Home demand and trade pattern: a support for the Linder conjecture in the environmental sector

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Abstract

This paper theoretically and empirically explores the Linder conjecture (the home market effect (HME) in terms of trade pattern) in the environmental sector. Using a general equilibrium model for a two-country, two-sector economy, we demonstrate the existence of a strong/weak HME and highlight the crucial role of trade costs in the HME. Empirically, by utilizing a dataset of international air purifier trade and $PM_{2.5}$ concentration, we investigate the causal relationship between environmental demand and trade patterns. The results show that for every 1% rise in $PM_{2.5}$, the exports and net exports of air purifiers increase by 4.337% and 3.835%, respectively. We also illustrate that the strong secondary magnification effect exists in the environmental sector, especially among developing countries. In conclusion, a country with a larger environmental home demand tends to be a net exporter of environmental products. It provides a new path for high-polluting countries to upgrade their traditional manufacturing toward an environmentally friendly economy.

Keywords: environmental demand, trade pattern, home market effect, air pollution

JEL Classification: Q56, F12, R12

1 INTRODUCTION

This paper analyzes the home market effect (HME) in terms of trade pattern. Specifically, by employing a general-equilibrium model and the trade data of air purifiers, we theoretically and empirically explore the relationship between air pollution and the trade patterns of environmental goods.

The well-known Leontief paradox (Leontief, 1953) led to the prevailing notion since the 1950s that international trade in manufactures depends on home demand. Regarding

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the trade pattern based on demand, while some researchers believe that a country imports products when home production falls short of home demand (e.g., Valavanis-Vail, 1954, p.525), Linder (1961, p.87) argues that a local demand for a product is necessary for that product to be exported, which is called the *Linder conjecture* and linked to the HME theory (Krugman, 2009).

Homogeneous consumers have been assumed in the HME literature since Krugman (1980). To model the aggregate demand in different countries, authors assume different populations. Therefore, the Linder conjecture is interpreted as "a larger country is a net exporter in an economy of two countries" (referring to the HME in terms of trade pattern).[1] This model is not convenient for us to study a small country since it predicts that a smaller country is always a net importer of manufactured goods. In contrast, our paper allows for heterogeneous preferences in different countries. The demand in a country is modeled by a parameter of consumption share in the Cobb-Douglas utility function. We are able to explore how trade patterns change with this demand parameter, even when the country size is small. We theoretically prove the existence of the HME (in terms of trade pattern), formerly defined as the phenomenon that an increase in the home demand for products in a country leads to larger net exports of the products, by developing a new two-country two-sector model with heterogeneous demand across the countries.

Existing empirical studies show that the existence of the HME depends on industry characteristics. Davis & Weinstein (1999) find the HME only exists in eight of nineteen sectors, including transportation equipment, iron and steel, electrical machinery, and chemicals. This view is also supported by the results of Hanson & Xiang (2004), which state that the HME is more likely to occur in industries with high trade costs and low substitution elasticity (more differentiated goods). Resting on the assumption of home-biased demand, Brülhart & Trionfetti (2009) also find the HME in differentiated-goods sectors, such as machinery, precision engineering, and transport equipment industries. Meanwhile, some studies show that the HME is not only related to the preferences of exporting countries and the intensity of scale economies of sectors (Pham et al., 2014), but also related to fixed production costs (Holmes & Stevens, 2005; Behrens & Picard, 2007). Moreover, Costinot et al. (2019) suggest that the pharmaceutical industry, with low freight and high elasticity of substitution, also exhibits the HME. In addition, some studies indicate that the agglomeration force of the HME in larger countries can counterbalance the "pollution haven effect" in smaller countries (Zeng & Zhao, 2009; Forslid et al., 2017). To date, however, there is no research on the HME in the environmental sector itself. This paper attempts to unravel the mystery of the HME in the environmental sector.

The environmental industry has some features that make the existence of the HME unclear. On the one hand, compared with steel, chemicals, transportation equipment, etc.,

[1] The definition of the HME in terms of trade pattern is given by Krugman (1995, p.1261). There are other definitions of the HME. The HME in terms of firm share refers to the fact that a larger local demand succeeds in attracting a more-than-proportionate share of firms (Krugman, 1980, Section III; Takahashi et al., 2013). The HME in terms of wages refers to the fact that the wage rate in a larger market is higher (Krugman, 1995, p.491). While Takahashi et al. (2013) show that these definitions are equivalent in the case of two production factors and two countries, Zeng & Uchikawa (2014) demonstrate that the HME in terms of trade pattern may not be equivalent to the HME in terms of firm share when there are multiple countries in the economy.

environmental products are characterized by relatively lower trade costs and a higher elasticity of substitution, which are considered to be negatively related to the HME according to Hanson & Xiang (2004)[2] and Takatsuka & Zeng (2012b). Furthermore, the fixed production costs of environmental goods in R&D are much lower than those in pharmaceuticals and other highly technological manufacturing industries, which are considered to be negatively related to the existence of the HME (Holmes & Stevens, 2005). On the other hand, the HME can be further enhanced by the varying preferences of consumers with different incomes (Yu, 2005; Pham et al., 2014; Coşar et al., 2018), which is applicable to environmental products as well. environmental products. The superposition of various positive and negative factors makes HME in environmental industry complicated and extraordinary. Clarifying the HME in the environmental industry helps us to understand the economic mechanism of agglomeration more deeply.

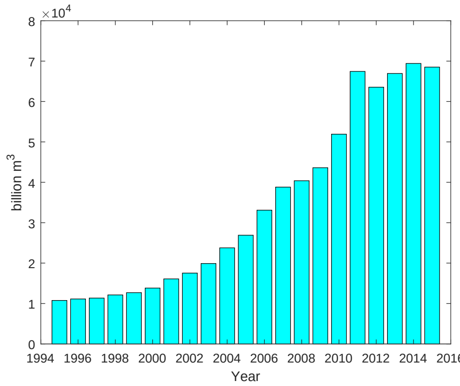
Exploring the HME in the environmental industry leads to helpful suggestions for government policymakers to develop their national economies in an environmentally friendly way. Global environmental conditions have sharply deteriorated in recent decades. According to a World Health Organization report, nine out of ten people worldwide breathe polluted air.[3] This has directly resulted in growing demand for environmental products. Yet, the impact of this environmental demand on trade patterns among countries is seldom studied. Investigating this issue is helpful in identifying new pathways for pollution reduction and industrial upgrades in high-pollution countries.

In the empirical analysis, the first challenge is to find an appropriate proxy variable to reflect environmental demand. This paper adopts air pollution indicators as proxy variables for the environmental demand shifter, mainly because of their causal correlation with environment-related health risks (Chay et al., 2003), infant mortality (Bombardini & Li, 2020), and inhabitants' environmental preventive investments (Ito & Zhang, 2020). By examining the causal relationship between air pollution and air purifier trade, we investigate the magnitude of the HME in the environmental industry. We also explore multifarious approaches for robustness checks and conduct a placebo test. Referring to Acemoglu & Linn (2004) and Costinot et al. (2019), we construct a relatively exogenous instrumental variable (IV) for retesting, i.e., the predicted environmental health risk (PEHR). We further empirically examine the sensitivity of this effect to residential income level and productivity level. In addition, to explore the generality of our results, we expand the analysis to 238 environment-related products belonging to 11 sub-environment sectors. Finally, we examine the effect of trade costs/tariffs on the HME, which is also referred to as the secondary magnification effect (SME).

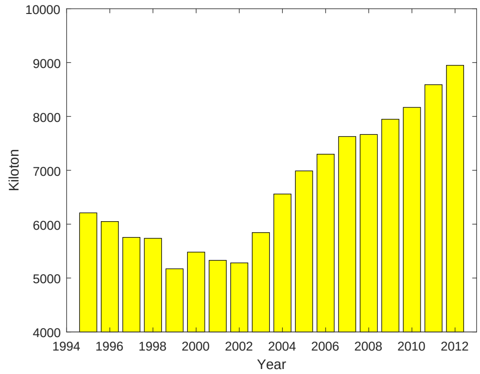
China is a typical example of a country whose trade pattern of air purifiers has changed rapidly in recent decades. Meanwhile, it also experienced severe air pollution problems,

[2]Hanson and Xiang divide representative industries into two groups: one with high trade costs and low elasticity of substitution (mainly the SITC code 6 series), and the other with low trade costs and high elasticity of substitution (SITC code 5, 7, 8 series). The environmental industry, although not explicitly classified into the above groups, is inferred to have low transportation costs and high elasticity of substitution based on product characteristics and its SITC code (e.g., air purifiers, SITC code – 7436).

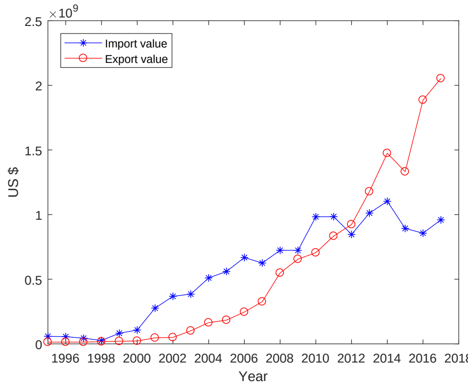
[3]The World Health Organization also reports that approximately 7 million people die each year from diseases caused by ambient and household air pollution, with 90% of these deaths occurring in developing countries. http://www.emro.who.int/media/news/9-out-of-10-people-worldwide-breathe-polluted-air.html.



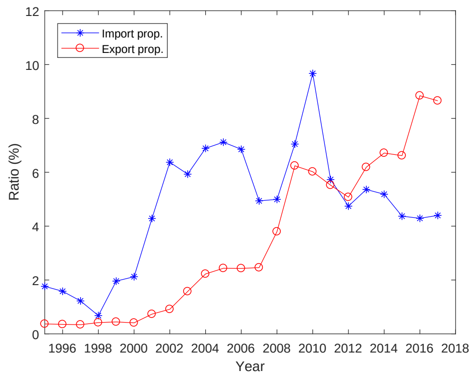
(a) Industrial exhaust emssions



(b) $PM_{2.5}$ emissions of fossils



(c) Value of air purifier trade



(d) Proportion of air purifier trade

FIGURE 1 The air purifier trade and air pollution in China
Notes: The data on China's air purifier trade are sourced from from the UN Comtrade Database. Industrial exhaust emission data come from the EPS database, while the data of $PM_{2.5}$ emissions from the use of fossil fuels are provided by the Emissions Database for Global Atmospheric Research v4.3.2 (Janssens-Maenhout et al., 2017).

such as "smog" events in an endless stream. From 1995 to 2015, its industrial emissions increased by approximately 6.4 times (Figure 1(a)), and from 1995 to 2012, the $PM_{2.5}$ emissions from the use of fossil fuels increased by 1.4 times (Figure 1(b)). Remarkably, this trend highly coincides with the rise in China's air purifier trade. According to Figures 1(c) and (d), from 1995 to 2017, China's imports of air purifiers went up from 58.4 million to 959.1 million US dollars. More strikingly, compared with the imports, China's exports show an explosive upward tendency. The export value was 13.4 million US dollars in 1995, accounting for less than 0.4% of the world's air purifier trade. By 2017, it had increased to 2053.2 million US dollars, accounting for almost 9% of the air purifier trade worldwide. This implies that with exposure to severe air pollution, China has transitioned from a net importer to a net exporter of air purifiers. Its trade share in the world has also grown considerably.

Following Costinot et al. (2019), we consider two HMEs in the environmental industry, weak and strong. (i) The weak HME refers to the phenomenon in which the more severe the air pollution is, the more environmental products are exported. (ii) The strong HME refers to the phenomenon in which, when air pollution worsens, the increase in exports of environmental products is greater than that in imports, i.e., the net exports increase.

This paper differs from existing studies in several aspects. First, in contrast to the partial-equilibrium model of Costinot et al. (2019), the theoretical model presented here is a general-equilibrium setup. We are able to explore the effects of trade costs on the strong and weak HMEs, both theoretically and empirically. Second, we formulate the HME in terms of trade pattern based on the change in demand, even when the country is small. In contrast, the existing theoretical HME results are all based on the country size, focusing on a large country (e.g., Davis, 1998; Helpman & Krugman, 1985; Takatsuka & Zeng, 2012a,b). Third, we address the environmental sector. More specifically, utilizing a comprehensive dataset of 46 countries from 1995 to 2017, this paper examines the causal relationship between the $PM_{2.5}$ concentration and the export value, import value, and net export value of air purifiers.

The remainder of this article is organized as follows. Section 2 presents the theoretical analysis of the weak and strong HMEs. Section 3 describes the benchmark empirical model and discusses the sample and data. Section 4 presents the estimation results for the magnitude of the HME and considers alternative measures of air pollution and heterogeneity. In Section 5, we empirically examine how tariffs affect trade and the magnitude of the HME. Section 6 provides the conclusion.

2 THEORETICAL ANALYSIS OF THE HME

In this section, from the trade-pattern perspective, we establish a two-country, two-sector model to examine the trade pattern of the weak and strong HMEs. We also demonstrate that trade costs play a crucial role in determining trade and the magnitude of the HME.

2.1 The model

We consider an economy consisting of two countries (1 and 2) and two sectors. Sector M produces differentiated manufactured products, and sector A produces a homogeneous agricultural good. We assume that the residents in the two countries have a Cobb-Douglas utility, but the parameters are independent (μ_1 and μ_2). Specifically,

$$U_1 = M_1^{\mu_1} A^{1-\mu_1}, \quad U_2 = M_2^{\mu_2} A^{1-\mu_2}.$$

The quantity M_i is defined by a constant elasticity of substitution (CES) function over a continuum of varieties of manufactured goods:

$$M_i \equiv \left[\int_0^{n_i} q_{ii}(\omega)^{\frac{\sigma-1}{\sigma}} d\omega + \int_0^{n_j} q_{ji}(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}}, \quad i, j = 1, 2,$$

where $q_{ij}(\omega)$ denotes the consumption of manufactured product ω produced in country i and consumed in country j, n_i is the mass of varieties in sector M produced in country

i, and $\sigma > 1$ represents the elasticity of substitution between any two manufactured products.

Let L be the worldwide population and θ be the population share in country 1. As in most literature on spatial economics, we assume that the composite good A is freely transported between the two countries and choose it as the numeraire. Furthermore, we assume that the labor endowment is large enough for the composite good to be produced in both countries. Thus, the price of the agricultural good in either country is equal to 1.

Labor is the only input of production. The production of A is perfect competition in two countries. We take the unit of the composite good as the output of one worker in country 2 so that the wage rate in country 2 is 1. We allow for different productivity levels in two countries and let w be the wage rate in country 1. Since wages are the only source of residents' income in both countries, the total incomes in country 1 and 2 are, respectively,

$$Y_1 = \theta L w \quad \text{and} \quad Y_2 = (1-\theta)L,$$

where w is the relative wage rate. Country 1 is interpreted as a developed country if $w \geq 1$ and as a developing country if $w < 1$.

In the differentiated-good sector, transactions across countries are subject to iceberg cost $\tau \geq 1$ (including tariffs). Notation $\phi = \tau^{1-\sigma} \in (0, 1]$ is called trade freeness. In the manufacturing sector, we choose the unit of a variety as the output of $(\sigma - 1)/\sigma$ workers. Using the property of constant markups in a CES framework (Dixit & Stiglitz, 1977), the equilibrium price p_{ij} of a differentiated variety produced in country i and consumed in country j is

$$p_{11} = w, \quad p_{12} = \tau w, \quad p_{22} = 1, \quad p_{21} = \tau.$$

The price indices in the manufacturing sector of countries 1 and 2 are

$$P_1 = (w^{1-\sigma} n_1 + \phi n_2)^{\frac{1}{1-\sigma}} \quad \textit{and} \quad P_2 = (w^{1-\sigma}\phi n_1 + n_2)^{\frac{1}{1-\sigma}},$$

respectively. The demand q_{ij} for a variety in country j produced in country i is

$$\begin{aligned} q_{11} &= \frac{w^{1-\sigma}\mu_1}{n_1 w^{1-\sigma} + \phi n_2}\theta L, \quad q_{12} = \frac{\phi}{\tau}\frac{w^{-\sigma}\mu_2}{\phi n_1 w^{1-\sigma} + n_2}(1-\theta)L, \\ q_{21} &= \frac{\phi}{\tau}\frac{\mu_1 w}{n_1 w^{1-\sigma} + \phi n_2}\theta L, \quad q_{22} = \frac{\mu_2}{\phi n_1 w^{1-\sigma} + n_2}(1-\theta)L. \end{aligned} \tag{1}$$

If $w = 1$ and $\mu_1 = \mu_2$ hold, our model degenerates to the model of Helpman & Krugman (1985, Chapter 10).

2.2 The HME

2.2.1 Interior equilibrium

In an interior equilibrium, $n_i > 0$ holds for $i = 1, 2$. Assume that F units of labor are the fixed input for a firm to produce a variety in the differentiated sector. The free-entry condition and the market-clearing condition in countries 1 and 2 imply

$$q_{11} + \tau q_{12} = F\sigma, \quad \tau q_{21} + q_{22} = F\sigma.$$

Substituting (1) into the above equations, we obtain

$$
\begin{aligned}
&\frac{w^{1-\sigma}\mu_1}{n_1 w^{1-\sigma}+\phi n_2}\theta L+\phi\frac{w^{-\sigma}\mu_2}{\phi n_1 w^{1-\sigma}+n_2}(1-\theta)L=F\sigma,\\
&\phi\frac{\mu_1 w}{n_1 w^{1-\sigma}+\phi n_2}\theta L+\frac{\mu_2}{\phi n_1 w^{1-\sigma}+n_2}(1-\theta)L=F\sigma.
\end{aligned}
\tag{2}
$$

Let

$$
\mathcal{A}_1=1-w^{\sigma}\phi,\quad \mathcal{A}_2=1-w^{-\sigma}\phi. \tag{3}
$$

Equations of (2) immediately give

$$
\frac{\mu_1}{n_1 w^{1-\sigma}+\phi n_2}=\frac{F\sigma w^{\sigma}\mathcal{A}_2}{Lw\theta(1-\phi^2)},\quad \frac{\mu_2}{\phi n_1 w^{1-\sigma}+n_2}=\frac{F\sigma\mathcal{A}_1}{L(1-\theta)(1-\phi^2)}.
$$

Since the left-hand sides (LHSs) of the above two equations are evidently positive, the following conditions are necessary for the existence of an interior equilibrium:

$$
\mathcal{A}_1>0,\quad \mathcal{A}_2>0. \tag{4}
$$

Furthermore, the equations of (2) determine n_1 and n_2 as follows:

$$
n_1=\frac{L}{F\sigma w\mathcal{A}_1\mathcal{A}_2}\Phi_1(\phi),\quad n_2=\frac{L}{F\sigma\mathcal{A}_1\mathcal{A}_2}\Phi_2(\phi), \tag{5}
$$

where

$$
\begin{aligned}
\Phi_1(\phi)\equiv&w\theta\mu_1\mathcal{A}_1-w^{\sigma}\mu_2(1-\theta)\phi\mathcal{A}_2 &(6)\\
=&w\theta\mu_1-w^{\sigma}[w\theta\mu_1+\mu_2(1-\theta)]\phi+\mu_2(1-\theta)\phi^2, &(7)\\
\Phi_2(\phi)\equiv&\mu_2(1-\theta)\mathcal{A}_2-w^{1-\sigma}\theta\phi\mu_1\mathcal{A}_1 &(8)\\
=&\mu_2(1-\theta)-w^{-\sigma}[w\theta\mu_1+\mu_2(1-\theta)]\phi+w\theta\mu_1\phi^2. &(9)
\end{aligned}
$$

Under (4), function Φ_i increases with μ_i and decreases with μ_j for $i,j=1,2, i\neq j$. In general, $\Phi_1(0)=w\theta\mu_1$ and $\Phi_2(0)=(1-\theta)\mu_2$ represent the market sizes of two countries (up to a constant L). Without loss of generality, we assume that the market size of country 1 is smaller:

$$
w\theta\mu_1<(1-\theta)\mu_2. \tag{10}
$$

This assumption is contrastive to the assumption of a large home country in the existing HME literature but (10) is more reasonable because country 2 is taken as the rest of the world in our empirical analysis.

We have the following properties of Φ_1 and Φ_2.

Lemma 1 *(i) For any $\phi\in[0,1]$, $\Phi_1(\phi)$ and $\Phi_2(\phi)$ cannot be negative simultaneously; (ii) $\Phi_1(\phi)$ and $\Phi_2(\phi)$ cross at most once in $\phi\in[0,1]$; (iii) if $w\geq 1$, $\Phi_1(\phi)$ has a unique root $\tilde\phi_1$, while $\Phi_2(\phi)$ is always positive in $[0,1)$; (iv) if $w<1$, $\Phi_2(\phi)$ has a unique root $\tilde\phi_2$ in $[0,1)$; (v) if $w<1$, $\Phi_1(\phi)$ is always positive when σ is large such that*

$$
4w(w^{-2\sigma}-1)\theta(1-\theta)\mu_1\mu_2>[w\theta\mu_1-(1-\theta)\mu_2]^2, \tag{11}
$$

holds. Meanwhile, $\Phi_1(\phi)$ is negative in an interval $(\tilde\phi_{1a},\tilde\phi_{1b})\subset(0,\tilde\phi_2)$ when σ is small violating (11).

Proof: See Appendix A. □

Later, we provide examples of $\tilde{\phi}_1$, $\tilde{\phi}_2$, $\tilde{\phi}_{1a}$, and $\tilde{\phi}_{1b}$ in Figures B.1(a), B.2(a), and B.3(a) of Appendix B. An interior equilibrium exists if and only if the firm masses of (5) are positive. Based on Lemma 1, the conditions of positive firm masses can be written as

$$\Phi_i(\phi) > 0 \text{ for } i = 1, 2 \Leftrightarrow \phi \in \begin{cases} [0, \tilde{\phi}_1) & \text{if } w \geq 1 \\ [0, \tilde{\phi}_2) & \text{if } w < 1 \text{ and } \sigma \text{ is large} \\ [0, \tilde{\phi}_2) - [\tilde{\phi}_{1a}, \tilde{\phi}_{1b}] & \text{if } w < 1 \text{ and } \sigma \text{ is small.} \end{cases} \tag{12}$$

Next, we calculate the trade value of manufactured products in country 1. Noting that $p_{11} = w$ and $p_{22} = 1$, the export value in sector M in country 1 is

$$\mathrm{EX}_1 = \tau w q_{12} \cdot n_1 = \frac{L\phi}{\mathcal{A}_2 w^{\sigma-1}(1-\phi^2)}[\mathcal{A}_1 \theta \mu_1 - \mathcal{A}_2 w^{\sigma-1}(1-\theta)\mu_2 \phi], \tag{13}$$

and the net export in sector M in country 1 is

$$\begin{aligned} \mathrm{NE}_1 =& \tau w q_{12} n_1 - \tau q_{21} n_2 \\ =& \frac{L\phi[\mathcal{A}_1 \theta \mu_1(\mathcal{A}_1 + \mathcal{A}_2 w^\sigma \phi) - \mathcal{A}_2 w^{\sigma-1}(1-\theta)\mu_2(\mathcal{A}_2 w^\sigma + \mathcal{A}_1 \phi)]}{\mathcal{A}_1 \mathcal{A}_2 w^{\sigma-1}(1-\phi^2)}, \end{aligned} \tag{14}$$

where the equalities of (13) and (14) are obtained from (5), (6), and (8).

The above explicit expressions are convenient for us to derive the following results of weak and strong home market effects.

Lemma 2 *In the interior equilibrium under (12), both the export value and the net export of a country increase with its home demand and decrease with foreign demand.*

Proof: Regarding country 1, we have

$$\frac{d\mathrm{EX}_1}{d\mu_1} = \frac{\mathcal{A}_1 L \theta \phi}{\mathcal{A}_2 w^{\sigma-1}(1-\phi^2)} > 0, \tag{15}$$

$$\frac{d\mathrm{NE}_1}{d\mu_1} = \frac{L\theta\phi}{\mathcal{A}_2 w^{\sigma-1}(1-\phi^2)}[\mathcal{A}_1 + \mathcal{A}_2 w^\sigma \phi] > 0, \tag{16}$$

$$\frac{d\mathrm{EX}_1}{d\mu_2} = -\frac{L(1-\theta)\phi^2}{1-\phi^2} < 0,$$

$$\frac{d\mathrm{NE}_1}{d\mu_2} = -\frac{L(1-\theta)\phi}{\mathcal{A}_1(1-\phi^2)}[\mathcal{A}_1 \phi + \mathcal{A}_2 w^\sigma] < 0,$$

where the inequalities are from (4). Similar results hold for country 2. □

2.2.2 Corner equilibria

Next, we analyze the corner equilibria for ϕ in $[\tilde{\phi}_1, 1]$, $[\tilde{\phi}_2, 1]$, and $[\tilde{\phi}_{1a}, \tilde{\phi}_{1b}]$.

First, if $w < 1$, we know that all manufacturing firms fully agglomerate in country 1 (i.e., $n_1 > 0$, $n_2 = 0$) when $\phi \in [\tilde{\phi}_2, 1]$. Thus, (2) is replaced by

$$\frac{\mu_1}{n_1}\theta L + \frac{\mu_2}{n_1 w}(1-\theta)L = F\sigma, \tag{17}$$

$$\phi \frac{\mu_1}{n_1 w^{-\sigma}} \theta L + \frac{\mu_2}{\phi n_1 w^{1-\sigma}} (1-\theta) L \leq F\sigma. \tag{18}$$

Equation (17) implies that

$$n_1 = \frac{L}{Fw\sigma} [w\theta\mu_1 + (1-\theta)\mu_2]. \tag{19}$$

Substituting (19) into (18), we know that (18) is equivalent to $\Phi_2(\phi) \leq 0$. Given the full agglomeration in country 1, we have

$$\text{NE}_1 = \text{EX}_1 = \mu_2(1-\theta)L, \tag{20}$$

which is independent of μ_1 but increases with μ_2.

Second, if $w \geq 1$, we have full agglomeration in country 2 (i.e., $n_1 = 0$, $n_2 > 0$) if $\phi \in [\tilde{\phi}_1, 1]$. Given the full agglomeration in country 2, we have

$$\text{NE}_1 = -\text{EX}_2 = -w\mu_1\theta L, \tag{21}$$

which is independent of μ_2 and decreases with μ_1. The same corner equilibrium occurs for $\phi \in [\tilde{\phi}_{1a}, \tilde{\phi}_{1b}]$ when $w < 1$ and σ is small violating (11).

Summarizing the above discussion, we get the following proposition.

Proposition 1 *Let $i, j = 1, 2, i \neq j$. (i) An interior equilibrium exists under (12), in which the exports and the net exports of country i increase with μ_i and decrease with μ_j (i.e., both the strong and the weak HMEs are observed). (ii) When (12) is violated, a corner equilibrium exists in which the manufacturing industry agglomerates in a country i. Country i is the only exporter, whose export value is independent of μ_i and increases with μ_j.*

Proof: Part (i) is given by Lemma 2, and part (ii) is given by (20) and (21). □

2.3 Trade pattern and trade costs

The previous results show that a larger demand leads to larger net exports when bilateral trade occurs in the manufacturing sector. This section investigates how a country's trade pattern depends on trade costs. In the literature, a widely used definition of the HME based on the trade pattern states that a larger country is always a net exporter. In our model, the restriction on country size is replaced by (10) due to the heterogeneity in preferences and productivity. The country satisfying (10) is more likely to be a small one in a space of two countries. However, we will see that it is not definitely a net importer.

To illustrate the results, we first explore the case when ϕ approaches 0. When the trade costs in the manufacturing sector are infinite, we have $\text{EX}_1 = \text{NE}_1 = 0$. The marginal effects of trade freeness at $\phi = 0$ are

$$\left. \frac{d\text{EX}_1}{d\phi} \right|_{\phi=0} = Lw^{1-\sigma}\theta\mu_1 > 0, \tag{22}$$

$$\left. \frac{d\text{NE}_1}{d\phi} \right|_{\phi=0} = Lw^{\sigma}[w^{1-2\sigma}\theta\mu_1 - (1-\theta)\mu_2]. \tag{23}$$

The inequality of (22) indicates that any slight relaxation of trade freeness can stimulate the export of country 1 at $\phi = 0$. In contrast, the sign of (23) depends on the parameters.

Specifically, (23) is negative if $w \geq 1$, according to (10). A numerical example is given in Figure B.1(b) of Appendix B. Therefore, if country 1 is a developed country, then the policy of opening trade leads it to become a net importer. This is consistent with Krugman (1980), since country 1 is more likely to be a small country.

The sign of (23) is not definitely negative when $w < 1$. We have

$$\left.\frac{d\mathrm{NE}_1}{d\phi}\right|_{\phi=0} \gtreqless 0 \text{ if } \frac{\theta\mu_1 w}{(1-\theta)\mu_2} \gtreqless w^{2\sigma}. \tag{24}$$

Figure B.2(b) is an example of the positive case, and Figure B.3(b) is an example of the negative case. Three parts of Appendix B examine the developed and developing countries for a general ϕ.

Overall, the relationship between the exports of country 1 and trade costs is summarized as follows.

Proposition 2 *(i) If $w \geq 1$, the exports of country 1 have a non-monotonic shape with respect to ϕ, while country 1 is a net importer both at small and large ϕ. All firms agglomerate in country 2 if $\phi \in [\tilde{\phi}_1, 1]$. (ii) If $w < 1$, country 1 is a net exporter both at small and large ϕ when σ is large. Meanwhile, if σ is small, country 1 is a net importer at small ϕ and a net exporter at large ϕ.*

Proof: Part (i) is shown in the context of Appendix B.1, and part (ii) is given in Appendices B.2 and B.3. □

2.4 The SME

In the HME literature based on country size, the secondary magnification effect (SME) (Head & Mayer, 2004) is used to study how the magnitude of the HME depends on trade costs. We explore their relationship by examining the effect of ϕ on $d\mathrm{EX}_1/\mathrm{d}\mu_1$ and $d\mathrm{NE}_1/\mathrm{d}\mu_1$.

First, we calculate the derivatives of (15) and (16) at $\phi = 0$ and find

$$\left.\frac{d^2\mathrm{EX}_1}{d\mu_1 d\phi}\right|_{\phi=0} = \left.\frac{d^2\mathrm{NE}_1}{d\mu_1 d\phi}\right|_{\phi=0} = Lw^{1-\sigma}\theta > 0.$$

Thus, any slight drop in trade costs can enhance the HME of country 1 when the trade costs are large (i.e., ϕ is close to 0). Regarding another end $\tilde{\phi} \in \{\tilde{\phi}_1, \tilde{\phi}_2\}$, we need to consider the developed- and developing-country cases separately again.

In general, in an interior equilibrium, we have

$$\frac{d\mathrm{EX}_1}{d\mu_1} = \frac{d\mathrm{EX}_1}{d\left(\frac{n_2}{\phi n_1}\right)} \cdot \frac{d}{d\mu_1}\left(\frac{n_2}{\phi n_1}\right), \tag{25}$$

$$\frac{d^2\mathrm{EX}_1}{d\mu_1 d\phi} = \frac{2Lw^{2\sigma+1}(1-\theta)\mu_2}{(\phi n_1 w + w^\sigma n_2)^3}\phi^3 n_1^3 \cdot \frac{d}{d\phi}\left(\frac{n_2}{\phi n_1}\right) \cdot \frac{d}{d\mu_1}\left(\frac{n_2}{\phi n_1}\right)$$

$$- \frac{Lw^{1-\sigma}(1-\theta)\mu_2}{(w^{1-\sigma} + \frac{n_2}{\phi n_1})^2} \cdot \frac{d^2}{d\mu_1 d\phi}\Big(\frac{n_2}{\phi n_1}\Big) \tag{26}$$

$$= \frac{L(1-\theta)\theta\mu_2}{(\phi\Phi_1 + w^\sigma\Phi_2)^2}\Big\{[(w^\sigma - \phi)\phi + 1 - \phi^2](1 - w^\sigma\phi)(1-\theta)\mu_2\phi$$

$$+ w\theta\mu_1\phi(1 - w^\sigma\phi)^2 - w^\sigma\phi^2\Phi_1 + (1 - 2w^\sigma\phi)w^\sigma\Phi_2\Big\} \tag{27}$$

$$= \frac{wL\theta[w^\sigma(1+\phi^2)^2 - 2w^{2\sigma}\phi - 2\phi^3]}{(w^\sigma - \phi)^2(1-\phi^2)^2}. \tag{28}$$

Regarding the exports of country 2, we have

$$\mathrm{EX}_2 = \frac{L\phi}{(1 - w^\sigma\phi)(1-\phi^2)}[(w^\sigma - \phi)(1-\theta)\mu_2 - w\theta\mu_1\phi(1 - w^\sigma\phi)],$$

$$\frac{d^2\mathrm{EX}_2}{d\mu_1 d\phi} = -\frac{2Lw\theta\phi}{(1-\phi^2)^2} < 0. \tag{29}$$

Thus, in an interior equilibrium, we have

$$\frac{d^2\mathrm{NE}_1}{d\mu_1 d\phi} = \frac{d^2\mathrm{EX}_1}{d\mu_1 d\phi} - \frac{d^2\mathrm{EX}_2}{d\mu_1 d\phi} \tag{30}$$

$$= \frac{wL\theta}{(1-\phi^2)^2}\Big[\frac{(w^\sigma - \phi^3)\mathcal{A}_1}{w^{2\sigma}\mathcal{A}_2^2} + \phi\Big], \tag{31}$$

where (31) is directly from (28) and (29).

Appendix C discusses how the strong and weak SMEs vary with trade costs for developed and developing countries in detail. The results show that, regardless of whether σ is large or small and whether (11) holds, $d\mathrm{EX}_1/d\mu_1$ and $d\mathrm{NE}_1/d\mu_1$ increase with ϕ in interior equilibrium. In other words, both the strong and weak SMEs are valid when country 1 is a developing country ($w < 1$).

Summarizing the above discussions, we have the following proposition.

Proposition 3 *In the interior equilibrium, (i) when $w \geq 1$, the strong SME is valid, while the weak SME is ambiguous; (ii) when $w < 1$, the strong and weak SMEs are valid when ϕ is small or close to $\tilde{\phi}$. Their intermediate processes are likely to be monotonic in the path of interior equilibrium.*

Proof: Part (i) is given in the context of Appendix C.1, and part (ii) is given in Appendix C.2. □

3 DATA AND EMPIRICAL APPROACH

Propositions 1 to 3 provide the theoretical results for the existence of the HME and its relationship to trade costs. We verify these propositions empirically, specifying the manufacturing sector in the theoretical model as the environmental sector. This section constructs a baseline regression model and describes a comprehensive dataset for estimation.

3.1 Data

This paper builds a comprehensive panel dataset involving trade in air purifiers, air quality, national economy characteristics, etc., including 46 major countries, with the time interval ranging from 1995, 2000, 2005, 2010 to 2017. The selection of sample countries is based primarily on the Penn World Table (version 9.1), which depicts various economic characteristics of major countries, such as average working hours and productivity.[4] In addition, the discontinuity of the time interval is attributed to $PM_{2.5}$ data released by the World Bank every five years before 2010. Compared with previous studies utilizing OECD countries as samples, this dataset includes not only developed countries with clean air but also developing countries suffering severe pollution, e.g., China, India, and Argentina. Moreover, both large and small countries are considered. This feature makes the dataset conducive to horizontal comparisons between countries. For the detailed composition of sample countries, see Figure D.1 of Appendix D.

3.1.1 The trade of environmental products

We choose air purifiers as a typical environmental product, focusing on the collection of export and import values in sample countries. The trade data for air purifiers are derived from the UN Comtrade Database. The product under the following category: "machinery for filtering or purifying gases, other than intake air filters for internal combustion engines" (the HS code is 842139).[5]

We take air purifiers as a typical environmental good to analyze the HME in the environmental sector, mainly for two reasons. (i) It is an affordable appliance for most purchasers, so the demand is effective and achievable. In fact, the price information released by some e-commerce companies indicates that common indoor air purifiers range from dozens to hundreds of dollars.[6] (ii) There is a direct link between the sales of air purifiers and the air pollution level. Residents exposed to excessive air pollutants, especially the elderly, infants, and patients with respiratory diseases, are in need of domestic air purifiers to improve indoor air quality. In response to environmental complaints from the public, manufacturers also purchase industrial air purifiers to cut emissions. In other words, air purifiers can better reflect the environmental demand of both the residential and corporate sides simultaneously.

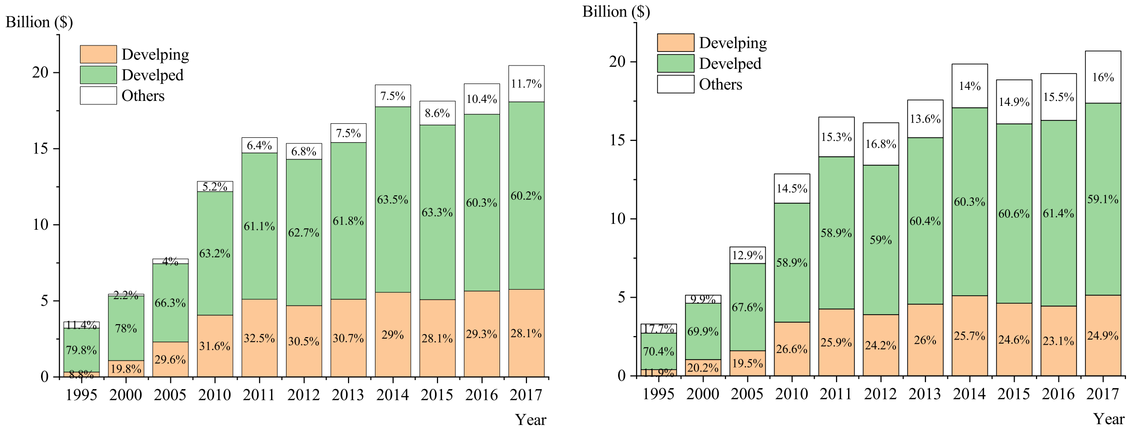
In Figure 2, we visualize the changes in the world air purifier trade and the share of the sample countries. As an overall temporal trend, the total export and import value

[4]For indicators such as average working hours and total factor productivity, the Penn World Table (Version 9.1) provides statistics for only about 60 countries, and the data for the remaining countries are missing. We further exclude countries with data gaps in air purifier trade and $PM_{2.5}$, as well as countries with a tiny scale, leaving us with 46 sample countries.

[5]It involves two types of air purifiers: those for domestic application and those for industrial application. Unfortunately, the global commodity trade data for the HS 8-digital code is not available in the UN Comtrade or other databases. One reason for this is that the HS codes beyond the 6-digit level are not consistent across countries worldwide. In this case, it is difficult to directly distinguish between the two types of demand. However, the subsequent robustness analyses indicate that this does not affect our conclusions.

[6]We can search for price information at Amazon.com, Taobao.com, and other platforms. Generally speaking, a domestic air purifier costs no more than a refrigerator or TV.

of air purifiers worldwide increase significantly, including those of sample countries and others remaining. Specifically, from 1995 to 2017, the export share of the sample countries (the sum of developing and developed) almost always remains above 90% (Figure 2(a)), and the import share is also above 80% (Figure 2(b)). This also supports the rationality of our sample selection, which can better reflect the overall trend and basic pattern of the world air purifier trade. It is worth noting that the status of developing countries in the export market for air purifiers is rising, but the traditional advantages of developed countries are shrinking.



(a) Export value and share (b) Import value and share

FIGURE 2 The total trade value and share of air purifiers in sample countries from 1995 to 2017

Notes: "Developing" and "Developed" represent the 19 developing countries and 27 developed countries in our sample, respectively; "Others" represents the remaining non-sample countries. The different colored bars represent the export or import value of the corresponding category of air purifier. The number labels on the bars refer to their respective shares of the global air purifier exports or imports.

In addition, we also present the trade trend of air purifiers in each observed country in Figure D.1 of Appendix D. It suggests that many countries experiencing growth in air purifier exports also suffer air pollution, either light or heavy, such as China, India, the Republic of Korea, Malaysia, Mexico, Thailand, and Romania. This seems to imply some correlation between environmental needs (caused by air pollution) and the trade pattern in environmental products, which is yet to be verified.

For a general overview, we also collect the trade data of 238 environment-related products based on 11 different environmental media. The defining criteria for each medium and product list are derived from the OECD Statistics, while the trade data for each product come from the UN Comtrade Database. This includes not only the medium of "air pollution control" but also media such as "environmental monitoring equipment" and "environmentally preferable products." In addition, some environmental media related to water pollution, solid waste, noise, energy, and other forms of disposal are also included. A wide variety of media allows us to take a broader look at the HME in the environment sector based on the typical environmental product (air purifier).

3.1.2 The environmental demand shifter

To empirically test the magnitude of the HME, a critical challenge is to find an appropriate proxy variable as the environmental demand shifter. Although some studies directly adopt the health expenditure or the number of patients with certain diseases (e.g., respiratory problems, cardiovascular diseases, and even sleeplessness) (Brook et al., 2010; Beatty & Shimshack, 2014; Janke, 2014; Heyes & Zhu, 2019; Hvidtfeldt et al., 2021), we cannot conclude that these diseases originate solely from the environmental factors. Health demand is not equivalent to environmental demand.

In contrast, we choose pollution indicators as the environmental demand shifter. The most typical indicator is the annual $PM_{2.5}$ concentration weighted by population in a country, which is widely used in the empirical analysis of this paper and is obtained from the World Bank database.

Table 1 shows the percentage of differentiated $PM_{2.5}$ concentration in different years, thus reflecting the structural characteristics of environmental demand. Overall, air quality in most of the observed countries improves significantly. From 1995 to 2017, the percentage of countries with $PM_{2.5}$ less than $10\mu g/m^3$ rises from 17.4% to 28.3%, with a similar trend in the $10\sim15\mu g/m^3$ interval. In contrast, the percentage of countries in the interval of $15\sim25\mu g/m^3$ plunges from 47.8% to 26.1%; the percentage in $25\sim35\mu g/m^3$ falls after an initial rising. Notably, the share of $PM_{2.5}$ greater than $35\mu g/m^3$ remains constant. It shows that three countries, i.e., India, China, and Turkey, are still plagued by $PM_{2.5}$.

Table 1 here

We adopt $PM_{2.5}$ concentration as the environmental demand shifter, mainly based on the following reasons. First, the pollutant concentration is highly correlated with environment-related health risks (Chay & Greenstone, 2003; Chay et al., 2003), which is accompanied by greater potential environmental demand. As shown in Figure E.1 of Appendix E, we consider four environment-related risks caused by ambient particulate matter: the total Disability-Adjusted Life Years (DALYs), DALYs per thousands inhabitants (PDALY), the total number of premature deaths (DEATH), and premature deaths per million inhabitants (PDEATH). We preliminarily find that $PM_{2.5}$ concentration is positively correlated with DALYs and premature deaths from exposure to ambient particulate matter (i.e., lnDALY, lnPDALY, lnDEATH, lnPDEATH).

The second reason is that environmental pollution can stimulate residents' defensive investment in environmental goods. Some studies find that if inhabitants cannot avoid harsh environmental conditions, they will turn to more defensive expenditures (Escofet & Bravo-Peña, 2007). Purchasing more air purifiers is one approach to offset potential health damage. Ito & Zhang (2020) find that for every $1\mu g/m^3$ reduction in air pollutants, a household is willing to pay $1.34 more for air purifiers. There are similar results with regard to facemasks (Zhang & Mu, 2018).

Last but not the least, the pollution indicators can better overcome endogenous problems such as the two-way causality. Relative to indicators of environment-related morbidities, this indicator is relatively exogenous as an environmental demand shifter. Specifically, $PM_{2.5}$ concentration can influence people's purchasing decisions concerning environmentally friendly products. However, it is hard to say that, in turn, sales of those products directly affect $PM_{2.5}$ concentration.

3.1.3 Country-level characteristics

We also collect data on country-level characteristics, in addition to the aforementioned indicators. Classified by application, it involves data from two aspects: control variables and additional variables.

Regarding control variables, this mainly includes foreign environmental demand, global per capita GDP (lnWPCGDP), average annual hours by employees (lnAVH), total factor productivity (TFP), and domestic per capita GDP (lnPCGDP). These indicators may also potentially affect trade in environmental goods and thus interfere with the identification of the role of environmental demand.

- To reflect foreign environmental demand, we use the average $PM_{2.5}$ concentration in the rest of the world. Its function is to separate the domestic and foreign environmental demand, so as to more accurately assess the impact of domestic environmental demand. The calculation rule is that the world $PM_{2.5}$ concentration minus the observed $PM_{2.5}$ concentration weighted by its population share. The world average $PM_{2.5}$ concentration and population data are obtained from the World Bank database.

- Domestic per capita GDP (lnPCGDP) is widely seen as one of the key factors affecting trade. As a country becomes richer, it is more likely that citizens' aspirations for environmental products will be transformed into actual purchases. In particular, income inequality between countries has a profound impact on trade patterns (Fajgelbaum et al., 2011; Marjit et al., 2020). This data are also sourced from the World Bank database.

- The data on average annual hours worked by people engaged (lnAVH) also come from the Penn World Table (version 9.1). Average working hours not only affect the productivity of enterprises at a macro level (Collewet & Sauermann, 2017), but also affect the leisure time and consumption pattern of residents at a micro level (Gerold & Nocker, 2018). These effects may eventually spill over into trade patterns.

- Total factor productivity (TFP) is used to reflect different productivities among countries. This is consistent with the assumption of endogenous wage differences in our theoretical part. Specifically, based on the assumption of different productivities in the agricultural sector across countries, the country with higher productivity inputs less labor into the agricultural sector, resulting in a higher wage rate. The TFP indicator is calculated based on current PPPs, denominated in the United States, and is published by the Penn World Table (version 9.1) (Feenstra et al., 2015).

- World per capita GDP (lnWPCGDP), excluding the value of the observed country, can measure changes in the budget constraints of foreign residents. We calculate GDP and population size data for the rest of the world from the World Bank database and then extrapolate the world per capita GDP (excluding the observed country). Some studies indicate that foreign income levels have a positive impact on export trade (Onafowora & Owoye, 2008; Chisiridis et al., 2018).

We also collect some additional data for subsequent robustness and trade cost analyses. (i) REX, RIM, and RNE refer to the export, import, and net export shares of domestic air purifiers in the total merchandise trade, respectively, derived from calculations. (ii) The proportion of the population exposed to excess air pollution (PPMT) and the population in poor air quality (PMPOP) are used as alternative core independent variables for robustness checks, which are sourced from the World Bank database and calculations, respectively. (iii) $\ln PM_{2.5}fos$ and $\ln NH_3$ are used as indicators of pollutant emissions rather than the previous air quality indicators, and they are sourced from the Emissions Database for Global Atmospheric Research of the European Commission. (iv) TARIFF represents the average tariff level in a country's manufacturing industry, also derived from the World Bank database.

Appendix F summarizes the data on air purifier trade, $PM_{2.5}$ concentration and country-level characteristics. Detailed descriptive statistics and variable definitions are shown in Table F.1.

3.2 Empirical approach

To verify proposition 1 (the strong HME), first we construct a benchmark model and empirically estimate the relationship between environmental demand and the trade of environmental goods. The baseline model can be expressed as

$$\text{Trade}_{i,t}^{j} = \beta_0^j + \beta_1^j \text{Pollution}_{i,t} + \beta_2^j \text{WP}_{i,t} + \mathbf{S}' \cdot \mathbb{Z}^j + \nu_i^j + \lambda_t^j + \varepsilon_{i,t}^j, \tag{32}$$

where the superscript $j = x, d, n$ represents three directions of export, import, and net export, respectively. $\text{Trade}_{i,t}^{j}$ is the dependent variable, which represents the trade value of air purifiers in country i in year t in trade direction j, rather than trade volume. More specifically, $\text{Trade}_{i,t}^{x}$ refers to the export value ($\text{Exvalue}_{i,t}$), $\text{Trade}_{i,t}^{d}$ refers to the import value ($\text{Import}_{i,t}$), and $\text{Trade}_{i,t}^{n}$ refers to net export value ($\text{Nettrade}_{i,t}$).

$\text{Pollution}_{i,t}$ is the core independent variable — the environmental demand shifter (i.e., μ_i in Section 2), indicating the $PM_{2.5}$ concentration of country i in year t. β_1^j (i.e., β_1^x, β_1^d, β_1^n) is the coefficient of $\text{Pollution}_{i,t}$ to be estimated, which is the focus of our study. A positive relationship between the trade of air purifiers and $PM_{2.5}$ in direction j exists if $\beta_1^j > 0$. Conversely, a negative correlation exists if $\beta_1^j < 0$. In our empirical model, the two HMEs defined in Section 1 are interpreted as follows. (i) The weak HME exists if $\beta_1^x > 0$. (ii) The strong HME exists if $\beta_1^x > \beta_1^d$ further holds. The latter inequality is a primary criterion in the sense that it has no requirements for the sign and significance level of β_1^d. As a supplement, we also use $\beta_1^n > 0$ as an auxiliary standard.

Apart from its domestic demand, the trade value of air purifiers in one country may also be affected by foreign demand. Given this, we apply WP_t to the benchmark model to represent $PM_{2.5}$ concentration in the rest of the world, i.e., excluding the observed country. As a special control variable, we list it separately in the regression model, but its coefficient is not our focus. Vector $\mathbb{Z}^j$ represents the control variables that affect $\text{Trade}_{i,t}^{j}$ other than foreign environmental demand, including domestic per capita GDP (lnPCGDP), average annual hours worked by people engaged (lnAVH), total factor productivity, and world per capita GDP (lnWPCGDP) excluding the observed country. Vector $\mathbf{S}$ refers to the coefficients of control variables.

Finally, ν_i^j represents the country fixed effect in trade direction j to solve country-varying missing variables, while λ_t^j refers to the year fixed effect to solve time-varying missing variables. β_0^j and $\varepsilon_{i,t}^j$ are the intercept term and stochastic error term, respectively.

4 EMPIRICAL FINDINGS

In this empirical part, we examine the causal relationship between $PM_{2.5}$ and air purifier exports, imports, and net exports. To prove robustness and persuasiveness, we address several potential threats to the basic findings and also conduct placebo tests. The sensitivity of HMEs to some contributing factors is also further analyzed. Finally, we conduct a general analysis of the HME at the environmental industry level.

4.1 Benchmark findings

Table 2 presents the estimation results of the basic model (32). Specifically, Columns (i), (iv), and (vii) are the regressions of exports, imports, and net exports to $PM_{2.5}$, respectively. Columns (ii), (v), and (vii) add control variables. In addition, Columns (iv), (vi), and (ix) further introduce the $\text{lnWPM}_{2.5}$ term to isolate the potential impact of foreign environmental demand. Notably, each column controls the year fixed effect and country fixed effect.

Table 2 here

After control variables and foreign demand are added, Column (iii) indicates $\beta_1^x > 0$. More specifically, for every 1% increase in $PM_{2.5}$, the export value of air purifiers increases significantly, by 4.337%. Meanwhile, the coefficient of $\text{lnPM}_{2.5}$ in Column (vi) is non-significantly positive and lower than that in Column (iii) (i.e., $\beta_1^x > \beta_1^d$). The results provide resounding support for the strong HME between the $PM_{2.5}$ concentration and the trade of air purifiers according to the HME definitions in Section 3.2. In other words, the more severe the air pollution, the larger the increase in exports relative to that in imports. We also provide auxiliary evidence in Columns (vii) to (ix). Column (ix) suggests that net exports go up by 3.835% with a 1% increase in $PM_{2.5}$. All the evidence strongly supports the theoretical results of Proposition 1 regarding the strong HME.

4.2 Robustness checks

In this section, we investigate whether certain potential threats impact the robustness of the benchmark findings. By addressing these threats, we confirm that the benchmark results are credible and consistent with Proposition 1.

4.2.1 The population exposed to $PM_{2.5}$

Intuitively, the global population distribution is uneven due to economic, geographical, and other complex factors. This raises the possibility that in some countries with small populations, even if pollution is more severe, the scale of their environmental demand may still be smaller than that of large countries. Although the variable ln$PM_{2.5}$ is weighted by population, we attempt to more directly reflect the demand by considering the population factor to verify the robustness of the HME.

Therefore, we adopt two alternative indicators: PMPOP, representing the number of domestic people exposed to excessive ambient particulate matter ($PM_{2.5} \geq 10\mu g/m^3$), and PPMT, indicating the proportion of people exposed to excessive ambient particulate matter relative to the total domestic population. Analogously, WPMPOP and WPPMT refer to the total population and the proportion of people (excluding the observed country) exposed to excessive air pollution, respectively.

Columns (i) and (ii) of Table 3 demonstrate that for every 1% increase in the population exposed to excessive pollution, a country's exports of air purifiers increase by 0.345%, while imports only rise by 0.102%. A significant positive relationship between PMPOP and Nettrade is also found in Column (iii). Therefore, the strong HME exists even when the core independent variable is PMPOP.

Table 3 here

Furthermore, Column (iv) suggests that with a 1% increase in PPMT, exports can significantly increase by 2.8%. In contrast, the relationship between PPMT and imports is non-significant in Column (v). That is probably because the rising domestic demand is largely met by domestic supply rather than foreign supply. Column (vi) also indicates that for each 1% increase in PPMT, net exports will increase by 2.5%.

Therefore, we find that the strong HME remains significant. This empirical evidence further supports Proposition 1.

4.2.2 Pollutant emission indicators

As an air quality indicator, $PM_{2.5}$ may be affected by factors such as climate, weather, and geography. Additionally, $PM_{2.5}$ data were only available every five years before 2010. Consequently, we conduct a retest of the benchmark-estimated results using alternative indicators.

Specifically, we use two pollutant emission indicators: $PM_{2.5}$ emissions from fossil fuel burning (ln$PM_{2.5}$fos) and NH_3 emissions (lnNH_3) to replace the above-mentioned air quality indicator. The dataset spans from 1995 to 2012 and is sourced from "Global Greenhouse Gases Emissions EDGAR v4.3.2," released by the Emissions Database for Global Atmospheric Research of the European Commission.[7]

The retest results are summarized in Table 4. Columns (i) to (iii) demonstrate that every 1% increase in $PM_{2.5}$ from fossil fuel sources results in a 0.933% increase in exports and a 0.819% increase in net exports. Similarly, Columns (iv) and (vi) reveal a significant relationship between NH_3 and the trade of air purifiers. Based on the signs and the significance levels, we conclude that the strong HME is still active. Overall, any potential measurement error from the air quality indicator does not compromise the robustness of the strong HME.

[7]We sincerely thank the EDGARv4.3.2 website (`http://edgar.jrc.ec.europa.eu/overview.php?v=432\&SECURE=123`) and Janssens-Maenhout et al. (2017) for providing this data.

Table 4 here

4.2.3 Environmental policy and media coverage

In addition to the aforementioned air quality indicators, we also incorporate several alternative environmental demand shifters to explore potential measurement biases.

The first alternative indicator is government policy related to environmental regulation. Some studies suggest that public environmental demand is largely driven by severe environmental pollution, which is closely linked to lenient environmental regulation policies (Cole et al., 2005; Tanaka, 2015). In other words, all elses being equal, a country with less stringent environmental policies may exhibit a higher environmental demand. Using the OECD database, we approximate environmental demand by taking the reciprocal of the non-market based environmental policy stringency index. This index primarily relies on a country's emission limits for NOx, SOx, PM, sulfur, and other pollutants. As demonstrated in Columns (i) to (iii) of Table 5, a larger lnNMEP (indicating lower environmental stringency) is associated with higher exports and net exports of air purifiers.

The second alternative indicator is media coverage. If the media extensively report on $PM_{2.5}$ concentrations, domestic consumers may have a higher demand for air purifiers. Specifically, we employ the Google Trends index, with "$PM_{2.5}$" as the search term, to measure environmental demand, and its search scope is "web search." This not only reflects the online media coverage intensity of $PM_{2.5}$ in a country but also directly indicates public interest and attention toward it. Notably, since the majority of Chinese consumers lack access to Google search, Google Trends data regarding "$PM_{2.5}$" in China may be underestimated. Therefore, we use the Baidu Index regarding "$PM_{2.5}$" after a simple transformation to replace China's observations in the Google Trends index.[8] Additionally, we discuss cases involving all Google Trends observations and the exclusion of China in Table G.1 of Appendix G. In Columns (iv) to (vi) of Table 5, the Google Trends index regarding $PM_{2.5}$ is significantly positively correlated with exports and net exports of air purifiers.

To sum up, even when the environmental demand is measured in terms of environmental policy and media coverage, empirical results are consistent with the baseline findings. Therefore, the potential risk of environmental demand measurement bias is not sufficient to affect the robustness of the strong HME.

Table 5 here

4.2.4 The effect of reverse causation

Another potential threat that requires discussion is whether industrial air purifiers might undermine the empirical results. Given that the UN Comtrade and other databases cannot

[8]According to Vaughan & Chen (2015), the Baidu Index, published by China's largest search engine — Baidu Search, exhibits a high correlation with the search volume of the Google Trend index. This implies that there is commonality in revealing certain characteristics and patterns, despite differences in measurement methods between the two. To address the numerical mismatch arising from these methodological distinctions, we divide China's observations of the Baidu index by 10,000 and apply logarithmic transformations to all the observations in our empirical study.

offer higher precision commodity trade data (HS codes greater than 6-digit), it appears more feasible to employ alternative approximation methods to differentiate the impact of household and industrial air purifiers.

First, we use the relative shares of service and manufacturing industries to decompose the air purifier trade value. In general, a manufacturing-based economy may exhibit a greater demand share for industrial-scale air purifiers to filter air pollutants. In contrast, the demand share in service-based economies is likely to lean more toward household-scale air purifiers for residential buildings, offices, hospitals and other indoor establishments.

Let RGDP2 be the share of manufacturing value-added in the gross domestic product (GDP), and RGDP3 be the share of service value-added in the GDP. We use the product of the relative share of the service industry (RGDP3/(RGDP2+RGDP3)) and $\text{Trade}_{i,t}^{j}$ to approximate the trade value of household air purifiers (Trade-H). Similarly, the product of the relative share of manufacturing (RGDP2/(RGDP2+RGDP3)) and $\text{Trade}_{i,t}^{j}$ is used to approximate the trade value of industrial air purifiers (Trade-I). This is illustrated in the following equations (33) and (34):

$$\text{Trade-H}_{i,t}^{j} = \frac{\text{RGDP3}_{i,t}}{\text{RGDP2}_{i,t} + \text{RGDP3}_{i,t}} \cdot \text{Trade}_{i,t}^{j}, \tag{33}$$

$$\text{Trade-I}_{i,t}^{j} = \frac{\text{RGDP2}_{i,t}}{\text{RGDP2}_{i,t} + \text{RGDP3}_{i,t}} \cdot \text{Trade}_{i,t}^{j} = \text{Trade}_{i,t}^{j} - \text{Trade-H}_{i,t}^{j}. \tag{34}$$

All other settings remain unchanged.

In Columns (i) to (iii) of Table 6, Panel A demonstrates that $PM_{2.5}$ significantly influences the growth of exports and net exports of household air purifiers, indicating the existence of a strong HME. In contrast, Columns (iv) to (vi) of Panel A show that the relationship between $PM_{2.5}$ and industrial air purifier (net) exports is not significant or is weak. In other words, even when excluding the trade value of industrial air purifiers, the benchmark findings remain robust.

Second, we explore the search intensity for different types of air purifiers to decompose their trade value. Using the Google Trends index, we gauge internet searches for household air purifiers with the term "air purifier" and "air filter." Industrial air purifiers, which are more commonly referred to as dust collectors, dusters, and precipitators, are also taken into account. Similar to the first method, the proportion of household searches in total searches (comprising the aforementioned five keywords) is multiplied by $\text{Trade}_{i,t}^{j}$ to approximate the trade value of household air purifiers. The trade value of industrial air purifiers is likewise estimated by multiplying the proportion of industrial searches by $\text{Trade}_{i,t}^{j}$. In Panel B of Table 6, the estimated results in most columns closely resemble those in Panel A. Although the evidence in Column (iii) is not as strong as desired, it still contributes to the inherent argument that the increase in exports of household air purifiers surpasses that in imports due to the rising $PM_{2.5}$ levels. This further reinforces that the potential reverse causality in industrial air purifiers poses a weak threat to the empirical results.

Lastly, we impose a scenario hypothesis: the deployment of industrial air purifiers leads to a reduction in industrial emissions, thereby contributing to an enhancement in overall air quality (including a decrease in $PM_{2.5}$ concentration). In this scenario, the baseline estimations may capture the association between improved $PM_{2.5}$ levels and the trade in air purifiers. It is inferred that by excluding the reverse impact of industrial air purifiers, the positive effect of $PM_{2.5}$ on trade value could be more pronounced. In essence, if such reverse causality exists, it would strengthen the robustness of the strong HME.

Table 6 here

4.2.5 Exclusion of special observations

We further discuss the potential threat of whether the baseline results are influenced by observations from a few special countries. Notably, some countries have been plagued by severe environmental pollution since the 1990s with the explosive growth of manufacturing. India and China are the most representative of these countries. Specifically, from 1995 to 2017, India's population-weighted $PM_{2.5}$ ranged from 82.8 to 97.6μg/m^3, ranking first among our sample countries. Meanwhile, China's indicator ranged from 52.7 to 70.5μg/m^3, coming in second only to India.[9] It becomes necessary to examine whether the HME exists even when India and China are excluded.

To assess this robustness, Columns (i) to (iii) of Table 7 re-estimate the causal correlation between $PM_{2.5}$ and the trade of air purifiers by excluding those special observations from India and China. Columns (i) and (iii) suggest that every 1% increase in $PM_{2.5}$ still significantly drives export growth by 4.594% and net export growth by 3.765%, respectively. The two coefficients only change slightly compared to the coefficients presented in Columns (iii) and (ix) of Table 2, indicating that the threat of special observations is not sufficient to undermine the validity of our basic findings. Again, Column (ii) of Table 7 indicates that the effect of $PM_{2.5}$ on imports is ambiguous, consistent with Table 2.

Table 7 here

4.2.6 Increasing manufacturing capacity

Furthermore, consider the influence of manufacturing capacity. Namely, the expansion of a country's manufacturing industry may bring about an increase in pollutant emissions and, simultaneously, an expansion in the export of air purifiers. As an alternative measure of our dependent variable, we adopt the share of air purifier exports in a country's total merchandise exports. By replacing the previous absolute quantity with the relative share, we can avoid the impact of the growing manufacturing capacity on air purifiers.

Columns (iv) and (v) of Table 7 indicate that with the increasing $PM_{2.5}$ concentration, the air purifier export growth is significantly positive at the level of 5%, while the import level is not significantly changed. Therefore, we can infer that the strong HME still exists in the environmental industry, unaffected by the growth in manufacturing. The positive coefficient of $\ln PM_{2.5}$ in Column (vi), though not as strongly significant as desired, also adds support for the strong HME (the p-value equals 11.6%, close to the significance level of 10%). The baseline findings are once again confirmed to be robust.

[9] This indicator, the core explanatory variable of our empirical estimation, is sourced from the World Bank. Remarkably, India's $PM_{2.5}$ level has dropped slightly from the peak of 97.6 to 90.9μg/m^3 in 2017. China's efforts were even more prominent, resulting in a decrease from 70.5μg/m^3 in 2011 to 50.7μg/m^3 in 2017.

4.2.7 Detrending analysis

Finally, the potential threat to be discussed is that some factors, which systematically change over time, may lead to a spurious regression problem in the relationship between the air purifier trade and $PM_{2.5}$ concentration (Wooldridge, 2015, p.332). We attempt to eliminate the potential time trend in two cases.

One case is that some unobserved confounding factors are time-varying. We introduce the time polynomial $f(t)$ into the benchmark model (Moser & Voena, 2012; Wooldridge, 2015, p.332). The new regression model is

$$\text{Trade}^j_{i,t} = \beta^j_0 + \beta^j_1 \text{Pollution}_{i,t} + \beta^j_2 \text{WP}_{i,t} + \mathbf{S}' \cdot \mathbb{Z}^j + f(t) + \nu^j_i + \lambda^j_t + \varepsilon^j_{i,t}, \tag{35}$$

where $f(t)$ is a cubic polynomial with respect to t; if year is 1995 then $t = 1$, and so on. The other case is that the control variables contain a systematic time trend. Referring to Li et al. (2016), we eliminate the possible time trend of all control variables in the following regression model (36):

$$\text{Trade}^j_{i,t} = \beta^j_0 + \beta^j_1 \text{Pollution}_{i,t} + \beta^j_2 \text{WP}_{i,t} + \mathbf{S}' \cdot (\text{T} \times \mathbb{Z}^j) + \nu^j_i + \lambda^j_t + \varepsilon^j_{i,t}. \tag{36}$$

In Table 8, Columns (i) to (iii) show that the coefficients are consistent with the baseline results, with only minor changes in the standard errors. This means that the time trend of unobserved confounding factors does not substantially interfere with the baseline findings. Furthermore, similar results appear in Columns (iv) to (vi) after adding the interaction terms of control variables and T. The rising $PM_{2.5}$ concentration in a country still significantly boosts its exports and net exports of air purifiers. In other words, the potential time trends of unobserved confounding factors and control variables pose a negligible threat to the benchmark regression results. The results of the HME remain robust and credible.

Table 8 here

4.3 Placebo and instrumental variable tests

To further verify the validity of the benchmark findings, we conduct placebo tests with several household appliances and emerging electronics. We also construct two instrumental variables to eliminate the possible endogeneity caused by unobservable confounding factors.

4.3.1 Placebo tests

The foregoing results indicate a positive correlation between $PM_{2.5}$ concentration and the export of air purifiers, but this relationship may be accidental. In other words, there could be other concurrent events that influence the purchase of air purifiers and ultimately drive this result. To rule out this possibility, placebo tests are conducted.

The first approach is to replace the trade value of air purifiers with that of household appliances as the dependent variable. As shown in Table H.1 of Appendix H, products with a 4-digit HS code are selected as placebos, e.g., air conditioners (HS 8415), washing machines (HS 8450) and televisions (HS 8528). Moreover, two specific products with a 6-digit HS code, window or wall air conditioners (HS 841510) and color televisions (HS 852810/852812/852872), are also used in placebos tests. These appliances are similar to air purifiers in that they are subject to large demand elasticity. The crucial difference is that they have little to do with changes in ambient particulate matter, as opposed to air purifiers, and their demand is more likely influenced by household disposable income. The above characteristics suggest that these appliances are suitable placebos. Columns (i) to (xv) of Table H.1 show that the trade of the above products, whether exports or net exports, is not significantly correlated with $PM_{2.5}$.

The second idea is to utilize emerging electronics as placebos, including tablets, robot vacuum cleaners and their parts, smartwatches, wireless headphones, capacitive screens for smartphones, digital music players, as shown in Table H.2 of Appendix H. The distinguishing feature of these electronics is their similarity to air purifiers in terms of market dynamics. As "new products," they mainly emerged in the last one or two decades and experienced a substantial increase in sales. Across all columns of Table H.2, no significant evidence is found to support that $PM_{2.5}$ concentration drives the export and net export growth of these emerging electronics.

The aforementioned insignificant estimated coefficients indicate that the benchmark findings are not affected by concurrent events. Moreover, the results validate that the growing $PM_{2.5}$ concentration (environmental demand) does indeed improve the domestic exports and net exports of air purifiers.

4.3.2 Instrumental variable approach

To address the potential endogeneity issue in the baseline results, we also adopt the instrumental variable (IV) approach. Referring to Acemoglu & Linn (2004) and Costinot et al. (2019), we construct a relatively exogenous instrumental variable, i.e., the predicted environmental health risk (PEHR). The key feature is that the differences in environmental health risk across ages and genders are combined with temporal changes in demographic characteristics driven by exogenous factors.

Specifically, $\mathrm{PEHR}_{i,t}$ is represented by two specific indicators: one is $\mathrm{IVD}_{i,t}$ (the absolute indicator), derived from DEATH as given by (37); the other is $\mathrm{IVPD}_{i,t}$ (the relative indicator), derived from PDEATH as given by (38):

$$\mathrm{IVD}_{i,t} = \sum_a \sum_g [\mathrm{DEATH}_{i,a,g,t_0} \cdot (1 + \mathrm{G}_{i,a,g,t})], \tag{37}$$

$$\mathrm{IVPD}_{i,t} = \frac{1}{6} \sum_a \sum_g [\mathrm{PDEATH}_{i,a,g,t_0} \cdot (1 + \mathrm{G}_{i,a,g,t})], \tag{38}$$

$$\mathrm{PEHR}_{i,t} = \{\mathrm{IVD}_{i,t}, \mathrm{IVPD}_{i,t}\},$$

where $\mathrm{DEATH}_{i,a,g,t_0}$ refers to the total premature deaths of country i, age group a, and gender g in the base year t_0, implying that it is time-invariant. $\mathrm{G}_{i,a,g,t}$ represents the population growth rate of country i, for age group a and gender g in year t, relative to base year. The base year is set as 1995 based on the dataset in Section 3.1, and age a is divided into three groups, i.e., less than 15, 15 to 64, and more than 64 years old, while gender g includes female and male. Thus, $\text{DEATH}_{i,a,g,t_0} \cdot (1 + \text{G}_{i,a,g,t})$ represents the change over time in total premature deaths caused by exogenous demographic changes. After summing up the age and gender dimensions, $\text{IVD}_{i,t}$ is finally obtained.

Compared with (37), the prominent difference is that $\text{IVPD}_{i,t}$ in (38) is a relative indicator, so a constant is added on the right-hand side to calculate the mean of age groups (3 types) and genders (2 types), i.e., $1/6 = 1/3 \times 1/2$. Likewise, $\text{PDEATH}_{i,a,g,t_0}$ is the per million preature deaths of country i, age group a and gender g in year t_0. Other settings remain the same. Again, the environmental health risks (DEATH, PDEATH) data are derived from the OECD statistics and demographic data from the World Bank database.

For a valid IV, two basic assumptions need to be satisfied (Angrist & Pischke, 2008, p.85): one is a strong correlation with the core independent variable (possible endogenous), and the other is not directly related to the dependent variable ($\text{Trade}^j_{i,t}$). We consider $\text{PEHR}_{i,t}$ to be a valid IV for the following reasons. First, $\text{PEHR}_{i,t}$ is positively correlated with the core independent variable, $\text{Pollution}_{i,t}$. This is derived from the significant correlation between environmental health risks (DEATH, PDEATH) and $\text{PM}_{2.5}$, as illustrated in Section 3.1.2 and Figure E.1. Second, only the base year of environmental health risks is included in the construction of $\text{PEHR}_{i,t}$ (i.e., $\text{IVD}_{i,t}$ and $\text{IVPD}_{i,t}$), thereby avoiding the endogenous interference of time-varying confounding factors on the IV. Third, the population growth rate $\text{G}_{i,a,g,t}$ of various age groups and genders ensures the exogeneity of $\text{PEHR}_{i,t}$, i.e., not directly related to the dependent variable $\text{Trade}^j_{i,t}$. In (37) and (38), the temporal variation of $\text{PEHR}_{i,t}$ mainly depends on demographic changes.

Empirically, we built a two-stage least squares (2SLS) estimation model by using $\text{PEHR}_{i,t}$ as the instrumental variable. In the first stage, we conduct a regression of the core explanatory variable ($\text{Pollution}_{i,t}$) on the instrumental variable ($\text{PEHR}_{i,t}$), and the model is

$$\text{Pollution}_{i,t} = \gamma_0 + \gamma_1 \text{PEHR}_{i,t} + \gamma_2 \text{WP}_{i,t} + \mathbf{S}'\mathbb{Z} + \nu_i + \lambda_t + \varepsilon_{i,t}, \tag{39}$$

where $\text{WP}_{i,t}$, $\mathbf{S}', \mathbb{Z}$ and other settings are the same as in the benchmark model (32).

In the second stage, the estimated value $\widehat{\text{Pollution}}_{i,t}$, obtained from (39), is substituted into (32) for regression. The new model is

$$\text{Trade}^j_{i,t} = \beta^j_0 + \beta^j_1 \widehat{\text{Pollution}}_{\text{i,t}} + \beta^j_2 \text{WP}_{i,t} + \mathbf{S}'\mathbb{Z}^j + \nu^j_i + \lambda^j_i + \varepsilon^j_{i,t}. \tag{40}$$

Table I.1 of Appendix I reports the 2SLS regression results. Specifically, in both Panels A and B, Column (i) suggests that the instrumental variables, i.e., IVD and IVPD, are significantly positively correlated with $\text{PM}_{2.5}$. In Columns (ii) and (iv), the second stage estimates show that the higher $\text{PM}_{2.5}$ concentration, the more exports and net export of air purifiers, but the less significant import. Remarkably, the estimated coefficient of $\ln\text{PM}_{2.5}$ using the 2SLS method in Table I.1 is greater than that by the ordinary least squares (OLS) method in Table 2.[10] However, at least the two regression methods can

[10]There are several possible explanations for this phenomenon (Card, 2001). On the one hand, the IV approach estimates the local average treatment effect, while OLS estimates the global one. If the estimated individuals are heterogeneous, the IV will positively deviate from the OLS estimate. On the other hand, negatively omitted variables will also cause the OLS estimate to deviate downwards. Nevertheless, the OLS regression results can be regarded as conservative estimates of the impact of $\ln\text{PM}_{2.5}$ on air purifier exports and net exports.

reach a consensus that an increase in $PM_{2.5}$ does lead to an increase in the exports of air purifiers, which is greater than the variation in imports. In other words, the IV approach reconfirms the existence of the HME in the environmental sector.

4.4 Sensitivity

In this section, we assess the sensitivity of the HME to some crucial factors that, to some extent, modulate the magnitude.

4.4.1 Resident income

In previous theoretical studies, the final influence of growing resident income is ambiguous. Specifically, if the residents' income is driven by rising wages, it may not only weaken the price advantage of domestic products (negative effect), but also expand the scale of the domestic market (positive effect). However, Takatsuka & Zeng (2012a,b) argue that including capital gains may enlarge the benefits of market expansion and reduce the effect of price differences. In any case, the ultimate impact of residents' income on the HME needs to be tested empirically. Therefore, we further introduce the interaction term $\ln PM_{2.5} \times \ln PCGDP$ into the baseline model (32) to evaluate how resident income affects the magnitude of the HME.

In Columns (i) and (iii) of Table 9, the results suggest that with a higher income level, $PM_{2.5}$ has a higher positive impact on exports, imports, and net exports of air purifiers. In particular, the positive contribution of income level to the relationship between $PM_{2.5}$ and exports is much greater than that between $PM_{2.5}$ and imports. Above all, the domestic residential income can enhance both the strong and weak HMEs in the environmental sector.

Table 9 here

4.4.2 Productivity level

In the theoretical part, we assume that productivity is differentiated between different countries. From the empirical perspective, we will further explore how the productivity in a country affects the magnitude of the HME. Total factor productivity (TFP), as a manifestation of technological progress in a country, is frequently utilized to reflect its productivity level. Similarly, we add an interaction term, $\ln PM_{2.5} \times TFP$, to the baseline estimation model (32). The results are shown in Columns (iv) to (vi) of Table 9.

Column (iv) shows that a higher TFP level significantly improves the effects of $PM_{2.5}$ on the exports and net exports of air purifiers. In contrast, a high or low TFP level does not significantly affect the relationship between $PM_{2.5}$ and the imports of air purifiers. The results indicate that the productivity level in a country can also significantly promote the magnitude of the HME. One explanation is that countries with higher productivity foster more agglomeration activities (Tabuchi et al., 2018).

4.5 Generality

Is the HME in terms of trade pattern ubiquitous in sub-environmental sectors? In other words, is the HME limited to specific goods, such as air purifiers? To answer this question, we construct a new dataset for regression estimation with three dimensions of "country–year–product," comprising 238 environment-related products that fall into 11 different categories of sub-environment industries.[11] Our definition of sub-environmental industries is based on different environmental media, and its classification criteria are derived from the OECD statistics. We examine the general relationship between air pollution and the trade of environment-related products from the perspective of sub-environmental industries and the whole. In particular, we further incorporate the product fixed effect into the baseline model (32) to control the product-varying confounding factors.

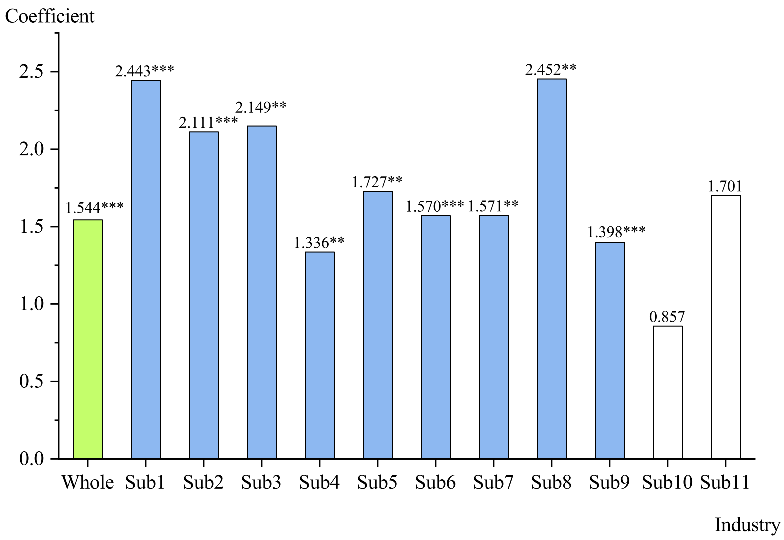


FIGURE 3 The coefficients of lnExvalue to $\ln PM_{2.5}$ in different sub-industries
Notes: "The whole" refers to the environmental industry, including 238 environment-related products. The definition of each sub-environmental industry is as follows: Sub1 – air pollution control; Sub2 – environmental monitoring, analysis and assessment equipment; Sub3 – environmentally preferable products based on end-use or disposal characteristics; Sub4 – heat and energy management; Sub5 – noise abatement; Sub6 – renewable energy plant; Sub7 – solid and waste management; Sub8 – soil and water remediation; Sub9 – wastewater management; Sub10 – cleaner or more resource-efficient technologies and products; Sub11 – natural resource protection.

For the whole environmental industry, Columns (i) to (iii) of Table J.1 in Appendix J show that the rising $PM_{2.5}$ concentration leads to a significant increase in exports and net exports, while imports do not. It is consistent with Table 2, implying the (strong) HME. As shown in Figure 3, we find the (strong) HME in 9 of 11 sub-industries, accounting

[11]According to the OECD Statistics classification criteria, there are 255 environment-related products belonging to different environmental media. We select 238 of these products and add them to the sub-environmental industries and the whole. The remaining 17 products are removed because of missing data.

for 81.8% of the total, indicating that the HME is not a special phenomenon; on the contrary, it exists universally in most sub-environmental sectors. Considering that these sub-industries have different correlations with air pollution due to environmental media, we discuss the regression results separately.

First, and most directly, $PM_{2.5}$ is positively correlated with the export of the air pollution control industry (Sub1). Columns (iv) to (vi) of Table J.1 show that for a 1% increase in $PM_{2.5}$ concentration, the export and net export of products in this sub-industry go up by 2.443% and 1.784% on average, respectively. The possible explanation is that the rising $PM_{2.5}$ leads to more defensive investments in air pollution control products, typically air purifiers.

Second, air pollution also positively affects the trade of supporting industries, such as environmental equipment (Sub2) and environmentally preferable products (Sub3). Specifically, Columns (vii) to (xii) show that the exports in Sub2 and Sub3 increase significantly with $PM_{2.5}$, more strongly than imports. The possible explanation is that deteriorating air quality, on the one hand, raises the demand of relevant authorities and NGOs for environment monitoring, analysis, and assessment; on the other hand, it profoundly affects consumers' purchasing behavior regarding environmental products based on end-use or disposal characteristics.

Third, air pollution is also positively correlated with the exports of most other sub-environmental industries that are non-air-pollution media (from Sub4 to Sub9). For example, there are significant strong HMEs in noise-related products, wastewater-related products, as shown in Figure 3 and with more details in Appendix I. This may be because various environmental problems are not independent. Countries with severe air pollution often also have poor water quality, massive solid waste, ecological destruction, or inefficient energy management.[12]

Overall, we can confirm that the HME in terms of trade pattern exists in the environmental sector, which is a general conclusion not affected by the selected product. We emphasize that countries with greater home demand will turn out to be net exporters of environmental products.

5 TRADE COSTS ANALYSIS

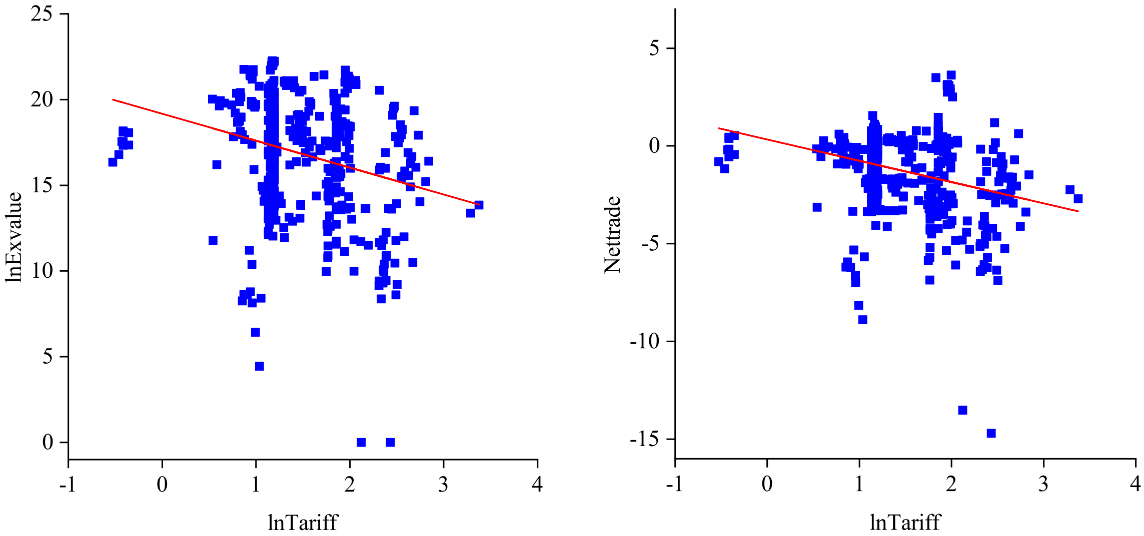
In the theoretical part, we demonstrate that trade costs profoundly affect the trade pattern. In this section, by using import tariffs to characterize trade costs, we empirically reexamine the impact of trade costs on trade and the SME.

5.1 The effect of trade costs on trade

For visualization, we preliminarily depict the scatter diagrams of the correlation between air purifier trade and import tariffs. Figure 4 shows that the exports and net export

[12]In the sub-industries of "cleaner or more resource efficient technologies and products" (Sub10) and "natural resources protection" (Sub11), we do not find similarly significant results. The possible reason is that green technologies are subject to more confounding factors, while resources conservation is relatively dependent on pollution issues.

of air purifiers are strongly negatively related to import tariffs, i.e., positively related to trade freeness (ϕ). It suggests that trade costs, as represented by tariffs, may have some influence on the trade pattern of environmental goods.



(a) Exports and tariffs (b) Nettrade and tariffs

FIGURE 4 The correlation between air purifiers trade and import tariffs
Notes: For comparison purposes, we carry out logarithmic processing on the export and net export values of air purifiers and on tariffs. The solid lines in the subfigures are fitted trend lines.

We construct a new model to estimate the impacts of tariffs on air purifiers trade by adding terms of $\text{Pollution}_{i,t}$ and $\text{WP}_{i,t}$ to isolate the interference of domestic and foreign environmental demand as follows:

$$\text{Trade}^j_{i,t} = \alpha^j_0 + \alpha^j_1 \text{Tariff}_{i,t} + \alpha^j_2 \text{Pollution}_{i,t} + \alpha^j_3 \text{WP}_{i,t} + \mathbf{S}' \cdot \mathbb{Z}^j + \nu^j_i + \lambda^j_t + \varepsilon^j_{i,t}. \quad (41)$$

In addition, we further introduce a cross-term, Dping×Pollution, to model (41) for country heterogeneity analysis. The new estimated model is

$$\begin{aligned}\text{Trade}^j_{i,t} = &\alpha^j_0 + \alpha^j_1 \text{Dping} \cdot \text{Pollution}_{i,t} + \alpha^j_2 \text{Tariff}_{i,t} + \alpha^j_3 \text{Pollution}_{i,t} + \alpha^j_4 \text{WP}_{i,t} \\ &+ \mathbf{S}' \cdot \mathbb{Z}^j + \nu^j_i + \lambda^j_t + \varepsilon^j_{i,t},\end{aligned} \quad (42)$$

where Dping_i refers to a dummy variable for developing countries (Dping $= 1$ if country i is developing, and 0 otherwise). The single term Dping is eliminated due to complete multicollinearity.

In Columns (i) to (iii) of Table 10, we perform pooled regressions for all sample countries. Specifically, Panel A shows that no significant impact of tariffs on exports, imports and net exports of air purifiers is observed. Even in Panel B, where we further separate the domestic and foreign environmental demand, the result remains the same. Since the impacts of tariffs (or trade costs) on air purifier trade in developing and developed countries are strikingly different, the overall effect is possibly offset in the mixed sample.

Table 10 here

In fact, in the theoretical part of Section 2.3, the curves EX_1 and NE_1 in interior equilibrium are distinctly different in the cases of $w < 1$ and $w \geq 1$. Therefore, we need to further explore the inter-country heterogeneity of the impact of trade costs. In particular, according to Hanson & Xiang (2004) and Footnote 2 of this paper, the environmental industry has a relative high elasticity of substitution, suggesting that the relationship between trade pattern and trade cost might be more consistent with Figure B.2 when country 1 is a developing country (i.e., $w < 1$ and large σ).

The empirical results indeed support the theoretical analysis for developing countries (i.e., $w < 1$) in Section 2.3 and the simulations of Figure B.2. Columns (iv) and (vi) of both Panels A and B show that higher import tariffs in developing countries (i.e., $\tau \uparrow$, $\phi \downarrow$) cause their exports and net exports of air purifiers to drop significantly, compared to those in developed countries.[13] However, Column (v) shows that the decrease in imports caused by increasing tariffs is much smaller than that of exports and net exports, i.e., $0.627\% < 1.859\% < 2.486\%$. We can infer that in developing countries, higher import tariffs do not substantially impede imports from abroad but rather harm their own exports more. From this result, tariff reduction in developing countries may improve exports and promote their trade status in environmental products.

Overall, this section shows the different impacts of tariffs on developing countries ($w < 1$) and developed countries ($w \geq 1$). Freer trade (tariff cutting) is conducive to developing countries and global trade, while exorbitant trade liberalization has an adverse side effect on developed countries. Our findings are consistent with Proposition 2.

5.2 Test for the SME

Proposition 3 theoretically supports the existence of the strong SME. To empirically estimate the effect of tariffs on the HME, we introduce a cross term, $\text{Pollution}_{i,t} \times \text{Tariff}_{i,t}$, into (41). This interaction term refers to the role of tariffs in moderating the causal relationship between air pollution and trade. The model is as follows:

$$\begin{aligned}\text{Trade}^j_{i,t} =& \alpha^j_0 + \alpha^j_1 \text{Pollution}_{i,t} \times \text{Tariff}_{i,t} + \alpha^j_2 \text{Tariff}_{i,t} + \alpha^j_3 \text{Pollution}_{i,t} \\ &+ \alpha^j_4 \text{WP}_{i,t} + \mathbf{S}' \cdot \mathbb{Z}^j + \nu^j_i + \lambda^j_t + \varepsilon^j_{i,t}.\end{aligned} \tag{43}$$

In addition, for the heterogeneity comparison at the country level, we further introduce a cubic interaction term, $\text{Pollution}_{i,t} \times \text{Tariff}_{i,t} \times \text{Dping}_i$. The new model is

$$\begin{aligned}\text{Trade}^j_{i,t} =& \alpha^j_0 + \alpha^j_1 \text{Pollution}_{i,t} \times \text{Tariff}_{i,t} \times \text{Dping}_i + \alpha^j_2 \text{Pollution}_{i,t} \times \text{Tariff}_{i,t} \\ &+ \alpha^j_3 \text{Tariff}_{i,t} + \alpha^j_4 \text{Pollution}_{i,t} + \alpha^j_5 \text{WP}_{i,t} + \mathbf{S}' \cdot \mathbb{Z}^j + \nu^j_i + \lambda^j_t + \varepsilon^j_{i,t},\end{aligned} \tag{44}$$

where the single term Dping is eliminated due to complete multicollinearity.

[13] In accordance with the IMF's classification criteria, we classify 19 countries as developing countries (also known as "Emerging and Developing Economies") and the remaining 27 as developed countries (also known as "Advanced Economies"). `https://www.imf.org/external/pubs/ft/weo/2020/01/weodata/groups.htm`.

Columns (i) to (iii) of Table 11 summarize the SME of tariffs in all the sample countries. Specifically, Column (i), estimated by model (43), suggests that for a 1 % tariff reduction, the positive impact of environmental demand on exports (the HME) goes up by 0.846%. It can be inferred that lowering tariffs ($\phi \uparrow$) would significantly enhance the (weak) HME, which is known as the weak SME. Furthermore, we find that lowering tariffs also increases the effect of demand on imports, but to a lesser extent than that on exports (0.396% < 0.846%). One explanation is that lower trade costs can foster stronger industrial agglomeration force (Ottaviano et al., 2002; Tabuchi & Thisse, 2006). In other words, cutting tariffs would strengthen the final positive effect of environmental demand on net exports, known as the strong SME. The result of Column (iii) also supports this finding. Thus, in the worldwide economy, lowering tariffs ($\phi \uparrow$) can enhance the (strong/weak) HME, which is consistent with the overall trend in Figures C.1 and C.2.

Table 11 here

Furthermore, Columns (iv) to (vi) of Table 11 reflect the heterogeneity of SMEs across different countries, as indicated by (44). Column (iv) indicates that compared with developed countries, the SME in developing countries is 1.095% higher. Similarly, Column (vi) also provides significant support for the SME. Similar evidence is found in the case of developing countries in the theoretical part of Figures C.2(b) and (d), where the vertical axis value is distinctly higher than that of developed countries in Figures C.1(b) and (d).

Overall, the above results provide empirical evidence for the strong SME. The lower the tariffs (the higher the trade freeness), the larger the strong HME. These results support Proposition 3, as well as Figures C.1 and C.2. Thus, for countries with greater environmental home demand, lowering tariffs and improving trade freeness may be a reasonable choice to improve their trade status with regard to environmental products.

6 CONCLUSION

This paper theoretically and empirically examines the Linder conjecture (the home market effect in terms of trade pattern) in the environmental sector and analyzes the role of trade costs in trade and the magnitude of the HME.

In the general equilibrium structure, we establish a two-country, two-sector model to examine the magnitude of the HME in terms of trade pattern. We allow heterogeneous productivity across countries in the homogeneous composited sector so that the wage rates in the two countries may be different. First, we find that in the interior equilibrium, both the exports and the net exports of a country increase with its domestic demand (i.e., the strong and weak HMEs). Second, the impact of trade costs on the trade pattern depends on wage rates. For developing countries, lower trade costs (freer trade) lead to more exports and net exports. For developed countries, however, the impact of trade costs is ambiguous. In particular, we find that even small countries are likely to become net exporters rather than net importers as predicted in previous studies. Third, we find that the strong HMEs in both developing and developed countries are monotonically positively related to trade freeness (or negatively related to trade costs), which is the strong SME.

In the empirical estimation, we further provide supporting evidence for the strong HME in the environmental sector. We take air purifiers as a typical environmental products and the $PM_{2.5}$ concentration as the environmental demand shifter. By using a dataset of air purifier trade and $PM_{2.5}$ concentration from 46 major economies, we first find that for every 1% increase in $PM_{2.5}$, exports and net exports of air purifiers go up by 4.337% and 3.835%, respectively. This significantly supports the existence of the strong HME in the environmental sector.

This baseline finding is robustly confirmed by various approaches: considering the population exposed to pollution, replacing the pollutant emission indicators, excluding special observations, stripping off growing manufacturing capacity, and conducting detrending analysis. Furthermore, the placebo and IV tests prove that this conclusion is not coincidental. Second, the sensitivity checks show that the (strong) HME is highly positively correlated with urban population size and residential income level. Third, through a generalized analysis, the HME is observed in the whole environmental industry as well as in most of its sub-industries, based on 238 environment-related goods.

Furthermore, we empirically explore how trade costs (represented by import tariffs) affect the trade pattern of environmental goods and the SME. The results show that lower tariffs (higher trade liberalization) do not cause de-industrialization in developing countries but rather improve their exports and net exports of environmental goods. In contrast, lower tariffs do not have a significant positive impact on developed countries. Finally, we find that a strong SME of lower tariffs on the HME exists and is larger in developing countries.

Overall, some implications can be highlighted by our main conclusions. On the one hand, it is reiterated that this paper is absolutely not an exhortation to countries to pollute more in order to export more. On the contrary, the HME provides an opportunity for high-polluting countries to upgrade their traditional manufacturing toward a cleaner and more environmentally friendly economy. With a larger home demand for environmental products, a more-than-proportionate share of environmental industries may locate in these countries. What the governments need to do is to renovate their industrial policies, eliminating those high-pollution and energy-intensive industries to make room for the expansion of emerging environmentally-friendly industries. This strategy is well-known as "vacating the cage to change birds" (Yang, 2012; Yin et al., 2017).

On the other hand, the strong SME in developing countries indicates that increasing trade freeness or lowering trade costs, instead of employing a trade barrier, may be a wise way to improve their trade status in the environmental sector, at least for a developing and high-pollution country. Trade liberalization is still relevant for reducing international division and optimizing the allocation of resources. All of these implications are worth further pondering in the future.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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TABLE 1 Percentage of differentiated $PM_{2.5}$ concentration by year

Year	$<10\mu g/m^3$	$10\sim15\mu g/m^3$	$15\sim25\mu g/m^3$	$25\sim35\mu g/m^3$	$>35\mu g/m^3$
1995	17.4%	21.7%	47.8%	6.5%	6.5%
2000	17.4%	30.4%	34.8%	10.9%	6.5%
2005	19.6%	28.3%	34.8%	10.9%	6.5%
2010	19.6%	23.9%	39.1%	10.9%	6.5%
2011	17.4%	30.4%	34.8%	10.9%	6.5%
2012	21.7%	30.4%	30.4%	10.9%	6.5%
2013	23.9%	30.4%	30.4%	8.7%	6.5%
2014	26.1%	30.4%	30.4%	6.5%	6.5%
2015	26.1%	30.4%	30.4%	6.5%	6.5%
2016	28.3%	32.6%	26.1%	6.5%	6.5%
2017	28.3%	32.6%	26.1%	6.5%	6.5%
Total	22.3%	29.2%	33.2%	8.7%	6.5%

Notes: The differentiated $PM_{2.5}$ concentrations are divided into five intervals: <10, 10∼15, 15∼25, 25∼35, and $>35\mu g/m^3$. The percentage represents the number of samples within a certain $PM_{2.5}$ interval divided by the total number of samples for that year.

TABLE 2 Estimation of the relationship between $PM_{2.5}$ and trade

	lnExvalue			lnImvalue			Nettrade		
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
$\ln PM_{2.5}$	5.951***	4.477**	4.337**	1.731*	0.635	0.502	4.220**	3.841**	3.835*
	(1.751)	(1.666)	(1.715)	(0.992)	(0.716)	(0.794)	(1.621)	(1.821)	(1.952)
$\ln WPM_{2.5}$			-2.813			-2.684			-0.129
			(8.064)			(3.007)			(7.666)
lnPCGDP		1.931***	1.924***		1.437***	1.430***		0.494	0.494
		(0.563)	(0.568)		(0.223)	(0.224)		(0.518)	(0.524)
lnAVH		-3.395	-3.412		3.140***	3.123***		-6.535	-6.536
		(4.439)	(4.426)		(1.026)	(1.021)		(4.257)	(4.253)
TFP		-2.768*	-2.771*		-0.057	-0.060		-2.711*	-2.711*
		(1.576)	(1.575)		(0.529)	(0.529)		(1.516)	(1.516)
lnWPCGDP		2.501	1.797		12.568***	11.897***		-10.067**	-10.100*
		(4.120)	(4.782)		(2.144)	(2.547)		(4.154)	(5.248)
Year fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	501	499	499	501	499	499	501	499	499
Adjusted R^2	0.908	0.915	0.915	0.936	0.957	0.957	0.766	0.773	0.772

Notes: Columns (i) to (ix) report the estimated results of (32). Standard errors are clustered at the country level and reported in parentheses below the coefficients. *, **, and *** indicate a significance level of 10%, 5%, and 1%, respectively. Both the year fixed effect and country fixed effect are considered in every column.

TABLE 3 Robustness test I: the population exposed to excessive $PM_{2.5}$

	PMPOP			PMMT		
	lnExvalue (i)	lnImvalue (ii)	Nettrade (iii)	lnExvalue (iv)	lnImvalue (v)	Nettrade (vi)
lnPMPOP	0.345***	0.102***	0.243***			
	(0.082)	(0.027)	(0.085)			
lnWPMPOP	-13.911	4.953	-18.864			
	(28.325)	(8.349)	(25.581)			
PPMT				0.028***	0.003	0.025***
				(0.008)	(0.003)	(0.009)
WPPMT				0.098	0.046	0.052
				(0.298)	(0.125)	(0.288)
Control var.	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Observations	485	485	485	499	499	499
Adjusted R^2	0.915	0.957	0.769	0.917	0.957	0.776

Notes: PMPOP and WMPOP refer to the domestic population and the total foreign population exposed to excessive $PM_{2.5}$ ($\geq 10\mu g/m^3$), respectively. PPMT represents the proportion of the polluted population among the total domestic population, and WPPMT is the proportion of the polluted foreign population in the remaining world population. Clustered standard errors at the country level are reported in parentheses below the estimates. *, **, and *** indicate a significance level of 10%, 5%, and 1%, respectively.

TABLE 4 Robustness test II: the pollutant emission indicators

	Indicator 1: $PM_{2.5}$ by fossils			Indicator 2: NH_3		
	lnExvalue (i)	lnImvalue (ii)	Nettrade (iii)	lnExvalue (iv)	lnImvalue (v)	Nettrade (vi)
$\ln PM_{2.5}fos$	0.933***	0.123	0.819**			
	(0.331)	(0.164)	(0.337)			
$\ln WPM_{2.5}fos$	-11.461***	-7.924***	-3.483			
	(3.882)	(2.121)	(3.159)			
$\ln NH_3$				1.102*	-0.217	1.328**
				(0.608)	(0.264)	(0.568)
$\ln WNH_3$				-36.698**	-19.959***	-16.647
				(15.006)	(6.900)	(15.584)
Control var.	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Observations	808	812	808	808	812	808
Adjusted R^2	0.930	0.945	0.789	0.929	0.944	0.789

Notes: The two pollution indicators from 1995 to 2012 are emission statistics rather than air quality indices. $\ln WPM_{2.5}fos$ and $\ln WNH_3$ refer to the total world remaining emissions excluding the home country. Clustered standard errors are reported in parentheses below the estimates. *, **, and *** indicate a significance level of 10%, 5%, and 1%, respectively.

TABLE 5 Robust III: non-market environmental policy and Google Trends

	Non-market environmental policy			G oogle Trends & Baidu Index: $PM_{2.5}$		
	lnExvalue (i)	lnImvalue (ii)	Nettrade (iii)	lnExvalue (iv)	lnImvalue (v)	Nettrade (vi)
lnNMEP	0.526**	-0.087	0.613**			
	(0.238)	(0.183)	(0.301)			
lnWNMEP	23.690*	-5.221	28.911*			
	(11.827)	(9.871)	(14.449)			
lnGT-$PM_{2.5}$				2.208**	-0.433	2.641*
				(0.904)	(0.672)	(1.424)
lnWGT-$PM_{2.5}$				0.976**	0.226	0.751
				(0.457)	(0.347)	(0.654)
Control var.	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Observations	379	379	379	411	411	411
Adjusted R^2	0.947	0.959	0.827	0.966	0.964	0.900

Notes: lnNMEP and lnWNMEP refer to the logarithm of the reciprocal of the non-market based environmental policy stringency index for a country and the world remaining, respectively. lnGT-$PM_{2.5}$ and lnWGT-$PM_{2.5}$ represent the logarithm of Google Trends and Baidu Index data related to the keyword "$PM_{2.5}$" for a country and the world remaining. Standard errors in parentheses are clustered at the country level. *, **, and *** represent a significance level of 10%, 5%, and 1%, respectively.

TABLE 6 Robust IV: the effects decomposition of domestic and industrial air purifiers

	Household air purifier			Industrial air purifier		
	lnExvalue-H (i)	lnImvalue-H (ii)	Nettrade-H (iii)	lnExvalue-I (iv)	lnImvalue-I (v)	Nettrade-I (vi)
Panel A: decomposed by the relative share of industries						
ln$PM_{2.5}$	3.495**	0.760	2.735*	0.854	-0.422	1.276*
	(1.588)	(0.674)	(1.427)	(0.706)	(0.862)	(0.688)
lnW$PM_{2.5}$	7.806	7.598	0.207	-10.364***	-12.015**	1.651
	(10.006)	(5.929)	(5.555)	(3.578)	(4.478)	(2.095)
Observations	494	494	494	494	494	494
Adjusted R^2	0.928	0.947	0.793	0.920	0.933	0.700
Panel B: decomposed by the Google Trends index						
ln$PM_{2.5}$	3.250*	1.626	1.624	-1.959	-1.604	-0.355
	(1.700)	(1.319)	(1.173)	(1.528)	(1.337)	(0.311)
lnW$PM_{2.5}$	10.244	7.093	3.151	-10.425*	-7.939	-2.486***
	(8.842)	(6.434)	(9.632)	(5.352)	(5.295)	(0.890)
Observations	413	413	413	413	413	413
Adjusted R^2	0.912	0.824	0.902	0.696	0.683	0.538

Notes: lnExvalue-H, lnImvalue-H, and Nettrade-H represent the logarithm of export value, import value, and net trade value, respectively, for household air purifiers. Similarly, lnExvalue-I, lnImvalue-I, and Nettrade-I represent the logarithm of those indicators for industrial air purifiers. Standard errors in parentheses are clustered at the country level. *, **, and *** represent a significance level of 10%, 5%, and 1%, respectively.

TABLE 7 Robust V: special countries and growing manufacturing capacity

	Exclude special observations			Relative share		
	lnExvalue	lnImvalue	Nettrade	lnREX	lnRIM	lnRNE
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
$\ln PM_{2.5}$	4.594***	0.829	3.765*	2.292*	0.015	2.330
	(1.594)	(1.043)	(1.892)	(1.198)	(0.701)	(1.453)
$\ln WPM_{2.5}$	232.845	158.755*	74.090	-2.760	1.941	-4.531
	(164.544)	(87.783)	(179.242)	(6.577)	(2.316)	(7.514)
Control var.	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Observations	477	477	477	497	499	497
Adjusted R^2	0.914	0.956	0.772	0.871	0.751	0.826

Notes: Columns (i) to (iii) present the results of re-estimation that excluding India and China. The dependent variables in Columns (iv) to (vi) are replaced with lnREX, lnRIM, and lnRNE, respectively, which represent the share of air purifiers in domestic merchandise trade. Standard errors in parentheses are clustered at the country level. *, **, and *** represent a significance level of 10%, 5%, and 1%, respectively.

TABLE 8 Robustness test VI: Time detrending analysis

	Detrend 1: $f(t)$			Detrend 2: Control × T		
	lnExvalue	lnImvalue	Nettrade	lnExvalue	lnImvalue	Nettrade
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
$\ln PM_{2.5}$	4.337**	0.502	3.835*	3.768**	0.294	3.474**
	(1.801)	(0.833)	(2.050)	(1.859)	(1.123)	(1.712)
$\ln WPM_{2.5}$	-2.813	-2.684	-0.129	5.741	-1.142	6.883
	(8.469)	(3.158)	(8.051)	(6.579)	(5.173)	(5.075)
$f(t)$	Yes	Yes	Yes			
Control var.	Yes	Yes	Yes			
Control×T				Yes	Yes	Yes
Year fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Observations	499	499	499	499	499	499
Adjusted R^2	0.915	0.957	0.773	0.913	0.940	0.774

Notes: Columns (i) to (iii) are estimated using equation (35), while Columns (iv) to (vi) are derived from equation (36). Clustered standard errors are reported in parentheses below the estimates. *, **, and *** indicate a 10%, 5%, and 1% significance level, respectively.

TABLE 9 Sensitivity to resident income and productivity level

	Resident income			Productivity level		
	lnExvalue (i)	lnImvalue (ii)	Nettrade (iii)	lnExvalue (iv)	lnImvalue (v)	Nettrade (vi)
$\ln PM_{2.5} \times \ln PCGDP$	0.760***	0.295***	0.465*			
	(0.218)	(0.097)	(0.252)			
$\ln PM_{2.5} \times TFP$				3.628**	0.165	3.464**
				(1.360)	(0.952)	(1.551)
$\ln PM_{2.5}$	-5.056	-3.140**	-1.916	1.749	0.385	1.364
	(3.153)	(1.428)	(3.595)	(1.817)	(1.212)	(2.267)
$\ln WPM_{2.5}$	-5.207	-3.612	-1.595	-3.045	-2.694	-0.350
	(6.416)	(3.456)	(6.197)	(5.245)	(2.939)	(5.814)
Control var.	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Observations	499	499	499	499	499	499
Adjust R^2	0.918	0.958	0.775	0.916	0.956	0.774

Notes: Standard errors in parentheses are clustered at the country level. *, **, and *** represent a significance level of 10%, 5%, and 1%, respectively.

TABLE 10 The impact of tariffs on air purifier trade in differentiated countries

	All sample countries			Developing countries		
	(i) lnExvalue	(ii) lnImvalue	(iii) Nettrade	(iv) lnExvalue	(v) lnImvalue	(vi) Nettrade
Panel A: tariffs and trade						
$Dping \times \ln Tariff$				-2.644***	-0.633***	-2.011**
				(0.785)	(0.231)	(0.849)
$\ln Tariff$	-0.403	-0.099	-0.305	1.391**	0.331	1.060
	(0.438)	(0.174)	(0.365)	(0.593)	(0.203)	(0.703)
Adjust R^2	0.913	0.956	0.767	0.921	0.958	0.780
Observations	498	498	498	498	498	498
Panel B: further isolate demand effect						
$Dping \times \ln Tariff$				-2.486***	-0.627**	-1.859**
				(0.768)	(0.239)	(0.847)
$\ln Tariff$	-0.328	-0.082	-0.246	1.318**	0.333	0.986
	(0.398)	(0.166)	(0.349)	(0.581)	(0.206)	(0.695)
$\ln PM_{2.5}$	4.251**	0.483	3.768*	2.189*	-0.037	2.226
	(1.694)	(0.800)	(1.941)	(1.159)	(0.887)	(1.553)
$\ln WPM_{2.5}$	-1.693	-2.397	0.704	0.289	-1.897	2.186
	(6.756)	(2.802)	(6.979)	(4.952)	(2.710)	(5.926)
Adjust R^2	0.914	0.956	0.770	0.922	0.958	0.780
Observations	498	498	498	498	498	498

Notes: Columns (i) to (iii) present the estimated results of (41), while Columns (iv) to (vi) present the results of (42). Control variables, the constant term, the year fixed effect, and the country fixed effect are included in all columns. Standard errors in parentheses are clustered at the country level. *, **, and *** represent a significance level of 10%, 5%, and 1%, respectively.

TABLE 11 Tariffs and the SME

	All sample countries			Developing countries		
	lnExvalue (i)	lnImvalue (ii)	Nettrade (iii)	lnExvalue (iv)	lnImvalue (v)	Nettrade (vi)
$\ln PM_{2.5} \times \ln Tariff \times Developing$				-1.095**	-0.081	-1.014**
				(0.454)	(0.136)	(0.486)
$\ln PM_{2.5} \times \ln Tariff$	-0.846***	-0.396***	-0.450*	1.132	-0.244	1.376
	(0.231)	(0.104)	(0.258)	(0.811)	(0.267)	(0.869)
lnTariff	2.229***	1.114***	1.115	-1.233	0.842	-2.075
	(0.822)	(0.360)	(0.944)	(1.639)	(0.562)	(1.736)
$\ln PM_{2.5}$	4.437***	0.570	3.867**	0.319	0.309	0.010
	(1.648)	(0.852)	(1.896)	(1.660)	(0.932)	(2.004)
$\ln WPM_{2.5}$	3.548	0.056	3.493	1.243	-0.264	1.507
	(6.260)	(4.221)	(6.141)	(4.798)	(4.138)	(6.780)
Control var.	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed eff.	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Observations	498	498	498	498	498	498
Adjust R^2	0.916	0.958	0.771	0.921	0.958	0.781

Notes: Columns (i) to (iii) are estimated using equation (43), while Columns (iv) to (vi) present the results of equation (44). Clustered standard errors are reported in parentheses below the estimates. *, **, and *** indicate a 10%, 5%, and 1% significance level, respectively.