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Trade Openness and Environmental Emissions: Evidence from a Meta-Analysis

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Abstract

How trade affects environmental emissions has generated heterogeneous results over the years. This is due to empirical ambiguities that are endemic in the literature. In order to evaluate and explain the discrepancy in the literature, this paper conducts a meta-analysis of 88 empirical studies published until 2018. Our results show that trade contributes to environmental emissions after controlling for publication bias and heterogeneity. In explaining the heterogeneous results across the primary studies, our findings largely suggest the estimated elasticities depend systematically on the estimation characteristics, the choice of pollutants and the publication characteristics of the primary studies. Accounting for heterogeneity, the result remains robust only for CO_2 emissions compared to SO_2. Overall, the trade elasticity of emissions effect remains robust when we decompose the analyses for different groups of countries, however, the emissions-content of trade is more pronounced for developed compared to developing countries.

Keywords Emissions · Environment · Meta-analysis · Trade openness

JEL Classification F6 · F14 · F18 · C81

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1 Introduction

The trade-environmental literature has generated intense political and economic debates over the years mainly because of the contradictory results, especially in the empirical literature (van Bergeijk 1991). The debate is about whether the degree of exposure of a country in global trade or trade openness affects the level of environmental emissions. Not surprising, the debate has generated several empirical studies (see, e.g., Copeland and Taylor 2003; Rose and Stanley 2005; Managi et al. 2009; Shahbaz et al. 2017a). However, there is still ambiguity in the results because of the endemic heterogeneity in the empirical studies. The relationship between trade openness (hereafter trade) and environmental emissions is a sensitive global concern according to van Bergeijk (1991). This is due to the anecdotal evidence that shows a simultaneous surge in trade and environmental emissions globally.[1] These heightened global concerns and the anecdotal evidence have generated a keen research interest both from theoretical and empirical perspectives.

The traditional trade theories do not consider the welfare losses if international trade results in environmental emissions (hereafter emissions) (van Bergeijk 1991). However, Antweiler et al. (2001) provide a plausible mechanism through which trade openness can partially improve environmental quality. Through the positive impact of trade on income, in line with the popular evidence provided by Frankel and Romer (1999), Antweiler et al. (2001) argue a positive consequence of trade on the environment. This argument is premised on the basis that there is a higher tendency for the populace to demand more environmentally friendly (eco) products as their income rises. This is mainly because the environment is considered a normal good (Copeland and Taylor 2003). In contrast, environmentalists and economists alike have also argued that increased global trade generates increased production through economies of scale.[2] The growth in production directly contributes to over exploitation of the environment through increased production and consumption of pollution-intensive goods (Aklin 2016). The main argument is premised on the fact that the free market economy lacks the necessary impetus to efficiently allocate these environmental resources in a way that ensures the negative externalities are internalized.

Increasingly, many studies have also provided empirical evidence supporting either side of the theoretical positions. However, available empirical literature has deepened this uncertainty about the effect of trade on the environment. The uncertainty about the trade-environment nexus was acknowledged by van Bergeijk (1991), while a number of recent studies such as Rose and Stanley (2005), Managi et al. (2009) and Li et al. (2015) also reiterate it. These studies acknowledge the rapidly growing literature, as well as the contradictory results endemic in the empirical literature. Reviewing the past and recent literature confirms the uncertainty of these results. This emphasizes the fact that the trade-emissions debate has been lingering on for a long time without a consensus. Figure 1 highlights the discrepancy that is endemic in the 88 empirical studies used in our meta-analysis. The figure shows a 50-50 split between the results that the trade elasticity of emissions can either be positive or negative. The discrepancy also extends to the statistical significance of the

[1] According to the World Bank, world trade as a percentage of GDP has more than doubled over five decades, rising from 24 percent in 1960 to about 50 percent in 2016. Similarly, trends in global greenhouse gas (GhG) emissions indicate that GhG emissions are about 55% higher than in 1990 and 40% higher than in 2000 (Olivier et al. 2017)

[2] https://www.theatlantic.com/business/archive/2014/01/the-dark-side-of-globalization-why-seattles-1999-protesters-were-right/282831/, accessed on 1 January 2020

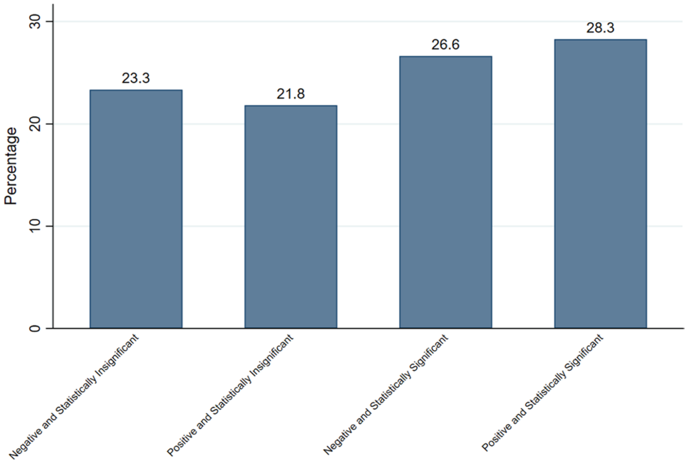

Fig. 1 The trade-emissions elasticity reported in the studies published in 1991-2018 (N=789). Data Source: Based on studies for the meta-analysis

effect as we see 55% of the studies find significant trade-emissions elasticity compared to 45% that find insignificant results.

The opposing evidence in the empirical literature makes it necessary to re-visit the subject to critically assess the state of knowledge. From the political economy perspective, this may have wider implications for many governments because the trade-environment nexus is a sensitive and policy-relevant concern. In response to this uncertainty, the main objective of this paper is to use the tool of meta-analysis to systematically determine whether the increasing level of trade openness is good or bad for the environment, especially after accounting for publication bias and heterogeneity.

Specifically, this paper has two main objectives. First, to estimate the average effect size or magnitude of the trade-emissions elasticity which would provide the underlying impact of trade on emissions. This is important because policy-makers are particularly interested in knowing how changes in trade openness would affect emissions. Therefore, it is imperative to identify the economic and statistical significance of these elasticities (Stanley and Doucouliagos 2012). For instance, Copeland and Taylor (2003) estimate that if trade liberalization increases economic activity by 1%, pollution concentrations would increase within the range of 0.25–0.5%, while an increase in income per capita decreases pollution concentration by 1.25–1.5%. Using the tool of meta-analysis, we can derive the underlying trade-environment elasticities.

Second, the paper seeks to explain the heterogeneity of the results in previously published empirical studies. Through a multivariate meta-regression analysis (MRA), we provide a quantitative assessment of the factors that can explain the heterogeneity of these studies. Thus, we can understand how the different characteristics of the studies such as study design, environmental indicators, sample of countries, econometric methods, and time period influence the results both qualitatively (sign of estimated coefficients) and quantitatively (size and significance of coefficients).

The next section of the paper provides a theoretical note and a brief empirical literature review on the relationship between trade and the environment. Section 3 discusses the data and the empirical strategy adopted in accordance with the Meta-Analysis of Economics

Research Network (MAER-Net) reporting guidelines. In Sect. 4, we provide and discuss the results. Section 5 concludes the paper and offers some policy implications and limitation of the study.

2 Relationship Between Trade and the Environment

2.1 A Theoretical Perspective

The basic theory of comparative advantage in international economics proposes countries specialize in the production of different products and then trade those products among themselves by transporting the goods from the point of production to consumption. Through the channels of production and transportation, these introduce a simple complementarity relationship between trade and the environment as increases in trade contribute to increases in emissions. However, Grossman and Krueger (1993) who were the first to postulate the trade-emissions nexus discard this simple linkage between trade and emissions as they analyze the environmental implications of the North America Free Trade Agreement (NAFTA). Following on the works of Grossman and Krueger (1993), Copeland and Taylor (2003) use a general equilibrium model that decomposes the net effect into three components; scale, technique and composition effects. In doing so, they take into consideration the possible exogenous and endogenous variations that are likely to exist between trade and the environment.

According to Grossman and Krueger (1993), the scale effect measures the increase in emissions as a result of an increase in the value of production in the economy, holding constant the mix of goods and production techniques. This scale effect is an adverse effect of trade on the environment as the scaling up of the endowments of the economy also expands the scale of production and emissions proportionately. The opening of trade could lead to a greater use of unemployed factors of production such as land and capital resources that may constitute environmental damage. The scale effect is aligned with the popular perception that more opened economies would adopt looser environmental standards for fear of losing competitiveness in international markets. This mechanism was confirmed by Copeland and Taylor (2003) in their pollution haven model of international trade in which they explain that trade may encourage pollution-intensive production processes to move from regions with high environmental standards to regions with low environmental standards.

A number of studies support this deleterious view of trade on the environment (see e.g., Managi et al. 2009; Shahbaz et al. 2017a; Li et al. 2015). They base their view on the theoretical premise that globalization leads to an increase in global demand, resulting in increased production that exploits the natural resources and pollutes the environment (van Bergeijk 1991). For instance, references are made to the Maquiladora zone established in Mexico with high concentration of polluting industries because of NAFTA, increased deforestation as result of timber trade, threats to endangered species due to international demand and low environmental quality in China as a result of export-led growth (Copeland and Taylor 2003; Aklin 2016) .

Conversely, through the technique effect, the increasing level of global trade may be benefical to the environment by curbing the the level of emissions. Grossman and Krueger (1993) identify two main channels through which this could occur. First, improvements in the production methods through increased access and the adoption of climate-friendly technologies. Firms that want to remain competitive in the global market would have incentives to develop and produce environmentally friendly goods. In addition, opening up for international trade could lead to a more efficient allocation of resources. This reduces the duplication of production processes in different locations, hence would reduce emissions. If every country has to produce to meet its domestic demand, this could result in duplication in the production process and therefore higher emissions. In line with the gains-from-trade hypothesis, trade can spur managerial and technical innovations and this can trigger the adoption of environmentally friendly technologies. Second, trade liberalization would also increase the availability of eco-friendly goods. Without international trade, consumers would have limited choices, and could be forced to purchase only domestic goods that may have been produced under lax environmental standards. In addition, Copeland and Taylor (2003) point to the fact the increasing levels of income that are as a result of the gain from trade may lead the general public to demand less pollution-intensive products thereby lowering emissions .

Also, the WTO through its green provisions has spurred enthusiasm among its members for environmental sustainable trade policies. Free trade agreements (FTAs), which are a major appendage of global trade, are also increasingly making an effort to make trade and environmental policies compatible. As countries seek to join FTAs, they are also made to simultaneously embrace environmental cooperation agreements. According to the joint report by the United Nations Environment Program (UNEP) and the WTO (2009), the European Communities (EC), Canada and the US are all ensuring that their trade and environmental policies are compatible as they require environmental impact assessments to be carried out before any FTA is signed. These countries have promulgated national policies that ensure trade is environmentally sustainable. For example, in 1999 the Canadian government issued a directive that requires a strategic environmental assessment of any policy, plan, or program before it receives ministerial or cabinet approval. Demonstrating how relevant the trade-environment nexus is to Canada, the government developed a framework in 2001 that stipulates environmental impact assessments are carried out before it signs any trade agreement.

Similarly, in the 1999, the EC also stipulated that environmental considerations should be integrated into the EC's trade negotiations strategy. The US also through an executive order in 1999, committed to conduct environmental assessments of certain trade agreements. Most proponents of trade liberalization emphasize that restricting international trade may not be a panacea to reduce emissions. For instance, Paarlberg (2013) argues that one of the unintended consequences of the US restriction of sugar imports using quotas contributed to a high domestic price of sugar for industrial use in the US and this led to substituting away from sugarcane ethanol to corn ethanol. However, the processing of ethanol from corn is less energy efficient and the agriculture of corn also depletes the land though the applications of fertilizer (Paarlberg 2013).

The composition effect measures the share of polluting goods in the total or national output. Depending on whether the pollution-intensive sector expands (contracts), this may be harmful (helpful) for the environment. The composition effect is ambiguous as this depends on changes in the structure of the economy. The net effect of trade on the environment depends on these three components and this effect can either be positive or negative depending on which of the effect dominates the others. Thus, we construct our main hypothesis taking into consideration that the effect of trade openness on emissions could be either positive or negative.

Hypothesis 1 An increase in trade openness leads to a significant change (i.e, increase or decrease) in environmental emissions.

The level of development of a country also dictates the depth of integration of that country in global trade and emissions. Frankel and Romer (1999) provide robust evidence of this by stating that countries that trade more experience higher economic growth as trade raises income by spurring the accumulation of physical and human capital and by increasing output for given levels of capital. Similarly, the level of development of a country is an important determinant of pollution. Copeland and Taylor (2003) argue that changes in per capita income will lead to an increase in the demand for lower environmental emissions. Peters et al. (2011) clarify this further by differentiating the effect of international trade on emissions from production and consumption perspectives for both developing and developed countries. From the consumption perspective, they argue that although emissions from developed countries have stabilized over the years, they are still largely responsible for emissions generated in developing countries since developed countries are large importers of emission-intensive products produced in developing countries. In a sense that through emission transfer a country that is not directly involved in the production of pollution-intensive goods can also contribute to emissions increase through its consumption (import) of pollution or energy-intensive products.

From the production perspective, developed countries are also specializing in knowledge intensive service, research and development and high-value segments of the global value chains. At the same time there is reallocation of dirty or pollution-intensive production from developed to developing countries. Thus, it is intuitive to expect a lesser production-induced emission in developed countries compared to developing countries. This is important as Peters et al. (2011) made the point that significant share of global emissions are from production of internationally traded goods and services. Differentiating the effect of FDI on emissions for developed and developing countries, Demena and Afesorgbor (2020) find a pronounced reducing effect of FDI on emissions for developed countries compared to developing countries, and they explain that this could be due to stricter environmental regulations on emissions in developed countries than in developing countries. That notwithstanding, for manufacturing products which tend to be more capital and pollution-intensive, this is still more concentrated in developed countries than developing countries. For example, WTO (2019) indicates that among the top 10 largest exporters of manufacturing goods in 2018, the EU accounts for 39% , the US accounts for 9% compared to China which accounts for 18%. China and Mexico are the only developing countries among the 10 top exporters of manufacturing goods.

This therefore leads to our second hypothesis in which we hypothesize that the trade-emission elasticity differs qualitatively and quantitatively for developed and developing countries. We define qualitative in terms of sign - whether the trade-emission elasticity is positive or negative while quantitative is define in terms of the size or magnitude of the trade-emission elasticity.

Hypothesis 2 The trade-emission elasticity differs qualitatively or quantitatively for developed and developing countries.

2.2 Empirical Overview of the Literature

Since, the overall effect depends on the three effects (scale, technique and composition effects), this introduces an empirical uncertainty about the effect of trade on the environment. Empirically, a number of studies have tested this theoretical exposition by decomposing the trade effect on the environment into the three different components. For instance, Antweiler et al. (2001) confirm that the impact of trade on the environment can be positive or negative. Using the sulfur dioxide (SO_2) concentration, they show that trade-induced technique effect on pollutant concentration outweighs the scale effect, while the composition effect is close to zero. Cole and Elliott (2003) also indicate that the net effect of trade in terms of sign and size on the environment depends to a large extent on the specific type of pollutant. In particular, they find that trade liberalization increases nitrogen oxide (NO_x) and carbon dioxide (CO_2) while it decreases the emissions of SO_2. The distinction of the trade effect on a specific pollutant is important as Frankel and Rose (2005) argue that the effect would depend on whether a pollutant is a local or global in nature.

The negative effect of trade on the environment is similarly supported in a recent study by Shahbaz et al. (2017a). They indicate that trade openness increases emissions through significant expansions in industrial output. As a result of rapid globalization and the quest to be competitive in global markets, both developing and developed countries have greater energy utilization leading to potential emissions of CO_2. Other empirical studies that find similar results that trade impedes air quality for both developing and developed countries (Li et al. 2015) and intensifies pollution in non-OECD countries compared to OECD countries (Managi et al. 2009). Contrary to this popular view, there are also studies such as Eiras and Schaefer (2001), Frankel and Rose (2005) and Kohler (2013) who also claim that the trade appears to have a beneficial effect for certain environment pollutants.

The pollution haven hypothesis (PHH) has direct implication for the effect of trade on the environment as the effect would depend on the specific country or level of development of the country. Antweiler et al. (2001) emphasize this point by stating that it is implausible to only focus on how trade affects the environment, but rather suggest that trade should be conditioned on a country's characteristics. In evaluating the effect of NAFTA on the environment, Grossman and Krueger (1993) identify a differential effect of NAFTA for the US and Mexico. They explain that through the mechanism of comparative advantage, increased trade among the NAFTA member countries would lead to an expansion of the labor-intensive sector in Mexico while leading to an expansion of the capital-intensive sector in the US. With labor-intensive production being a less pollution-intensive sector, emissions may decline in Mexico. Conversely, the US may see an increase in emissions because capital-intensive production is more pollution-intensive.

This example provides the nuance of the effect of trade on the environment, explaining that the effect may be conditional on a country's level of development. Different studies focus on a specific country as a case study or use a group of countries to assess the impact of trade on emissions. Using a large sample of developing and developed countries, Kim et al. (2019) confirm the heterogeneous results of trade on CO_2 emissions for different permutations of trade flows in terms of North-North, North-South, South-North and South-South trade. They find that for developed countries' trade with the North or the South, increases in trade flows lead to a reduction in CO_2 emissions. Whereas for developing countries, their trade with the North leads to an increase in emissions; however trade among themselves mitigates emissions. These differential results point to the fact that the effect of trade on emissions can be influenced by various institutional, economic and political factors. These factors differ for many countries and from one empirical study to the other as they evaluate the effect of trade on emissions using different set of countries, different proxies to control for institutional, economic and political factors. Thus, to effectively account for this variation in the different studies, it is very important to employ a multivariate meta-regression technique . By so doing, we can explain how country characteristics influence the effect of trade on the environment, as well as how different sets of control variables influence the reported results.

These conflicting positions in the empirical literature point to the need to synthesize existing knowledge in order to have a consensus about the effect of trade on the environment. The closest attempt made in the literature to derive a general consensus on the trade-environmental linkage was done almost a decade ago by Kirkpatrick and Scrieciu (2008). Although Kirkpatrick and Scrieciu conclude that trade liberalization is bad for the environment, they employ a conventional narrative review that relies on simple summaries instead of a systematic and objective review that is possible with meta-analysis. A meta-analytical review is an important tool to objectively review literature and also explain the heterogeneity in the previous studies. By using meta-analysis, we can filter out the personal biases and influences of the authors by controlling for biasing factors in econometric models (Stanley and Doucouliagos 2012). Apart from the methodological challenges of Kirkpatrick and Scrieciu (2008), the literature has also grown rapidly since their study was published in 2008. More specifically, 94% (i.e., 83 of the 88) of the empirical studies included in our analysis were published after 2008.

3 Data and Empirical Strategy

3.1 Data

Following the MAER-Net reporting guidelines of Stanley et al. (2013), we identify and collect data from empirical studies that estimate the effect of trade on the environment. To do this, we employ a search method from the economics, energy and environmental literature using a combination of keywords. Specifically, we use the Boolean connectors for the two keywords: *Trade (OR trade openness, globalization, import, export, international trade), AND Emissions (OR environment, pollution,* CO_2, SO_2, NO_x, *climate change, environmental quality)*. The search was conducted using different bibliographic databases including Google Scholar, Web of Science and Scopus. Using, for instance, the keywords (*trade and emissions*) produce about 2,300 individual studies. In addition, we complement our search using a backward search approach by looking at the bibliographies of previous studies. Apart from the backward search, we also use forward search by checking for papers that have cited previous papers. The search period was between May to August 2018, and coding of the papers was done by two independent researchers (one author and a research assistant) and the other author double-checked the data entry to ensure the highest standard of quality.

Out of the large number of studies produced from the search, we restrict the selection to journal articles and unpublished working papers that employed an econometric approach to determine the effect of trade on the environment. Through the inspection of the titles, abstracts, introductions and conclusions, we finally identify 88 studies that were relevant for our study objectives. Our final data set contains 789 observations which are estimated coefficients from the 88 primary studies published between 1991 and 2018. The large number of studies confirm that the trade-environment nexus is a topical issue and hence conducting a meta-analysis is long overdue.

In the identification of the relevant papers, we realize that while some studies adopt an econometric approach, they restrict their estimations to only Granger causality tests rather than elasticities. Thus, we eliminate such studies from the identified sample of studies. In terms of publication status, about 90% of the primary studies are peer-reviewed journal articles (78 out of the 88 primary studies included) and the other 10 are working papers.

The top five outlets in which the studies are published include Energy Policy (11 studies), Renewable and Sustainable Energy Reviews (9 studies) , Environmental Science and Pollution Research (6 studies), Economic Modeling (5 studies) and Natural Hazards (4 studies). The newest primary study was published in 2018 in Natural Hazards. Although the oldest study was published in 1991 by the Journal of World Trade, half of our primary studies were published in the last three years. As a result, the median study was published in 2015, indicating the environmental consequences of globalization have become a more sensitive issue recently as concerns related to climate change grow.

$$\begin{aligned} ln(emissions_{it}) &= \beta_0 + \beta_1 ln(GDPpc)_{it} + \beta_2[ln(GDPpc_{it}]^2 + \beta_3 ln(\mathbf{C})_{it} \\ &+ \boldsymbol{\delta} ln\left(\frac{X+M}{GDP}\right)_{it} + \alpha_i + \alpha_t + \epsilon_{it} \end{aligned} \tag{1}$$

Data on elasticities (coefficients), standard errors (t-statistics), sample size, econometric methods and empirical settings (city or country) from the identified empirical papers were then collected. A typical econometric model estimated by the studies from which we collect the necessary statistics uses the log-log regression as specified in Eqn. (1). The model is estimated at country level, where i and t capture the country and time effects respectively. The dependent variable is captured by $emissions_{it}$ which measures the emissions of different environmental pollutants. Different types of environmental pollutants were used as the outcome variable by different studies: 66% of the studies used CO_2, 19% using SO_2, while the remaining used other pollutants. The main variable of interest is the trade openness index, which produces δ that captures the trade-emissions elasticity. Table 9 in the appendix provides information on the studies used in our meta-analysis.

The conventional approach of measuring trade openness, $\frac{export(X)+import(M)}{GDP}$ is dominant in the empirical studies. The studies selected mostly measure trade using the conventional definition of trade openness, hence making them comparable. However, some studies compute trade openness as a ratio or percentage.[3] In terms of the functional form, about one-third of the studies employ a log-linear form and thus instead estimated semi-elasticities rather than elasticities. With such studies, we employ the Delta method in Gujarati (2009) to transform these effect sizes and their standard errors from semi-elasticities into full elasticities using the means, thus making the estimates comparable. If semi-elasticity is reported in the case of a log-linear functional form where the outcome variable is specified in a log form whereas the explanatory variable is in level, we use the sample mean for the trade variable to convert the semi-elasticity coefficients into full elasticity coefficients (Iršová and Havránek 2013; Demena and Afesorgbor 2020).

In addition, different studies used different sets of control variables (C_{it}). Apart from including GDP per capita (pc) and its square term to test for Environmental Kuznets Curve (EKC) hypothesis, most studies also control for the political, economic and institutional characteristics of the countries. These variables can also affect environmental quality in line with Torras and Boyce (1998) who show that literacy, political rights, and civil liberties tend to create a better environmental quality. In the case of panel regressions, the studies also control for individual country fixed effects (α_i) and time effects (α_t). Furthermore, there are also studies that employ a time series model, especially if they focused on a single country over longer time period. In case of the time series estimation, the estimated model

[3] Although not reported, our results remains robust when we decompose the results according to these different variants

Table 1 Simple and weighted means of the trade-emissions elasticity

Method	Effect size	S.E	95% confidence interval	
Simple average effect[a]	– 0.020	0.019	– 0.051	0.017
Weighted average effect[b]	0.011	0.008	– 0.04	0.027

Note: [a]represents the arithmetic mean of the trade-emissions elasticity, and [b]uses inverse variance as weight

is similar to (1), but without the *i* dimension. Because of the similarity of the primary studies in the specification of their econometric models, our coefficients are comparable across different studies. Although some studies employ different control variables, this could be accounted for by using the multivariate MRA.

3.2 Empirical Strategy

A meta-analysis involves collecting empirical estimates from previously published studies with the purpose of summarizing, integrating and synthesizing the combined effect sizes of the contrasting studies for a similar hypothesis, research question, and/or empirical effect (Stanley 2005). The combination of different studies helps to derive more precision and investigates the discrepancies. Stanley (2001) indicates that combining the results taken from individual studies would give more insight and greater explanatory power. Historically, meta-analysis has long been a standard for evidence-based research in medicines (Stanley and Doucouliagos 2012). Recent application of the meta-analysis approach in the trade literature include studies such as Afesorgbor (2017) and Cipollina and Salvatici (2010), which examine the effect of regional trade agreements on trade; Rose and Stanley (2005) which examine the effect of common currency on trade. For the environmental literature, Bel and Gradus (2016) examine the effects of unit-pricing on household waste collection while Ma et al. (2015) also examine consumers' willingness to pay for renewable energy. More recently, Demena and Afesorgbor (2020) also look at the effect of FDI on environmental emissions using 65 empirical papers.

For our empirical approach, we adopt a two-step method in line with the meta-analysis literature. In the first-step, we calculate the meta-average or the combined effect size using both unweighted and weighted averages. According to Card (2015), to avoid the erroneous method of giving equal weight to estimates from different studies, it is important to also construct weighted averages using the variance as weights. Thus, in Table 1, we compute the simple and weighted average effect of trade openness on environmental emissions. The simple average shows a negative value contradicting that of the weighted average and both effects are insignificant. However, in the presence of potential publication bias and heterogeneity, these mean values would be spurious.

$$\delta_j = \beta_0 + \beta_1 SE_j \tag{2}$$

Publication bias occurs largely when research papers with statistical significant results or consistent with the theory are preferred by editors, referees, or authors themselves, and thus, more likely to be accepted, and over-represented within research record (Stanley and Doucouliagos 2012; Havranek and Irsova 2011). To test and account for publication bias, we require the funnel asymmetry test (FAT) and the precision effect test (PET) analyses which are specified in Eqn. (2), where j captures the individual studies. The FAT is used to test the absence of publication bias. In the FAT test, a simple regression of the effect sizes (δ_j) on standard errors (SE_j) is conducted. A significant β_1 parameter indicates the presence of publication bias because without publication bias, the effect sizes will be independent of the standard errors. Apart from an econometric approach for testing publication bias, it can also be examined graphically using the funnel plot (see Fig. 2). From Eqn. (2), we can also derive the PET which indicates whether there is any genuine effect beyond publication bias. The coefficient β_0 captures the PET and the size of the coefficient indicates the average effect of trade on environmental emissions.

$$\delta_j = \beta_0 + \beta_1 SE_j + \beta_k \sum_{j=1}^{n} X_{kj} \tag{3}$$

In the second-step, a meta-regression or moderator analysis is conducted to determine how the differences in the individual studies affect the heterogeneity of the estimates. The individual studies differ in various dimensions, including sampled countries, sample size, environmental pollutants (CO_2, SO_2, NO_x), econometric models (log-log or log-linear, short and long-run, OLS or fixed effects), and types of data (panel or time series). These differences can drive the heterogeneous results in the literature. Taking stock of the literature shows substantial heterogeneity in terms of different pollutants, countries, econometric methods, time period and empirical results. To do this, we augment Eqn. (2) with the individual study characteristics (X_k). X_k represents the vector of variables that captures the individual heterogeneity in the studies. The multivariate MRA is relevant in order to filter out how the individual differences in the design of each empirical study affect the effect sizes reported. The relevant moderator variables are categorized into data, estimation and publication characteristics as well as macroeconomic, emissions and trade variables. Table 2 provides information on the detailed variables that were used for the moderator analysis.

In the estimation of these equations, there are some econometric concerns. First, the presence of outliers that deviate from the majority of the effect sizes that are clustered around zero. To deal with this and identify the possible outliers, we use the Hadi (1994) method to filter out both the effect sizes and their standard errors. This method has been identified as suitable for outliers in multivariate data and commonly used in various applications of meta-analysis (for recent literature, see Havranek and Irsova (2011); Demena and van Bergeijk (2017)). The application of this method resulted in the availability of 688 reported estimates from 84 studies for the analysis after excluding 101 observations (13% of the reported elasticities).[4] Second, the presence of heteroskedasticity makes ordinary least squares (OLS) econometrically infeasible to estimate the meta-regressions. Stanley and Doucouliagos (2012) indicate that since the effect sizes are coming from different studies, the variances of the effect sizes and the error terms would vary across studies and this violates the classical linear regression model. Homoskedasticity is a relevant assumption in estimation of classical linear regression model. Thus, they strongly suggest using the weighted least squares (WLS) approach by dividing the equations by the standard errors of the effect sizes. Using the WLS approach solves the problem of heteroskedasticity as this makes the variance approximately constant. Mathematically, the WLS procedure means

[4] So we excluded four studies on the basis of the Hadi (1994) approach namely; Dogan and Seker (2016), Kearsley and Riddel (2010), Onoja et al. (2014) and Opoku et al. (2014).

Table 2 Definition and descriptive statistics of collected variables

Moderator Variables	Definition	Mean	Std. Dev.
Outcome characteristics			
E	Trade-emissions elasticity	− 0.02	0.490
SE	Standard error of elasticity	0.174	0.428
Data characteristics			
Log duration of data	Logarithm of the number of years of the data used	3.17	0.662
Log observation	Logarithm of number of observations	5.45	1.714
Log number of countries	Logarithm of number of countries	1.855	1.603
Panel	= 1 if data set type is panel	0.51	0 .5
Time series	= 1 if data set type is time series	0.467	0.499
Data source	= 1 if data come from international sources	0.821	0.383
Estimation Characteristics			
Short run	= 1 if estimated elasticity is short-run	0.747	0.435
Long run	= 1 if estimated elasticity is long-run	0.253	0.435
OLS	= 1 if estimation method is OLS	0.185	0.388
Endogeneity	= 1 if endogeneity is controlled for either using an IV or GMM	0.516	0.5
Double log	= 1 if the coefficient is taken from a log-log form	0.59	0.492
Year FE	= 1 if year fixed effects are included	0.359	0.48
Country FE	= 1 if country fixed effects are included	0.432	0.496
Lag	= 1 if effect size represents lagged trade variable	0.07	0.255
Macroeconomic variables			
GDP	= 1 if GDP is included	0.922	0.268
Institution	= 1 if institutional variable is included	0.292	0.453
Energy consumption	= 1 if energy consumption is controlled for	0.574	0.495
Urbanization	= 1 if urbanization variable is controlled for	0.535	0.495
Emissions variables			
Carbon dioxide	= 1 if dependent is measured with carbon dioxide emissions	0.658	0.475
Sulfur dioxide	= 1 if dependent is measured with sulfur dioxide emissions	0.189	0.392
Other pollutants	= 1 if dependent is measured with other pollution measures	0.172	0.377
Trade variables			
Trade openness -value	= 1 if trade measured with values of export and import	0.125	0.331
Trade openness-ratio	= 1 if trade measured at per capita level	0.642	0.48
Trade openness -percentage	= 1 if trade measured as percentage of GDP	0.233	0.423
Publication characteristics			
Log publication year	Logarithm of the publication year of the study	2.198	0.494
Published	= 1 if published in a peer-reviewed journal	0.801	0.334
Log citations	Logarithm of citations in Google Scholar per age of the stud	1.97	1.157
Journal impact	Recursive journal impact factor from RePEc	0.081	0.203

The list of variables used to account for heterogeneity. Not all these potential moderator variables are included in our multivariate MRA. Since we adopted the G-to–S technique, insignificant variables during our first-regressions were dropped in the second stage. Moreover, some of the moderator variables were used as base/reference variables

Table 3 Bivariate MRA for FAT-PET: publication bias and underlying effect

	(1) OLS	(2) FE	(3) MEM
Genuine effect (PET/Precision)	0.030*	0.024	0.021***
	(0.017)	(0.016)	(0.005)
Bias (FAT/Constant)	− 0.518	− 0.370	− 0.394
	(0.425)	(0.361)	(0.300)
Observations	688	688	688
R squared	0.056	0.034	
Number of Studies	84	84	84

The dependent variables are the t-values of the associated reported elasticities. Robust standard errors clustered at the level of the study are reported in the parenthesis and all estimates use the inverse variance as weights. The R-square for the FE model in this Table and all subsequent tables report the within R-square. *$P < 0.1$, **$P < 0.05$, ***$P < 0.01$

that Eqn. (2) is equivalently estimated using Eqn. (4). t_j is the t-statistics, while $\frac{1}{SE_j}$ is the precision of the effect size.

$$t_j = \beta_1 + \beta_0 \frac{1}{SE_j} \tag{4}$$

Another important empirical concern is the issue of within-study dependence which emanates from the practice of collecting multiple effect sizes from each study. To guard against this, we cluster the standard errors at the level of the individual study to address the issue of within-study correlation for all the different estimators (Oczkowski and Doucouliagos 2015). In addition, we also employ fixed effect (FE) estimation clustered at the level of studies to address the issue of individual within-variation. Apart from these, between-study dependence is also a concern as we have collected reported estimates across studies published by the same authors. This is an important concern as reported estimates from different studies are likely to be correlated. Empirically, we have tested for the existence of between-study correlation, applying the Breusch-Pagan Langrange multiplier (BP-LM) method. The BP-LM revealed between-study level effect of 558.32 with p< 0.001, statistically significant at 1% level for the presence of between-study dependence. To account for this concern, we employ the mixed-effects multilevel (MEM) model as recommended by Stanley and Doucouliagos (2012). MEM is estimated using the restricted maximum likelihood when there is data dependence as a result of multiple effect sizes from the same study and authors.[5] Following this representation, therefore, estimates of trade-emissions elasticities as nested within each study and the estimates are modeled to differ between studies. Importantly, the relevance of controlling for between-study correlation using the MEM has been emphasized in recent studies such as Demena and van Bergeijk (2017), Floridi et al. (2020) and Havranek and Irsova (2011).

[5] We extend Eqn. 4 to account for data dependence using a two-level model: $t_{ij} = \beta_1 + \beta_0 \frac{1}{SE_{ij}} + \frac{\alpha_{kij} X_{kij}}{SE_{ij}} + \varsigma_j + \epsilon_{ij}$, where the subscript i is the estimate from the j study while k refers to the group for each category of the moderator variable presented in Table 2. ς_j refers to the study-level random

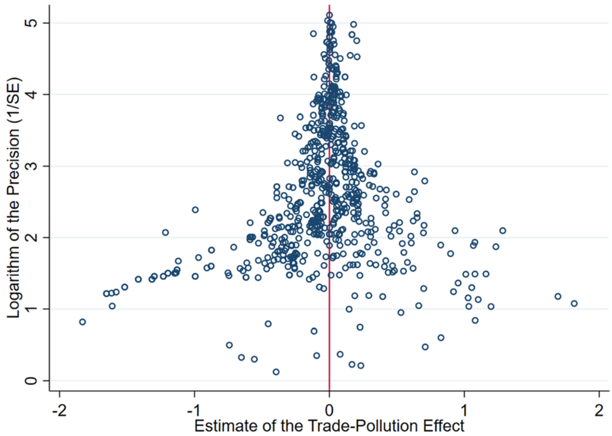

Fig. 2 The funnel plot: relationship between precision and effect sizes. Data Source: Based on studies for the meta-analysis

4 Results and Discussion

4.1 Bivariate FAT-PET Analysis

We present the bivariate results for the FAT-PET in Table 3. The results are estimated using three estimation techniques, OLS, FE and MEM, however, the MEM is our preferred method because it controls for both between and within heterogeneity. In all these estimations, we adjust for the data by using the WLS and cluster at the individual study level. The results show that there is a genuine effect of trade on the environment. The positive effect size for the PET is consistent across the three different estimation methods. The positive coefficient indicates that trade openness leads to a significant increase in emissions. Put differently, this means that more open-economies contribute more in terms of global emissions. On the basis of the MEM estimator, the size of the coefficient indicates that a 1% increase in trade openness contributes to about 0.02% increase in environmental emissions. The magnitude of meta-average is also plausible as Cole and Elliott (2003) find that 1% increase in trade intensity increases emissions for a median country by 0.04%. This confirms that increases in trade stimulate the scale of economic activity and through the scale effect, trade leads to an increase in emissions. Plausibly, increased global trade is mostly accompanied with increases in capital-intensive production techniques that have high emissions intensity (Copeland and Taylor 2003). The results therefore signals that the emission-increasing impacts of the scale and composition effects dominate the emission-reducing technique effect, thereby resulting in a positive net effect on emissions.

Turning to the FAT analysis, our results indicate the absence of publication bias as β_1 is statistical insignificant. This indicates that the effect sizes are independent of the standard errors. Thus, we can objectively conclude that there is no selection bias for significant

Footnote 5 (continued)

effects (random intercepts). This modeling represents individual reported estimates, which are level 1, and are clustered and nested within studies, which are level 2. This representation follows closely the work of Doucouliagos and Stanley (2009).

effect sizes in the literature. The FAT result is also confirmed by the funnel plot in Fig. 2. The figure is a scatter plot of the relationship between the effect sizes and the their precision (inverse of the standard errors). The figure is also symmetric from a pictorial point of view and that is in line with the assertion of Stanley and Doucouliagos (2012) that an asymmetric funnel is an antecedent for publication bias.

In line with the arguments of Copeland and Taylor (2003), we decompose the results for studies that use countries at different levels of development. We classify the countries into two main groups; developing and developed on the basis of the United Nations (UN) classification. Developed countries represent single country (e.g., Canada, the US and Japan) and multi-country (e.g., EU, OECD and groups of hing-income countries) case studies.

Similarly, developing countries also involve single country as well as multi-country case studies. In terms of single country studies, the countries include: Algeria, Bahrain, Bangladesh, Benin, Botswana, Brazil, Burkina Faso, Cameroon, China , Côte d'Ivoire, Egypt, Gabon, Gambia, Ghana, India , Indonesia, Iran, Ivory Coast, Jordan, Kenya, Korea, Kuwait, Laos, Lebanon, Malaysia, Mexico, Morocco, Myanmar, Niger, Nigeria, Oman, Pakistan, Philippines, Qatar, Saudi Arabia, Senegal, Sierra Leone, South Africa, Syria, Thailand, Togo, Tunisia, Turkey, UAE, Vietnam, and Yemen. Whereas, a group of developing countries represented as, Africa, LDCs, Middle East and North African (MENA) countries, low-income economies (LIE), emerging and developing economies. To account for studies that used a mix of these groups, we add another category for studies that include both developing and developed countries.[6]

Table 4 presents the FAT-PET results for different groups of countries. Consistently we find that trade increases emissions under the three different categories of countries. Although the results are similar qualitatively in terms of sign of the PET coefficient, quantitatively, the size or magnitude differs. We find a pronounced effect for developed countries compared to developing countries. The greater trade-emission elasticity for developed countries compared to developing countries supports the emission transfer argument by Peters et al. (2011) in which developed countries may not be directly involved in the production of pollution or energy-intensive products, but can also contribute to emission increase through their consumption (import) of those dirty goods. In addition, looking at it from consumption rather than production perspective, developed countries are more-opened economies, and they still account for relatively larger share of import of goods and services produced in developing countries. Thus, emission transfer via international trade as argued by Peters et al. (2011) may be responsible for why developed countries still have a pronounced effect compared to developing countries. This may not be surprising especially when Peters et al. (2011) indicate that the level of emissions reduction in developed countries is far less than emission transfer via international trade.

4.2 Multivariate Analysis

In addition to the bivariate analysis, we also conduct a multivariate or moderator analysis in order to account for the heterogeneity in the studies. This is important as the effect sizes reported in the empirical studies may have been influenced by several factors such as different countries, pollutants, time period, methodology and explanatory variables included

[6] The third category is the pool of both developing and developing countries in most case representing a global sample/cross country analysis.

Table 4 Bivariate MRA for FAT-PET: publication bias and underlying effect for different group of countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Developing Countries			Developed Countries			Both Countries		
	OLS	FE	MEM	OLS	FE	MEM	OLS	FE	MEM
Genuine effect (PET/Precision)	0.025 (0.017)	0.0162 (0.017)	0.0136*** (0.005)	0.012 (0.024)	0.0332*** (0.005)	0.031*** (0.009)	0.076 (0.049)	0.064 (0.046)	0.062*** (0.0152)
Bias (FAT/Constant)	− 0.712 (0.507)	− 0.499 (0.393)	− 0.248 (0.349)	− 0.010 (0.723)	− 0.389*** (0.089)	− 0.752 (0.833)	− 0.170 (0.583)	0.083 (1.005)	− 0.127 (0.715)
Observations	501	501	501	83	83	83	104	104	104
R squared	0.047	0.018		0.006	0.152		0.202	0.150	
Number of Studies	60	60	60	15	15	15	15	15	15

The dependent variables are t-values of the associated reported elasticities. Robust standard errors clustered at the level of the study are reported in the parenthesis and all estimates use the inverse variance as weights. Both countries represent regression specification including both developing and developed countries. $^{*}P < 0.1$, $^{**}P < 0.05$, $^{***}P < 0.01$

Table 5 Explaining heterogeneity in the trade-emissions elasticity for all countries

VARIABLES	(1) OLS	(2) FE	(3) MEM
Genuine effect (PET/Precision)	0.146*** (0.0503)	0.117 (0.133)	0.139*** (0.0443)
Bias (FAT/Constant)	− 0.273 (0.398)	0.0363 (0.185)	0.258 (0.259)
Countries	0.000319** (0.000137)	0.000160 (0.000198)	0.000178 (0.000127)
OLS	− 0.0273** (0.0116)	− 0.0263 (0.0233)	− 0.0279*** (0.0103)
Double Log	− 0.0785*** (0.0162)	− 0.0868*** (0.0207)	− 0.0857*** (0.0126)
Country FE	0.0291* (0.0174)	0.0481** (0.0227)	0.0407*** (0.0134)
Lag	0.0259*** (0.00865)	0.0168 (0.0136)	0.0191 (0.0137)
Trade percentage	0.0283** (0.0133)	0.0246 (0.0247)	0.0287** (0.0113)
Carbon dioxide	0.0147 (0.0117)	0.0115 (0.0204)	0.0159* (0.00931)
Sulfur dioxide	− 0.0831*** (0.0237)	− 0.0623** (0.0282)	− 0.0629*** (0.0130)
Urbanization	− 0.0482*** (0.0107)	− 0.0266 (0.0194)	− 0.0304*** (0.00914)
Publication year	− 0.0501** (0.0193)	− 0.0428 (0.0490)	− 0.0486*** (0.0173)
Reviewed	0.0883*** (0.0146)	0.0876** (0.0389)	0.0863*** (0.0160)
Citations	− 0.0239*** (0.00751)	− 0.0267 (0.0161)	− 0.0297*** (0.00607)
Observations	685	685	685
R-squared	0.344	0.247	
Number of Studies	83	83	83

The dependent variables are the t-values of the associated reported elasticities of Eqn. (5): Robust standard errors clustered at the level of the study are reported in the parenthesis and all estimates use the inverse variance as weights. *$P < 0.1$, **$P < 0.05$, ***$P < 0.01$. All the covariates have been divided by the standard errors

in the econometric models. Stanley and Doucouliagos (2012) highlight that if the heterogeneity is non-random, then the results from bivariate analysis may be biased. Econometrically, we account for the heterogeneity in line with the MAER-Net guidelines by coding explicitly any differences in research dimensions such as data, estimation and publication of the empirical studies (Stanley et al. 2013).

To capture these dimensions, we use dummy variables as defined in Table 2 that could potentially explain the effect sizes. However, because of the high dimensionality and possible multicollinearity of the moderator variables, we employ the general-to-specific (G-to-S) approach. The G-to-S approach begins with the inclusion of all potential moderator variables in the Eqn. (3) and then removing the insignificant variable one at time until only statistically significant variables remain (Stanley and Doucouliagos 2012). This is in line with the MAER-Net reporting guidelines. The guidelines recommend the use of the G-to-S modeling approach to simplify the multivariate MRA. The G-to-S approach has an added advantage of improving the degrees- of-freedom and avoiding the situation of multicollinearity. Table 5 reports the results for the multivariate analysis. The moderator variables included in Table 2, but not in Table 5, are insignificant variables that are excluded due to the G-to-S approach. Thus, the following 13 moderator variables; trade openness-ratio, long run, year FE, endogeneity, log duration of the data, data source, institution, panel, time series, GDP, log of observation, journal impact, and energy consumption were excluded. Empirically, the joint test [F(13, 657)=0.99] of the excluded moderator variables did not reject the null hypothesis of a zero-joint effect (p-value: 0.459), supporting that the excluded variables are not only individually but also jointly insignificant.

The genuine effect of trade on the environment remains robust even after accounting for various dimensions of heterogeneity. The PET finds a positive and significant coefficient for the trade-emissions elasticity. Thus, confirming the robustness of the result that trade spurs environmental emissions. The result for FAT also confirms the absence of publication bias. Our results from the multivariate MRA also show that the different moderator variables affect the effect sizes differently. First of all, the estimation characteristics tend to have a significant effect on trade-emission elasticities. Based on column (3) of Table 5, studies that employ OLS estimation tend to report lower effect sizes by 0.0279. Conversely, including country fixed effects in the regression models also produces a greater effect size. For instance, for studies that control for country fixed effects on average have emissions that are higher by 0.0407 compared to studies without country fixed effects. In addition, the double logarithmic functional form leads to less pronounced effect of trade on environmental emissions by 0.0857.

Similarly, studies that define trade openness in terms of exports plus imports as a percentage of GDP as compared to the studies that measure trade openness with values of export plus imports (i.e., not weighted by GDP) find a more pronounced effect of trade on emissions, reporting on average 0.0287 higher emissions. Importantly, we find that the choice of the pollutant matters and has an underlying effect on the trade-emissions elasticity. Studies that use CO_2 as a pollutant find larger effects compared to studies that used other pollutants. For CO_2 as a pollutant, reported effects increase by 0.0159, providing more positive trade-emissions effects as compared to other pollutants such as nitrogen dioxide, other volatile organic compounds or other pollutant measures. For SO_2 the effect goes in the opposite direction, reducing emissions by 0.0629.

Studies that include urbanization as an additional control variable in explaining the variation in emissions also have a smaller effect of trade on emissions. This simply confirms trade and urbanization are correlated such that if urbanization is omitted this is likely to bias the trade-emission elasticity. Theoretically, this is expected as urbanization and trade can be related (Charfeddine and Khediri 2016). For instance, Ades and Glaeser (1995) and Krugman and Elizondo (1996) relate trade and urbanization by arguing that trade restriction and low levels of international trade increase the concentration of urban population while increasing trade liberalization would likely weaken urbanization. Empirically, Kasman and Duman (2015) find that there is a unidirectional causality running from energy consumption, trade and urbanization to emissions. A sub-sample analysis for different groups of countries (developing vs. developed countries in Table 7) indicates that controlling for urbanization has a negative and significant effect for developing countries but insignificant for developed countries. Martínez-Zarzoso and Maruotti (2011) confirm the differential

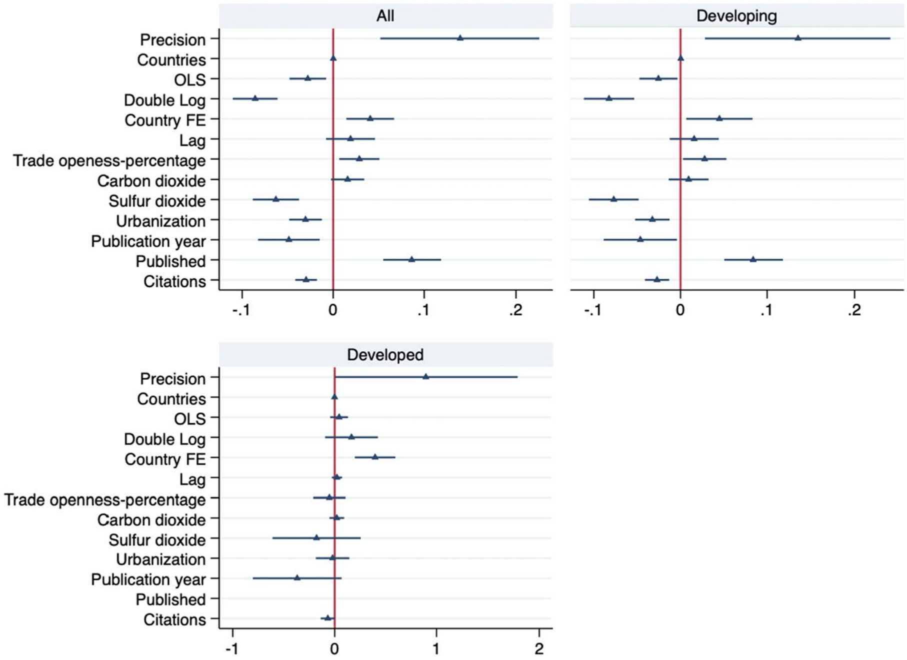

Fig. 3 The plot of the estimated coefficients and their 95% confidence intervals. Note: This is based on the the MEM results for Table 5 (All) and Table 6 (developing and developed countries)

effect of urbanization on emissions for both developing and developed countries. Most importantly, the pace of urbanization has been more rapid for developing countries while that of developed countries has remained largely the same (Yuan and Guanghua 2015).

For the publication characteristics, our results show that the year of publication has a negative and significant effect. This means that more recent studies tend to produce lower trade-emissions elasticities (on average 0.0486 lower). This finding is in line with the 'economics research cycle' hypothesis (Goldfarb 1995) which suggests that seminal research often produces large and significant estimates. While skeptical follow-up studies become common and may dominate the literature and commonly exhibit a downward trend of the empirical effect in question. Similarly, the quality of the papers considered in our meta-analysis as captured by the moderator variable, number of citations in Google Scholar, has a significant effect on the reported effect sizes. If the number of citations increases by one this significantly reduces the effect sizes by a magnitude of 0.0297. Apart from these, studies that have been reviewed and published in academic journals tend to report a greater impact (peer-reviewed studies likely to report about 0.0863 higher emissions).

4.3 Further Analyses and Best Practice Approach

We conduct two main further investigations by running the multivariate analysis for different groups of countries and also for different pollutants. Table 6 presents the results for different groups of countries. Consistently, we find that there is a genuine underlying effect of trade on the environment irrespective of the country of study. From the qualitative point

Table 6 Explaining heterogeneity in the trade-emissions elasticity for different group of countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Developing Countries			Developed Countries			Both Countries		
	OLS	FE	MEM	OLS	FE	MEM	OLS	FE	MEM
Genuine effect (PET/Precision)	0.139** (0.0569)	0.160 (0.179)	0.135** (0.0543)	1.627 (1.170)	1.245*** (0.186)	0.895** (0.455)	0.711*** (0.176)	− 0.780** (0.342)	0.432 (0.506)
Bias (FAT/Constant)	− 0.496 (0.531)	− 0.223 (0.233)	0.275 (0.315)	− 0.0900 (0.650)	0.165 (0.118)	− 0.614 (0.0935)	0.330 (0.498)	0.689 (0.671)	0.615 (0.599)
Countries	0.000556** (0.000246)	0.000457 (0.000332)	0.000401 (0.000275)	0.000290 (0.00146)	− 0.000314 (0.000256)	− 0.000516 (0.000932)	− 0.000671 (0.000594)	− 0.00105 (0.000961)	− 0.000675 (0.000437)
OLS	− 0.0250* (0.0130)	− 0.0261 (0.0259)	− 0.0255** (0.0112)	− 0.177 (0.114)	0.0644* (0.0349)	0.0439 (0.0447)	− 0.0542 (0.117)	0.0717 (0.191)	− 0.0409 (0.0616)
Double Log	− 0.0734*** (0.0197)	− 0.0870*** (0.0271)	− 0.0824*** (0.0148)	0.345 (0.279)	− 0.0439 (0.0865)	0.165 (0.132)	− 0.0999 (0.105)	0.0424 (0.252)	− 0.0656 (0.0623)
Country FE	0.0308 (0.0247)	0.0593* (0.0344)	0.0450** (0.0195)	0.278 (0.224)	0.536*** (0.0564)	0.397*** (0.101)	0.0486 (0.133)	0.198 (0.191)	0.0853 (0.0680)
Lag	0.0213** (0.00834)	0.0189 (0.0154)	0.0158 (0.0144)	0.0305 (0.0245)	0.0380*** (0.00317)	0.0225 (0.0256)			
Trade percentage	0.0247 (0.0162)	0.0272 (0.0246)	0.0279** (0.0128)	− 0.00209 (0.121)	− 0.180*** (0.0405)	− 0.0515 (0.0807)	− 0.0520 (0.0913)	− 0.238 (0.202)	− 0.0937 (0.0671)
Carbon dioxide	0.00930 (0.00919)	0.00381 (0.0121)	0.00939 (0.0118)	0.0913** (0.0314)	0.0190*** (0.000338)	0.0211 (0.0368)	0.0917*** (0.0175)	0.123*** (0.0391)	0.104*** (0.0246)
Sulfur dioxide	− 0.106*** (0.0110)	− 0.0736*** (0.0252)	− 0.0770*** (0.0146)	0.126 (0.306)	− 0.680*** (0.164)	− 0.177 (0.221)	0.0455*** (0.0152)	0.0583* (0.0318)	0.0454 (0.0307)
Urbanization	− 0.0511*** (0.0117)	− 0.0300 (0.0196)	− 0.0325*** (0.0101)	0.114 (0.154)	0.0846 (0.0545)	− (0.0836) 0.0203	− 0.0356 (0.0431)	0.0718 (0.0768)	− 0.0143 (0.0351)
Publication year	− 0.0448** (0.0212)	− 0.0661 (0.0717)	− 0.0463** (0.0215)	− 0.807 (0.595)	− 0.348*** (0.103)	− 0.367* (0.222)	0.0325 (0.0919)	0.348 (0.296)	0.00578 (0.0860)
Reviewed	0.0858*** (0.0172)	0.0952* (0.0478)	0.0839*** (0.0170)				− 0.600* (0.315)	− 0.338 (1.031)	− 0.286 (0.514)

Table 6 (continued)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Developing Countries			Developed Countries			Both Countries		
	OLS	FE	MEM	OLS	FE	MEM	OLS	FE	MEM
Citations	− 0.0209* (0.0109)	− 0.0206 (0.0197)	− 0.0270*** (0.00714)	− 0.0688* (0.0388)	− 0.182*** (0.00714)	− 0.0668* (0.0356)	− 0.0281 (0.0598)	0.144 (0.265)	− 0.0469 (0.0469)
Observations	501	501	501	80	80	80	104	104	104
R-squared	0.314	0.237		0.377	0.618		0.624	0.559	
Number of Studies	60	60	60	14	14	14	15	15	15

The dependent variables are t-values of the associated reported elasticities. Robust standard errors clustered at the level of the study are reported in the parenthesis and all estimates use the inverse variance as weights. $^{*}P < 0.1$, $^{**}P < 0.05$, $^{***}P < 0.01$. We lose the coefficients for some variables as results of lack of variation within the sub-sample. All the covariates have been divided by the standard errors of view, the results indicate that the trade-emissions elasticity is positive and significant for both developing and developed economies. Quantitatively, we again find the trade-emissions elasticity is more pronounced for developed countries than for developing countries. For studies that mix developed and developing countries (both countries), although the effect is positive and this is not significant. The results as to how the heterogeneity or differences in the design of the studies explain the effect sizes are summarized in Fig. 3.

A further robustness check is the multivariate regression for different pollutants as indicated in Table 7. First, we find a significant FAT which is a clear indication of publication bias when we disaggregate the sample by the type of pollutants. Specifically, using the partitions of Doucouliagos and Stanley (2013), the size of the bias for CO_2 will be classified as little to modest, but substantial for SO_2. This means that publication selectivity was only significant for studies that focused on SO_2. In addition, this could be an indication that there was a possible offset between CO_2 and SO_2 when these studies are combined. Second, we find that the trade-emissions elasticity is positive and strongly significant when environmental pollutant of interest is CO_2. Although the trade-emissions elasticity is positive for SO_2, the effect is not statistically significant. This differential effect on CO_2 and SO_2 is in line with Frankel and Rose (2005). They argue CO_2 has a free-rider problem as its adverse effects transcend national borders. Thus, individual countries are less committed to reduce their CO_2 emissions, especially for the reason of remaining competitive in the global market. This differential effect for CO_2 and SO_2 is also supported empirically by Demena and Afesorgbor (2020) in which they found that the effect of FDI in reducing emissions was more pronounced for SO_2 compared to CO_2. They explain that since SO_2 is a local pollutant, governments are more eager to clamp down on its emissions in order to prevent the associated health hazards for the local populace.

The inclusion of observable sources of heterogeneity provides a better estimation of the genuine effect (PET) of trade on the environment. However, the PET coefficient is no longer the measure of the underlying effect like in the case of bivariate MRA. The underlying effect is obtained from the combination of the PET variable and other variables that are included in the multivariate MRA. With the multivariate MRA, neither publication bias nor the authentic effect is represented by one single moderator variable (Stanley and Doucouliagos 2012). They argue that there is no single variable that can be regarded as the authentic one, but rather a combination of selected moderator variables used to capture the heterogeneity. Largely, the underlying effect would depend on the professional judgment of the meta-analyst conditional on the selected sources of heterogeneity.[7]

In what follows, we explore the findings presented in Table 5 to derive the "best practice" genuine effect. We apply the 'best practice' approach by limiting the explanatory variables to a subset consisting of indicator variables for CO_2, country fixed effect, double-log and urbanization. We select these variables because they are widely used by most of the primary studies included in our analysis. We also consider a set of publication characteristics of studies included in our analysis. Thus, a subset of the following variables; publication year of the study, peer-reviewed, as well as the citation of the primary studies were included. We select these variables for three reasons. First, recent studies report lower elasticities (as shown in Table 5) and this is consistent with the 'economics research cycle' hypothesis. Second, 80% of our samples is constructed from peer-reviewed publications. Most researchers would argue that peer-reviewed studies are of higher quality

[7] This approach is labeled as the "best practice" in Stanley and Doucouliagos (2012).

Table 7 Robustness: Effect of trade on different pollutants

	(1)	(2)	(3)	(4)	(5)	(6)
	Carbon dioxide			Sulfur dioxide		
	OLS	FE	MEM	OLS	FE	MEM
Genuine effect (PET/Precision)	0.190** (0.0723)	0.417** (0.182)	0.241*** (0.0646)	0.526 (0.532)	0.538 (0.608)	0.392 (0.436)
Bias (FAT/Constant)	0.272 (0.332)	0.810*** (0.206)	0.601** (0.295)	− 2.292*** (0.598)	− 2.212*** (0.119)	− 1.291* (0.779)
Countries	2.02e-05 (0.000135)	− 0.000445** (0.000204)	− 0.000174 (0.000173)	0.00536*** (0.00136)	0.00234* (0.00101)	0.00266* (0.00155)
OLS	− 0.0410** (0.0170)	− 0.0321 (0.0289)	− 0.0311* (0.0163)	0.123** (0.0507)	0.0833*** (0.0148)	0.0898*** (0.0232)
Double Log	− 0.0914*** (0.0175)	− 0.0952*** (0.0241)	− 0.0897*** (0.0162)	0.193* (0.0858)	2.301*** (0.0516)	0.593 (0.459)
Country FE	0.0678** (0.0299)	0.0523* (0.0306)	0.0759*** (0.0222)			
Lag	0.0206* (0.0120)	0.00682 (0.0103)	0.00893 (0.0154)			
Trade percentage	0.0434** (0.0171)	0.0682*** (0.0253)	0.0521*** (0.0144)			
Urbanization	− 0.0334* (0.0176)	0.0490 (0.0354)	− 0.00385 (0.0157)	− 0.114* (0.0507)	− 0.0533 (0.0325)	− 0.0569* (0.0294)
Publication year	− 0.0613** (0.0288)	− 0.188** (0.0774)	− 0.0944*** (0.0277)	− 0.154 (0.185)	− 0.180 (0.222)	− 0.124 (0.159)
Reviewed	0.121*** (0.0209)	0.188*** (0.0429)	0.128*** (0.0213)	− 0.0277 (0.0548)	− 0.0316 (0.0263)	− 0.0315 (0.0281)
Citations	− 0.0424*** (0.00963)	− 0.0659*** (0.0233)	− 0.0468*** (0.00892)	− 0.176 (0.0991)	− 0.113 (0.103)	− 0.0995 (0.0873)
Observations	452	452	452	129	129	129
R-squared	0.333	0.171		0.596	0.267	
Number of groups	75	75	75	8	8	8

The dependent variables are t-values of the associated reported elasticities. Robust standard errors clustered at the level of the study are reported in the parenthesis and all estimates use the inverse variance as weights. $*P < 0.1$, $**P < 0.05$, $***P < 0.01$. We lost coefficients for some variables as a result of lack of variation within the sub-samples. All the covariates have been divided by the standard errors

Table 8 Meta-effect based on best practices

MEM method	(1) Meta-effect	(2) S.E	(3) *P*-value	(4) 95% confidence interval
Meta-effect for full sample	0.116***	0.031	0.000	0.054–0.178
Meta-effect for developing countries	0.113***	0.040	0.005	0.034–0.191
Meta-effect for developed countries	0.973***	0.352	0.006	0.284–1.662

*$P < 0.1$, **$P < 0.05$, ***$P < 0.01$

than those that are not (Stanley and Doucouliagos 2012). Third, we also use the number of citations of the studies as this could be an indicator of the quality of study and the reliability of the effect sizes.

For our 'best practice' results, we present the results based on Table 5 (the full sample) and Table 6 (for developing and developed economies data separately) to obtain the genuine effect conditional on observable sources of heterogeneity, using our preferred estimation - MEM. The results are provided in Table 8. The best practice effect produces an elasticity of 0.113 which is strongly statistically significant at 1% level of significance for the full sample. When we conduct the analysis for the sub-sample groups of developing and developed countries separately, the approach yields similar positive results, but different in terms of the magnitude of the effect. Specifically, we find genuine and significant effects of 0.097 and 0.947 for developing and developed countries, respectively. In this regard, the genuine effect results suggest that trade openness contributes to emissions more significantly for developed countries compared to developing countries. Therefore, after correcting for publication bias, controlling for the potential moderator variables and the best-practice approach, all these findings indicate that the meta effect is positive and significant, suggesting trade openness contributes to environmental emissions.

5 Conclusion

Without doubt, the effect of trade on the environment is a controversial topic. Although there is a rapidly growing literature on the linkage between trade and the environment, there is no certainty about the underlying effect as there is a wide range of conclusions from similar studies. Thus, the simple question of whether trade is good or bad for the environment has received a great deal of attention both theoretically and empirically, however, we are far from reaching a definite conclusion or consensus.

The conflicting positions in the literature may have implications for environmental policies in many countries as countries may be selective of research to support their (in) actions for the environment. Individually, many countries have also recognized the strong linkage between globalization and the environment, and are thus making polices to ensure that their quest to remain competitive globally are not achieved at the expense of the environment. In contrast, there are also countries that have not taken the needed actions or designed environmental regulations to formalize their environmental commitments of reducing emissions. Shahbaz et al. (2017a), for instance, argue that the lack of consensus on the trade-environmental linkage as one of the key reasons for inaction on appropriate environmental regulation policies to curb emissions. This paper makes the first attempt to synthesize the trade-emissions effect size by employing the tool of meta-analysis which is the most objective and quantitatively rigorous approach to do a systematic review of empirical literature. Our main findings are as follows:

First, our results discount the presence of publication bias in the literature. This means that, the personal bias of researchers, reviewers and editors does not follow any systematic trend in the literature. After accounting for publication bias, we find that trade increases emissions level. Specifically, employing the bivariate FAT-PET analysis in accordance with the MAER-Net guidelines, we find that a 1% increase in the trade openness of a country leads to an increase in the level of emissions ranging from 0.02 to 0.06%. However, estimating the corrected effect from the multivariate MRA, conditional on observable sources of heterogeneity, improves the size of the effect. We find that the underlying meta effect is 0.113 and this is strongly statistically significant. This suggests trade openness has a positive and significant effect on emissions notably after controlling for publication bias and heterogeneity. Overall, increases in trade intensity increase environmental emissions due to a large scale effect that dominates the technique effect. This finding supports the view that globalization can result in the adoption of loose-environmental production techniques. The increased production coupled with increased global demand indirectly contribute to the exploitation of the environment and the depletion of natural resources.

In addition, the magnitude of the effect size depends on whether a country is developed or developing as we find a more pronounced effect for developed economies. This could largely be explained from the concept of emission transfer where developed countries although are not dominantly involved in the manufacturing of energy-intensive products, but still contribute to emissions through their consumption of those environmental dirty products produced in developing countries.

With significant heterogeneity across the empirical studies, it is imperative that we account for differences in the study designs. By accounting for the heterogeneity, we can also explain how specific differences such as data, publication, estimation and other variations affect the validity of the results. Using moderator regression analysis and the G-to-S modeling approach, we find that the positive effect of trade on environmental emissions is strongly robust. For the various dimensions of the study that affect the effect sizes, we find that estimation techniques (OLS or FE) significantly reduce the trade-emissions elasticity. In addition, the functional form of the regression model, the inclusion of country fixed effects, the definition of trade openness as exports and imports as percentage of GDP, the type of pollutant, the inclusion of urbanization as an additional control variables, the year of publication, the number of citations and whether a study has been published or not all have significant effects on the effect sizes.

The findings of this study may have interesting policy implications, as trade could be used to minimize or avoid the potential adverse environmental effects and maximize the positive impacts of globalization on environment. Our results that trade contributes to increased global emissions highlight the importance of making trade policies more compatible with sustainable environment policies by incorporating environmental decision-making into trade policy formulation. For instance, this emphasizes that environmental taxes should be aligned with a firm's participation in global trade. This also reinforces the relevance of including the distribution or transportation component in the calculations of carbon taxes. The results also put the WTO in the limelight as it may be required that they play a directly active role in clamping down on environmental emissions. The WTO could use the gains associated with global trade as effective bargaining strategies to demand environmental accountability from countries hoping to benefit from global trading systems.

In addition, regional trade agreements (RTAs) that are major appendage of the global trading systems could be used to effectively promote sustainable trade and environmental policies simultaneously. As countries seek to join RTAs, they also embrace environmental cooperation agreements. For instance, many countries including Canada and those in the EU, have developed national policies that stipulate that prior to signing any trade agreement, environmental impact assessments must be carried out. That means that any country that signs trade agreements with those countries would also automatically sign environmental cooperation deals.

In the light of our meta-analysis, future research should focus particularly on increasing the number of studies as this topic has generated keen debate within policy circles and the literature is continuously growing. Our data collection ended in August 2018 and the literature on this topic has increased already from that time period. In addition, we have excluded some studies because of the lack of information on key variables that are required for conducting meta-analysis (e.g., some studies that do not report t-values and standard errors). Although we did make frantic effort to contact the authors of these excluded studies to obtain those missing data in their papers, the success rates are very low.

Appendix

Table 9.

Table 9 Appendix A: List of studies

Count	Study (year)	Pub type	Country	Data start	Data end	No of est.	Mean E.S	S.D.	Min	Max
1	Akin (2014)	PR	Mixed	1990	2011	6	0.348	0.52	– 0.121	1.011
2	Ali et al. (2016)	PR	Nigeria	1971	2011	2	– 0.326	0.098	– 0.395	– 0.257
3	Aller et al. (2015)	PR	Mixed	1996	2010	20	0.287	0.581	– 0.994	1.285
4	Al-mulali (2012)	PR	Mixed	1990	2009	6	1.834	0.595	1.055	2.436
5	Al-Mulali et al. (2015)	PR	Europe	1990	2013	5	– 0.302	0.122	– 0.493	– 0.19
6	Al-Mulali et al. (2016)	PR	Kenya	1980	2012	8	0.242	0.065	0.136	0.331
7	Atici (2009)	PR	Central and Eastern Europe	1980	2002	2	– 0.033	0.004	– 0.035	– 0.03
8	Atici (2012)	PR	Southeast Asian	1970	2006	7	0.394	0.235	0.05	0.63
9	Aung et al. (2017)	PR	Myanmar	1970	2014	5	– 0.03	0.013	– 0.049	– 0.017
10	Ayeche et al. (2016)	PR	Europe	1985	2014	1	0.077	0	0.077	0.077
11	Baghdadi et al. (2013)	PR	Mixed	1980	2002	10	– 0.033	0.045	– 0.086	0.042
12	Bernard and Mandal (2016)	PR	Mixed	2002	2012	10	0.013	0.104	– 0.115	0.209
13	Boutabba (2014)	PR	India	1971	2008	2	– 0.007	0.076	– 0.061	0.047
14	Bouznit and Pablo-Romero (2016)	PR	Algeria	1970	2010	16	– 0.061	0.47	– 0.97	0.65
15	Çetin and Ecevit (2017)	PR	Turkey	1960	2011	8	0.21	0.234	0.029	0.699
16	Charfeddine and Khediri (2016)	PR	United Arab Emirates	1975	2011	1	– 0.373	0	– 0.373	– 0.373
17	Choi et al. (2010)	WP	China and Korea	1971	2006	6	– 0.731	0.391	– 0.908	0.001
18	de Sousa et al. (2015)	WP	China	2003	2012	25	– 0.77	0.52	– 1.652	– 0.017
19	Dogan and Turkekul (2016)	PR	USA	1960	2010	2	– 0.03	0.071	– 0.08	0.02
20	Dogan et al. (2017)	PR	Mixed	1995	2010	1	– 0.13	0	– 0.13	– 0.13
21	Farhani and Ozturk (2015)	PR	Tunisia	1971	2012	2	0.296	0.173	174	0.418
22	Farhani et al. (2014)	PR	Tunisia	1971	2008	2	0.173	0.181	0.045	0.301
23	Farzanegan and Markwardt (2012)	WP	Middle East and North African	1980	2005	26	0.14	0.312	– 0.27	0.954
24	Fotros and Maaboudi (2011)	PR	Iran	1971	2008	6	– 0.604	0.897	– 1.83	0.237
25	Frankel and Rose (2005)	PR	Mixed	1990	1990	14	– 0.152	0.482	– 0.709	1.08
26	Gani (2012)	PR	Mixed	1998	2007	12	0.186	0.03	0.117	0.235
27	Gu and Li (2014)	WP	China	1990	2010	5	– 0.002	0.087	– 0.119	0.125

Table 9 (continued)

Count	Study (year)	Pub type	Country	Data start	Data end	No of est.	Mean E.S	S.D.	Min	Max
28	Hakimi and Hamdi (2016)	PR	Tunisia and Morocco	1971	2013	8	0.377	0.736	0.023	2.183
29	He and Richard (2010)	PR	Canada	1948	2004	20	0.17	0.255	− 0.145	0.825
30	Hossain and Hasanuzzaman (2012)	WP	Bangladesh	1975	2010	4	0.364	0.293	− 0.005	0.71
31	Hossain (2011)	PR	Mixed	1971	2007	20	− 0.011	0.111	− 0.217	0.213
32	Hossain (2012)	PR	Japan	1960	2009	2	0.604	0.495	0.254	0.954
33	Islam and Shahbaz (2012)	WP	Bangladesh	1971	2010	2	− 0.047	0.058	− 0.088	− 0.006
34	Jalil and Feridun (2011)	PR	China	1953	2006	32	0.081	0.337	− 0.311	0.954
35	Jalil and Mahmud (2009)	PR	China	1975	2005	2	− 0.053	0.019	− 0.067	− 0.04
36	Jamel and Maktouf (2017)	PR	Europe	1985	2014	6	0.059	0.198	− 0.204	0.306
37	Jayanthakumaran et al. (2012)	PR	China	1971	2007	9	− 0.02	0.054	− 0.103	0.047
38	Jebli and Youssef (2015)	PR	Tunisia	1980	2009	4	0.078	0.334	− 0.288	0.374
39	Jorgenson (2007)	PR	Mixed	1975	2000	4	0.064	0.043	0.03	0.123
40	Jorgenson (2009)	PR	Mixed	1980	2000	8	0.044	0.027	0.018	0.091
41	Kang et al. (2016)	PR	China	1997	2012	8	− 0.065	0.049	− 0.12	0.011
42	Keho (2016)	PR	Africa	1970	2010	2	0.024	0.01	0.017	0.031
43	Kleemann and Abdulai (2013)	PR	Mixed	1990	2003	6	− 0.038	0.054	− 0.134	0.018
44	Kohler (2013)	PR	South Africa	1960	2009	2	− 0.16	0.021	− 0.175	− 0.145
45	Kasman and Duman (2015)	PR	European Union	1992	2010	1	0.112	0	0.112	0.112
46	Le et al. (2016)	PR	Mixed	1990	2013	24	0.096	0.243	− 0.602	0.607
47	Li et al. (2015)	PR	Mixed	1990	1990	5	− 0.532	0.238	− 0.742	− 0.124
48	Li et al. (2016)	PR	China	1996	2012	41	0.036	0.221	− 0.354	1.033
49	Lim et al. (2015)	PR	Mixed	1980	2005	23	− 0.009	0.123	− 0.296	0.074
50	Lin (2017)	PR	China	2004	2011	22	0.079	0.114	− 0.084	0.308
51	Managi et al. (2009)	PR	Mixed	1973	2000	17	0.247	0.213	0.032	0.707
52	McCarney et al. (2005)	WP	Mixed	1970	2000	8	0.971	0.541	0.176	1.815

Table 9 (continued)

Count	Study (year)	Pub type	Country	Data start	Data end	No of est.	Mean E.S	S.D.	Min	Max
53	Nasir and Rehman (2011)	PR	Pakistan	1972	2008	3	0.15	0.339	− 0.07	0.54
54	Nolen et al. (2017)	PR	Mexico	1993	2000	2	0.657	0.371	0.395	0.92
55	Oganesyan (2017)	Thesis	BRICS	1980	2013	2	0.082	0.054	0.044	0.121
56	Ohlan (2015)	PR	India	1970	2013	2	0.022	0.06	− 0.02	0.065
57	Ozatac et al. (2017)	PR	Turkey	1960	2013	1	− 0.038	0	− 0.038	− 0.038
58	Ozturk and Acaravci (2013)	PR	Turkey	1960	2007	3	0.032	0.03	− 0.001	0.056
59	Pazienza (2015)	PR	OECD	1981	2005	3	0.04	0.02	0.016	0.052
60	Phimphanthavong et al. (2013)	PR	Laos	1980	2010	2	0.018	0.021	0.003	0.033
61	Poncet et al. (2015)	WP	China	2003	2012	49	− 0.722	0.55	− 2.232	− 0.017
62	Rafindadi (2016a)	PR	Nigeria	1971	2011	2	− 0.445	0.201	− 0.587	− 0.303
63	Rafindadi (2016b)	PR	Japan	1961	2012	4	0.066	0.113	− 0.094	0.167
64	Saidi and Mbarek (2017)	PR	Emerging Countries	1990	2013	3	− 0.002	0.037	− 0.042	0.03
65	Salahuddin et al. (2016)	PR	OECD	1991	2012	3	− 0.796	1.08	− 2.042	− 0.145
66	Sbia et al. (2014)	PR	United Arab Emirates	1995	2011	2	− 0.235	0.181	− 0.363	− 0.107
67	Sehrawat et al. (2015)	PR	India	1971	2011	4	0.007	0.099	− 0.079	0.094
68	Shahbaz et al. (2012)	PR	Pakistan	1971	2009	2	− 0.072	0.019	− 0.086	− 0.058
69	Shahbaz and Leitão (2013)	PR	Indonesia	1975	2011	4	− 0.187	0.031	− 0.227	− 0.159
70	Shahbaz et al. (2014)	PR	Bangladesh	1975	2010	2	0.096	0.009	0.089	0.102
71	Shahbaz et al. (2013)	PR	South Africa	1965	2008	3	− 0.075	0.03	− 0.11	− 0.058
72	Shahzad et al. (017b)	PR	Pakistan	1971	2011	2	0.185	0.088	0.122	0.247
73	Solarin et al. (2017)	PR	Ghana	1980	2012	4	0.294	0.137	0.173	0.416
74	Sulaiman et al. (2013)	PR	Malaysia	1980	2004	18	0.068	0.061	− 0.002	0.26
75	Sun et al. (2017)	PR	China	1980	2012	2	1.566	1.045	0.827	2.305
76	ul Haq et al. (2016)	PR	Morocco	1971	2011	2	− 0.59	0.75	− 1.12	− 0.06
77	van Bergeijk (1991)	PR	OECD	1980	1985	3	− 0.163	0.144	− 0.327	− 0.057

Table 9 (continued)

Count	Study (year)	Pub type	Country	Data start	Data end	No of est.	Mean E.S	S.D.	Min	Max
78	Yazdi and Mastorakis (2014)	PR	Iran	1975	2011	2	0.115	0.007	0.11	0.12
79	You et al. (2015)	PR	Mixed	1985	2005	6	0.178	0.379	− 0.116	0.701
80	Zerbo (2015)	WP	Africa	1981	2010	10	0.031	0.278	− 0.262	0.53
81	Zhang et al. (2018)	PR	Pakistan	1970	2011	2	− 0.133	0.025	− 0.15	− 0.115
82	Zhu et al. (2016)	PR	Asia	1981	2011	37	− 0.245	0.155	− 0.662	− 0.06
83	Al-Mulali and Lean (2015)	PR	Vietnam	1981	2011	8	0.015	0.114	− 0.092	0.124
84	Aklin (2016)	PR	Mixed	1950	2000	6	0.105	0.056	0.025	0.171

Under publication type, PR denotes peer-reviewed publication while WP denotes working paper. Under country, mixed indicates a mix of countries was used for the study

References

Ades AF, Glaeser EL (1995) Trade and circuses: explaining urban giants. Q J Econ 110(1):195–227

Afesorgbor SK (2017) Revisiting the effect of regional integration on african trade: evidence from meta-analysis and gravity model. J Int Trade Econ Dev 26(2):133–153

Akin CS (2014) The impact of foreign trade, energy consumption and income on CO_2 emissions. Int J Energy Econ Policy 4(3):465

Aklin M (2016) Re-exploring the trade and environment nexus through the diffusion of pollution. Environ Resource Econ 64(4):663–682

Al-Mulali U, Lean HH (2015) The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. Nat Hazards 79(1):621–644

Al-Mulali U (2012) Factors affecting CO_2 emission in the Middle East: a panel data analysis. Energy 44(1):564–569

Al-Mulali U, Saboori B, Ozturk I (2015) Investigating the environmental Kuznets curve hypothesis in Vietnam. Energy Policy 76:123–131

Al-Mulali U, Solarin SA, Ozturk I (2016) Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach. Nat Hazards 80(3):1729–1747

Ali HS, Law SH, Zannah TI (2016) Dynamic impact of urbanization, economic growth, energy consumption, and trade openness on CO2 emissions in Nigeria. Environ Sci Pollut Res 23(12):12435–12443

Aller C, Ductor L, Herrerias MJ (2015) The world trade network and the environment. Energy Econ 52:55–68

Antweiler W, Copeland BR, Taylor MS (2001) Is free trade good for the environment? Am Econ Rev 91(4):877–908

Atici C (2009) Carbon emissions in Central and Eastern Europe: environmental Kuznets curve and implications for sustainable development. Sustain Dev 17(3):155–160

Atici C (2012) Carbon emissions, trade liberalization, and the Japan-ASEAN interaction: a group-wise examination. J Jpn Int Econ 26(1):167–178

Aung TS, Saboori B, Rasoulinezhad E (2017) Economic growth and environmental pollution in Myanmar: an analysis of environmental Kuznets curve. Environ Sci Pollut Res 24(25):20487–20501

Ayeche MB, Barhoumi M, Hammas MA (2016) Causal linkage between economic growth, financial development, trade openness and CO_2 emissions in European Countries. Am J Environ Eng 6(4):110–122

Baghdadi L, Martinez-Zarzoso I, Zitouna H (2013) Are RTA agreements with environmental provisions reducing emissions? J Int Econ 90(2):378–390

Bel G, Gradus R (2016) Effects of unit-based pricing on household waste collection demand: a meta-regression analysis. Resource Energy Econ 44:169–182

Bernard J, Mandal S (2016) The impact of trade openness on environmental quality: an empirical analysis of emerging and developing economies. WIT Trans Ecol Environ 203:195–208

Boutabba MA (2014) The impact of financial development, income, energy and trade on carbon emissions: evidence from the Indian economy. Econ Model 40:33–41

Bouznit M, Pablo-Romero MDP (2016) CO_2 emission and economic growth in Algeria. Energy Policy 96:93–104

Card NA (2015) Applied meta-analysis for social science research. New York: Guilford Press

Çetin M, Ecevit E (2017) The impact of financial development on carbon emissions under the structural breaks: empirical evidence from Turkish economy. Int J Econ Perspect 11(1):64–78

Charfeddine L, Khediri KB (2016) Financial development and environmental quality in UAE: cointegration with structural breaks. Renew Sustain Energy Rev 55:1322–1335

Choi E, Heshmati A, Cho Y (2010) An empirical study of the relationships between CO_2 emissions, economic growth and openness. The Institute for the Study of Labor (IZA) Discussion Paper No. 50304

Cipollina M, Salvatici L (2010) Reciprocal trade agreements in gravity models: a meta-analysis. Rev Int Econ 18(1):63–80

Cole MA, Elliott RJ (2003) Determining the trade-environment composition effect: the role of capital, labor and environmental regulations. J Environ Econ Manag 46(3):363–383

Copeland BR, Taylor SM (2003) Trade and the environment. Princeton University Press, Princeton

de Sousa J, Hering L, Poncet S (2015) Has trade openness reduced pollution in China? Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) Working Paper 2015-11

Demena BA, Afesorgbor SK (2020) The effect of FDI on environmental emissions: evidence from a meta-analysis. Energy Policy 138(11192):1–17

Demena BA, van Bergeijk PA (2017) A meta-analysis of FDI and productivity spillovers in developing countries. J Econ Surv 31(2):546–571
Dogan E, Seker F (2016) An investigation on the determinants of carbon emissions for OECD countries: empirical evidence from panel models robust to heterogeneity and cross-sectional dependence. Environ Sci Pollut Res 23(14):14646–14655
Dogan E, Seker F, Bulbul S (2017) Investigating the impacts of energy consumption, real GDP, tourism and trade on CO_2 emissions by accounting for cross-sectional dependence: a panel study of OECD countries. Curr Issue Tour 20(16):1701–1719
Dogan E, Turkekul B (2016) CO_2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. Environ Sci Pollut Res 23(2):1203–1213
Doucouliagos C, Stanley TD (2013) Are all economic facts greatly exaggerated? Theory competition and selectivity. J Econ Surv 27(2):316–339
Doucouliagos H, Stanley TD (2009) Publication selection bias in minimum-wage research? a meta-regression analysis. Br J Ind Relat 47(2):406–428
Eiras A, Schaefer B (2001) Trade: the best way to protect the environment. The Heritage Foundation Report
Farhani S, Chaibi A, Rault C (2014) CO_2 emissions, output, energy consumption, and trade in Tunisia. Econ Model 38:426–434
Farhani S, Ozturk I (2015) Causal relationship between CO_2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia. Environ Sci Pollut Res 22(20):15663–15676
Farzanegan MR, Markwardt G (2012) Pollution, economic development and democracy: evidence From the MENA countries. Technical report, Joint Discussion Paper Series in Economics
Floridi A, Demena BA, Wagner N (2020) Shedding light on the shadows of informality: a meta-analysis of formalization interventions targeted at informal firms. Labour Econ 67:101925
Fotros MH, Maaboudi R (2011) Trade openness and CO_2 emissions in Iran, 1971-2008. Int J of Busi and Dev Stud 3(1):73–84
Frankel JA, Romer DH (1999) Does trade cause growth? Am Econ Rev 89(3):379–399
Frankel JA, Rose AK (2005) Is trade good or bad for the environment? Sorting out the causality. Rev Econ Stat 87(1):85–91
Gani A (2012) The relationship between good governance and carbon dioxide emissions: Evidence from developing economies. J Econ Dev 37(1):77
Goldfarb RS (1995) The economist-as-audience needs a methodology of plausible inference. J Econ Methodol 2(2):201–222
Grossman GM, Krueger AB (1993) Environmental impacts of a North American free trade agreement. National Bureau of Economic Research Working Paper 3914
Gu Z, Li J (2014) A Comparative analysis on carbon emission Eeffect of trade in Eastern, Middle and Western Regions in China. In: 3rd international conference on science and social research (ICSSR 2014)
Gujarati DN (2009) Basic econometrics. Tata McGraw-Hill, London
Hadi AS (1994) A modification of a method for the detection of outliers in multivariate samples. J R Stat Soc Ser B (Methodological) 39:393–396
Hakimi A, Hamdi H (2016) Trade liberalization, FDI inflows, environmental quality and economic growth: a comparative analysis between Tunisia and Morocco. Renew Sustain Energy Rev 58:1445–1456
Havranek T, Irsova Z (2011) Estimating vertical spillovers from FDI: Why results vary and what the true effect is? J Int Econ 85(2):234–244
He J, Richard P (2010) Environmental Kuznets curve for CO_2 in Canada. Ecol Econ 69(5):1083–1093
Hossain MS (2011) Panel estimation for CO_2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. Energy Policy 39(11):6991–6999
Hossain NA, Hasanuzzaman S (2012) The Impact of energy consumption, urbanization, financial development, and trade openness on the environment in Bangladesh: an ARDL Bound Test Approach
Hossain S (2012) An econometric analysis for CO2 emissions, energy consumption, economic growth, foreign trade and urbanization of Japan. Low Carbon Econ 3(3):1069
Iršová Z, Havránek T (2013) Determinants of horizontal spillovers from FDI: evidence from a large meta-analysis. World Dev 42:1–15
Islam F, Shahbaz M (2012) Is there an environmental Kuznets curve for Bangladesh? Munich Personal RePEc Archive Working Paper 38490, University Library of Munich, Germany
Jalil A, Feridun M (2011) The impact of growth, energy and financial development on the environment in China: a cointegration analysis. Energy Econ 33(2):284–291
Jalil A, Mahmud SF (2009) Environment Kuznets curve for CO_2 emissions: a cointegration analysis for China. Energy Policy 37(12):5167–5172

Jamel L, Maktouf S (2017) The nexus between economic growth, financial development, trade openness, and CO_2 emissions in European countries. Cogent Econ Finance 5(1):1341456
Jayanthakumaran K, Verma R, Liu Y (2012) CO_2 emissions, energy consumption, trade and income: a comparative analysis of China and India. Energy Policy 42:450–460
Jebli MB, Youssef SB (2015) The environmental Kuznets curve, economic growth, renewable and non-renewable energy, and trade in Tunisia. Renew Sustain Energy Rev 47:173–185
Jorgenson AK (2007) Does foreign investment harm the air we breathe and the water we drink? a cross-national study of carbon dioxide emissions and organic water pollution in less-developed countries, 1975 to 2000. Organ Environ 20(2):137–156
Jorgenson AK (2009) Foreign direct investment and the environment, the mitigating influence of institutional and civil society factors, and relationships between industrial pollution and human health: a panel study of less-developed countries. Organ Environ 22(2):135–157
Kang Y-Q, Zhao T, Yang Y-Y (2016) Environmental Kuznets curve for CO_2 emissions in China: a spatial panel data approach. Ecol Ind 63:231–239
Kasman A, Duman YS (2015) CO_2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis. Econ Model 44:97–103
Kearsley A, Riddel M (2010) A further inquiry into the Pollution Haven Hypothesis and the environmental Kuznets curve. Ecol Econ 69(4):905–919
Keho Y (2016) Trade openness and the environment: a time series study of ECOWAS countries. J Econ 4(4):61–69
Kim D-H, Suen Y-B, Lin S-C (2019) Carbon dioxide emissions and trade: evidence from disaggregate trade data. Energy Econ 78:13–28
Kirkpatrick C, Scrieciu SS (2008) Is trade liberalisation bad for the environment? a review of the economic evidence. J Environ Planning Manage 51(4):497–510
Kleemann L, Abdulai A (2013) The impact of trade and economic growth on the environment: revisiting the cross-country evidence. J Int Dev 25(2):180–205
Kohler M (2013) CO_2 emissions, energy consumption, income and foreign trade: a South African perspective. Energy Policy 63:1042–1050
Krugman P, Elizondo RL (1996) Trade policy and the third world metropolis. J Dev Econ 49(1):137–150
Le T-H, Chang Y, Park D (2016) Trade openness and environmental quality: international evidence. Energy Policy 92:45–55
Li T, Wang Y, Zhao D (2016) Environmental Kuznets curve in China: new evidence from dynamic panel analysis. Energy Policy 91:138–147
Li Z, Xu N, Yuan J (2015) New evidence on trade-environment linkage via air visibility. Econ Lett 128:72–74
Lim S, Menaldo V, Prakash A (2015) Foreign aid, economic globalization, and pollution. Policy Sci 48(2):181–205
Lin F (2017) Trade openness and air pollution: City-level empirical evidence from China. China Econ Rev 45:78–88
Ma C, Rogers AA, Kragt ME, Zhang F, Polyakov M, Gibson F, Chalak M, Pandit R, Tapsuwan S (2015) Consumers? Willingness to pay for renewable energy: a meta-regression analysis. Resource Energy Econ 42:93–109
Managi S, Hibiki A, Tsurumi T (2009) Does trade openness improve environmental quality? J Environ Econ Manag 58(3):346–363
Martínez-Zarzoso I, Maruotti A (2011) The impact of urbanization on CO_2 emissions: evidence from developing countries. Ecol Econ 70(7):1344–1353
McCarney GR, Adamowicz WL, et al. (2005) The effects of trade liberalization on the environment: An empirical study. In Annual Meeting, July 6-8, 2005, San Francisco, CA, number 34157. Canadian Agricultural Economics Society
Nasir M, Rehman FU (2011) Environmental Kuznets curve for carbon emissions in Pakistan: an empirical investigation. Energy Policy 39(3):1857–1864
Nolen E C. J, Cantú J d J. S, Guajardo R CR, García HG (2017) Free trade and pollution in the manufacturing industry in Mexico: A verification of the inverse Kuznets curve at a state level. Ensayos Revista de Economía (Ensayos Journal of Economics) 29(2)
Oczkowski E, Doucouliagos H (2015) Wine prices and quality ratings: a meta-regression analysis. Am J Agr Econ 97(1):103–121
Oganesyan M (2017) Carbon emissions, energy consumption and economic growth in the BRICS. Jönköping University, Jönköping International Business School Thesis
Ohlan R (2015) The impact of population density, energy consumption, economic growth and trade openness on CO_2 emissions in India. Nat Hazards 79(2):1409–1428

Olivier JG, Schure K, Peters J (2017) Trends in global CO_2 and total greenhouse gas emissions. PBL Netherlands Environmental Assessment Agency
Onoja AO, Ajie E, Achike A (2014) Econometric analysis of influences of trade openness, economic growth and urbanization on greenhouse gas emissions in Africa (1960–2010). J Econ Sustain Dev 5(10):85–93
Opoku E, Amoako S, Amankwa I (2014) Trade openness, economic growth and the environment: the case of Ghana. Int J Econ Commerce Manag 2(8):1–13
Ozatac N, Gokmenoglu KK, Taspinar N (2017) Testing the EKC hypothesis by considering trade openness, urbanization, and financial development:the case of Turkey. Environ Sci Pollut Res 24(20):16690–16701
Ozturk I, Acaravci A (2013) The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. Energy Econ 36:262–267
Paarlberg R (2013) Food politics: what everyone needs to know®. Oxford University Press, New York
Pazienza P (2015) The relationship between CO_2 and Foreign Direct Investment in the agriculture and fishing sector of OECD countries: evidence and policy considerations. Intell Econ 9(1):55–66
Peters GP, Minx JC, Weber CL, Edenhofer O (2011) Growth in emission transfers via international trade from 1990 to 2008. Proc Natl Acad Sci 108(21):8903–8908
Phimphanthavong H et al (2013) The impacts of economic growth on environmental conditions in Laos. Int J Bus Manag Econ Res 4(5):766–774
Poncet S, Hering L, de Sousa J (2015) Has trade openness reduced pollution in China? Foundation for studies and Research on International Development (FERDI) Development Policies Working Paper 132
Rafindadi AA (2016a) Does the need for economic growth influence energy consumption and CO_2 emissions in Nigeria? Evidence from the innovation accounting test. Renew Sustain Energy Rev 62:1209–1225
Rafindadi AA (2016b) Revisiting the concept of environmental Kuznets curve in period of energy disaster and deteriorating income: empirical evidence from Japan. Energy Policy 94:274–284
Rose AK, Stanley TD (2005) A meta-analysis of the effect of common currencies on international trade. J Econ Surv 19(3):347–365
Saidi K, Mbarek MB (2017) The impact of income, trade, urbanization, and financial development on CO_2 emissions in 19 emerging economies. Environ Sci Pollut Res 24(14):12748–12757
Salahuddin M, Alam K, Ozturk I (2016) The effects of Internet usage and economic growth on CO_2 emissions in OECD countries: a panel investigation. Renew Sustain Energy Rev 62:1226–1235
Sbia R, Shahbaz M, Hamdi H (2014) A contribution of foreign direct investment, clean energy, trade openness, carbon emissions and economic growth to energy demand in UAE. Econ Model 36:191–197
Sehrawat M, Giri A, Mohapatra G (2015) The impact of financial development, economic growth and energy consumption on environmental degradation: evidence from India. Manag Environ Qual Int J 26(5):666–682
Shahbaz MH, Leitão NC (2013) Economic growth, energy consumption, financial development, international trade and CO_2 emissions in Indonesia. Renew Sustain Energy Rev 25:109–121
Shahbaz M, Lean HH, Shabbir MS (2012) Environmental Kuznets curve hypothesis in Pakistan: cointegration and Granger causality. Renew Sustain Energy Rev 16(5):2947–2953
Shahbaz M, Nasreen S, Ahmed K, Hammoudeh S (2017a) Trade openness-carbon emissions nexus: the importance of turning points of trade openness for country panels. Energy Econ 61:221–232
Shahbaz M, Tiwari AK, Nasir M (2013) The effects of financial development, economic growth, coal consumption and trade openness on CO_2 emissions in South Africa. Energy Policy 61:1452–1459
Shahbaz M, Uddin GS, Rehman IU, Imran K (2014) Industrialization, electricity consumption and CO_2 emissions in Bangladesh. Renew Sustain Energy Rev 31:575–586
Shahzad SJH, Kumar RR, Zakaria M, Hurr M (2017b) Carbon emission, energy consumption, trade openness and financial development in Pakistan: a revisit. Renew Sustain Energy Rev 70:185–192
Solarin SA, Al-Mulali U, Musah I, Ozturk I (2017) Investigating the pollution haven hypothesis in Ghana: an empirical investigation. Energy 124:706–719
Stanley TD (2001) Wheat from chaff: Meta-analysis as quantitative literature review. J Econ Perspect 15(3):131–150
Stanley TD (2005) Beyond publication bias. J Econ Surv 19(3):309–345
Stanley TD, Doucouliagos H (2012) Meta-regression analysis in economics and business, vol 5. Routledge, London

Stanley TD, Doucouliagos H, Giles M, Heckemeyer JH, Johnston RJ, Laroche P, Nelson JP, Paldam M, Poot J, Pugh G et al (2013) Meta-analysis of economics research reporting guidelines. J Econ Surv 27(2):390–394

Sulaiman J, Azman A, Saboori B (2013) Evidence of the environmental Kuznets curve: implications of industrial trade data. Am J Environ Sci 9(2):130

Sun C, Zhang F, Xu M (2017) Investigation of pollution haven hypothesis for China: an ARDL approach with breakpoint unit root tests. J Clean Prod 161:153–164

Torras M, Boyce JK (1998) Income, inequality, and pollution: a reassessment of the environmental Kuznets curve. Ecol Econ 25(2):147–160

UlHaq I, Zhu S, Shafiq M (2016) Empirical investigation of environmental Kuznets curve for carbon emission in Morocco. Ecol Indic 67:491–496

van Bergeijk PA (1991) International trade and the environmental challenge. J World Trade 25:105

UNEP & WTO (2009) Trade and climate change. World Trade Organization and United Nations Environment Program

WTO (2019) World trade statistical review 2019

Yazdi SK, Mastorakis N (2014) Renewable, CO_2 emissions, trade openness, and economic growth in Iran. Latest Trend Energy Environ Dev 25:360–370

You W-H, Zhu H-M, Yu K, Peng C (2015) Democracy, financial openness, and global carbon dioxide emissions: heterogeneity across existing emission levels. World Dev 66:189–207

Yuan Z, Guanghua W (2015) International trade and the urbanization of developing countries: evidence from Asia. Soc Sci China 36(2):186–204

Zerbo E (2015) CO_2 emissions, growth, energy consumption and foreign trade in Sub-Sahara African countries. HAL Working Paper hal-01110769

Zhang B, Wang Z, Wang B et al (2018) Energy production, economic growth and CO_2 emission: evidence from Pakistan. Nat Hazards 90(1):27–50

Zhu H, Duan L, Guo Y, Yu K (2016) The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: evidence from panel quantile regression. Econ Model 58:237–248