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The Porter hypothesis revisited: the cross-border spillover effects of foreign environmental regulations on national competitiveness

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Abstract

This study extends the Porter hypothesis by adopting a cross-border approach because, in a hyper-globalized economy, the impact of foreign policies might diffuse across borders through international trade. We examine the cross-border spillover effects of foreign environmental policies on innovation and economic growth of other countries. Using a country-year panel dataset, our study empirically finds that environmental policy spillovers contribute to improving green innovations, total factor productivity, and gross domestic product growth of other countries, which implies the borderless effect of the Porter hypothesis.

Keywords: Cross-border spillovers; Environmental policy stringency; the Porter hypothesis; Green innovation; Total factor productivity; Gross domestic product growth

JEL Classifications: F63, O33, O44, Q55, Q56, Q58

I. Introduction

Environmental laws and regulations have increasingly proliferated across countries because of the emerging global challenges of energy resource exhaustion, environmental degradation, and climate change. Globally, only three countries had an environmental framework law in place in the early 1970s, which shot up to 176 countries by May 2017 (United Nations Environment Programme, 2019). Nonetheless, gaps among countries in fully implementing and enforcing these laws remain one of the most significant challenges to mitigating climate change, reducing pollution, and preventing the mass extinction of species. Such differences in environmental policy stringency (EPS) among countries have also engendered a long-standing debate about their potential for the country-, industry-, and firm-level competitiveness (Dechezlepretre and Sato, 2017; Martinez-Zarzoso et al., 2019; Wang et al., 2019).

One stream of the environmental economics literature on the relationship between asymmetric environmental policies and performance in the same market is the Porter hypothesis (PH) (Porter, 1991; Porter and Van der Linde, 1995). The question of whether such differences in EPS are material, that is, how environmental policy influences competitiveness, remains inconclusive (Cohen and Tubb, 2018; Dechezlepretre and Sato, 2017). Previous studies regarding the PH have focused strictly on the domestic effect of environmental policies (Herman and Xiang, 2019). The literature exploring the dynamic nature of the impact of environmental regulations crossing borders and moving along a global supply network is scant (Herman and Xiang, 2019; Nair et al., 2016; Dechezlepretre et al., 2011). In a world that is increasingly characterized by the integration of trade and capital flows, the impact of environmental regulations in one region can diffuse to other regions directly or indirectly. Companies that face little scrutiny from a government in one region are often under considerable environmental pressure from indirect regulations of other regions' governments, conveyed by their customer firms (Lee et al., 2014).

Motivated by these gaps in the literature, in this study, we examine whether foreign environmental regulations have cross-border effects on domestic competitiveness in terms of green and general innovations, productivity, and economic growth. Today's world is increasingly characterized as being hyper-globalized, and economies ranging from emerging to developed are all connected. Our focus on the spillover effect of foreign environmental policies is not on geographical proximity but on trade interactivity, which is conceptually approached as a “foreign policy pull” through international trade. This study goes beyond previous research by analyzing such effects on the overall economy of other countries, as well as on technological innovation, with the latter predominantly examined in the literature on the foreign environmental policy inducement effect (e.g., Herman and Xiang, 2019; Dechezlepretre and Glachant, 2014; Groba, 2014). Our main research questions are as follows: First, does the cross-border effect of foreign EPS on innovation intensify with closer trading relationships among countries? Second, is this foreign policy-induced effect linked to the economy such that trading countries respond to stringent foreign environmental regulations?

This study relates to two strands of the literature on the relationship between environmental regulations and competitiveness. The first research stream investigates the direct effect of domestic EPS. The PH posits that strict environmental policies can positively affect competitiveness by promoting cost-cutting efficiency improvements and fostering innovation in eco-friendly technologies. It implies a win-win possibility for environmental and economic performance. The literature examines the PH in its three versions: weak, strong, and narrow. The weak PH focuses on innovation as the effect of stringent environmental regulations, while the strong PH emphasizes the overall economy. The narrow PH examines the impact of environmental regulations on specifically targeted outcomes such as renewable energy technologies.

Previous studies testing the PH have also provided mixed results. For instance, several studies offer support for the weak PH, illustrating that stringent environmental regulation promotes R&D activity (Kneller and Manderson, 2012; Jaffe and Palmer, 1997) and green and general patents (Hassan and Rousseliere, 2022; Rubashkina et al., 2015; Lanole et al., 2011; Johnstone et al., 2010). However, the literature on the strong PH examines the relationship between environmental regulation and economic growth or productivity but provides inconclusive results, implying that the strong PH does not hold in general, and the impact of environmental regulation on competitiveness at a country level varies across pollutants, innovation types, and countries (Martinez-Zarzoso et al., 2019; Dechezlepretre and Sato, 2017; Rexhausler and Rammer, 2014; Gray and Shadbegian, 2003; Greenstone et al., 2012).

The second research stream relevant to our study is about the extended version of the PH, exploring the impact of foreign environmental policy across borders. In one of the seminal studies, Lanjouw and Mody (1996) investigate the impact of the US vehicle emission regulations on the German and Japanese automobile industries and reveal that the stringent vehicle policy of the US spurred innovation in Germany and Japan. Evidence of foreign environmental regulations' effect on innovation across borders in the automobile industry has been reported in Germany, Japan, and South Korea (Aghion et al., 2016). Much of the recent literature on this topic focuses on clean energy sectors. Dechezlepretre and Glachant (2014) were among the first to examine the effects of foreign policy inducement on wind technologies and found that both domestic and foreign regulations lead to innovation in wind technology. A more recent study also provides evidence that foreign environmental policies serve as an attractive explanation for innovation in clean energy technologies (Herman and Xiang, 2019).

In general, the long-standing debate on the relationship between environmental regulations and competitiveness remains inconclusive. The literature on the weak, strong, and narrow versions of the PH across borders is at its early stage. This study goes beyond previous research by analyzing the dynamic strong and weak versions of the PH. This study contributes to the existing literature in three distinct ways.

First, it is one of the first studies exploring the PH's dynamic nature. Surprisingly, empirical research on exploring how foreign environmental regulations affect borders is scant. We extend prior research on the effects of foreign environmental policies by exploring the spillover effect of foreign environmental regulations on the competitiveness of a home country in the strong and weak versions of the PH. Previous studies on the cross-border effects of foreign environmental regulations have focused on testing the narrow version of the PH. This study examines the cross-border spillover effects of environmental regulations on innovation activity (weak PH) and other countries' economic performance (strong PH). Second, we present a new measure for the spillover effect of foreign environmental policy by combining EPS and export volume. Geographical distance measures based on the gravity model of international trade (Herman and Xiang, 2019; Constantini and Crespi, 2008; Groba, 2014; Van Beers and Van den Bergh, 1997) have a shortcomings in representing differences in trade volume among countries. We argue that a particular country that exports more than its neighboring countries might be more exposed to pressures from importing countries' environmental regulations. Third, using a Bartik instrument, this study examines the spillover effect of foreign environmental regulations. Regarding the results of previous studies, concerns about endogeneity and reverse causality may be raised (Herman and Xiang, 2019). As one of the first to address the endogeneity issue, our study provides more robust evidence of the positive spillover effect of foreign environmental regulations to the literature.

The rest of this paper is organized as follows: Section 2 articulates the empirical framework, including the variables and empirical models. Section 3 presents the results and discusses them. Section 4 provides academic and policy implications and some suggestions for future research. Section 5 concludes this study.

II. Empirical Framework

1. Empirical model

This study examines the spillover and cross-border effect of foreign environmental policies on competitiveness at the national level, which implies the dynamic weak and strong versions of the PH. We construct a time-series regression model. A two-way fixed effect regression equation specifies the model as follows:

$$\Delta Y_{i,t+k} = \beta_0 + \beta_1 \Delta f\widetilde{EPS}_{i,t} + \beta_2 dEPS_{i,t} + \beta_3 GRD_{i,t} + \beta_4 PSTOCK_{i,t} + \beta_5 IMPORT_{i,t} +$$

$$+\alpha_6 EXPORT_{i,t} + +\alpha_7 CARBON_{i,t} + \alpha_8 ENERGY_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \text{ (Eq. 1)}$$

where *i* and *t* denote country and year, respectively. μ_i and λ_t indicate country and year fixed effects, respectively. The corresponding dependent variable, ΔY, indicates a time difference of the outcome variable, including the total patents (*T_PAT*), environment-specific patents (*E_PAT*), GDP growth rate (*GDP_GROWTH*), and total factor productivity (*TFP*). $\Delta f\widetilde{EPS}$ is the independent variable, a fitted estimate of the EPS of foreign country *j*. *d*EPS is the EPS index in domestic country *i*, the national R&D capacity (*GRD*), patent stocks (*PSTOCK*), import and export volumes (*IMPORT* and *EXPORT*), carbon intensity (*CARBON*), and energy intensity (*ENERGY*) are country-specific control variables.

Instead of regressing the outcome variables (i.e., *PAT*, *E_PAT*, *GDP_GROWTH*, and *TFP*) on the

EPS of foreign country j ($fEPS$), this study utilizes the identification strategy using an instrumental variable to mitigate possible endogeneity and reverse causality problems. $fEPS$ can be endogenous for some reasons. First, there may be a shock $\varepsilon_{i,t}$ that affects both the outcome $\Delta Y_{i,t+k}$ and $fEPS_{i,t}$. This could be because the shock that affects both $Y_{i,t}$ and $fEPS_{i,t}$ and some serial correlation impacting $Y_{i,t+K}$ through $Y_{i,t}$. Second, we can argue that the outcome $Y_{i,t}$ itself is impacting $fEPS_{i,t}$ (i.e., reverse causality), and $Y_{i,t}$ is correlated with $Y_{i,t+K}$.

The identification has two competing views: the shock view (Borusyak et al., 2022) and the shift-share view (Goldsmith-Pinkham et al., 2020). The shock view focuses on identifying exogenous shocks that affect certain regions or sectors, which come from outside and are not caused by local conditions. In contrast, the shift-share view identifies causal effects by breaking down the observed variation into a shift and a share component.

We construct a Bartik-instrument variable (BI) by employing the shift-share view. First, the shock approach seems unreasonable in this case because the environmental protection levels are an endogenous object. Second, the shift-share view is valid in the following context. While the environmental protection level can be endogenous, the exposure to foreign policy changes may be exogenous. For instance, the increases in a country's total factor productivity (*TFP*) result in higher $fEPS$ because the country can now sell to developed countries with more stringent environmental regulations. The serial correlation in *TFP* will result in spurious causation between *TFP* and $fEPS$.

This study's Bartik-instrument variable is as follows:

$$BI = \sum_j w_{j,0} \cdot \Delta EPS_j \qquad \text{(Eq. 2)}$$

where $w_{j,0}$ is the proportion of exports to country j at a historical reference time point 0, namely, in 1990 in our analysis. ΔEPS_j indicates a change in the environmental policy stringency in country j in time t to time $t + k$. Our BI variable captures an EPS index weighted with the initial trade share.

In the first-stage regression, we regress $\widetilde{\Delta fEPS}$ on *BI* along with all other control variables and fixed effects as follows:

$$\widetilde{\Delta fEPS}_{i,t} = \alpha_0 + \alpha_1 BI_{i,t} + \alpha_2 dEPS_{i,0} + \alpha_3 GRD_{i,0} + \alpha_4 PSTOCK_{i,0} + \alpha_5 IMPORT_{i,0} +$$

$+\alpha_6 EXPORT_{i,0} + +\alpha_7 CARBON_{i,0} + +\alpha_8 ENERGY_{i,0} + \mu_i + \lambda_t + v_{i,t}$ (Eq. 3)

where i and t denote country and year, respectively. μ_i and λ_t indicate country and year fixed effects, respectively. *dEPS*, *GRD*, *PSTOCK*, *IMPORT*, *EXPORT*, *CARBON*, and *ENERGY* are country-specific initial control variables (e.g., *GRD* in 1990). The result of the first-stage regression is presented in Appendix (Table 2A). The coefficient on *BI* is significantly positive at the cut-off p-value of 0.01, which indicates that the Bartik instrumental variable (*BI*) and the endogenous variable ($\Delta fEPS$) are positively correlated. The F-statistics for a weak instrument are 19.755 and significant at the 1% cut-off level, which provides evidence that the instrument is not weak.

2. Variables and measures

1) Dependent variables

We use patents, gross domestic product growth (*GDP_GROWTH*), and total factor productivity (*TFP*) as dependent variables.

First, patents, which are believed to represent innovation, have been widely used in the environmental economics literature and innovation research, particularly in testing the narrow version of the PH (e.g., Johnstone et al., 2010; Johnstone et al., 2012; Noailly and Ryfisch, 2015; Przychodzen et al., 2019). Patents also represent a statistically sound technique to measure a country's macroeconomic capabilities regarding innovation at the national level (Herman and Xiang, 2019; Christensen and Raynor, 2013; Griliches, 1990). This study compiles the patent data from the Organisation for Economic Co-operation and Development (OECD)-stat website. We use two technology domains: total patents (*T_PAT*) and environmental technology-specific patents (*E_PAT*). The total number of patents applied simultaneously to the three patent offices represents the extent of technological innovation of a country. We identified environmental-specific patents using International Patent Classification (IPC) symbols and keywords. This study categorized environment-related technologies into eight domains and thirty-four sub-domains. We classified patents into environmental technology-specific patents if they belong to one of the environmental-related technology domains (Appendix 1). For instance, if a patent is related to post-combustion technologies such as chemical or biological purification of waste gases (i.e., its IPC code is one of B01D53/34–72), then this patent is classified as E_PAT because it belongs to the air pollution abatement category as one of the technologies regarding emissions abatement from stationary sources. We operationalized the natural logarithm of total patent applications (*T_PAT*) and environmental technology patent applications (*E_PAT*) as proxies for technology and environmental innovation, respectively.

Second, we employ two proxies for a country's economic performance: *GDP_GROWTH* and *TFP*. *TFP* not only captures technological changes conceptually but also reflects efficiency changes, economies of scale, and variations in capacity utilization in practice (Martinez-Zarzoso et al., 2019; Rubashkina et al., 2015). Hence, *TFP* has been widely applied to test the strong PH (Martinez-Zarzoso et al., 2019; Zhao et al., 2019; Albrizio et al., 2017). We measure *GDP_GROWTH* as the annual percent change in GDP, which captures how fast an economy grows. We extract data on annual GDP changes (based on constant 2015 prices, expressed in US dollars) from the World Development Indicators.

2) Independent variable

The primary explanatory variable of this study is foreign EPS (*fEPS*). Several previous studies testing the PH have used the EPS index as a proxy for stringent environmental regulations because it is comparable across countries and combines quantitative and qualitative information related to environmental policy, accounting for the multi-dimensional nature of environmental stringency (Martinez-Zarzoso et al., 2019; Botta and Kozlak, 2014). The index is calculated based on the degree of stringency of 15 environmental policy instruments, including taxes, trading schemes, standards, and R&D subsidies. It ranges from 0 (the least stringent) to 6 (the most stringent) and provides the most prolonged time horizon suitable for studies using longitudinal panel data (Herman and Xiang, 2019). In practice, the credibility of the EPS index as a proxy for the stringency of environmental regulations is confirmed by comparison with other available measures of EPS (Albrizio et al., 2017).

To construct the primary explanatory variable, *fEPS*, we first take the EPS index of each foreign country in the sample annually and multiply it by the share of exports to each foreign country. We calculate the share of exports by dividing export volumes by the total export volume to each foreign country. Prior research has measured *fEPS* using a generalized gravity model (e.g., Herman and Xiang, 2019; Constantini and Mazzanti, 2012). Instead, in this study, we consider export contributions. We argue that a country exporting more than its neighbors may be influenced by importing countries' environmental regulations to a greater extent. Subsequently, we operationalize *fEPS* as the EPS weighted by export ratios, as expressed in the following equation:

$$fEPS = [\Sigma_{i \neq j} w_j EPS_j] \qquad \text{(Eq. 1)}$$

where EPS_j indicates the EPS index of a foreign country j, and w_j is the proportion of exports to country j to total exports.

3) Control variables

We include several critical explanatory variables for national-level competitiveness based on previous studies examining the PH. First, we consider the R&D capacity (*GRD*) at the country level as a control variable because R&D expenditure is a plausible indicator representing national innovation inputs (Martinez-Zarzoso et al., 2019). We measure *GRD* as the gross domestic R&D expenditure ratio to GDP (Martinez-Zarzoso et al., 2019; Rubashkina et al., 2015). Second, we control the effect of knowledge stock on innovation performance. The knowledge stock represents the technological competence of a country. New technologies generally build upon past innovations (Johnstone et al., 2010; Rubashkina et al., 2015). Isolating the effects of previous innovation experience, scientific capacity, and propensity to patent across countries on innovations is necessary. We include patent stocks (*P_STOCK*) constructed using the perpetual inventory method of 10 years as the useful life (Herman and Xiang, 2019; Martinez-Zarzoso et al., 2019; Rubashkina et al., 2015). Third, export and import volumes (*EXPORT* and *IMPORT*) based on constant 2015 prices, expressed in US dollars, capture the impact of international trade on a country's competitiveness, which are normalized to GDP (Kneller and Manderson, 2012; Martinez-Zarzoso et al., 2019; Rubashkina et al., 2015). Fourth, we include control variables related to carbon emissions and energy uses. We use the carbon intensity (*CARBON*), measured as the ratio of total carbon dioxide (CO_2) emissions to GDP, and the energy intensity (*ENERGY*), calculated as the ratio of total energy use to GDP (Wahab et al., 2021). In addition, we also control the effect of a country's EPS (*dEPS*).

3. Data

We compile an unbalanced-panel dataset from 1990 to 2012 for 28 OECD countries and Brazil, Russia, India, China, and South Africa (BRICS). We select this sample because the EPS index covers all these countries with sufficient time series. We apply the EPS index to measure the foreign and domestic EPS (i.e., *fEPS* and *dEPS*). The patent data are collected from the Worldwide Patent Statistical Database (PATSTAT) built by the OECD, providing data on triadic families. We obtain TFP and GDP from the EU KLEMS database and the World Bank, respectively. Table 1 illustrates the variables, definitions, and data sources.

---- Insert Table 1 about here----

III. Results and Discussion

1. Cross-border effect of regulations on technological innovations

Table 2 presents the test results of the weak dynamic version of the PH, indicating a positive relationship between foreign environmental regulation stringency and technological innovation. This result does not support our prediction that foreign environmental regulations have a positive effect on general technology innovation, measured by patent numbers (*T_PAT*).

Regarding control variables, gross R&D expenditure (GRD) is positively associated with patents at periods t+2 and t+3 at the 0.05 cut-off level. This supports the literature reporting that research-intensive countries are more innovative (Martinez-Zarzoso et al., 2019). The patent stock (PSTOCK) also positively affects technological innovations. The strong positive relationship between PSTOCK and T_PAT aligns with the path dependence theory in the innovation literature (Perello-Marin et al., 2013; Redding, 2002). The domestic environmental regulation stringency (dEPS) is positively associated with technological innovation at periods t+1 and t+2 at the 0.01 and 0.05 cut-off level, respectively, which is very consistent with the findings of previous studies (Johnstone et al., 2010; Lanoie et al., 2011; Rubashkina et al., 2015).

---- Insert Table 2 about here----

Table 3 presents the results of the analysis, indicating that the dynamic weak version of the PH is supported at period t+1 at the cut-off p-value of 0.01 and at periods t+2, t+3, and t+4 at the 0.05 cut-off level. Foreign environmental regulation stringency (*fEPS*) is strongly associated with green innovation (*E_PAT*). This result supports the positive effect of the cross-border spillover effect of environmental regulations on green innovation, consistent with previous studies (e.g., Herman and Xiang, 2019). Specifically, one standard deviation (0.671) increase in the foreign EPS index leads to a 29.2% (= 0.671×0.435) increase in green patent applications a year later, a 7.5% (= 0.671×0.112) increase two years later, a 6.8% (= 0.671×0.101) increase three years later, and a 6.7% (=0.671×0.100) increase in four years. This result implies that a country's environment-related technological innovations are strongly triggered by the environmental regulations of foreign countries to which the country exports.

Regarding control variables, GRD, PSTOCK, and dEPS are positively associated with green patents. CARBON is negatively related to green innovation, and ENERGY is positively associated with green innovation.

---- Insert Table 3 about here----

2. Cross-border effect of regulations on total factor productivity and GDP growth

We test the dynamic strong version of the PH. Table 4 presents the results of our analysis, demonstrating that foreign environmental regulation stringency (*fEPS*) is strongly associated with *TFP* at periods t+1 and t+2 at the 0.05 cut-off level. This result supports the positive effect of the cross-border spillover effect of environmental regulations on national competitiveness.

Regarding control variables, IMPORT is negatively associated with *TFP* at period t+1 at the 0.05 cut-off level. This result does not provide evidence that the domestic EPS index (*dEPS*) affects *TFP*.

---- Insert Table 4 about here----

Table 5 displays that foreign environmental regulation stringency (*fEPS*) affects GDP growth at periods t+1 and t+2. However, this effect becomes insignificant three years later. This result is in line with those in previous studies (e.g., Martinez-Zarzoso et al., 2019; Rubashkina et al., 2015) and implies that GDP growth is influenced by foreign environmental regulation stringency.

Regarding control variables, import penetration (*IMPORT*) is negatively associated with GDP growth, whereas export intensity (*EXPORT*) positively affects GDP growth. This result illustrates the importance of exports in national economic development (e.g., Ram, 1985; Subasat, 2002). Similar to the results regarding *TFP*, the domestic EPS (*dEPS*) is not associated with GDP growth.

Collectively, the results of this study provide evidence that foreign EPS contributes to the national economy, which indicates that the dynamic strong PH is supported by this study.

---- Insert Table 5 about here----

IV. Implications and Further Research

1 Academic and policy implications

The findings of this study provide significant implications for academia and policymakers. This study makes three contributions to the literature. First, it is one of the first studies to explore how the effects of environmental regulations diffuse across borders. Previous studies focus on the relationship between domestic environmental policies and industry and country competitiveness. This study adds to the environmental economics and innovation literature by extending the PH regarding global competitiveness dynamics. Second, in this study, we provide evidence for the positive cross-border spillover effects of EPS, supporting the dynamic version of the PH. Our study presents an empirical observation that the effect of environmental regulations moves across borders through international trade. This study paves the way for extending arguments regarding the dynamic nature of the intersection between environmental policies, innovation, and competitiveness from an international trade perspective. Third, in this study, we propose a new measure for the spillover effect of foreign environmental policy by considering the actual export volume. Compared with conventional measures based on geographical distance, this export-based measure better reflects pressures imposed on exporting countries by foreign environmental regulations.

The results of this study are also important for policymakers for various reasons. First, this study demonstrates how environmental policy changes encourage foreign innovators simultaneously. That implies that pioneer developed countries can drive the global environment, energy, and climate-related innovation frontier. In line with a dynamic version of the PH, our research provides strong evidence that countries (mainly driven by firms) are adequately attuned to innovative possibilities and react to environmental policy stringency both at home and abroad.

Second, this study presents that stringent foreign environmental policies affect the productivity and economic growth of exporting countries, which implies that they are attuned to improvement and growth possibilities while meeting the environmental needs specified by importers' policies. Governments, especially those dependent on exports, must vigorously push ahead with their economies to keep pace with advanced foreign regulations. Environmental policies are, at least, not likely to harm industry and national competitiveness. Regardless of domestic regulations, exporting countries' industries and businesses are likely to be affected by foreign environmental policies. In this international trade context, policymakers should realize that exposing domestic industries to international regulatory regimes catalyzes their innovation and, thus, enhances competitiveness.

Third, EPS might differ among countries, particularly developed and developing countries. However, in a hyper-globalized economy in which most emerging and developed countries are connected, the impact of environmental regulations in a particular region diffuses to other regions directly or indirectly. In particular, the types of environmental regulations have diversified from a typical factory-focused regulation, targeting pollutants emitted by production facilities in a local area, to a product-focused one, targeting products consumed in the area, regardless of where they are produced. For instance, the restriction of hazardous substances regulation (the RoHS directive), a European product-focused environmental policy, has influenced exporting companies in emerging economies, as their customers impose it along the global supply chain (Lee et al., 2014). This is also exemplified by the EU's recently enacted Global Supply Chain Due Diligence Act, which illustrates how environmental regulations in a specific region have a uniform impact regardless of geographical boundaries through exports and trade.

2. Limitations and further research directions

We suggest directions for future research by outlining some cautions that should be considered in interpreting this study's results. First, in this study, we used a sample compiled for OECD and BRICS countries because of the EPS index availability. The cross-border spillover effect of foreign environmental policies might be significant to countries where exports have a large share of the national economy. Some countries from the Association of Southeast Asian Nations, such as Vietnam and Indonesia, have emerged as the factories of the world. The current study should be replicated using a larger sample, including more emerging countries. Second, the EPS index, calculated by combining the 15 areas of quantitative and qualitative information regarding environmental policies, has two main subsets of policy instruments: market-based and non-market-based policies. Some previous studies have examined the effect of the EPS index by separating these two dimensions (e.g., Hassan and Rousseliere, 2021; Galeotti et al., 2020). The market-based and non-market-based policy instruments have different characteristics and, thus, might engender distinct cross-border spillover effects. Future research needs to explore this aspect. Third, to address endogeneity concerns regarding the spillover effect of foreign EPS, we employed a two-stage regression model using a Bartik instrument based on the shift-share view. Further studies can provide more justifications for the contexts in which the share-shift approach for Bartik instruments is valid.

V. Conclusion

This study explores a connection between foreign EPS and domestic national-level competitiveness. Using a country-year panel dataset compiled from the OECD and BRICS countries regarding the EPS index, we examine the cross-border spillover effects of foreign environmental regulations. We provide some of the first empirical results that the foreign EPS positively influences environmental innovation, total factor productivity, and GDP growth, supporting the dynamic weak and strong versions of the PH. These findings also indicate that the effects of environmental regulations from frontier policy countries disperse across borders through international trade.

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Appendix 1. Environment-related technology patent categories

Table A1. Environment-specific patents categories

Category	**Sub-category**	**Related Technology**
1. Environmental management		
	1.1. Air pollution abatement	Emissions abatement from stationary sources; Emissions abatement from mobile sources
	1.2. Water pollution abatement	Water and waste treatment; Fertilizers from wastewater; Oil spill cleanup
	1.3. Waste management	Solid waste collection; Material recycling; Fertilizers from waste; Incineration and energy recovery; Landfilling
	1.4. Soil remediation	Soil remediation
	1.5. Environmental monitoring	Environmental monitoring
2. Water-related adaption technology		
	2.1. Demand-side technology	Indoor water conservation; Irrigation water conservation; Water conservation in thermoelectric power production; Water distribution
	2.2. Supply-side technology	Water collection; Water storage; Desalination of seawater
3. Climate change mitigation related to energy generation, transmission, and distribution		
	3.1. Renewable energy generation	Wind energy; Solar thermal energy; Solar PV energy; Solar thermal-PV energy; Geothermal energy; Marine energy; Hydro energy
	3.2. Energy generation from fuels of non-fossil origin	Biofuels; Fuel from waste
	3.3. Combustion technologies with mitigation potential	Technologies for improved output efficiency; Technologies for improved input efficiency
	3.4. Nuclear energy	Nuclear fusion reactors; Nuclear fission reactors
	3.5. Efficiency in electrical power generation	Superconducting electric elements or equipment
	3.6. Enabling technologies in the energy sector	Energy storage; Hydrogen technology; Fuel cells; Smart grids in energy sectors
4. Capture, storage, sequestration, or disposal of GHG		
	4.1. CO2 capture or storage	CO2 capture or storage
	4.2. Capture or disposal of non-CO2 GHG	Non-CO2 greenhouse gas capture or disposal
5. Climate change mitigation related to transportation		

5.1. Road transport	Hybrid vehicles; Electric vehicles; Fuel efficiency-improving vehicle design
5.2. Rail transport	Climate change mitigation related to rail transport
5.3. Air transport	Climate change mitigation related to air transport
5.4. Maritime or water transport	Climate change mitigation related to maritime or water transport
5.5. Enabling technologies in transport	Electric vehicle charging; Application of fuel cell and hydrogen technology to transport
6. Climate change mitigation related to building	
6.1. Integration of renewable energy sources in buildings	Integration of renewable energy sources in buildings
6.2. Energy efficiency in buildings	Lighting; Heating ventilation or air conditioning; Home appliances; Elevators, escalators, and moving walkways; Information and communication technologies; End-user side technology
6.3. Architectural or constructional elements improving the thermal performance of buildings	Architectural or constructional elements improving the thermal performance of buildings
6.4. Enabling technologies in buildings	Enabling technologies in buildings
7. Climate change mitigation related to wastewater treatment or waste management	
7.1. Wastewater treatment	Climate change mitigation related to wastewater treatment
7.2. Solid waste management	Waste collection, transport, transfer, or storage; Waste processing or separation; Landfill technologies aiming to mitigate methane emissions; Bio-organic fraction processing; Reuse, recycling, or recovery technologies
7.3. Architectural or constructional elements improving the thermal performance of buildings	Architectural or constructional elements improving the thermal performance of buildings
7.4. Enabling technologies in waste treatment or management	Enabling technologies in waste treatment or management with a potential or indirect contribution to GHG emissions mitigation
8. Climate change mitigation technologies in the production or processing of goods	
8.1. Metal processing	Reduction of GHG emissions; Process efficiency
8.2. Chemical industry	General improvement of production processes causing GHG emissions; Improvements in chlorine, adipic acid, caprolactam, chlorodifluoromethane, or other chemicals and pharmaceuticals production
8.3. Oil refining and petrochemical industry	Reduction of GHG emissions during production processes; Bio-feedstock; Carbon capture or storage to

	hydrogen production; Ethylene production
8.4. Minerals processing	Production of cement; Cement grinding; Manufacturing or processing of sand or stone; Production or processing of lime; Glass production; Production of ceramic materials or ceramic elements
8.5. Agriculture, livestock, or agro-alimentary industry	Agricultural machinery or equipment; Reduction of GHG emissions in agriculture; Land use policy measures; Livestock or poultry management; Fishing and aquaculture; Apiculture; Food processing
8.6. Technologies in the production process for final industrial or consumer products	Climate change mitigation technologies in the production process for final industrial or consumer products
8.7. Sector-wide applications	Climate change mitigation technologies for sector-wide applications
8.6. Enabling technologies with a potential contribution to GHG emission mitigation	Enabling technologies with a potential contribution to GHG emission mitigation

Appendix 2. The first-stage regression using the Bartik instrument

Table A2. First-stage regression using the Bartik instrument
*** and ** indicate significance at the 0.01 and 0.05 cut-off levels, respectively. The t-statistics calculated HAC robust standard errors are in parentheses.

	First-stage
	ΔfEPS
BI	0.028*** (4.12)
dEPS	0.338*** (7.65)
GRD	0.003 (0.76)
PSTOCK	0.228*** (4.11)
IMPORT	0.711 (0.35)
EXPORT	1.635*** (8.95)
CARBON	1.772*** (7.28)
ENERGY	0.339** (2.21)
Constant	-0.008 (0.35)
Country- and Year-fixed Effects	Included
Number of observations	554
Adjusted R^2	0.635
Wald F Statistics	19.755***

Table 1. Variables, operationalized definitions, and data sources

Variable (code)	**Definition**	**Source**
Foreign environmental policy stringency (*fEPS*)	The EPS index of all foreign countries (except for the domestic country) is weighted by export ratios to the target countries.	OECD Statistics
Domestic environmental policy stringency (*dEPS*)	The EPS index of the domestic country	OECD Statistics
Innovation (*T_PAT*)	The natural logarithm of total patent applications (triadic families)	OECD Statistics
Environmental technology-specific innovation (*E_PAT*)	The natural logarithm of environmental technology patent applications (triadic families)	OECD Statistics
GDP growth (*GDP_GROWTH*)	Annual change in GDP (%) (constant 2015 US$)	World Development Indicators
Total factor productivity (*TFP*)	Annual change in total factor productivity (%)	OECD Statistics
R&D expenditures (*GRD*)	Gross R&D expenditures / GDP (constant 2015 US$)	OECD Statistics
Patent stocks (*P_STOCK*)	Patent stocks are constructed by using the perpetual inventory method	OECD Statistics
Import penetration (*IMPORT*)	Total import volume / GDP (constant 2015 US$)	World Development Indicators
Export intensity (*EXPORT*)	Total export volume / GDP (constant 2015 US$)	World Development Indicators
Carbon intensity (*CARBON*)	CO_2 emissions (Kt) / GDP (million dollars)	World Development Indicators
Energy intensity (*ENERGY*)	Total energy use (Kg of oil equivalent)/ GDP (million dollars)	World Development Indicators

Table 2. Cross-border effect of foreign EPS on technological innovation

*** and ** indicate significance at the 0.01 and 0.05 cut-off levels, respectively. The t-statistics calculated HAC robust standard errors are in parentheses.

	Dependent variable = Δln(the number of total patent applications)$_{t+k}$			
	t+1	**t+2**	**t+3**	**t+4**
Fitted fEPS	0.035 (0.75)	0.043 (0.97)	0.003 (0.21)	0.045 (1.09)
dEPS	0.115*** (2.97)	0.085** (2.03)	0.030 (1.43)	-0.073 (-0.39)
GRD	-0.445 (-0.45)	3.998** (2.15)	3.773** (2.00)	4.198*** (2.79)
PSTOCK	0.515*** (11.59)	0.917*** (13.97)	0.835*** (12.45)	0.876*** (13.73)
IMPORT	0.005 (0.23)	0.091 (0.63)	-0.076 (-1.33)	-0.005 (-0.31)
EXPORT	0.303 (0.75)	0.419 (0.93)	0.039 (0.21)	0.011 (0.05)
CARBON	-1.490*** (-3.15)	-2.033*** (-3.79)	-1.455*** (-3.00)	-1.311*** (-2.66)
ENERGY	7.661*** (3.59)	10.033*** (4.39)	8.003*** (3.69)	8.935*** (4.09)
Constant	3.359*** (10.56)	3.793*** (11.49)	3.337*** (10.05)	3.799*** (11.59)
Country- and Year-fixed Effects	Included	Included	Included	Included
Number of observations	554	554	554	554
Adjusted R^2	0.454	0.450	0.349	0.315
Wald F Statistics	30.455***	31.931***	30.008***	27.677***

Table 3. Cross-border effect of foreign EPS on green innovation

***, **, and * indicate significance at the 0.01, 0.05, and 0.1 cut-off levels, respectively. The t-statistics calculated HAC robust standard errors are in parentheses.

	Dependent variable = Δln (the number of environment-related patent applications)$_{t+k}$			
	t+1	**t+2**	**t+3**	**t+4**
Fitted fEPS	0.435*** (2.81)	0.112** (2.48)	0.101** (2.45)	0.100** (2.03)
dEPS	0.575*** (3.35)	0.438** (2.22)	0.411** (2.00)	0.414** (2.00)
GRD	13.395*** (2.76)	8.235** (2.03)	8.077** (1.95)	8.339** (2.33)
PSTOCK	0.395*** (5.55)	0.338** (5.23)	0.337*** (5.23)	0.390*** (5.34)
IMPORT	-0.577 (-0.12)	-0.638 (-0.45)	-0.615 (-0.33)	-0.600 (-0.30)
EXPORT	0.632 (0.48)	0.668 (0.75)	0.665 (0.75)	0.630 (0.47)
CARBON	-2.228** (-1.98)	-0.979 (-1.00)	-1.003 (-1.11)	-1.000 (-1.11)
ENERGY	12.121** (2.05)	2.888 (0.38)	2.766 (0.35)	2.757 (0.33)
Constant	0.003 (0.29)	0.442* (1.85)	0.455* (1.89)	0.009 (0.35)
Country- and Year-fixed Effects	Included	Included	Included	Included
Number of observations	554	554	554	554
Adjusted R^2	0.332	0.297	0.295	0.243
Wald F Statistics	41.358***	40.115***	39.997***	30.091***

Table 4. Cross-border effect of foreign EPS on total factor productivity
***, **, and * indicate significance at the 0.01, 0.05, and 0.1 cut-off levels, respectively. The t-statistics calculated HAC robust standard errors are in parentheses.

	Dependent variable = ΔTotal factor productivity$_{t+k}$			
	t+1	**t+2**	**t+3**	**t+4**
Fitted fEPS	3.332** (2.00)	3.375** (2.45)	2.335* (1.79)	2.340* (1.79)
dEPS	0.023 (0.29)	0.015 (0.29)	0.003 (0.35)	0.044 (0.59)
GRD	33.359 (1.22)	30.765 (0.48)	29.118 (0.45)	33.978 (1.50)
PSTOCK	1.223 (0.44)	1.000 (0.25)	1.119 (0.40)	1.337 (0.75)
IMPORT	-7.333** (-2.45)	-2.314 (-0.33)	-4.448 (-0.97)	-4.038 (-0.75)
EXPORT	4.456 (1.11)	4.375 (1.23)	3.731 (1.09)	4.099 (1.11)
CARBON	1.225 (0.75)	0.735 (0.25)	1.339 (1.15)	1.339 (1.20)
ENERGY	2.557 (0.22)	15.538 (1.05)	8.999 (0.87)	6.003 (0.55)
Constant	-0.762 (-0.84)	-0.335 (-0.15)	-0.073 (-0.08)	0.124 (0.90)
Country- and Year-fixed Effects	Included	Included	Included	Included
Number of observations	397	397	397	397
Adjusted R^2	0.228	0.219	0.197	0.202
Wald F Statistics	39.753***	36.448***	30.302***	31.118***

Table 5. Cross-border effect of foreign EPS on GDP growth
***, **, and * indicate significance at the 0.01, 0.05, and 0.1 cut-off levels, respectively. The t-statistics calculated HAC robust standard errors are in parentheses.

	Dependent variable = ΔGDP growth$_{t+k}$			
	t+1	**t+2**	**t+3**	**t+4**
Fitted fEPS	0.725* (1.76)	0.835** (2.03)	0.335 (0.97)	0.337 (0.97)
dEPS	-0.008 (-0.45)	-0.075 (-1.22)	0.033 (0.60)	0.008 (0.05)
GRD	35.557 (0.68)	8.373 (0.49)	-10.339 (-1.05)	-16.118 (-1.39)
PSTOCK	-0.075 (-0.49)	0.135 (0.49)	-0.105 (-0.45)	-0.088 (-0.40)
IMPORT	-3.765*** (-3.59)	-4.371*** (-4.05)	-2.775*** (-3.33)	-2.818*** (-3.60)
EXPORT	10.505*** (2.68)	11.732*** (3.05)	10.597*** (2.75)	10.661*** (2.80)
CARBON	-1.115 (-1.00)	-1.035 (-0.75)	-3.339** (-2.05)	-1.033 (-0.75)
ENERGY	-7.771 (-1.54)	0.788 (0.35)	15.973*** (3.39)	11.008*** (2.11)
Constant	2.227 (0.41)	0.123 (0.05)	0.176 (0.10)	0.333 (0.35)
Country- and Year-fixed Effects	Included	Included	Included	Included
Number of observations	554	554	554	554
Adjusted R^2	0.397	0.303	0.317	0.288
Wald F Statistics	35.575***	36.075***	36.339***	35.197***