassagnon V, Haned N (2015) The relevance of innovation leadership for environmental benefits: a firm-level empirical analysis on French firms. *Technol Forecast Soc Chang* 91:194–207. <https://doi.org/10.1016/j.techfore.2014.02.012>
- Chen W, Wu Y (2021) China’s new environmental protection law and green innovation: evidence from prefecture-level cities. *Complexity* 1–13. <https://doi.org/10.1155/2021/5566357>
- Chen Z, Zhang X, Chen F (2021) Do carbon emission trading schemes stimulate green innovation in enterprises? Evidence from China. *Technol Forecast Soc Change* 168:120744–120758. <https://doi.org/10.1016/j.techfore.2021.120744>
- Christmann P, Taylor G (2006) Firm self-regulation through international certifiable standards: determinants of symbolic versus substantive implementation. *J Int Bus Stud* 37(6):863–878. <https://doi.org/10.1057/palgrave.jibs.8400231>
- Cohen MA, Tubb A (2017) The impact of environmental regulation on firm and country competitiveness: a meta-analysis of the Porter hypothesis. *J Assoc Environ Resour Econ* 5(2):371–399. <https://doi.org/10.2139/ssrn.2692919>
- Creswell JW, Creswell JD (2017) *Research design: qualitative, quantitative, and mixed methods approaches*. Sage Publications
- Cui J, Dai J, Wang Z, Zhao X (2022) Does environmental regulation induce green innovation? A panel study of Chinese listed firms. *Technol Forecast Soc Change* 176:121492–121500. <https://doi.org/10.1016/j.techfore.2022.121492>
- Dangelico RM (2016) Green product innovation: where we are and where we are going. *Bus Strateg Environ* 25(8):560–576. <https://doi.org/10.1002/bse.1886>
- Dechezleprêtre A, Sato M (2017) The impacts of environmental regulations on competitiveness. *Rev Environ Econ Policy* 11(2):183–206. <https://doi.org/10.1093/reep/rer013>
- del Rio Gonzalez P (2005) Analysing the factors influencing clean technology adoption: a study of the Spanish pulp and paper industry. *Bus Strateg Environ* 14:20–37. <https://doi.org/10.1002/bse.426>
- Desrochers P (2008) Did the invisible hand need a regulatory glove to develop a green thumb? Some historical perspective on market incentives, win-win innovations and the Porter hypothesis. *Environ Resour Econ* 41:519–539. <https://doi.org/10.1007/s10640-008-9208-x>
- Doran J, Ryan G (2012) Regulation and firm perception, eco-innovation and firm performance. *Eur J Innov Manag* 15(4):421–441. <https://doi.org/10.1108/14601061211272367>
- Doran J, Ryan G (2016) The importance of the diverse drivers and types of environmental innovation for firm performance. *Bus Strateg Environ* 25(2):102–119. <https://doi.org/10.1002/bse.1860>
- Fang J, Gao C, Lai M (2020) Environmental regulation and firm innovation: evidence from national specially monitored firms program in China. *J Clean Prod* 271:122599–122609. <https://doi.org/10.1016/j.jclepro.2020.122599>
- Feng Z, Zeng B, Ming Q (2018) Environmental regulation, two-way foreign direct investment, and green innovation efficiency in China’s manufacturing industry. *Int J Environ Res public health* 15(10):2292–2311. <https://doi.org/10.3390/ijerph15102292>
- Frenz M, Ietto-Gillies G (2007) Does multinationality affect the propensity to innovate? An analysis of the third UK Community innovation survey. *Int Rev Appl Econ* 21(1):99–117. <https://doi.org/10.1080/02692170601035033>
- Franco A, Malhotra N, Simonovits G (2014) Publication bias in the social sciences: unlocking the file drawer. *Science* 345(6203):1502–1505. <https://doi.org/10.1126/science.1255484>
- Fu W, Li C, Ondrich J, Popp D (2018) Technological spillover effects of state renewable energy policy: Evidence from patent counts. Technical Report. National Bureau of Economic Research. Cambridge, MA. <https://doi.org/10.3386/w25390>
- Geyskens I, Krishnan R, Steenkamp JBE, Cunha PV (2009) A review and evaluation of meta-analysis practices in management research. *J Manag* 35(2):393–419. <https://doi.org/10.1177/0149206308328501>
- Guo LL, Qu Y, Tseng ML (2017) The interaction effects of environmental regulation and technological innovation on regional green growth performance. *J Clean Prod* 162:894–902. <https://doi.org/10.1016/j.jclepro.2017.05.210>
- Guo Y, Xia X, Zhang S, Zhang D (2018) Environmental regulation, government R&D funding and green technology innovation: evidence from China provincial data. *Sustainability* 10(4):940–960. <https://doi.org/10.3390/su10040940>
- Greco M, Germani F, Grimaldi M, Radicic D (2020) Policy mix or policy mess? Effects of cross-instrumental policy mix on eco-innovation in German firms. *Technovation* 102194–102230. <https://doi.org/10.1016/j.technovation.2020.102194>
- Han MS, Chen W (2021) Determinants of eco-innovation adoption of small and medium enterprises: an empirical analysis in Myanmar. *Technol Forecast Soc Change* 173:121146–121154. <https://doi.org/10.1016/j.techfore.2021.121146>
- Horbach J (2008) Determinants of environmental innovation—new evidence from German panel data sources. *Res Policy* 37:163–173. <https://doi.org/10.2139/ssrn.879707>
- Hou J, Chen H, Xu J (2017) External knowledge sourcing and green innovation growth with environmental and energy regulations: evidence from manufacturing in China. *Sustainability* 9(3):342–358. <https://doi.org/10.3390/su9030342>
- Hu S, Liu S (2019) Do the coupling effects of environmental regulation and R&D subsidies work in the development of green innovation? Empirical evidence from China. *Clean Technol Environ Policy* 21(9):1739–1749. <https://doi.org/10.1007/s10098-019-01745-6>
- Huang JH, Yang XG, Cheng G, Wang SY (2014) A comprehensive eco-efficiency model and dynamics of regional eco-efficiency in China. *J Clean Prod* 67:228–238. <https://doi.org/10.1016/j.jclepro.2013.12.003>

- Jiménez-Parra B, Alonso-Martínez D, Godos-Díez JL (2018) The influence of corporate social responsibility on air pollution: analysis of environmental regulation and eco-innovation effects. *Corp Soc Responsib Environ Manag* 25(6):1363–1375. <https://doi.org/10.1002/csr.1645>
- Jin J, Du J, Long X, Boamah KB (2019) Positive mechanism of foreign direct investment enterprises on China's environment: analysis of host country regulation and parent company management. *J Clean Prod* 227:207–217. <https://doi.org/10.1016/j.jclepro.2019.04.143>
- Jaffe AB, Palmer K (1997) Environmental regulation and innovation: a panel data study. *Rev Econ Stat* 79(4):610–619. <https://doi.org/10.3386/w5545>
- Johnstone N, Haščić I, Popp D (2010) Renewable energy policies and technological innovation: evidence based on patent counts. *Environ Resour Econ* 45(1):133–155. <https://doi.org/10.3386/w13760>
- Keshminder JS, del Río P (2019) The missing links? The indirect impacts of drivers on eco-innovation. *Corp Soc Responsib Environ Manag* 26(5):1100–1118. <https://doi.org/10.1002/csr.1789>
- Kim I, Pantzalis C, Zhang Z (2021) Multinationality and the value of green innovation. *J Corp Financ* 69:101996–102018. <https://doi.org/10.2139/ssrn.3562104>
- Lankoski L (2010) Linkages between environmental policy and competitiveness. OECD Environment Working Papers, No. 13, <http://www.oecd.org/dataoecd/0/8/44392874.pdf>. <https://doi.org/10.1787/218446820583>
- Li D, Tang F, Zhang L (2020) Differential effects of voluntary environmental programs and mandatory regulations on corporate green innovation. *Nat Hazards* 103(3):3437–3456. <https://doi.org/10.1007/s11069-020-04137-y>
- Li D, Zhao Y, Zhang L, Chen X, Cao C (2017) Impact of quality management on green innovation. *J Clean Prod* 170:462–470. https://doi.org/10.1007/978-3-030-22964-1_18
- Li D, Zeng T (2020) Are China's intensive pollution industries greening? An analysis based on green innovation efficiency. *J Clean Prod* 259:120901–120908. <https://doi.org/10.1016/j.jclepro.2020.120901>
- Li J, Du Y (2020) Spatial effect of environmental regulation on green innovation efficiency: evidence from prefectural-level cities in China. *J Clean Prod* 286:125032–125043. <https://doi.org/10.1016/j.jclepro.2020.125032>
- Li X, Hamblin D (2016) Factors impacting on cleaner production: case studies of Chinese pharmaceutical manufacturers in Tianjin, China. *J Clean Prod* 131:121–132. <https://doi.org/10.1016/j.jclepro.2016.05.066>
- Li X, Du K, Ouyang X, Liu L (2022) Does more stringent environmental regulation induce firms' innovation? Evidence from the 11th five-year plan in China. *Energy Econ* 112:106110–106118. <https://doi.org/10.1016/j.eneco.2022.106110>
- Li X, Hu Z, Zhang Q (2021) Environmental regulation, economic policy uncertainty, and green technology innovation. *Clean Technol Environ Policy* 23(10):2975–2988. <https://doi.org/10.21203/rs.3.rs-164186/v1>
- Li Z, Zou F, Mo B (2022) Does mandatory CSR disclosure affect enterprise total factor productivity? *Econom Res Ekon Istraž* 35:4902–4921. <https://doi.org/10.1080/1331677x.2021.2019596>
- Liao Z (2018) Environmental policy instruments, environmental innovation and the reputation of enterprises. *J Clean Prod* 171:1111–1117. <https://doi.org/10.1016/j.jclepro.2017.10.126>
- Liao Z, Liu Y (2022) What drives environmental innovation? A meta-analysis. *Bus Strategy Environ* 30(4):1852–1864. <https://doi.org/10.1002/bse.2720>
- Lin B, Wu R (2020) Designing energy policy based on dynamic change in energy and carbon dioxide emission performance of China's iron steel industries. *J Clean Prod* 256:120412–120425. <https://doi.org/10.1016/j.jclepro.2020.120412>
- Liu Y, Wang A, Wu Y (2021) Environmental regulation and green innovation: evidence from China's new environmental protection law. *J Clean Prod* 297:126698–126707. <https://doi.org/10.1016/j.jclepro.2021.126698>
- Liu Y, Zhu J, Li EY, Meng Z, Song Y (2020) Environmental regulation, green technological innovation, and eco-efficiency: the case of Yangtze River economic belt in China. *Technol Forecast Soc Change* 155:119993–120013. <https://doi.org/10.1016/j.techfore.2020.119993>
- Long X, Wan W (2017) Environmental regulation, corporate profit margins and compliance cost heterogeneity of different scale enterprises. *China Ind Econ* 6:155–174. (in Chinese)
- Lv C, Shao C, Lee CC (2021) Green technology innovation and financial development: do environmental regulation and innovation output matter? *Energy Econ* 98:105237–105250. <https://doi.org/10.1016/j.eneco.2021.105237>
- Lv X, Qi Y, Dong W (2020) Dynamics of environmental policy and firm innovation: asymmetric effects in Canada's oil and gas industries. *Sci Total Environ* 712:136371–136379. <https://doi.org/10.1016/j.scitotenv.2019.136371>
- Ma J, Hu Q, Shen W, Wei X (2021) Does the low-carbon city pilot policy promote green technology innovation? Based on green patent data of Chinese A-share listed companies. *Int J Environ Res Public Health* 18(7):3695–3712. <https://doi.org/10.3390/ijerph18073695>
- Maasoumi E, Heshmati A, Lee I (2020) Green innovations and patenting renewable energy technologies. *Empir Econ* 60(1):513–538. <https://doi.org/10.1007/s00181-020-01986-1>
- Marin G, Zanfei A (2019) Does host market regulation induce cross-border environmental innovation. *World Econ* 42(7):2089–2119. <https://doi.org/10.1111/twec.12784>
- Menegaki AN, Ahmad N, Aghdam RF, Naz A (2021) The convergence in various dimensions of energy–economy–environment linkages: a comprehensive citation-based systematic literature review. *Energy Econ* 104:105653–105670. <https://doi.org/10.1016/j.eneco.2021.105653>
- Mulaessa N, Lin L (2021) How do proactive environmental strategies affect green innovation? The moderating role of environmental regulations and firm performance. *Int J Environ Res Public Health* 18(17):9083–9101. <https://doi.org/10.3390/ijerph18179083>
- Nicolli F, Vona F (2016) Heterogeneous policies, heterogeneous technologies: the case of renewable energy. *Energy Econ* 56:190–204. <https://doi.org/10.1016/j.eneco.2016.03.007>
- Ouyang X, Li Q, Du K (2020) How does environmental regulation promote technological innovations in the industrial sector? Evidence from Chinese provincial panel data. *Energy Policy* 139:111310–111319. <https://doi.org/10.1016/j.enpol.2020.111310>
- Orsatti G, Quatraro F, Pezzoni M (2020) The antecedents of green technologies: the role of team-level recombinant capabilities. *Res Policy* 49(3):103919–103935. <https://doi.org/10.1016/j.respol.2019.103919>
- Palmer K, Wallace EO, Paul RP (1995) Tightening environmental standards: the benefit-cost or the no-cost paradigm? *J Econ Perspect* 9(4):119–132. <https://doi.org/10.4337/9781035305100.00010>
- Pan X, Cheng W, Gao Y, Balezantis T, Shen Z (2020) Is environmental regulation effective in promoting the quantity and quality of green innovation? *Environ Sci Pollut Res* 28(5):6232–6241. <https://doi.org/10.1007/s11356-020-10984-w>
- Pan Z, Liu L, Bai S, Ma Q (2021) Can the social trust promote corporate green innovation? Evidence from China. *Environ Sci Pollut Res* 28(37):52157–52173. <https://doi.org/10.1007/s11356-021-14293-8>
- Parker SK, Collins CG (2010) Taking stock: integrating and differentiating multiple proactive behaviors. *J Manag* 36(3):633–662. <https://doi.org/10.1177/0149206308321554>
- Parsad C, Mittal S (2022) Evolution of corporate environmentalism, a politico-social perspective: concept, command and control to self-regulatory and voluntary, and future directions. *J Public Aff* 22(3):2286–2294. <https://doi.org/10.1002/pa.2286>
- Peng B, Tu Y, Wei G (2018) Can environmental regulations promote corporate environmental responsibility? Evidence from the moderated mediating effect model and an empirical study in China. *Sustainability* 10(3):641–656. <https://doi.org/10.3390/su10030641>
- Peng X (2020) Strategic interaction of environmental regulation and green productivity growth in China: green innovation or pollution refuge? *Sci Total Environ* 732:139200–139213. <https://doi.org/10.1016/j.scitotenv.2020.139200>
- Petitjean M (2019) Eco-friendly policies and financial performance: was the financial crisis a game changer for large US companies? *Energy Econ* 80:502–511. <https://doi.org/10.2139/ssrn.3769043>
- Popp D (2002) Induced innovation and energy prices. *Am Econ Rev* 92(1):160–180. <https://doi.org/10.3386/w8284>
- Popp D (2019) Environmental policy and innovation: a decade of research. *Eurasia Bus Rev* 8:299–321. <https://doi.org/10.3386/w25631>
- Porter M, van der Linde C (1995) Toward a new conception of the environment–competitiveness relationship. *J Econ Perspect* 9(4):97–118. <https://doi.org/10.1257/jep.9.4.97>
- Rave T, Goetzke F (2016) Environmental innovation activities and patenting: Germany reconsidered. *J Environ Plan Manag* 60(7):1214–1234. <https://doi.org/10.1080/09640568.2016.1213706>
- Ren S, He D, Yan J, Zeng H, Tan J (2022) Environmental labeling certification and corporate environmental innovation: the moderating role of corporate ownership and local government intervention. *J Bus Res* 140:556–571. <https://doi.org/10.1016/j.jbusres.2021.11.023>
- Ren S, Hu Y, Zheng J, Wang Y (2020) Emissions trading and firm innovation: evidence from a natural experiment in China. *Technol Forecast Soc Change* 155:119989–120000. <https://doi.org/10.2139/ssrn.3117929>
- Ren S, Li X, Yuan B, Li D, Chen X (2018) The effects of three types of environmental regulation on eco-efficiency: a cross-region analysis in China. *J Clean Prod* 173:245–255. <https://doi.org/10.1016/j.jclepro.2016.08.113>
- Ren X, Xia X, Taghizadeh-Hesary F (2023) Uncertainty of uncertainty and corporate green innovation—evidence from China. *Econ Anal Policy* 78:634–647. <https://doi.org/10.1016/j.eap.2023.03.027>
- Ren X, Zeng G, Sun X (2023) The peer effect of digital transformation and corporate environmental performance: empirical evidence from listed companies in China. *Econ Model* 128:106515–106526. <https://doi.org/10.1016/j.econmod.2023.106515>
- Ringquist E (2013) Meta-Analysis for public management and policy. Wiley, New York
- Rothstein HR, Sutton AJ, Borenstein M (2005) Publication bias in meta-analysis. In: Rothstein HR, Sutton AJ, Borenstein M (Eds.) *Publication bias in meta-analysis: prevention, assessment and adjustments*. Wiley, Chichester, UK

- Ryan RM, Duineveld JJ, Di Domenico SI, Ryan WS, Steward BA, Bradshaw EL (2022) We know this much is (metaanalytically) true: a meta-review of meta-analytic findings evaluating self-determination theory. *Psychol Bull* 148(11-12):813–842. <https://doi.org/10.31234/osf.io/gk5cy>
- Sanni M (2018) Drivers of eco-innovation in the manufacturing sector of Nigeria. *Technol Forecast Soc Change* 131:303–314. <https://doi.org/10.1016/j.techfore.2017.11.007>
- Sáez-Martínez FJ, González-Moreno A, Hogan T (2014) The role of university in eco-entrepreneurship: evidence from the Eurobarometer survey on attitudes of European entrepreneurs towards eco-innovation. *Environ Eng Manag J* 13(10):2541–2549. <https://doi.org/10.30638/eemj.2014.284>
- Takalo SK, Tooranloo HS, Parizi ZS (2021) Green innovation: a systematic literature review. *J Clean Prod* 279:122474–122495. <https://doi.org/10.1016/j.jclepro.2020.122474>
- Tang K, Qiu Y, Zhou D (2020) Does command-and-control regulation promote green innovation performance? Evidence from China's industrial enterprises. *Sci Total Environ* 712:136362–136371. <https://doi.org/10.1016/j.scitotenv.2019.136362>
- Taylor MR (2012) Innovation under cap-and-trade programs. *Proc Natl Acad Sci USA* 109(13):4804–4809. <https://doi.org/10.1073/pnas.1113462109>
- Tian Y, Song W, Liu M (2021) Assessment of how environmental policy affects urban innovation: evidence from China's low-carbon pilot cities program. *Econ Anal Policy* 71:41–56. <https://doi.org/10.1016/j.eap.2021.04.002>
- Triguero A, Moreno-Mondéjar L, Davia MA (2013) Drivers of different types of ecoinnovation in European SMEs. *Ecol Econ* 92:25–33. <https://doi.org/10.1016/j.ecolecon.2013.04.009>
- Wang A, Hu S, Lin B (2021) Can environmental regulation solve pollution problems? Theoretical model and empirical research based on the skill premium. *Energy Econ* 94:105068–105082. <https://doi.org/10.1016/j.eneco.2020.105068>
- Wang A, Si L, Hu S (2023) Can the penalty mechanism of mandatory environmental regulations promote green innovation? Evidence from China's enterprise data. *Energy Econ* 125:106856–106873. <https://doi.org/10.1016/j.eneco.2023.106856>
- Wang F, Feng L, Li J, Wang L (2020) Environmental regulation, tenure length of officials, and green innovation of enterprises. *Int J Environ Res Public Health* 17(7):2284–2299. <https://doi.org/10.3390/ijerph17072284>
- Wang P, Dong C, Chen N, Qi M, Yang S, Nnenna AB, Li W (2021) Environmental regulation, government subsidies, and green technology innovation—a provincial panel data analysis from China. *Int J Environ Res Public Health* 18(22):11991–12009. <https://doi.org/10.3390/ijerph182211991>
- Wang W, Li Y, Lu N, Wang D, Jiang H, Zhang C (2020) Does increasing carbon emissions lead to accelerated eco-innovation? Empirical evidence from China. *J Clean Prod* 251:119690–119702. <https://doi.org/10.1016/j.jclepro.2019.119690>
- Wang X, Zhang T, Nathwani J, Yang F, Shao Q (2022) Environmental regulation, technology innovation, and low carbon development: Revisiting the EKC Hypothesis, Porter Hypothesis, and Jevons' Paradox in China's iron & steel industry. *Technol Forecast Soc Change* 176:121471–121482. <https://doi.org/10.1016/j.techfore.2022.121471>
- Weiss JF, Anisimova T (2018) The innovation and performance effects of well-designed environmental regulation: evidence from Sweden. *Ind Innov* 26(5):534–567. <https://doi.org/10.1080/13662716.2018.1468240>
- Wu B, Fang H, Jacoby G, Li G, Wu Z (2022) Environmental regulations and innovation for sustainability? Moderating effect of political connections. *Emerg Mark Rev* 50:100835–100846. <https://doi.org/10.1016/j.ememar.2021.100835>
- Wu J, Yang J, Zhou Z (2018) How does environmental regulation affect environmental performance? A case study of China's regional energy efficiency. *Expert Syst* 37(3):12326–12338. <https://doi.org/10.1111/exsys.12326>
- Xiang X, Liu C, Yang M, Zhao X (2020) Confession or justification: the effects of environmental disclosure on corporate green innovation in China. *Corp Soc Responsib Environ Manag* 27(6):2735–2750. <https://doi.org/10.1002/csr.1998>
- Yang L, Zhang J, Zhang Y (2021) Environmental regulations and corporate green innovation in China: the role of city leaders' promotion pressure. *Int J Environ Res Public Health* 18(15):7774–7794. <https://doi.org/10.3390/ijerph18157774>
- Yang Q, Gao D, Song D, Li Y (2021) Environmental regulation, pollution reduction and green innovation: the case of the Chinese Water Ecological Civilization City Pilot policy. *Econ Syst* 45(4):100911–100928. <https://doi.org/10.1016/j.ecosys.2021.100911>
- Yi M, Wang Y, Yan M, Fu L, Zhang Y (2020) Government R&D subsidies, environmental regulations, and their effect on green innovation efficiency of manufacturing industry: evidence from the Yangtze River economic belt of China. *Int J Environ Res Public Health* 17(4):1330–1346. <https://doi.org/10.3390/ijerph17041330>
- Yu Y, Cheng H (2021) Environmental taxes and innovation in Chinese textile enterprises: influence of mediating effects and heterogeneous factor. *Sustainability* 13(8):4561–4574. <https://doi.org/10.3390/su13084561>
- You D, Zhang Y, Yuan B (2018) Environmental regulation and firm eco-innovation: evidence of moderating effects of fiscal decentralization and political competition from listed Chinese industrial companies. *J Clean Prod* 207:1072–1083. <https://doi.org/10.1016/j.jclepro.2018.10.106>
- Zhang Y, Wang J, Xue Y, Yang J (2018) Impact of environmental regulations on green technological innovative behavior: an empirical study in China. *J Clean Prod* 188:763–773. <https://doi.org/10.1016/j.jclepro.2018.04.013>
- Zhao L, Zhang L, Sun J, He P (2022) Can public participation constraints promote green technological innovation of Chinese enterprises? The moderating role of government environmental regulatory enforcement. *Technol Forecast Soc Change* 174:121198–121208. <https://doi.org/10.1016/j.techfore.2021.121198>
- Zhao S, Teng L, Arkorful VE, Hu H (2023) Impacts of digital government on regional eco-innovation: moderating role of dual environmental regulations. *Technol Forecast Soc Change* 196:122842–122856. <https://doi.org/10.1016/j.techfore.2023.122842>
- Zhu JM, Fan YC, Deng XH, Xue L (2019) Low-carbon innovation induced by emissions trading in China. *Nat Commun* 10(1):1–8. <https://doi.org/10.1038/s41467-019-12213-6>
- Zhu Y, Sun Z, Zhang S, Wang X (2021) Economic policy uncertainty, environmental regulation, and green innovation—an empirical study based on Chinese high-tech enterprises. *Int J Environ Res Public Health* 18(18):9503–9520. <https://doi.org/10.3390/ijerph18189503>

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Author contributions

WZ (first author) contributed to the writing of the manuscript; BZ was involved in planning and supervised the work; YL performed the calculations; DY (corresponding author) designed and directed the project.

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The authors declare no competing interests.

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Additional information

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