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Abstract

This article investigates the relationship between the environment-related efficiency and export performance according to the recent international trade theory which has offered to a theoretical model to quantify the Ricardian comparative advantage. We find that the energy and environmental efficiency can be a source of the comparative advantage in industries. The largest magnitude and the smallest of the efficiency on exporting are estimated to be NOx and energy efficiency, respectively. The empirical results further show that the efficiency has a smaller impact on export performance in relatively less footloose industries, and the impact of the efficiency is found to depend on industrial characteristics.

Highlight

- We model trade theory can quantify the Ricardian comparative advantage considering energy and environmental efficiency.
- We analyze the environment-related efficiency and export performance empirically.
- The result shows that the efficiency can be a source of the comparative advantage in industries.
- The efficiency has a smaller impact on export performance in relatively less footloose industries.

Keywords:

Comparative advantage, trade and environment, energy efficiency, pollution emissions per production

1 Introduction

One of the fundamental questions that drive the literature that connects international trade and the environment is whether trade flow affects environmental aspects, such as environmental quality and regulation, and vice versa. The related literature can be classified into two categories. The first set of literature focuses on whether trade liberation influences environmental quality. The second set concerns how the stringency of environmental regulation in an exporting country affects trade flow. This paper falls into the latter category, but it differs from previous empirical analyses in that we shift the focus of analysis from regulatory effects to the effects of energy efficiency.

The influence of trade on the environment depends on scale, technique, and composition effects (Grossman and Krueger, 1991)[1]. Previous empirical analyses have attempted to quantify the influence of these effects (Antweiler et al., 2001; Arce et al., 2016; Cole and Elliott, 2003; Grossman and Krueger, 1995; Managi et al., 2009; McAusland and Millimet, 2013; Meng et al., 2015). In contrast, many theoretical and empirical works have studied the impact of environmental regulation on trade flow. The discussions particularly focus on the pollution haven hypothesis[2], which claims that stringent environmental regulations induce the comparative advantage of less pollution-intensive industries because regulation imposes relatively higher costs on pollution-intensive industries (Ederington et al., 2005; Ederington and Minier, 2003; Levinson and Taylor, 2008; Managi et al., 2009). However, the empirical studies provide little consensus on the relationship between environmental regulation and trade flow.

We focus on environment-related efficiency because the impact of technology that improves environmental externalities has received little attention in the main economics literature, although many economists recognize its vital importance (Carraro et al., 2014). Hence, this paper attempts to provide further insight into the roles of resources and the environment in economic activity, particularly in trade. We analyze the relationship between the environment and trade by studying the effect on export performance of environment-related efficiencies, which are measured by energy use (energy efficiency) and pollution emissions (pollution efficiency) as units of production in the exporting country.

Our work is closely related to the literature on trade and heterogeneous productivity across industries and firms. The models in the literature show positive relationships between firm scale, capital intensity, and productivity in most countries (Bernard et al., 2003; Bernard and Jensen, 1999; Pavcnik, 2002). In these analyses, productivity plays a central role in understanding the exporting variation among domestic industries as well as among the firms in a specific industry. The productivity in these models generally refers to total factor productivity, which captures all factors except for capital and labor. We contribute to the literature by quantifying the effect of environment-related efficiency rather than the more conventionally used productivity.

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[1] Pollution emissions through trade depend on a magnitude relationship between these effects, but a basket of the three effects is generally undetermined in advance because the composition effect is thought to depend on a comparative advantage across countries.

[2] In addition, the Porter hypothesis is also discussed in the context of the impact of environmental regulations.

We follow the setup and implication of Costinot et al. (2012), hereafter CDK, which tests a Ricardian comparative advantage based on a theoretical foundation. CDK uses labor per production as productivity. We apply their framework, which connects productivity and trade flow, by replacing the labor productivity in their model with environmental efficiency measured by energy use and emission levels. We test the theoretical implications using the trade flow data and the environment-related efficiency data from the World Input-Output Database (WIOD). Our analysis indicates that the degree of energy and pollution efficiency positively affects export levels across domestic industries.

The remainder of this article is organized as follows. Section 2 reviews previous studies that consider the relationship between trade and the environment and the effect of environmental regulation on trade. Section 3 explains the empirical models and the data. Section 4 provides estimation results. Section 7 discusses the results.

2 Trade, the Environment, and Productivity

This paper attempts to connect trade, energy and pollution efficiency. There are two sets of literature that are particularly relevant to this work. One concerns the impact of the environment on trade, and the other focuses on the relationship between trading patterns and productivity. We review the implications of both sets of studies separately.

2.1 The Environment and Trade

Tobey (1990) empirically showed that environmental regulation had little impact on net exports in the pollution-intensive industries in developed countries[3]. Similarly, Xu (1999) found that export performance is not particularly affected by variations in the stringency of environmental regulations; the export performance of environmentally sensitive goods was found to be stable between the 1960s and the 1990s, even as environmental standards became more stringent over this period. In contrast, Robison (1988) found a significant impact of environmental regulation on net exports using U.S. trade data. The author's result indicates that a marginal change in abatement cost negatively influences industrial trade volume, and thus the goods with higher abatement costs are imported whereas the goods with lower abatement costs are exported.

Earlier empirical analyses assumed the exogeneity of environmental regulations in trade patterns (Robison, 1988; Tobey, 1990), but recent studies have ruled out such assumptions and addressed the endogeneity between trade patterns and the stringency of regulations[4]. Taking endogeneity into account, the empirical results appear to support the statistically significant effect of environmental regulations on trading patterns. Ederington and Minier (2003) found that environmental regulation had a positive impact on net imports in the U.S. Their results showed that a usual ordinal least square (OLS) estimation that did not consider

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[3] Beers and Bergh (1997) highlight that his results were influenced by inaccurate environmental policy indicators in his analysis.

[4] The reason is that environmental regulation standards are commonly industry specific.

endogeneity underestimated the magnitude of the marginal effect of environmental regulation. The empirical results of Levinson and Taylor (2008) also support the possible underestimation of regulatory impact if endogeneity is ignored. Using the data on environmental regulations in the U.S. and net imports to Canada and Mexico, the authors show that the positive impact of abatement costs on net imports from Mexico and the endogeneity-adjusted impact of environmental regulations are larger than the impact of unadjusted models.

The pollution haven hypothesis is popularly discussed and tested in the literature. This hypothesis predicts that the industries that are affected by stringent environmental regulations move to less-regulated environments to avoid the added costs from the imposed regulations. There is no consensus about the hypothesis in the empirical analyses; whereas Antweiler et al. (2001) and Ederington et al. (2005)[5] find little support for the hypothesis, Managi et al. (2009) present empirical evidence that supports the predictions of the pollution haven hypothesis. Not only is the supportive empirical evidence for the hypothesis inconsistent, some argue that the pollution haven may be unrelated to environmental regulations. Chua (2003) built a theoretical model that implies that pollution taxes increase the prices of goods by increasing production costs, which consist of factor prices in a numeraire good and an abatement service.

There are empirical studies to investigate the relationship between a trade pattern and energy consumption at a country level. Sadorsky (2012a) shows that there is a positive relationship between them in the Middle East countries and Shahbaz et al. (2013) also find the positive bidirectional relationship between them in China. Moreover, the relationship is also found in the South American countries (Sadorsky, 2012b). These evidences illustrate that energy is an essential good for economic activities, but they seem to be hard to explain the structural mechanism of trade patterns to energy consumption and environmental regulations.

In order to connect the environment and trade, the previous studies have focused mainly on the effect of environmental regulations on the trade patterns of countries and industries. Where the importance of the regulation effect is typically emphasized, we consider the effect of the environment from a different angle, that of productivity rather than the regulations.

2.2 Trade and productivity

The effect of productivity variation on trade patterns is well documented. The previous studies on trade and firms have indicated a robust relationship between the scale of firm capital intensity, productivity and export performance. Bernard and Jensen (1999) investigated a relationship between exporting and producing at the firm level using census data, and they showed that high-performance firms become exporters but that past export performance does not necessarily boost a firm's current performance. Similarly, Aw et al. (2000) investigated the relationship using plant-level data from Korea and China, and Bernard and Wagner (2001) investigated using German data. Pavcnik (2002) analyzed the impact of tariff reductions on export performance using firm-level data in Chile and showed that tariff reductions encourage firms with relatively

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[5] They made three hypotheses regarding the superficially poor correlation between environmental regulation and trade. They indicated that the extent of the effect of regulatory stringency on trade in the `footloose' industries is understated and that pollution-intensive industries tend to be relatively immobile.

lower productivity to exit the market. According to that study, exiting firms' productivity is 8 percent lower than the average. Therefore, increased export performance is induced by the increase in average productivity, which is caused by the exit of lower-productivity firms.

One of the consistently observed facts is that the productivity of an engaged exporting firm is greater than that of firms that only operate in the domestic market[6]. The measure of productivity that is used in these studies is either estimated total factor productivity (Aw et al., 2000; Bernard and Jensen, 1999; Pavcnik, 2002)[7] or labor productivity (Bernard and Wagner, 2001). Environment-related productivity may play an increasingly significant as more attention is paid to the climate change in expanding global economy. It is possible that a change in trade pattern in exporters may reduce the global CO2 emissions (Arce et al., 2016). Therefore, it is important to investigate the relationship between the export and the productivity related to energy and environment. Many studies point out the insufficiency to implement cost-effective energy efficiency technologies, and there are possibilities to improve the energy and environmental efficiency in industrial sectors from engineering, social, and economic perspective (May et al., 2016; Palm and Thollander, 2010; Trianni et al., 2016). It is important to study the impact of the environment-related productivity improvement on exporting in industries, and we contribute to the literature by considering environment-related productivity, which may play an increasingly significant role.

The related literature suffers from a number of caveats. CDK highlights the "absence of clear theoretical foundations to guide the empirical analysis" in this field, and the authors emphasize the usefulness of the Ricardian comparative advantage framework to discuss the relationship between trade and the environment. Moreover, technology to improve environmental externalities is often ignored in the literature that studies the relationship between productivity and trade (Carraro et al., 2014). In an industry-level analysis that focuses on environment-related efficiency, CDK provides a theoretical model of Ricardian comparative advantage based on a micro-economic theoretical foundation. The model theorizes the effect of intra-industry heterogeneity in labor productivity on export performance and predicts that increases in relative productivity lead to better export performance. CDK also empirically test the prediction of their model. The dependent variable in the empirical model is the log of export, which is disaggregated by exporting and importing countries and differenced across exporters and industries. The productivity in CDK is a relative price using producer price indices[8]. We base our analysis on the CDK model by moving the focus from labor productivity to environment-related productivity, which is measured by energy usage and pollution emissions per unit of production. The roles of energy and environmental quality in economic activity, more specifically in trade, are further analyzed based on the CDK model in the next section.

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[6] Other facts can be summarized as follows: (i) large firms expand their scale and small firms exit the market when a trade policy increases export volume, and (ii) free trade of a good leads to increased productivity in the industry.

[7] Aw et al. (Aw et al., 2000) measured productivity using a multilateral index, and Pavcnik (Pavcnik, 2002) used the Olley-Pakes method.

[8] Costinot and Komunjer (Costinot and Komunjer, 2008), the previous version of CDK, use production per unit of labor as productivity.

3 Methodology and data

3.1 The empirical models

Our empirical analysis is based on the structure of the theoretical model built by CDK. CDK's theoretical model[9] leads to empirical estimation using the following structural model.

$$\log \tilde{x}_{ijt}^{k} = \delta_{ij} + \delta_{j}^{k} + \tau_{t} + \theta \log e_{it}^{k} + \epsilon_{ijt}^{k} \tag{1}$$

$$i = 1, \cdots, \text{Exporters}; j = 1, \cdots, \text{Importers}; k = 1, \cdots, \text{Industries}; t = 1, \cdots, \text{Time}$$

where $\tilde{x}_{ijt}^{k}$ is an export from country i to country j in industry k at time t; δ_{ij} and δ_{j}^{k} are dummy variables to indicate the ith exporter-jth importer and kth industry in jth importer; τ_{t} is a year-specific dummy variable; and ϵ_{ijt}^{k} is an error term. $\tilde{x}_{ijt}^{k}$ is the corrected export by import penetration ratio (IPR), which is defined as $1 - x_{iit}^{k}/\left(\sum_{i'=1}^{I} x_{i'it}^{k}\right)$. It is a fixed effect, and it captures any attribution between export country i and import country j whose examples are provided by trade barriers. The other fixed effect, δ_{j}^{k}, captures any attribution of industry k in import country j, and its example is provided by policy barriers[10] and/or preferences in industry k across import country j.

Our estimation model replaces the labor productivity in CDK's model with environment-related efficiency. CDK assumes labor's mobility across industries and immobility across countries. Similarly, we assume the same for the mobility of energy sources. Although our focus is not to defend this assumption, we see patterns of energy source mobility that support the implications of the assumption. For example, fossil fuel trade is restrained because of the destination clause, which prohibits a buyer from reselling crude oil and natural gas. Moreover, not all energy commodities are allowed to trade internationally.

In model (1), e_{it}^{k} expresses the efficiency in country i. The efficiencies that we focus on are energy efficiency and pollution efficiency, which are energy consumption per production, carbon dioxide (CO_2) emissions per production, sulfur oxide (SOx) emissions per production and nitrogen oxide (NOx) emissions per production in country i in industry k. We apply the energy intensity as a measure for energy efficiency, and note the discussion on the difference on these two[11]. According to the estimate model, we empirically analyze a parameter θ, which is an elasticity of an export with respect to the efficiencies, for exporting any good k from country i to country j.

Improving environment-related efficiency depends on technological progress. Compared with CDK's model, our model differs in that we consider the time effect as an underlying variable for progress. We, however, face difficulty in estimating our model because we need to estimate a fixed-effect model that contains the two individual effects as well as the time effect using panel data that consists of three factors[12]. Moreover, for the variables of individual effects, δ_{ij}, δ_{j}^{k} and τ_{t}, in total, there are more than sixteen

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[9] See theorem 1 in CDK.

[10] In a context of our analysis, effect of energy and environmental regulations on exports are captured by the variable, δ_{j}^{k}.

[11] See EIA (EIA, 2000) for further discussion

[12] The export in the model contains three factors: exporter i exports a good k to country j in a year.

thousand dummy variables.

The estimation model in CDK corresponds to their theoretical framework, and the estimated parameters are structural. Hence, the time effect in our estimation model is not based on their theoretical consideration but captures the difference between time units, which is influenced by economic repercussions in response to local and global events.

Additionally, we consider a variation of model (1) in order to capture the individual effects, which is expressed,

$$\log \tilde{x}_{ijt}^{k} = \nu_{ij}^{k} + \tau_t + \zeta \log e_{it}^{k} + \epsilon_{ijt}^{k} \tag{2}$$

where ν_{ij}^{k} represents one individual effect which means that an exporter i exports a good k, to a country j. The individual effect in the model captures the circumstance of a trade between exporter i and importer j in industry k and can be regarded as both δ_{ij} and δ_{j}^{k} in model (1). Model (2) can be estimated with regular panel data.

We consider two different models, one with the measures of environment-related efficiencies as the explanatory variable and the other with an additional labor-productivity-related variable. We provide the results of this alternative model in Appendix. A.

3.2 Data

Our analysis uses two separate datasets, data on trade flow and data on the measures of environment-related efficiencies. Both required datasets can be acquired from the WIOD, which consists of four parts: the world input-output (IO) table, the national IO table, and socioeconomic and environmental satellite accounts. The world IO and the national IO are available for the period of 1995 to 2011, but the environmental-efficiency-related data are only available up to 2009; therefore, we limit our analysis to the period of 1995 to 2009.

Trade flow data are derived from the world IO table. We use the bilateral export of final private consumption as the dependent variable. The bilateral exports are from 22 exporting countries i to each of 41 importing countries j for each of 20 industries k, which are equivalent to $\tilde{x}_{ijt}^{k}$ in our empirical models. Our selections of export countries i and industries k are listed in Table 1. Following CDK, we correct the export data using IPR.

We measure the efficiencies across countries and industries using the world IO table and environmental accounts. The environmental accounts include data on energy use and CO_2, SOx, and NOx emissions at the industry level. From energy use and the emissions data, we calculate the industry-level energy efficiency and pollution efficiency. These efficiencies are measured by the ratio of the value of energy use or emissions to total production by industry. An additional efficiency measure, namely, labor productivity, is used in our estimation, and we also use the variables from socioeconomic accounts. Labor productivity is calculated as the ratio of the labor force to the total output.

Table 1 lists the countries and the industries that are included in the analysis. Table 2 provides the descriptive statistics calculated across countries and industries. We code the absence of trades in a country and an industry as 0 in our analysis. Figure 1 shows the relationship between the exports and the environment-related efficiency in 40 countries. The figure also indicates a positive correlation between the exports and the four efficiencies.

<Table 1>

<Table 2>

<Figure 1>

4 The results of the estimation Equation Section (Next)

We estimate the effect of environment-related efficiency on the trade patterns across countries and industries. We focus on the parameters of θ and ζ, which represent an elasticity of export with respect to the efficiencies.

Table 3 reports the estimates of θ in model (1). Columns (1) to (4) show the results using bilateral export data without adjustment by IPR, and the remaining columns show the results using the adjusted export data. According to the theoretical implication in CDK, when we use the adjusted bilateral export data, we expect the negative estimates to be negative, and we also expect smaller estimates compared with when we use unadjusted data. From the results, ceteris paribus, a one percent improvement in the efficiencies leads to an increase in exports in the range of approximately 0.025 to 3.83, and the estimates with adjusted bilateral exports are found to be slightly smaller than the estimates without the adjustment. The difference in magnitude in the treatments for the exports agrees with the finding of CDK.

There is a correlation between explanatory variables and error terms when we consider the relationship between more disaggregated firm- or plant-level exports and environment-related efficiency. The correlation causes simultaneous equation and attenuation biases, which are caused by a measurement error in the efficiencies and leads to the underestimation of the parameters. Although the simultaneous bias is a potential concern for a relationship between unobserved firms' internal productivity and factor endowments[13], our main question is the impacts of environment-related efficiency, not those of total factor productivity.

To take the bias into account, model (1) is estimated using instrument variables for the endogenous regressor, $\log e_{it}^{k}$. A government generally makes different decisions from households and firms and intervenes to improve efficiencies. We use the government expenditures, taxes and subsidies in the WIOD as the instrument variables. Columns (9) to (12) in Table 3 show the instrument variable (IV) estimate of θ. The impacts of energy use, CO_2 emissions, and NOx emissions are negative and statistically significant, but the θ of SOx emissions is opposite in sign. The magnitude of θ from the IV estimation is larger than that of the estimates from OLS estimation. This difference is likely caused by the previously discussed attenuation bias.

The positive coefficient of SOx is not consistent with the theoretical consideration. The reason can be

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[13] Olley and Pakes (1996) measure productivity using a proxy for unobserved plant-level information. Pavcnik (2002) shows that the improved productivity caused by firms' exits because of cutoff tariffs leads to more exporting using the Olley-Pakes method.

derived from the cost of SOx emissions abatement and the limited market of the transboarder electricity transaction. SOx is mainly emitted in the electricity power generators where coal is burned (Shemwell et al., 2002), and the trade seems to be excessively concentrated in European countries. This may lead to the difference in the progress to take measures for SOx abatement across the countries. It is possible that the model can capture the relationship between SOx efficiency and export.

<Table 3>

The main result of this analysis is summarized in Columns (9) to (12) in Table 3. The magnitude of estimated result is $\hat{\theta}_{\mathrm{ene}} < \hat{\theta}_{\mathrm{CO_2}} < \hat{\theta}_{\mathrm{NOx}}$, and the coefficient of energy which is regarded as higher marginal abatement cost results in the least values. From our findings, we can offer the empirical fact that the energy and environment efficiency in energy use, CO2 emissions, and NOx emissions may be a source of the comparative advantage in industries. However, we cannot show the relationship between the environment efficiency in SOx and the export performance. A possible reason is that major SOx emitter in industries is the electric power supplier and the international trade in the electricity has been concentrated in euprean market. In addition, there is the difference in costs of pollution management between SOx and NOx, and the total cost to abate NOx emissions in the power plant is relatively expensive[14]. The high SOx pollution management cost may cause regional gaps of SOx emissions reduction in European couties. These factors can obfuscate the structural effect of SOx on export performance across industries.

Table 4 reports the results of the model (2). Columns (1) to (4) show the results using fixed-effect models. The impacts of energy efficiency and pollution efficiency, ζ, are larger compared with those in model (1). Considering the endogeneity of the regressor, we estimate model (2) using a dynamic generalized method of moments (GMM). When we compare columns (1) to (4) and (5) to (8), the magnitude of ζ with the dynamic GMM is found to be larger. Both models (1) and (2) show the expected impacts of the efficiencies.

<Table 4>

5 Impacts on industrial export performance

5.1 Extension of the empirical model

The results of the environment-related efficiency show that the industries with higher efficiency tend to export more, but the estimated models do not take the differences in industrial efficiency into account. We further investigate the impacts of environment-related efficiency by industry because energy consumption and emissions depend partly on industrial characteristics. In the context of the environmental economics literature, the industrial characteristics of energy use are important issue for environmental regulations. Pollution-intensive industries may face high abatement costs and are more likely to be influenced by

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[14] *NOx emitters have covered a relatively wide range of industries and the low-NOx cell burner is attached with the combustion equipment at small and medium-scale in manufacturing and service sectors. The cost of the low-NOx cell burner is the cheapest in the cost of other NOx control technologies and SOx pollution control technologies* (Shemwell et al., 2002).

economic regulatory instruments, such as environment taxes and other restrictions. Ederington et al. (2005) observe that the estimated average effect of abatement costs on all industries will lead to underestimation for some industries. Thus, given that we use the data of 20 different industries in this study, it is important to consider whether the impacts of environment-related efficiency differ by industry.

There are some reasons for which we expect industrial characteristics to affect relative energy efficiency. First, energy can be used as either a source of power or heat or as raw material. For example, petroleum can be used as a fuel in the form of gasoline, but it can also be used as a raw material in the petroleum chemical industry to produce vinyl and plastic. Even if both types of usage count as energy consumption, when the energy source is used as raw material, it is less likely to produce emissions.

Second, depending on the technology choice, the energy source and emission levels may vary. For example, the blast furnace is a conventional technology used in the iron and steel sectors. Furnaces use coke, but furnaces have been replaced by different technologies, such as direct-reduced iron, which uses natural gas. According to report by IEA (2010a), direct-reduced iron technology allows natural gas to replace coke as the main energy source in the iron and steel industry.

Third, the industries in energy-intensive sectors are more likely to be energy efficient because they utilize recovery technology to use the energy that is the by-product of their production processes as their power and heat sources. For example, coke oven gas in the steel and iron sector and refinery gas in the petroleum sector are generated from their production processes and are used as energy sources in the related production processes.

For a number of reasons, including the three points mentioned above, industry-specific technology and production processes influence environment-related efficiency. Thus, it is important to consider the industry-specific impact when we analyze the relationship between export performance and environment-related efficiency.

Additionally, we investigate the effect of environment-related efficiency by industry in each country. When we look at the same industry across different countries, we expect the impact of that industry's environment-related efficiency to be roughly the same because the elemental technology in each industry is essentially the same across countries. Although we expect relatively constant results across countries by industry, there may be cases in which the effect of environment-related efficiency in a particular industry may differ visibly by country. We may observe such differences owing to variations in energy access because countries vary in their endowment of natural resources. A country in which energy resource endowment is scarce may use energy more efficiently, and a country with a relatively rich endowment of less pollution-intensive energy has relatively low abatement costs.

Another factor that can cause within-industry differences across countries is country-specific regulations and subsidies. IEA (2010b) reports that the subsidies related to fossil fuel consumption amounted to roughly 312 billion dollars in 2009. Governments use energy subsidies to bring down the production costs in the energy sector. With heavy subsidies to the energy industry, other industries can benefit from lower energy prices. This may lead to reduced incentives to be energy efficient. Environmental regulations can also influence an industry's relative energy efficiency. The stringency of environmental regulations is different across countries, and some industries are legally allowed to opt out of the regulations to promote international competition.

In order to consider the environment-related efficiency by industry in detail, we use two separate models: one with an interaction variable between environment-related efficiency and industry dummies and the other with the additional triple interaction of environment-related efficiency, industry dummies, and country dummies.

$$\log \tilde{x}_{ijt}^{k} = \delta_{ij} + \delta_{j}^{k} + \tau_{t} + \theta \log e_{it}^{k} + \delta_{i} + \delta_{j} + \delta^{k} + \tilde{\theta}_{1} \cdot \delta^{k} \cdot \log e_{i}^{k} + \epsilon_{ijt}^{k} \quad (3)$$

where δ_i, δ_j and δ^k are dummy variables in the exporting country, importing country, and industry, respectively. This model is based on model (1(3), and we add individual effects to it. An estimate of $\theta + \tilde{\theta}_1$captures the marginal contribution of efficiency to export performance across industry, and we regard it as a measurement of the impact of each industry.

θ is one of the important parameters in CDK and measures intra-industry heterogeneity. In CDK, θ is assumed to be constant across exporting countries and across industries. In contrast to CDK, we lift the assumption of constant θ in our estimation models (3) and we let θ vary across industries. By allowing θ to vary, there may be a concern that the estimation model calculates absolute rather than comparative advantage. However, a closer look at the model indicates that it can be used to calculate comparative advantage.

From our definition of environment-related efficiency, the ratio of the efficiency in exporting country $\tilde{i}$ and i, $e_{\tilde{i}j,t}^{k}/e_{ij,t}^{k}$, shows the extent to which exporting country i holds an absolute advantage in efficiency related to country $\tilde{i}$ in industry k. From the results of CDK, the relationship between export performance and the absolute advantage of the efficiency in industry k is expressed as

$$\log\left(\frac{x_{ijt}^{k}}{x_{i'jt}^{k}}\right) = \vartheta \log\left(\frac{e_{it}^{k}}{e_{i't}^{k}}\right) - \vartheta \log\left(\frac{d_{ijt}^{k}}{d_{i'j}^{k}}\right) \quad (4)$$

where the ratio of $e_{it}^{k}/e_{i't}^{k}$ expresses the degree of the absolute advantage of the efficiency. The relationship between export performance and the efficiency in (4) is for any importer j and any pair of exporters i, and i' but for the identical industry k. Hence, ϑ is an industry-specific impact of efficiency on export performance. According to classical trade theory, trade patterns do not vary as long as the comparative advantage of the efficiency for any importer, any pair of exporters, and any pair of industries does not change even if the absolute advantage of the efficiency for any importer or pair of exporters in the same industry changes. Therefore, regardless of the results from model (3), the comparative advantage confirmed by the results of model (1) stands on its own. Thus, the estimated parameters from model (3) capture the impacts of industrial characteristics on export performance. An estimation model to investigate the impact across countries is written as

$$\log \tilde{x}_{ijt}^{k} = \delta_{ij} + \delta_{j}^{k} + \tau_t + \theta \log e_{it}^{k} + \delta_i + \delta_j + \delta^k + \tilde{\theta}_1 \log e_{it}^{k} \cdot \delta^k$$
$$+ \tilde{\theta}_2 \cdot \delta_i \cdot \delta^k \cdot \log e_{it}^{k} + \epsilon_{ijt}^{k} \quad (5)$$

where δ_i, δ_j and δ^k are the same dummy variables as in model (3). $\tilde{\theta}_2$ in model (5) captures the industry-specific impact of environment-related efficiency on trade performance across countries. The equation (4) is helpful to consider the industry-specific impact from model (5).

5.2 Results of industrial performance

Table 5 shows the industrial rank order of a marginal impact of environment-related efficiency. This order is based on the estimated $\theta + \tilde{\theta}_1$ in model (3) using the IV method. We are interested in the difference in impact between industries, and we show the industries in descending order of impact because the estimation results cannot easily be read. Table 6 shows the industry-specific impact of energy efficiency on export performance across countries. The number in the table is $\theta + \tilde{\theta}_1 + \tilde{\theta}_2$ in model (5) and is equal to the marginal impacts in each industry, which are divided into impact across countries. The sign of each marginal impact can be positive or negative, and a negative value indicates that more energy-efficient industries export more. Figure 2 describes the number of negative values of the marginal effects in environment-related efficiency.

The results of industrial impacts in Table 5 and Figure 2 have three features: 1) the top-ranked industries in Table 5 have more negative impact values across countries, 2) the industries that rank at the bottom have fewer negative values, and 3) the industries that are inversely related in ranking order have some negative impacts. The first and the second features are in line with expectations, but the third feature implies that country-specific factors influence particular industries.

From Table 5 and Figure 2, we find that the electric equipment and transport equipment industries are placed near the top of the ranking for all efficiency measures, and this result is robust when we look at the impact of environment-related efficiency on export performance by industry in each country. One possible explanation for why environment-related efficiency has a significant positive impact on the export performance of these industries is that these industries are highly competitive in the international market. Hence, a small difference in energy efficiency affects their performance. In other words, competition leads to high opportunity costs for not being energy efficient. Our result also shows that the food industry ranks in efficiency impact. Although the food industry is less susceptible to international competition compared with electric and transportation, the impact of efficiency on export performance may be strong because energy costs are a dominant cost factor and energy efficiency is key for business management in the industry (American Gas Funding, 2005; U.S. Environmental Proteciton Agency, 2007).

The industries that rank low in terms of impact of efficiency belong to energy-intensive sectors, such as coke and fuel, basic metals, and non-metals; these industries rank near the bottom in all efficiency measures. Moreover, when we consider these industry-specific efficiency impacts by country, we observe that the positive impacts of industry-specific environment-related efficiency on export performance are consistent across countries for the top-ranked industries. However, for the low-ranked industries, the industry-specific impacts vary across countries; they are sometimes positive and sometimes negative depending on the country. The reason we observe such variation in the impacts of low-ranked industries may be that these industries are what we often call the heavy industries, which heavily depend on natural resources.

The relatively lower ranked industries tend to share some characteristics of energy use and the international market. The iron and steel industry is ranked among the lower level group in all energy and environment efficiency in the result. China is the largest producer of the crude steel and followed by EU, Japan, and the US in order. It seems sure that the prominent difference in the stringency of environment regulation in China and developed countries (Botta and Koźluk, 2014). This implies that it is hard to shift the environment management cost on the product price, and the industry results in the lower level group.

China is also the largest exporter in the textiles and clothing and followed by EU and countries in the South-east Asia. The textile industry mainly uses electricity in the production process and relatively less pollution emitters compared to the energy intensive industry. Moreover, the industry tends to be labor intensive and then a relatively lower labor cost countries have an advantage in the production. The textile industries are a competitive market among competitors which involve producers with lower labor cost, and then the industries are conscious of the limited energy price change. The comparative advantage in the industrial production can be regarded as the country-specific factors which form into the key industry in a country, for example, economy, the technology level, and the available energy resources in a country. Thus the efficiency impacts depend on country-specific characteristics of energy source endowment.

<Table 5>

<Figure 2>

<Table 6>

6 Discussions

We find that environment-related efficiency explains the existence of comparative advantage in export performance. This implies that improved efficiency increases export performance. This result leads us to the next question: How do we increase environment-related efficiency given that increasing export performance is an important economic concern for countries? Although there are multiple ways to improve environment-related efficiency, we discuss two possible mechanisms.

One is improving the technology and labor skills that would contribute to increased energy efficiency in production processes. This could be accomplished through either government regulations and subsidies or voluntary efforts by firms themselves. Many countries address energy efficiency and climate change policy (see the IEA `Policy and Measure Database'[15]), and they structure their regulations and economic policies to meet certain goals and standards. Moreover, some empirical works show that environmental regulations enforced by governments improve firm performance (Lanoie et al., 2011; Rexhäuser and Rammer, 2014).

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[15] It is available at http://www.iea.org/policiesandmeasures/.

The migration of industries can achieve increases in average energy efficiencies in both developed and developing countries according to the assumption of the pollution haven hypothesis. The reason is that efficient industries migrate out of countries to avoid stringent environment regulations, and the average efficiency increases in the home country, where the industries with high environment-related efficiency can comply with more strict regulations. In contrast, however, those industries that migrated to the countries with relatively softer environmental regulations could have higher energy efficiency compared with the existing industries in the host countries. Therefore, the average efficiency can be increased in both countries.

Our analysis does not provide definite support for which mechanisms or what combinations of these mechanisms actually increase energy efficiency, but our results may provide some hints regarding what mechanisms lead to greater environment-related efficiencies. The results indicate that the positive impact of energy efficiency is larger in relatively mobile industries, such as electric and transport equipment, whereas the efficiency impact on export performance is low in relatively heavy industries. The top large firms in electric equipment and transport equipment, such as General Electrics, Samsung, Toyota and the other major companies, have built plants outside of their home countries. However, heavy industry by definition is energy-source-intensive and depends heavily on each country's specific endowment of natural resources. Therefore, the firms in heavy industry are less mobile given that migration is limited by the availability of access to energy sources. This result may imply that migration is relevant when we consider the relationship between energy efficiency and export performance.

Finally, we consider the implication of energy and environmental policy from the results. The results show the possibility of the energy and environmental efficiency as well as the other costs to be a source of the comparative advantage in industries. There two implications on the energy and environmental policy. Firstly, the environmental regulation is fairly implemented to all regulated participants in the international trade market. Second, the efficient market of the energy and the technology to reduce environment pollution is developed globally, and, if necessary, government support and administer the market. It is inadequate that the positive relationship between environmental efficiency and exporting is disturbed in the market.

7 Concluding Remarks

We analyze the impact of energy and pollution efficiencies on export performance based on the recent trade theory by Costinot et al. (2012) using comparative industry-level data. The empirical results indicate that industries with higher energy and emission efficiency tend to export more. Our estimation shows that 1 percent decreases in energy consumption, CO_2 emissions, and NOx emissions per unit of production lead to 1.6, 3.8, and 2.7 percent increases in exports, respectively.

We further investigate the impact of industry-specific efficiency on export performance as well as the effect of industry-specific efficiency by country. This extension is important because the effects of environment-related efficiency vary depending on industry characteristics, such as different energy source usage and production technologies. Our results indicate that the less energy-intensive industries tend to show a greater positive efficiency impact on export performance compared with the heavy industries, which tend to depend more on country-specific resource endowment.

These evidences illustrate that energy is an essential good for economic activities (Ozturk and Acaravci, 2013; Sadorsky, 2012b, 2011; Shahbaz et al., 2013b), but they seem to be hard to explain the structural mechanism of trade patterns to energy use. Our investigation can provide a suggestion on a relationship between international trade pattern and energy consumption across industries and countries. Our results show that the industrial sectors can have a comparative advantage at producing goods when they can produce them at less energy use. They are coherent to the classical trade theory. Our findings imply that it is possible that an industry to attain higher energy efficiency increases exports.

The related to our analysis is an elucidation of energy price and trade pattern, and Sato and Dechezleprêtre (2015) show the small impact of energy price on imports across 42 countries and 62 sectors. Their findings imply that domestic regulation on energy use, for example fossil fuel and carbon emissions tax, may lead to increase imports because of a decrease in domestic production and exports. A mechanism of their observed facts is that energy price affects cost functions of domestic goods and price of imported goods relatively declines. Most studies have indicated that energy price has an effect on production cost; an increasing in energy price induces to improve energy efficiency in order to save the energy cost. Our analysis to capture domestic regulations shows that it is possible to increase export from more efficient energy use under the regulations.

Given the indication that improving environment-related efficiency leads to increased export performance, it is in industries' as well as governments' interest to think about how to actually increase energy efficiency. Although there may be multiple ways to achieve this increase, we briefly highlight two possible mechanisms.

One is by developing and applying related technology that leads to increased energy efficiency in production. This could be accomplished through either government regulations and subsidies or voluntary efforts by firms themselves. Secondly, average energy efficiencies can be increased by the migration of industries. According to the pollution haven hypothesis, industries with low energy efficiency migrate out of countries with more stringent regulations, and this migration increases the average energy efficiency those countries. In contrast, those industries that migrate to developing countries with relatively more lax environmental regulations could have higher energy efficiency compared with the existing industries in the host countries. Therefore, in both countries, average energy efficiencies can be increased through industry migration. As we discussed above, our results appear to imply that industry migration may be important when we consider the effect of energy efficiency on export performance. As for future research, it would be important to empirically analyze whether regulations and/or industry migration actually contribute to increasing energy efficiencies and thus lead to improved export performance.

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Appendix

A. Labor productivity in estimated model

We consider a model with not only the environment-related efficiency variable but also the labor-productivity-related variable, which is considered to be influential in export performance. Our attempt is to add labor productivity X_{it}^{k} into model (1), and the resulting estimation model is expressed as

$$log\,\tilde{x}_{ijt}^{k} = \delta_{ij} + \delta_{j}^{k} + \tau_{t} + \theta \log e_{it}^{k} + \xi \log X_{it}^{k} + \epsilon_{ijt}^{k} \tag{A.1}$$

$$i = 1, \cdots, \text{Exporters}; j = 1, \cdots, \text{Importers}; k = 1, \cdots, \text{Industries}; t = 1, \cdots, \text{Time}$$

where the variables except labor productivity are the same as those for model (1).

Table A 1 reports the estimate θ in this model, on which we focus as the impact of environment-related efficiency on export performance. The estimates of θ and ξ are expected to carry the same negative sign as in previous two models in this paper.

Compared with the estimated parameters in Table 3, there is little parameter change from the additional regressor. However, there are also different magnitudes of the estimated coefficient between OLS and IV in the table; the magnitudes using IV are greater than those from OLS. This casus of parameters is observed in CDK, and the authors observed that the magnitude of θ by IV is thought to be derived from an attenuation bias that is caused by a measurement error in efficiency. It is likely that efficiency as an exogenous variable leads to a bias that increases the magnitude.

Figures

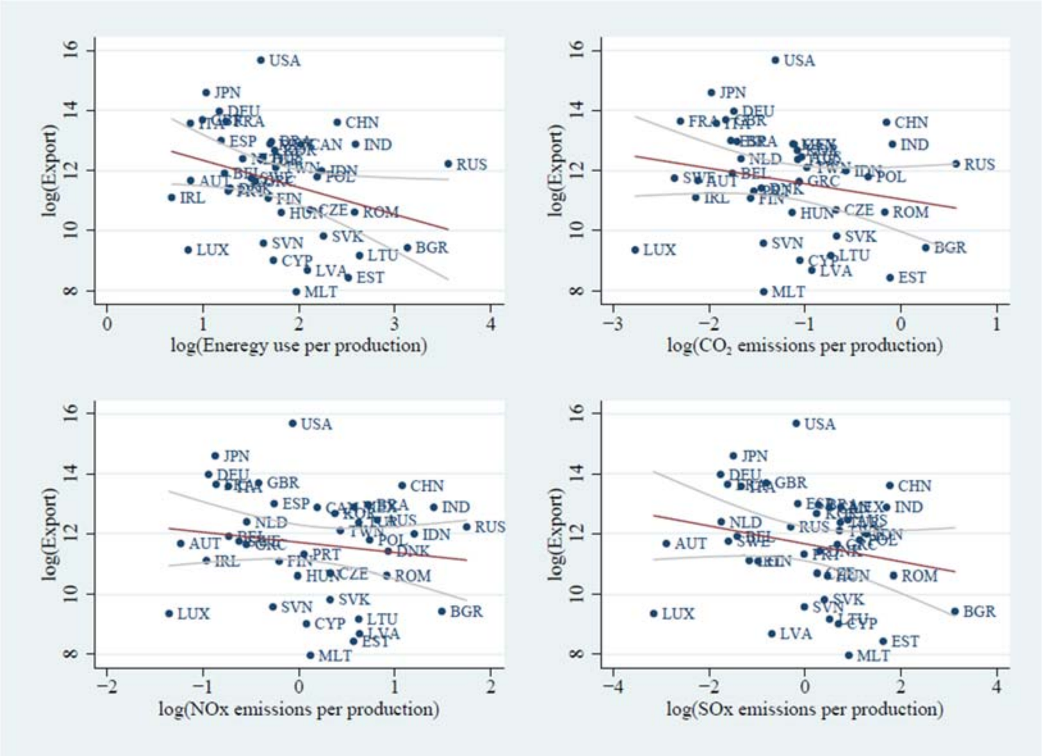

Figure 1 Export and the energy use per production and pollution emissions per production

Note: This plot depicts a relationship between the export and environment-related efficiency, which is measured by energy consumption and pollution emissions per unit of production in 40 countries. Each data point is an annual average amount of each country for all industries.

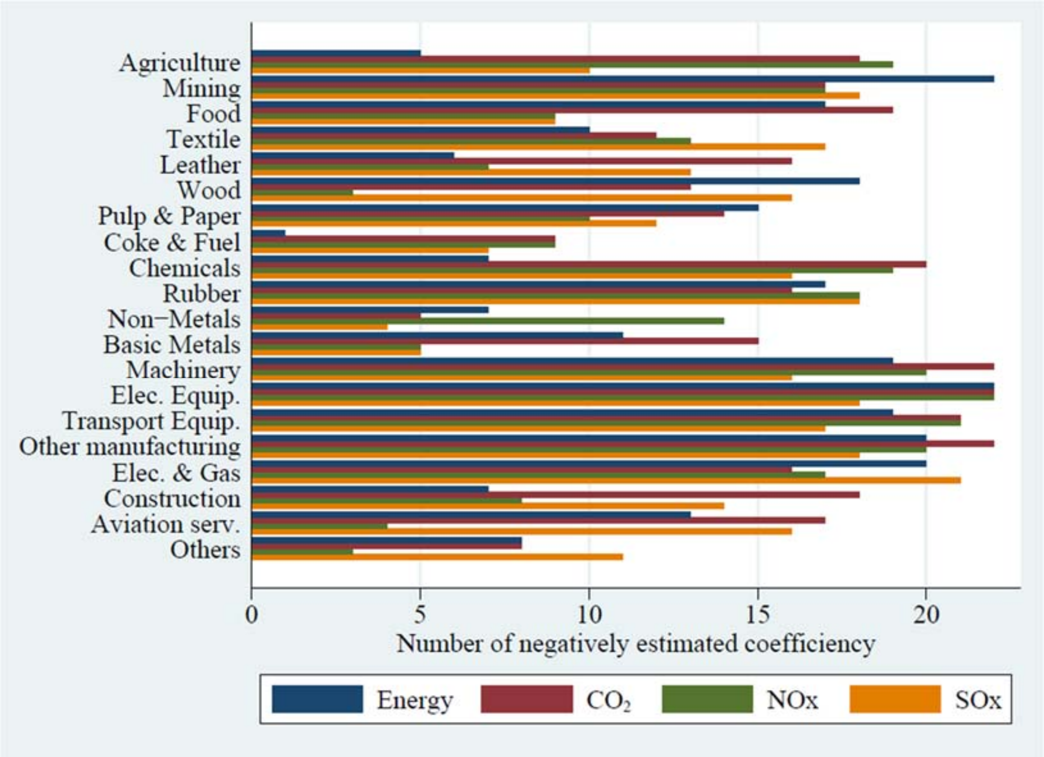

Figure 2 Number of negative impacts of the environment-related efficiency across country

Note: Negative impacts of the environment-related efficiency is equal to $\theta + \tilde{\theta}_1 + \tilde{\theta}_2$ in model (5) which is estimated as negative sign.Tables.

Table 1 Data source and description of data set.

Source	World Input Output Database http://www.wiod.org	
Data type	World Input-Output Tables released November 2013 National Input-Output Tables released November 2013 Socio Economic Accounts released February 2012 Environmental Accounts released March 2012	
Period	From 1995 to 2009	
Country	Exporter (22)	Australia, Belgium, Brazil, Canada, China, Germany, Spain, France, United Kingdom, Indonesia, India Italy, Japan, Korea, Mexico, Netherlands, Poland, Russia, Sweden, Turkey, Taiwan, and United States
	Importer (41)	Exporters and Austria, Bulgaria, Cyprus, Czech Republic, Denmark, Estionia, Finland, Greece, Hungary, Ireland Lithuania, Luxembourg, Latvia, Malta, Portugal, Romania, Slovak Republic, Slovenia, and Rest of the World

Industry (20)			
Sector	Description	Sector	Description
Agriculture	Agriculture, Hunting, Forestry and Fishing	Non-Metals	Other Non-Metallic Mineral
Mining	Mining and Quarrying	Basic Metals	Basic Metals and Fabricated Metal
Food	Food, Beverages and Tobacco	Machinery	Machinery, Nec
Textile	Textiles and Textile Products	Elec. Equip.	Electrical and Optical Equipment
Leather	Leather, Leather and Footwear	Transport Equip.	Transport Equipment
Wood	Wood and Products of Wood and Cork	Other manufacturing	Manufacturing, Nec; Recycling
Pulp & Paper	Pulp, Paper , Printing and Publishing	Elec. & Gas	Electricity, Gas and Water Supply
Coke & Fuel	Coke, Refined Petroleum and Nuclear Fuel	Construction	Construction
Chemicals	Chemicals and Chemical Products	Aviation serv.	Air Transport
Rubber	Rubber and Plastics	Others	Service sectors not elsewhere classified

Table 2 Summary statistics.

	Dimension	Observation (excl. missing obs.)	Mean	Maximum	Minimum	Standard deviation
Export	Million of U.S.$	270,601	981	6,287,692	0.0	42,516
Energy use per prod.	Million of joule per U.S.$	6,599	14.87	913.3	0.076155	42.15
CO_2 per prod.	Kilogram per $	6,584	0.90	47.8	0.000867	2.69
NOx per prod.	Tonnes per million $	6,584	2.76	172.7	0.001824	7.37
SOx per prod.	Tonnes per million $	6,584	3.73	376.8	0.000065	16.90
Labor per prod.	Person per $	6,599	0.040	2.06	0.000225	0.12
Capital stock per prod.	Dimesionless (million $ per million $)	6,280	1.06	12.0	0.007652	1.07

Table 3 Results of model (1).

Regressand	log (export of final goods)				log (corrected export of final goods)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
log (energy use per production)	-0.126***				-0.125***				-1.605***			
	(0.00746)				(0.00748)				(0.0491)			
log (CO₂ emissions from fuel combustion per production)		-0.138***				-0.138***				-3.825***		
		(0.00722)				(0.00724)				(0.0718)		
log (NOx emissions per production)			-0.109***				-0.109***				-2.668***	
			(0.00626)				(0.00627)				(0.0573)	
log (SOx emissions per production)				-0.0248***				-0.0234***				4.269***
				(0.00390)				(0.00391)				(0.214)
Individual effects												
» Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
» Export country x Import country	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
» Import country x Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation Method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	2SLS	2SLS	2SLS	2SLS
Observations	258437	257837	257837	257837	258318	257718	257718	257718	150188	149668	149668	149668
AIC	1033510	1028904	1029007	1029340	1034534	1031606	1031709	1032052				
R-square: overall	0.780	0.781	0.780	0.780	0.779	0.779	0.779	0.779	0.769	0.517	0.643	.

Note: We estimate the model (1) using data from 22 counties 20 industries from 1995 to 2009, which are listed in the Table 1. Corrected export of goods is adjusted using IPR.

Production in the regressors is output that is evaluated at the price in 1995. Year is time dummy. Export country x Import country is fixed effect of export and import, and Import country x Industry is fixed effect of import and industry. The test statistics is the White standard errors which is reported in the parentheses. *** represents statistical significance at 1 percent level. A test for the regressor with a correlation of error term or a measurement error is carried out, so the hypothesis of exogeneity of environment-related efficiency in the model is rejected. A test of over-identification is carried out to check the adequacy of instrument variables, which are capital stock, government expenditure, indirect tax and subsidy, and dummy variables. The hypothesis of over-identification is not rejected. It is likely that at least some of these instrument variables may not be exogenous.

Table 4 Estimation results of the model (2).

Regressand	log (corrected export of final goods)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log (corrected export of final goods) $_{t-1}$					0.682***	0.665***	0.631***	0.640***
					(0.0274)	(0.0259)	(0.0285)	(0.0286)
log (energy use per production)	-0.332***				-0.358			
	(-48.16)				(0.263)			
log (CO_2 emissions from fuel combustion per production)		-0.315***				-0.342		
		(-48.37)				(0.334)		
log (NOx emissions per production)			-0.282***				-0.414**	
			(-51.88)				(0.136)	
log (SOx emissions per production)				-0.158***				-0.124
				(-47.15)				(0.138)
Individual effects								
» Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
» Export x Import x Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation Method	OLS	OLS	OLS	OLS	GMM	GMM	GMM	GMM
Observations	258318	257718	257718	257718	152962	152442	152442	152442
R-square: overall	0.159	0.159	0.160	0.159				

Note: We estimate the model (2) using data from 22 counties 20 industries from 1995 to 2009, which are listed in the Table 1. Corrected export of goods is adjusted using IPR.

Production in the regressors is output that is evaluated at the price in 1995. Year is time dummy. Export country x Import country x Industry is fixed effect of the country to supply goods to forging countries. The test statistics is the t-value and the White standard errors in OLS and GMM, respectively, and they are reported in the parentheses. *** represents to be statistically significantly different from zero at the one percent level. The tests for the regressor with a correlation of error term or a measurement error are carried out, and the hypothesis of exogeneity of the environment-related efficiency in the empirical model is rejected. The specification test is carried out to check the adequacy of an instrument variable (government expenditure in columns (5) to (8)). In the Arellano-Bond test for autocorrelation, columns (5) and (6) do not reject the null hypothesis in AR(1) but reject it in AR(2), but in the J test of Hansen, columns (5) and (6) reject the null hypothesis. The results of the tests indicate that the columns (7) and (8) are not adequately explained.

Table 5 Industry ranking of environment-related efficiency impact on export performance.

Rank	Environment related efficiency			
	Energy	CO_2	NOx	SOx
1	Food	Food	Food	Elec. & Gas
2	Transport Equip.	Pulp & Paper	Construction	Coke & Fuel
3	Chemicals	Transport Equip.	Transport Equip.	Food
4	Elec. Equip.	Chemicals	Coke & Fuel	Chemicals
5	Pulp & Paper	Elec. Equip.	Chemicals	Elec. Equip.
6	Other manufacturing	Construction	Machinery	Transport Equip.
7	Machinery	Coke & Fuel	Elec. Equip.	Aviation serv.
8	Leather	Machinery	Pulp & Paper	Construction
9	Agriculture	Leather	Elec. & Gas	Machinery
10	Textile	Aviation serv.	Other manufacturing	Pulp & Paper
11	Construction	Elec. & Gas	Mining	Other manufacturing
12	Non-Metals	Other manufacturing	Basic Metals	Basic Metals
13	Basic Metals	Basic Metals	Leather	Rubber
14	Elec. & Gas	Rubber	Rubber†	Mining
15	Aviation serv.	Agriculture	Non-Metals	Others
16	Wood	Mining	Aviation serv.	Non-Metals
17	Coke & Fuel	Textile	Wood	Wood
18	Rubber	Wood	Textile	Leather
19	Mining	Non-Metals	Agriculture	Textile
20	Others	Others	Others	Agriculture

Note: The ranking is based on the model (3). †) Rubber in NOx is same rank as Leather.

Table 6 Industry specific impact of energy efficiency on export performance by country.

Exporting country	Agriculture	Mining	Food	Textile	Leather	Wood	Pulp & Paper	Coke & Fuel	Chemicals	Rubber	Non-Metals	Basic Metals	Machinery	Elec. Equip.	Trans-port Equip.	Other manufacturing	Elec. & Gas	Construction	Aviation serv.	Others
Australia	0.94	-0.35	0.79	0.03	1.03	0.21	0.24	0.24	0.21	0.20	-0.25	0.22	-0.63	-0.57	0.20	-0.13	-0.24	0.30	0.94	3.88
	(0.54)	(-0.39)	(1.16)	(-0.13)	(0.29)	(-0.07)	(0.26)	(-0.21)	(-0.12)	(0.58)	(-0.10)	(0.22)	(-0.57)	(-0.27)	(0.12)	(-0.05)	(-0.40)	(-1.63)	(0.43)	(3.38)
Belgium	1.71	-1.51	-0.12	-0.47	0.90	-0.15	-0.26	1.53	0.35	0.33	-0.11	0.55	0.89	-0.34	-0.88	-1.16	0.04	-0.67	0.13	1.68
	(-0.39)	(-1.51)	(1.22)	(-0.48)	(0.92)	(-0.27)	(-0.09)	(1.06)	(0.03)	(-0.18)	(0.24)	(0.61)	(0.81)	(-0.09)	(-0.86)	(-1.24)	(-0.18)	(-2.21)	(-0.28)	(1.47)
Brazil	1.71	-0.47	0.99	-1.26	-7.12	-0.92	-0.86	0.47	-0.0	-1.24	-0.04	-0.03	-1.26	-1.13	-1.29	1.17	-0.31	13.25	-1.17	-0.06
	(0.95)	(-0.49)	(0.96)	(-1.42)	(1.14)	(-1.05)	(-0.81)	(0.06)	(-0.64)	(-2.0)	(0.19)	(-0.10)	(-0.54)	(-0.48)	(0.47)	(-1.59)	(-1.65)	(-0.64)	(-2.04)	(-0.92)
Canada	1.71	-1.29	-0.70	0.36	0.43	-0.41	-0.01	0.47	0.98	-1.24	0.16	-0.03	-0.18	-5.37	-1.29	-3.69	-0.31	13.25	-0.78	1.07
	(0.69)	(0.75)	(0.61)	(-0.70)	(-1.15)	(-0.56)	(0.11)	(0.09)	(-0.36)	(-0.05)	(-0.51)	(0.29)	(0.04)	(-1.58)	(-0.81)	(-0.06)	(-0.02)	(-4.30)	(-0.10)	(1.12)
China	1.71	-1.29	-0.70	0.36	0.43	-0.41	-0.84	0.47	0.98	-1.24	0.16	-0.03	-0.18	-5.37	-1.29	-3.69	-0.31	13.25	-0.78	3.10
	(-1.05)	(-0.36)	(-1.33)	(-0.14)	(-0.50)	(0.14)	(-0.97)	(-0.57)	(-1.0)	(-0.67)	(0.29)	(0.03)	(-1.13)	(-1.04)	(-2.74)	(-0.92)	(-0.64)	(0.43)	(-0.80)	(-1.79)
Germany	-0.81	-0.44	-0.67	-0.18	0.53	-0.83	0.70	0.45	0.23	0.74	0.12	0.34	-0.65	-1.19	-2.35	-0.06	-0.13	-0.02	0.16	1.12
	(-0.95)	(-0.48)	(0.32)	(-0.19)	(-0.0)	(-0.84)	(0.84)	(0.20)	(-0.06)	(0.09)	(0.49)	(0.43)	(-0.78)	(-0.82)	(-2.11)	(-0.02)	(-0.25)	(-2.78)	(-0.28)	(1.0)
Spain	1.51	-1.90	-0.04	-0.32	2.35	-0.61	-0.30	0.44	-0.06	-0.36	0.0	-0.23	0.80	-0.27	-1.39	0.25	-0.50	0.77	0.02	-2.02
	(1.20)	(-1.91)	(0.59)	(-0.45)	(0.98)	(-0.87)	(-0.34)	(0.06)	(-0.41)	(-0.91)	(0.23)	(-0.28)	(0.84)	(0.21)	(-0.88)	(0.51)	(-0.69)	(-0.36)	(-0.39)	(-2.28)
France	1.92	-0.88	1.34	0.70	7.62	-0.41	0.24	0.96	0.98	-1.24	0.16	0.21	-0.18	-1.68	-1.70	-2.22	-0.16	3.70	0.65	-0.75
	(1.24)	(-1.02)	(1.40)	(0.19)	(-0.09)	(-1.08)	(0.02)	(0.44)	(0.36)	(-0.57)	(0.81)	(-0.01)	(-0.03)	(-0.95)	(-1.04)	(-1.38)	(-0.37)	(3.44)	(0.06)	(-1.67)
United Kingdom	-0.63	-0.15	-0.26	-0.26	0.43	-0.44	0.81	0.52	0.31	-0.01	0.06	0.09	-0.54	-1.58	-1.33	-0.42	-0.75	2.65	-0.78	0.02
	(-0.62)	(-0.12)	(0.78)	(-0.10)	(-0.06)	(-0.46)	(1.18)	(0.24)	(0.06)	(-0.34)	(0.48)	(0.22)	(-0.61)	(-1.22)	(-1.83)	(-0.21)	(-0.84)	(0.15)	(-0.05)	(-0.74)
Indonesia	1.71	-1.29	-0.70	0.36	0.43	-0.41	-0.84	0.47	0.98	-1.24	0.16	-0.03	-0.18	-5.37	-1.29	-3.69	-0.31	13.25	-0.78	3.10
	(0.44)	(-1.11)	(0.38)	(0.85)	(2.44)	(1.72)	(-0.15)	(0.23)	(-0.60)	(0.81)	(0.66)	(0.07)	(-0.03)	(1.58)	(-1.34)	(1.04)	(-1.60)	(-0.66)	(-0.10)	(0.48)
India	0.39	-0.58	-0.44	0.46	0.89	0.48	-0.85	0.27	-0.26	-0.26	-0.04	0.16	-1.84	-2.40	-1.49	-1.36	-1.39	-1.37	-0.78	-1.80
	(0.66)	(-0.47)	(-0.15)	(0.59)	(0.78)	(0.54)	(-0.66)	(0.06)	(-0.33)	(-0.37)	(0.26)	(0.33)	(-1.54)	(-2.73)	(-1.26)	(-1.45)	(-1.44)	(0.06)	(-1.10)	(-1.83)
Italy	-0.44	-1.29	-2.23	0.36	-2.42	1.11	-0.84	0.11	-0.53	-0.54	-0.07	0.25	-0.18	-0.15	0.73	-0.32	-0.65	1.68	-0.16	3.10
	(-0.58)	(-1.27)	(-0.96)	(0.30)	(-1.41)	(0.54)	(-0.71)	(-0.23)	(-0.91)	(-1.62)	(0.25)	(0.31)	(-0.56)	(0.20)	(0.59)	(-0.42)	(-0.84)	(0.51)	(-0.60)	(2.29)
Japan	1.71	-1.29	-0.70	0.36	0.43	-0.41	-0.84	0.47	0.98	-1.24	0.16	-0.03	-0.18	-5.37	-1.29	-3.69	-0.31	13.25	-0.78	3.10
	(-1.67)	(0.52)	(-1.13)	(-0.63)	(0.42)	(1.14)	(0.43)	(0.67)	(0.75)	(1.27)	(1.07)	(1.80)	(-4.58)	(-4.37)	(-5.18)	(2.33)	(-0.28)	(13.79)	(0.61)	(5.27)
Korea	1.71	-1.29	-0.70	0.36	0.43	-0.41	-0.84	0.47	0.98	-1.24	0.16	-0.03	-0.18	-5.37	-1.29	-3.69	-0.31	13.25	-0.78	0.77

	(-2.93)	(-1.77)	(-3.69)	(-0.14)	(-0.09)	(-3.45)	(-1.14)	(-0.46)	(-1.11)	(-1.51)	(-0.52)	(0.0)	(-0.51)	(-1.69)	(0.23)	(-0.65)	(-0.86)	(-1.67)	(-0.25)	(-0.60)
Mexico	0.41	-1.06	-0.19	-1.11	-1.32	-0.74	-0.74	0.26	-0.29	-0.15	-0.08	0.17	-1.64	-2.90	-3.28	-1.0	-0.50	-2.73	-0.53	0.98
	(0.40)	(-0.98)	(0.56)	(-1.0)	(-1.91)	(-0.73)	(-0.53)	(0.01)	(-0.48)	(-0.39)	(0.25)	(0.32)	(-1.38)	(-2.83)	(-3.78)	(-0.89)	(-0.59)	(-0.66)	(-0.88)	(1.22)
Netherlands	0.98	-0.27	1.35	-0.80	0.02	-0.41	0.82	0.66	0.35	0.54	0.16	0.55	0.90	-0.54	-0.10	-1.35	-0.24	-0.80	0.60	1.33
	(0.98)	(-0.23)	(2.36)	(-0.73)	(0.13)	(-0.21)	(1.07)	(0.47)	(0.21)	(-0.07)	(0.67)	(0.73)	(0.98)	(-0.41)	(-0.18)	(-2.21)	(-0.36)	(-2.04)	(0.22)	(1.49)
Poland	-0.33	-0.20	-0.79	-0.64	-0.46	0.20	-0.72	0.18	-0.56	-0.81	0.11	-0.08	-1.21	-0.83	-1.38	-1.02	-0.29	-0.83	-0.22	-0.71
	(-0.48)	(-0.24)	(-0.44)	(-0.75)	(-0.84)	(0.08)	(-0.69)	(-0.10)	(-0.76)	(-1.52)	(0.31)	(-0.06)	(-1.32)	(-0.70)	(-1.57)	(-1.23)	(-0.43)	(-2.89)	(-0.71)	(-0.82)
Russia	0.38	-1.29	0.04	-0.08	-0.07	-0.41	-0.84	0.47	0.09	-1.24	0.16	-0.03	-0.18	-5.37	0.04	-0.32	0.51	13.25	1.16	1.40
	(0.03)	(0.05)	(-0.0)	(-0.35)	(-0.60)	(-0.12)	(0.07)	(1.15)	(-0.19)	(-1.50)	(0.02)	(-0.54)	(0.43)	(0.17)	(-0.57)	(-0.75)	(0.28)	(1.51)	(0.53)	(1.08)
Sweden	-1.55	-0.88	-1.84	-1.62	-0.86	-0.49	0.22	0.64	0.38	0.30	-0.30	0.04	-0.58	-1.18	-1.75	-0.21	-0.30	1.41	0.06	-0.53
	(-1.56)	(-0.84)	(-0.51)	(-1.52)	(-1.11)	(-0.52)	(0.33)	(0.27)	(0.19)	(-0.0)	(0.16)	(0.23)	(-0.78)	(-1.03)	(-1.71)	(0.04)	(-0.38)	(-1.01)	(-0.38)	(-0.14)
Turkey	1.54	-1.23	-0.38	1.49	0.15	-0.16	-1.32	-0.01	-0.66	-0.20	0.51	0.02	-0.42	-0.27	-0.58	-0.88	-0.46	-1.94	-0.81	-7.11
	(1.47)	(-1.15)	(0.49)	(1.55)	(-0.18)	(-0.18)	(-1.08)	(-0.31)	(-0.81)	(-0.36)	(0.89)	(0.16)	(-0.19)	(-0.16)	(-0.51)	(-0.79)	(-0.58)	(-0.51)	(-1.12)	(-6.85)
Taiwan	1.71	-1.29	-0.70	0.36	0.43	-0.41	0.12	0.47	0.98	-1.24	0.16	-0.03	-0.18	-5.37	-1.29	-3.69	-0.31	13.25	0.30	-1.42
	(-2.10)	(-1.24)	(-3.22)	(-0.13)	(0.70)	(-0.32)	(-0.21)	(-0.44)	(-0.65)	(-1.81)	(0.20)	(0.48)	(-0.34)	(-3.07)	(0.07)	(-1.75)	(-0.81)	(4.75)	(-0.09)	(-1.98)
United States	1.71	-1.29	-0.70	0.36	0.43	-0.41	-0.84	0.47	0.98	-1.24	0.16	-0.03	-0.18	-5.37	-1.29	-3.69	-0.31	13.25	-0.78	3.10
	(0.49)	(0.19)	(0.28)	(-0.49)	(-1.51)	(-0.55)	(0.57)	(0.47)	(-0.07)	(-0.63)	(-0.08)	(0.10)	(0.79)	(-1.99)	(-0.37)	(-0.14)	(-0.41)	(-0.48)	(0.34)	(1.03)

Note: The upper values of each line are estimates using IV method, and lower values in parentheses are using OLS.

Table A 1 Two productivities using OLS and IV.

Regressand	log (corrected export of final goods)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log (energy use per production)	-0.140***				-0.269***			
	(0.00755)				(0.0477)			
log (CO_2 emissions from fuel combustion per production)		-0.157***				-3.941***		
		(0.00741)				(0.0981)		
log (NOx emissions per production)			-0.119***				-1.971***	
			(0.00630)				(0.0599)	
log (SOx emissions per production)				-0.0286***				5.093***
				(0.00395)				(0.156)
log (Labor per production)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual effects								
» Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
» Export country x Import country	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
» Import country x Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation Method	OLS	OLS	OLS	OLS	2SLS	2SLS	2SLS	2SLS
Observations	258318	257718	257718	257718	150188	149668	149668	149668
AIC	1034414.7	1031452.0	1031599.4	1031984.2				
R-square: overall	0.779	0.780	0.779	0.779	0.808	0.515	0.725	.

Note: We estimate the model (1) using data from 20 industries in 22 countries from 1995 to 2009. The industries and countries are listed in the Table 1. Export of goods is adjusted using IPR. Production variable is an output that is evaluated at the price in 1995. Year is time dummy. We control the fixed effects of Export country x Import country and Import country x Industry. *** represents statistical significance at 1 percent level. A test for the regressor with a correlation of error term or a measurement error is carried out, so the hypothesis of exogeneity of environment-related efficiency in the empirical model is rejected. A test of over-identification is carried out to check the adequacy of instrument variables, which are capital stock, government expenditure, indirect tax and subsidy, and dummy variables. The hypothesis of over-identification is not rejected. It is likely that at least some of these instrument variables may not be exogenous.