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RESEARCH ARTICLE

The environmental effects of trade openness in developing countries: conflict or cooperation?

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Abstract

Identifying environmental consequences of international trade has a crucial role in constructing and planning strategies of any country, especially in developing countries that are currently witnessing a significant increase in trade openness; however, little efforts are made to investigate the environmental consequences of trade openness. The paper attempts to investigate the dynamic relationship between trade openness and environmental pollutants incorporating potential factors affecting environmental quality in 66 developing economies over the period 1971–2017. This article employs the powerful approach two-step generalized method of moment's estimators with a finite sample correction to obtain more accurate inference. The key empirical results are as follows: (1) trade openness may be harmful for the environment while confirming the existence of an environmental Kuznets curve hypothesis. (2) An increase in pollutants, namely carbon dioxide emissions, ambient particulate matter and nitrous oxide emissions in the previous period, is associated with a rise in pollutants in the future suggesting that if no action in reducing pollutants is taken, environmental quality is worse. (3) Energy consumption, financial development and industrialization have a significant contribution to deteriorating environment. The implications of these results also are discussed and proposed for developing economies in this research.

Keywords Trade openness · Environmental pollutants · Economic growth · Economic indicators · System GMM · Developing countries

JEL classification F18 · P48 · Q56 · O13

Introduction

Economic integration is seen as an indispensable trend and a powerful means for countries to promote economic development and poverty reduction. This trend is, in turn, the result of the majority of the developing countries implemented trade policies based on a higher degree of international trade openness as an engine of fostering economic growth and rising living standards in recent decades. However, trade has resulted in an expansion of exchanging activities and energy-intensive industries with greater energy sources. This expansion is considered the potential source of the dramatic increase in energy use, pollutant emissions and environmental degradation leading to increasing the vulnerability of the ecosystem (Hakimi and Hamdi 2016; Shahbaz et al. 2017). Furthermore, according to Kirkpatrick and Scrieciu (2008), the potential effect of trade on the ambiguous natural environment rapidly raises public awareness on the demand to answer the tough question that does trade openness contribute to increased water and air pollution. Therefore, understanding the trade-environment nexus incorporating potential determinants of environment degradation would provide recommendations for policymakers and governments in trade policy to simultaneously achieve both spurring economic growth and better environmental quality. Despite its importance, the environmental impacts of trade openness have not received attention in the case of developing economies.

Furthermore, the environmental consequence of trade theoretically is relatively ambiguous and inconclusive; trade

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might result in environmental deteriorations or improvements. Advocates believe that the flow of advanced and environment-friendly technologies contributes to replacing the old ones with heavily relied on fossil consumption that is come from trade liberalization (e.g. Sbia et al. 2014). On the other hand, trade openness hinders environmental quality. To support for this, Hakimi and Hamdi (2016) and Lopez (1997) point out that international trade increases foreign direct investment in manufacturing and transportation as energy-based activities that directly produce a higher amount of emissions. Nevertheless, most of theoretical frameworks indicate trade adversely affects the environment in lower-income countries. The popular view shows that the richer countries export 'dusty industries' into the poorer ones as following the factor endowment hypothesis and the pollution haven hypothesis (e.g Dean 2002; Taylor 2004; Cole 2004; Frankel and Rose 2005 and Anouliès 2016). That is because, with lax environmental standards, developing countries have a comparative advantage in specialization in pollution-intensive industries to export pollution-intensive goods and attract multinational corporations. The end of the results is the poorer countries become 'pollution havens'. So, under what conditions is international trade beneficial for the environment? Beladi and Oladi (2011) categorized the environmental impacts of trade into technology and output effects. In which, output effect defines as increased trade expands global output that leads to increase pollution. Technology effect refers to technology substitution of liberalization, which improves environmental quality by utilizing cleaner technology. Trade is beneficial for the environment if and only if the latter effect outweighs the former one. In addition, the environmental impacts of international trade might be positive or negative, depending on the determinants of a country's comparative advantages, a country's pollutant and the strength of its' environmental standards (Managi et al. 2009; Cole and Elliott 2003). Shahbaz et al. (2017) found a turning point in the environment-trade nexus, in which the environmental effect of international trade will turn from negative at the initial stage into positive after a certain threshold of the level of degree of trade openness. Hence, it calls for the other study to closer look in as joined to design practical implications to address global warming in developing countries, because the answer should not be based on a basic theory but need to solve in specific cases (Williams 1993). All these motive us to implement research on the trade-pollution nexus in the case of developing counties.

Whether does trade openness appear to be good or bad for air quality? The question is still interesting because, although the empirical studies of the relationship between trade openness and the quality of environment have been explored by several scholars using different methodologies and datasets, the answer is relatively conflicting and inconclusive in recent decades. Literature is classified as the trade-environment nexus mostly into two different strands. The first stand is applied the theoretical frameworks of Antweiler et al. (2001), in which the environmental impact of trade can be decomposed into three channels, namely composition, technique and scale effects. The studies of Cole and Elliott (2003), Managi et al. (2009), Shen (2008) and Managi (2004) are stark example which followed the first strand. The second strand investigates the dynamic relationship between international trade and environmental quality. Specifically, while Hakimi and Hamdi (2016), Le et al. (2016) or Shahbaz et al. (2017) found trade liberalization is associated with environmental degradation in overall, Shahbaz et al. (2013) or Ahmed et al. (2016) claimed that increased trade openness improves environmental quality. Even, Sharma (2011) found there was an insignificant relationship between trade openness and emissions. Additionally, while a number of scholars mostly focused on investigating the factors affecting CO_2 emissions as a proxy of environmental quality, other pollutants such as particulate matter ($PM_{2.5}$) need to be taken into account. This is considered the major issue of environmental quality and has adverse impact on human health and serious diseases (World Health Organization, 2006). Furthermore, the empirical findings fail to capture potential factors affecting environmental quality and inverted U-shaped hypothesis. Instead, the major contribution of this paper is to offer a novel approach incorporating potential determinants as drawn from the literature of environment degradation.

In addition, the empirical results of the trade-environment nexus from developing countries are still unsolved. Most of the studies have failed to account for endogeneity of trade-environmental nexus (Kirkpatrick and Scrieciu 2008) leading to ongoing trade-environmental debate. Therefore, this issue is called to go for other research on one-size-fits-all results and it is important to analyse to take homogeneity issues and a case-by-case basis. The study, therefore, is the first attempt to fill the gap to contribute to the literature by examining the trade-environmental quality nexus incorporating potential determinants of environmental quality included foreign direct investment, economic growth, institutional quality, urbanization, population growth or industrialization in 66 developing countries over the period of 1971–2017. Additionally, this study provides new empirical evidence by employing novel econometric approaches, namely a dynamic system—GMM developed by Roodman (2009a and 2009b). To assure the appropriateness of the approach, diagnostic tests on the validity of the instruments and the second-order serial correlation in the first differenced equations are provided. It also is a powerful test for a short time and long cross-sectional panel dataset. Besides, we also check robustness tests to obtain more reliable results by adding various consistent and reliable proxies of trade openness and environmental quality from previous empirical evidence. The two-step covariance matrix provided by Windmeijer (2005) and Erickson and Whited (2002) for the finite-sample correction is applied to obtain better asymptotic and finite sample properties of estimators. The in-depth analysis of potential determinants of pollutants in developing economies constitutes and enriches the literature as well as provides a new room for policy implications.

The remaining sections of this paper are organized as follows: the "Literature review" section presents the summary of empirical studies and theoretical frameworks. The "Methodology and data collection" section describes the data and research methodology. The "Empirical results and discussion" section presents empirical results and discussions. Finally, concluding remarks and recommendations are stated in the "Conclusions and policy implications" section.

Literature review

Theoretical frameworks

Investigating the relationship between international trade and the environment is currently a prominent theme, following the first conceptual framework of Antweiler et al. (2001). Accordingly, international trade has simultaneously multiple and ambiguous effects on the environmental quality through three channels, which are technique, scale and composition effects. Whereas the impact of trade on environmental quality appears good or bad depending on different selected channels, the scale effect is associated with the negative environmental consequences that believed trade liberalization causes pollutant emissions due to an increase in economic activity. The technique effect refers to the import of environmentally friendly and more efficient technologies in producing cleaner production to replace traditional production methods that indicate the negative impact of GDP per capita on pollutant emissions. Finally, the composition effect has both negative and positive impacts on the environment depending on the comparative advantage of the country and environmental regulations. This effect explains the effect of the composition of output on emissions, which is determined by the country's comparative advantage and the degree of trade openness. Overall, trade liberalization is good for the environment (Antweiler et al. 2001). Furthermore, the detrimental effect of trade on the environment conceptualizes by Copeland and Taylor (2013), which are decomposed into scale and composition effects. They argue that the composition effect explains the popular notion that developed countries tend to shift polluting industries into developing countries following the population haven hypothesis (Cole 2004; Taylor 2004) and the race-to-the-bottom hypothesis (Frankel and Rose 2005). Specifically, poor countries have a comparative advantage in abundant natural resources yet lenient environmental standards incorporating with a higher degree of trade openness that deteriorates the environment. On the other hand, with tough environmental policies, the rich countries specialize in clean production. In addition, the greater economic scale is associated with greater economic activities resulting from trade liberalization that has led to increasing pollutant emissions (Copeland and Taylor 2013). The view is also consistent with the empirical finding of Le et al. (2016). They discovered that rich countries tend to dump pollution on the poor and less developed countries. On the other hand, environmental control costs have led to reducing specialization in the production of polluting outputs that encourage a country to create tough environmental regulations or trade barriers (Tobey 1990). Hence, the single equation with treating trade or environment indicators as exogenous variables might lead to counterfactual empirical results due to different channel effects of trade openness on environmental quality and endogeneity (Dean 2002; Frankel and Rose 2005; Antweiler et al. 2001). Our study attempts to use simultaneous equation models incorporating economic growth and various environmental indicators and treat variables as endogenous.

The theoretical relationship between international trade and the environment is relatively ambiguous and inconclusive. The theoretical frameworks suggested that the different patterns, country specifics and measurements might result in different results (Kirkpatrick and Scrieciu 2008). Furthermore, according to Williams (1993), there was a debatable argument between economists and environmentalists in the trade-environment nexus; therefore, the answers might not be relied on basic theory and should be solved in individual cases. This calls for a closer look at developing countries to formulate empirical evidence to reconcile competing arguments regarding the environmental impact of trade openness and open new directions for future research.

Empirical evidence from cross-country studies

There are a number of studies that investigate the relationship between trade and environmental degradation. However, there is no agreement on the trade-environment nexus as whether trade has a beneficial or detrimental effect on the environment. Only several empirical studies found trade liberalization is beneficial for the environment. Antweiler et al. (2001) examine the impact of freer trade on pollution concentrations such as sulfur dioxide (SO_2) in 43 countries covering the period from 1971 to 1996. Accordingly, the net impact of freer trade on the environment is beneficial in a combination of three channels. Similarly, also carrying out cross-country evidence, Cole and Elliott (2003) examine the relationship between freer trade and the environment following the theoretical framework of Antweiler et al. (2001). In their analysis, trade liberalization is positively associated with environmental quality in combination with all four pollutants. However, the empirical findings of the trade-environment nexus vary according to different environmental indicators. For example, trade liberalization contributes to reducing water pollution as measured by biochemical oxygen demand (BOD) per capita, while NO_x

and CO_2 emissions can be attributed by freer trade. Taking account of the endogeneity of trade and using cross-country dataset in 1990, the positive evidence was also obtained from the study of Frankel and Rose (2005). They believed that trade openness statistically improves environmental quality by statistically and significantly reducing SO_2 and NO_2 emissions. In the case of the newly industrializing economies, namely India, China, Brazil and South Africa, Ahmed et al. (2016) concluded that trade openness contributes reducing CO_2 emissions in the long run through employed Pedroni's panel cointegration approach.

On the other hand, a large number of scholarly works suggested that trade has a detrimental impact on environmental quality. Managi (2004) asserted the overall effects of trade on CO_2 emissions combined the technique, scale and composition effects in 63 countries from 1960 to 1999. The empirical finding shows a 1% increase in trade leads to raising CO_2 emissions by 0.579%. Similar evidence was observed in the study of Le et al. (2016), and their results reveal that trade openness is related to increased environmental pollution as measured by the basic indicator of environmental quality, namely the emission of particulate matter (PM_{10}) in 98 countries observed in the period from 1990 to 2013. However, in comparing the effects of trade openness among different income countries, while trade openness is beneficial for the environment in high-income countries, yet it has a harmful effect in low- and middle-income countries by using the generalized method of moments (GMM). The study of Managi et al. (2009) has very similar results as those of Le et al. (2016) because it supports for the popular notion that the developed countries tend to migrate pollution into the developing ones as following "pollution haven hypothesis". Furthermore, the study, using the panel data of 88 countries and a differenced GMM approach, also suggested that trade openness is associated with improving environmental quality in OECD countries, whereas it exerts a detrimental effect on the environment through increased CO_2 emissions and SO_2 emissions in non-OECD countries. In contrast, Aller et al. (2015) revisited to examine the indirect impacts of trade on the environment observing 177 countries in the period between 1996 and 2010. The results suggested that while the indirect effects of trade on the environment are positive in low-income countries, it found a negative impact on environmental quality in high-income countries. Recently, Shahbaz et al. (2017) studied the relationship between CO_2 emissions and trade openness in 105 countries covering the period 1980–2014. The results from panel VECM causality and panel cointegration tests reveal that trade openness increased CO_2 emissions, which directly contribute to environmental degradation. Furthermore, the hypothesis of the inverted U-shape relationship between CO_2 emissions and trade openness is valid in this study. This implies that at an initial stage, trade openness contributes to environmental degradation, whereas after a certain point of the degree of trade, it leads to improving environmental quality. Similarly, studying the effect of trade openness and environmental degradation in 14 Middle East and North African countries, Al-Mulali and Ozturk (2015) show that trade openness damages the environment through employed fully modified ordinary least square. In addition, the empirical findings of Sharma (2011) that evaluate the factors affecting carbon dioxide emissions in 69 countries using the dataset from 1985 to 2005 are relatively contradicting with above evidence because there is no statistical relationship between trade openness and environmental degradation. Accordingly, trade openness exerted a negative but insignificant impact on CO_2 emissions in a global sample, whereas an insignificant and positive effect on environmental pollution for three sub-panels including high-, middle- and low-income countries is found.

In summary, the cross-country evidence reveals that trade has a positive, negative or insignificant impact on the environment due to differences in methodologies, sample sizes, or proxies of environmental quality and trade openness variables; therefore, this issue requires for further empirical findings. Furthermore, the sub-panel data from developing countries are not fully investigated in the previous cross-country studies, and that could not be inferred from other studies because the one-size-fit-all assumptions for every economy and the homogeneity assumption do not guarantee. As far as we have known, only the study of Shahbaz et al. (2017) posits an inverted U-shaped relationship between trade openness and environmental quality. As the trade improves environmental quality, the degree of trade becomes sufficiently high. This research provides new empirical evidence by employing various proxies for both environmental degradation and trade openness indicators incorporating an inverted U-shaped pattern and controlling for economic growth, urbanization, industrialization, foreign direct investment, or population growth in developing regions.

Empirical evidence from individual countries

Using a VECM and cointegration techniques in Tunisia and Moroco observed in the period from 1991 to 2013, the result of Hakimi and Hamdi (2016) supports that despite boosting economic growth in both countries, trade liberalization exerts a negative impact on the environment through increased CO_2 emissions. The similar result was also found in the study of Lau et al. (2014) in Malaysia for the period 1970 to 2008. Additionally, investigating the short-run and long-run relationships between trade openness and CO_2 emissions by mainly employing the ARDL bounds testing approach, Naranpanawa (2011) found trade openness merely boosts emissions in the short run but no relationship is found in the long run in Sri Lanka covering the period of 1960–2006. Contradicting to this result in the case of Turkey and Tunisia with a similar approach, Halicioglu (2009) and Cetin et al.

(2018) conclude there is a long-run relationship between CO_2 emissions and international trade in Turkey while Farhani and Ozturk (2015) concluded that trade openness reduced CO_2 emissions in Tunisia, which is also found in the study of Ali et al. (2016) for Nigeria. Also carrying out the relationship between trade openness and environmental quality by employing the generalized least squares method, the negative evidence was also obtained from the study of Feridun et al. (2006). In their analysis, trade intensity is positively associated with environmental pollution in the Nigerian economy. In contrast, concerning the effect of trade openness, economic growth and financial development on environmental quality in South Africa covered the period between 1965 and 2008, Shahbaz et al. (2013) show the positive relationship between trade openness and environmental quality through reducing the growth of energy pollutants by applied the ARDL bounds testing approach. The authors also point out the existence of the environmental Kuznets curve. Concerning the environmental impacts of freer trade in Chinese provincial evidence covering the period from 1987 to 1995, Dean (2002) argued that trade liberalization exerts multiple effects on the environment. Specifically, free trade appears to be good for environmental quality by the technique effect, whereas the composition effect of trade liberalization contributes to increasing water pollution leading to environmental degradation. In overall, empirical evidence showed a positive effect of trade on environmental quality because the beneficial effects of trade outweighed the detrimental impacts. Also carrying out the trade-environment nexus in China, but focusing on 31 provinces and metropolitan cities and covering provincial data between 1993 and 2002, Shen (2008), following the methodology developed by Antweiler et al. (2001), argued that whether trade liberalization has positive or negative impacts on environmental quality depended on selected environmental indicators. In their analysis, increased trade is associated with increased air pollutants as measured SO_2 and dust fall, while it has a negative effect on three water pollutants as represented by arsenic water, chemical oxygen demand (COD) and cadmium in water. In the case of manufacturing plants in the USA, Cherniwchan (2017) investigated the impact of trade liberalization as represented by the NAFTA agreement between the USA and Mexico covering the period from 1991 to 1998. The empirical results provided evidence that trade labialization significantly improves environmental quality by decreasing both PM_{10} and SO_2 emissions from existing plants.

Given all these empirical evidences, trade openness is likely to matter for environmental quality; however, the results from the trade-environment nexus are relatively inconclusive and controversial. Whether trade appears to be good or bad for environmental quality strongly depends on the nature of a country's characteristics. In addition, there is still limited empirical evidence whether the degree of trade differently impacts on environmental quality following the inverted U-shaped hypothesis. As far as it is known, the study of Shahbaz et al. (2017) illustrated the relationship between trade openness and CO_2 emissions following the inverted U-shaped curve. Furthermore, most of the studies simply used trade openness as measured by the ratio of exports plus imports to GDP as a percentage; therefore, this research is one of the rare studies that obtained more robust results by adding more indicators on trade-environmental nexus equations.

Methodology and data collection

Econometric approach

The central objective of the present research is to evaluate the environmental impacts of trade openness in developing regions incorporating potential determinants of environmental indicators. Following the methodology of Le et al. (2016); Managi et al. (2009); Sharma (2011); and Frankel and Rose (2005), the prior research works consider trade openness and income as endogenous variables. To account for both endogenous and exogenous variables to a single framework, we employed an alternative dynamic methodology as the Arellano-Bond GMM estimator developed by Roodman (2009a) to control for the effect of the dynamic process and endogeinety. We also take into account the existing *environmental Kuznets curve* (EKC) hypothesis of the income effect in the long run and the presence of control variables. In this case, it is expected that the coefficient of GDP per capita squares is statistically negative. Therefore, we also integrate the square of GDP per capita following econometric modelling in a linear form and the baseline model might be written as in Eq. 1:

$$EQ_{it} = \mathcal{F}\left(OP_{it}, GDP_{it}, GDP^2_{it}, X_{it}, U_{it}\right) \quad (1)$$

where EQ denotes air pollutants as a proxy of environmental quality in country i at time t; OP is the trade openness in country i at time t; X represents a vector of potential determinants of environmental quality, namely urbanization, industrialization, population growth, financial development, landlocked, democracy, institutional quality and energy consumption; i shows the country effect; and t denotes the time dimension.

As drawn from the literature, there are several air pollutants as proxies of environmental quality, namely NO_x, SO_2, CO_2, PM_x and BOD. In this research, we rely on CO_2 emissions per capita as the main indicator of environmental quality, which is collected from the World Development Indicator. CO_2 emissions arising from economic activities are considered the major greenhouse gas emissions and contribute to climate change that poses a threat to human development and human health

(Boulatoff and Jenkins 2010; Pan 2005). Recently, the problem of rising global warming is the dominant feature and global debates, in which, in the 2015 United Nations Climate Change Conference in Paris, twenty countries both developed and developing nations agreed to support low-carbon strategies. As a result, low-carbon emissions become a high priority for policymakers of many developed and developing countries in attempting to address the problems of high amount emissions of carbon dioxide (Ahmad et al. 2018). The other reason is availability of panel datasets of developing countries in a long time period, in which, the data of carbon dioxide emissions is measurable and reliable for the longest time series and a large number of developing countries (66 economies). Furthermore, to obtain more robust results and look at these broader measures of environmental quality, we also exam other alternative indicators of environmental quality, namely NO emissions and particulate matter ($PM_{2.5}$). These emissions are considered the major issue of poor environmental quality that have adverse effects on human health and a potential cause of several serious diseases (Brunekreef and Holgate 2002; Landrigan 2017; Ouyang et al. 2019; World Health Organization 2006; Le et al. 2016).

Trade openness is the most common use as defined as the ratio of aggregate imports and exports to GDP as a well-known indicator from Alcalá and Ciccone (2004). We also followed Le et al. (2016), Shahbaz et al. (2013), Farhani and Ozturk (2015) and Halicioglu (2009), yet we do not expect any sign of trade openness coefficients, because, in the empirical literature, there is no agreement in both theories and empirical results whether trade openness exerts a positive, negative or no-existent effect on environmental quality. Expressed by the ratio of exports plus imports to GDP, trade openness represents the ratio of nominal imports and exports to GDP. The reasonable selection of variables in this study is based on empirical studies and theoretical frameworks, in which, following literature on the trade-environment nexus, in the paper, we consider potential control variables, which have influenced on environmental quality, namely financial development, energy consumption, urbanization, industrialization, landlocked, democracy and population growth.

To investigate the effects of trade openness and potential determinants on air quality in developing countries. We followed and extended and developed the empirical models from Shahbaz et al. (2017) for 105 countries, Le et al. (2016) for 98 nations and Shahbaz et al. (2013) in the case of South Africa by incorporating potential determinants of environmental quality: industrialization (Lin et al. 2015; Li and Lin 2015), urbanization (Li and Lin 2015; Sadorsky 2014), financial development (Ganda 2019; Solarin and Al-Mulali 2018), institutional quality or institutional developments (Tamazian and Rao 2010), and population growth (Sadorsky 2014). Furthermore, to control legal systems and reduce errors, the paper adds institutionalized democracy and institutionalized autocracy indexes as proxies of institutional quality or legal systems, which are more likely associated with governments' regulations (Kunčič 2014). Other determinants, being landlocked is a Dummy variable, which is regarded as a well-known proxy of economic openness (Tran et al. 2019). It takes a value of 1 if a country is completely surrounded by land and 0 otherwise. In our model, we strictly treat the control variables as exogenous variables. In addition, in this study, we decided to employ the system generalized method of moments (SGMM) developed by Arellano and Bover (1995). Thus, we added a lagged term of the dependent variable and interaction terms between trade openness and institutional quality as a measure of institutionalized democracy and institutionalized autocracy are included to control the effects of the dynamic process. We also account for dynamic forms of identified equations, in which we added a lagged term of the dependent variables for the effect of the dynamic process. The empirical equation is modelled as follows:

$$\begin{aligned} EQ_{it} = {} & \alpha + \beta_0 EQ_{i,t-1} + \beta_1 ENG_{it} + \beta_2 GDP_{it} + \beta_3 FDI_{it} + \beta_4 OP_{it} \\ & + \beta_5 UR_{it} + \beta_6 IN_{it} + \beta_7 POP_{it} + \beta_8 IQ_{it} + \beta_9 Landlocked_{it} \\ & + \beta_{10} GDP^2_{it} + u_{it} \end{aligned} \tag{2}$$

where

EQ_{it}	environmental quality as measured as CO_2 emissions per capita, NO emissions per capita and $PM_{2.5}$ in country i at time t
ENG_{it}	energy consumption per capita in country i at time t
GDP_{it}	GDP per capita in country i at time t
FDI_{it}	foreign direct investment in country i at time t
OP_{it}	trade openness in country i at time t
UR_{it}, IN_{it}, POP_{it}	urbanization, industrialization and population growth respectively in country i at time t
IQ_{it}	institutional quality as measured as institutionalized democracy and institutionalized autocracy
$Landlocked_{it}$	a dummy variable
U_{it}	is an error term and consist of an individual country effect $State_i$ and a random disturbance e_{it}.

Analogically, it is noted that it is important to take into account the non-linear form of trade openness following Shahbaz et al. (2017). Accordingly, the relationship between trade openness and environmental degradation follows the inverted U-shaped. As argued, the degree of international trade increases; environmental degradation increases up to a certain threshold level of trade openness (*a turning point*); after that, environmental pollution starts to decline. In this case, it is expected that the coefficient of trade openness squares is statistically negative. In this case, we elaborate our specification by adding the quadratic term of the trade openness variable following Eq. 3.

$$\mathrm{EQ}_{it} = \alpha + \beta_0 \mathrm{EQ}_{i,t-1} + \beta_1 \mathrm{ENG}_{it} + \beta_2 \mathrm{GDP}_{it} + \beta_3 \mathrm{FDI}_{it} + \beta_4 \mathrm{OP}_{it} + \beta_5 \mathrm{UR}_{it} + \beta_6 \mathrm{IN}_{it} + \beta_7 \mathrm{POP}_{it} + \beta_8 \mathrm{IQ}_{it} + \beta_9 \mathrm{OP}^2_{it} + u_{it} \quad (3)$$

Besides, to examine the role of institutional quality and democratic on the trade-environmental nexus, we added the interactive variables and analyse the quantitative importance of institutional quality and democratic governments on trade openness as follows:

$$\mathrm{EQ}_{it} = \alpha + \beta_0 \mathrm{EQ}_{i,t-1} + \beta_1 \mathrm{ENG}_{it} + \beta_2 \mathrm{GDP}_{it} + \beta_3 \mathrm{FDI}_{it} + \beta_4 \mathrm{OP}_{it} + \beta_5 \mathrm{UR}_{it} + \beta_6 \mathrm{IN}_{it} + \beta_7 \mathrm{POP}_{it} + \beta_8 \mathrm{IQ}_{it} + \beta_9 \mathrm{IQ}_{it}{*}\mathrm{OP}_{it} + u_{it} \quad (4)$$

However, there are five potential sources of bias estimators in Eqs. 2, 3 and 4: endogeneity, time-invariant country characteristics, heteroskedasticity, autocorrelation and a panel dataset with a short time and large countries dimensions. To control of econometric modelling might also arise and affect the estimates and it is difficult to assume strict exogeneity for all independent variables. Endogeneity, of course, is the most common issue any regression Wooldridge (2010). Hence, to control for potential endogeneity of explanatory variables by using fixed effects instrumental variables estimation, we apply lagged levels of the endogenous repressors of explanatories as instrument variables. By doing so, the endogenous explanatories are pre-determined and, therefore, might not correlate with the error term. Hence, explanatory variables are treated as endogenous variables excepting a dummy variable. Moreover, to eliminate the different country characteristics, we estimate the models by transforming the repressors by the first differencing and employ the Arellano-Bond dynamic panel GMM estimators in a general form (Roodman 2009a) as follows:

$$Y_{it} - Y_{i,t-1} = \delta\left(Y_{i,t-1} Y_{i,t-2}\right) + \beta'\left[X_{i,t} - X_{i,t-1}\right] + \mu_{i,t} - \mu_{i,t-1}$$

or, $\Delta Y_{it} = \delta \Delta Y_{it-1} + \Delta X'_{it} \beta + \Delta \mu_{it}$

By transforming the repressors by first differencing, the time-invariant country characteristics are removed. Furthermore, the Arellano-Bond estimator is the appropriate approach for a small-time and large country panel to test autocorrelation. Besides, We use the robust standard error to adjust for potential heteroskedasticity and Hansen's test for overidentifying restrictions. Additionally, for the GMM estimator to be consistent there should be no second-order serial correlation in the error term of the first-differenced equations, We apply the Arellano-Bond test for second-order serial correlation in first-differences (Arellano and Bond 1991; Arellano and Bover 1995). The paper also relies on the techniques developed by Roodman (2009a, b) in addressing the theme of too many instruments. Additionally, it is noted that given the sample size, to obtain more accurate estimators, we use the finite-sample correction to the two-step covariance matrix provided by Windmeijer (2005) and Erickson and Whited (2002). By doing so, the estimators have better asymptotic and finite sample properties when these diagnostics tests are supportive. Therefore, this study provides new empirical evidence on using the multivariate framework, which controls for potential determinants of environmental quality.

Data sources and description of variables

For reasons of data availability, annual data observing over the period from 1971 to 2014 concerning 66 developing countries are utilized in this paper. The dataset is an unbalanced panel due to data availability. The source of dataset is collected and calculated from World Bank Indicators (2019) excepting institutionalized democracy and institutionalized autocracy from Polity IV dataset (2019) developed from Marshall and Jaggers (2000). The sample size is the reasonable selection as it consists of all the developing countries where international trade is the logical way to foster economic growth. These selected countries are classified by the World Bank and belonged to the list of developing economies below.

- 24 Africa developing economies: Algeria, Egypt, Morocco, Sudan, Tunisia, Cameroon, Congo Rep, Gabon, Congo Dem Rep, Kenya, Tanzania, Angola, Botswana, Mauritius, Mozambique, South Africa, Zambia, Zimbabwe, Benin, Ghana, Niger, Nigeria, Senegal and Togo.
- 22 Asia developing economies: China, Indonesia, Mongolia, Myanmar, Philippines, Korea Republic, Singapore, Thailand, Vietnam, Bangladesh, India, Iran, Nepal, Pakistan, Sri Lanka, Iraq, Israel, Jordan, Lebanon, Oman, Saudi Arabia and Turkey
- 20 Latin America and the Caribbean developing economies: Dominican Republic, Jamaica, Costa Rica, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Panama, Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay and Venezuela.

The main advantage of these unbalance panel data is that they provide all potential and reliable determinants of environmental quality. The summary of descriptive statistics related to the variables used in the research is shown in Table 1. In the empirical analysis, energy consumption, GDP per capita, $PM_{2.5}$, NO emissions per capita and CO_2 emissions are the natural logarithm to reduce heteroskedasticity.

Table 1 Means of the variables used in this study

Indicators	Unit of measurement	No. Obs	Mean	Standard deviations	Data source
Carbon dioxide emissions (CO_2)	Tons per capita	2280	2.426295	3.24384	World Bank (2019)
Nitrous oxide emissions (NO)	Thousand metric tons of CO_2 equivalent per capita	2148	0.570062	0.57462	World Bank (2019)
Particular matter 2.5 air pollution ($PM_{2.5}$)	Micrograms per cubic meter	445	38.61291	29.0301	World Bank (2019)
GDP per capita (GDP)	Current US$ per capita	2280	3155.881	5161.49	World Bank (2019)
Energy consumption (ENG)	Kg of oil equivalent per capita	2280	976.9768	1023.99	World Bank (2019)
Foreign direct investment (FDI)	% of GDP	2280	2.413962	3.77776	World Bank (2019)
Trade openness (OP)	% of GDP	2280	68.81858	49.8508	World Bank (2019)
Export share GDP	% of GDP	2280	32.77204	26.2537	World Bank (2019)
Import share GDP	% of GDP	2280	36.04654	24.9716	World Bank (2019)
Industrialization (IN)	Industrial value added % of GDP	2280	30.60101	11.715	World Bank (2019)
Urbanization (UR)	% of population	2280	51.27068	21.6191	World Bank (2019)
IQ—democracy	Institutionalized democracy—levels	2280	2.092982	14.3819	Polity IV
IQ—autocracy	Institutionalized autocracy—levels	2280	0.567105	14.0219	Polity IV
Landlocked	0 and 1	2280	0.120175	0.32524	World Bank (2019)
Population growth (POP)	%	2280	2.137876	0.97889	World Bank (2019)

The sample period of CO_2 emissions and potential determinants are collected from 1971 to 2014, $PM_{2.5}$ is 2010–2016, NO is 1971–2012 and the remaining variables are 1971–2016; and all of values are before taking logarithm

Looking further into the relationship between air pollutants and trade openness, Figs. 1, 2 and 3 display scatter plot associations between trade openness and each of the three air pollutants emissions in this research. Figure 3 illustrates a close positive relationship between CO_2 emissions and trade openness implying that a higher degree of trade openness is associated with higher CO_2 emissions. The relationship between trade openness and $PM_{2.5}$ emissions is also depicted in Fig. 1, indicating that higher trade openness tends to have lower $PM_{2.5}$ emissions in developing countries. Additionally, Fig. 2 shows a relatively negative relationship between trade openness and nitrous emissions, suggesting that promoting policies towards a higher degree of trade might reduce nitrous emissions.

Empirical results and discussion

Table 2 investigates the results of factors affecting CO_2 emissions and suggests that the EKC hypothesis is accepted at 5% levels of significance. After selecting corresponding optimal lagged instruments, all models are free of autocorrelation (p-values of Arellano Bond test > 0.1) and endogeneity (p values of Hansen J tests > 0.1) at a 1% level of significance. Furthermore, to overcome biased estimators for a small sample, we applied *Windmeijer's errors correction* and reports two-step GMM results using robust standard errors corrected for finite samples and heteroskedasticity. The results reveal that the effect of trade openness as the main interest indicator on CO_2 emissions is statistically significant and positive at a conventional level of significance. The positive sign of this variable confirms that trade openness deteriorates environmental quality (i.e. increases carbon dioxide emissions). Specifically, the coefficient value of trade openness indicates that nearly 1% increase in trade openness is associated with nearly 0.2% increase in CO_2 emissions. It could be explained by the theoretical framework of Lopez (1994) that energy-based activities that consume a high amount of energy mainly driven from trade liberalization such as transportation and manufacturing produce pollution. Additionally, our results are also consistent with the pollution haven hypothesis (Taylor 2004) that developing countries have a comparative advantage in pollution-intensive production while developed ones have a comparative advantage in producing clean products (Wagner 2010). Therefore, developed countries tend to transfer pollution to developing countries via international trade (Cole 2004; Wagner 2010). This finding also is supported by and aligned with the results obtained by Grossman and Krueger (1995) suggesting that developing countries tend to release a high amount of pollutants due to relying on dirty industries. The negative view of environmental impacts of trade openness is in line with the findings from Managi (2004), Cole and Elliott (2003), Managi et al. (2009), Hakimi and Hamdi (2016) and Sharma (2011) who found that trade has a harmful effect on environmental quality through releasing carbon dioxide emissions, whereas our results is contradict with the findings of Ali et al. (2016) and Ahmed et al. (2016) who found that trade openness exerted a significantly negative impact on CO_2 emissions in Nigeria and in newly industrialized economies respectively. It is noted that

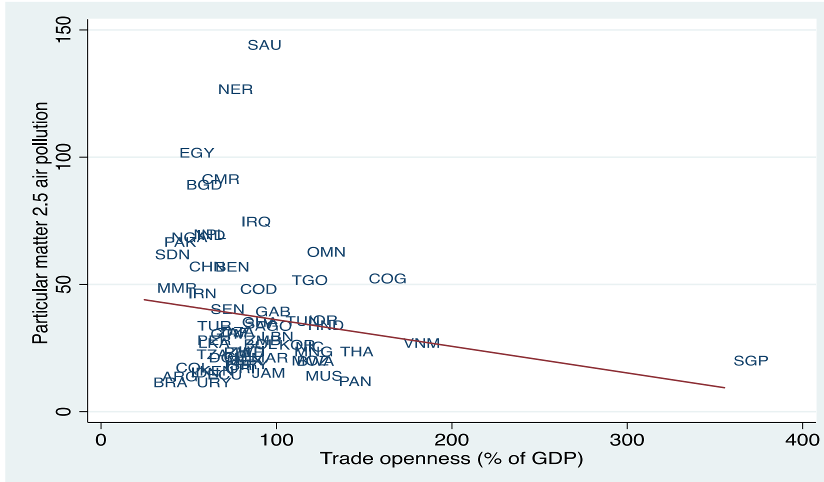

Fig. 1 Particular matter 2.5 air pollution and trade openness. The date points are average over the period from 2010 to 2016 for 65 developing countries

most of the results are from an individual country or a global sample while our research focuses on developing regions. Regarding different measures of trade openness, export share GDP and import share GDP have a positive yet statistically insignificant effect on emissions. The empirical results also demonstrate that a 1% increase in CO_2 emissions is associated with an approximate 0.7864% increase in CO_2 in the coming year. It is suggested that higher CO_2 emissions in previous period lead to deterioration of air quality in the future period. In addition, it is noted that rise in energy consumption has positive impact on carbon dioxide emission which is shown from Table 2 that around 0.4584% increase in CO_2 emissions would result from 1% increase in energy consumption. That is confirmed by the fact that most developing countries still rely on fossil fuels because of the cheapest and energy resource available. This result is consistent with the finding from Ehigiamusoe and Lean (2019) that higher energy consumption leads to higher CO_2 emissions. Likewise, it is evident from the table that a 1% increase in income per capita is associated with 0.3182% rise in CO_2 emissions per capita at high significance. This result also reveals that the opportunity cost between achieving economic growth and the cost of the environment has appeared in developing countries. However, an increase in income per capita until a threshold point leads to a statistically significant decrease in CO_2 emissions per capita which further provides evidence to support the existence of environmental Kuznets curve (EKC) hypothesis. Because the signs of ln(GDP per capita) and ln(GDP per capita)^2 are significantly positive and negative respectively, both are statistically significant at 5% levels of significance regardless of the change of openness variables. This confirms that at an initial stage of economic development economic growth leads to increased CO_2 emissions after the threshold point as economy achieves a sustainable level, CO_2 emissions start to decline. A turning point captured by the squared of GDP per capita is found in developing countries. This result supports to the framework of Narayan and Narayan (2010). The framework posits that because the short-run income elasticity is higher than the long-run income elasticity, thus, CO_2 emissions have decreased with an increase in income in developing countries. The results also are consistent with the findings of Shahbaz et al. (2013) in South Africa, Hua and Boateng (2015) for 167

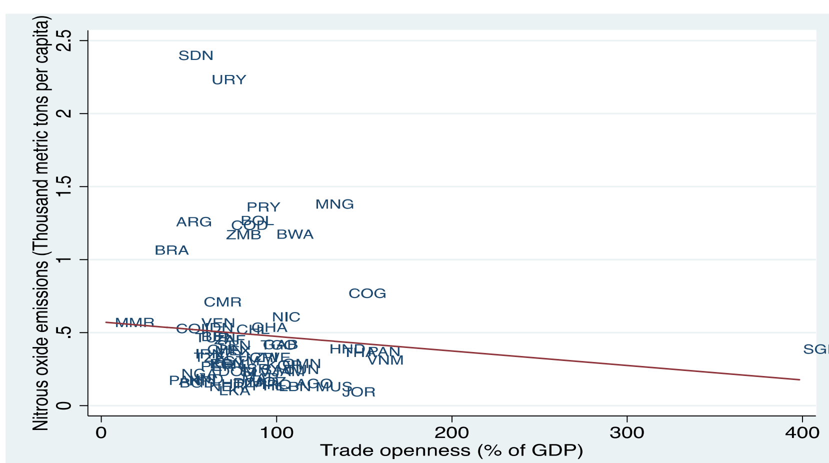

Fig. 2 Nitrous oxide emissions and trade openness. The date points are average over the period from 2004 to 2014 for 66 developing countries

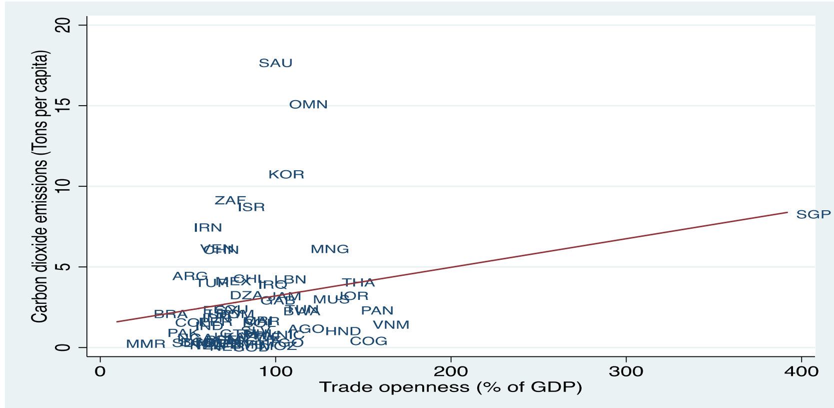

Fig. 3 Carbon dioxide emissions and trade openness. The date points are average over the period from 2004 to 2014 for 66 developing countries

countries and Cetin et al. (2018) and Halicioglu (2009) in Turkey yet contradict with the findings of Farhani and Ozturk (2015) and Solarin and Al-Mulali (2018), in which foreign direct investment (FDI) as a measure financial development is another vital factor that might influence environmental quality. Nevertheless, the result reveals that FDI exerts a statistically insignificant impact on CO_2 emissions in developing regions. However, when replaced the trade openness variable by export share GDP, there is a statistically significant positive between CO_2 emissions and FDI. The value suggests that a 1% increase in FDI is linked with 0.92% rise in CO_2 emissions. Similarly, industrialization has a statistically

Table 2 The contribution of determinants to ln(CO_2 emissions per capita)

Indicators	Models				
	(1)	(2)	(3)	(4)	(5)
Ln(CO_2 emissions) (− 1), lagged	0.7864*** (0.081)	0.7909*** (0.0845)	0.7844*** (0.0813)	0.8384*** (0.074)	0.8307*** (0.0773)
Ln(Energy consumption)	0.4584*** (0.169)	0.45317*** (0.1711)	0.4596** (0.17802)	0.3219** (0.147)	0.2351* (0.1306)
Trade openness	0.002* (0.001)	–	–	3.41e−06 (0.0027)	0.0023** (0.0009)
Trade openness^2	–	–	–	1.89e−06 (9.33e−06)	–
Export share GDP	–	0.0037 (0.0025)	–	–	–
Import share GDP	–	–	0.00328 (0.00213)	–	–
Ln(GDP per capita)	0.3182** (0.128)	0.3489** (0.1348)	0.2879** (0.1155)	− 0.0247 (0.0446)	− 0.0458 (0.0355)
Ln(GDP per capita)^2	− 0.0224** (0.009)	− 0.0247*** (0.0093)	− 0.01987** (0.0078)	-	-
Foreign direct investment	0.0054 (0.0048)	0.0092** (0.0039)	0.0036 (0.00731)	0.0124* (0.007)	0.002 (0.0065)
Industrialization	0.0052 (0.0036)	0.0039 (0.0036)	0.00648* (0.00338)	0.00764** (0.004)	0.0049 (0.003)
Urbanization	− 0.0055 (0.0037)	− 0.00511 (0.0039)	− 0.00568 (0.0036)	− 0.0012 (0.0056)	0.0054 (0.0052)
Population growth	− 0.0139 (0.0236)	− 0.01102 (0.0239)	− 0.0129 (0.0203)	− 0.036 (0.0288)	− 0.0193 (0.0189)
IQ1—democracy	− 0.0004 (0.0037)	0.00008 (0.0039)	− 0.00076 (0.0036)	− 0.0006 (0.0033)	0.00198 (0.0059)
IQ2—autocracy	0.00104 (0.0038)	0.00052 (0.0040)	0.0013 (0.0037)	0.00123 (0.0035)	− 0.0007 (0.0062)
IQ1 × Trade openness	-	-	-	-	− 0.0001 (0.00011)
IQ2 × Trade openness	-	-	-	-	0.00009 (0.00012)
Landlocked	− 0.1414 (0.0922)	− 0.14836 (0.0919)	− 0.13533 (0.0946)	− 0.0703 (0.0757)	− 0.0159 (0.0589)
Constant	− 4.0268*** (1.271)	− 4.0655*** (1.355)	− 3.9554*** (1.2821)	− 2.0074** (0.872)	− 1.6846** (0.8197)
Observations	2214	2214	2214	2214	2214
No. countries	66	66	66	66	66
Hansen *J* (*p_values*)	12.43 (0.332)	13.01 (0.293)	11.81 (0.378)	15.87 (0.146)	16.08 (0.187)
Arellano-Bond test for AR (*p* values)	− 0.72 (0.471)	− 0.74 (0.462)	− 0.73 (0.463)	− 0.83 (0.407)	− 0.70 (0.485)

Robust standard errors corrected for finite sample using Windmeijer's correction are reported in parentheses; empirical results based on collapsed instruments the second lag of the endogenous variables as valid instruments and estimation is from unbalanced panel of 66 developing countries covering the period 1971–2014. ***$p < 0.01$; **$p < 0.05$; and *$p < 0.1$

positive significant impact on emissions in model 3. Hence, these results confirm the fact that in developing countries higher industrialization and FDI lead to environmental degradation. Regarding other factors, we also found the remaining variables, namely urbanization, population growth, institutional quality and landlocked, have a statistically insignificant effect on the CO_2 emissions in all five models. Unfortunately, it is suggested that CO_2 emissions might not result from urbanization, population growth, institutional quality and landlocked in developing countries. The results have very similar results as those of Asane-Otoo (2015) and Sadorsky (2014) who release that urbanization and population exert an insignificant impact on CO_2 emissions across different income groups in Africa and emerging economies respectively. However, our results are not consistent with Al-Mulali and Ozturk (2015) in which both urbanization and industrialization exert a significantly negative effect on CO_2 emissions. It is noted that an inverted U-shaped relationship between trade openness and CO_2 emissions is not valid in this study because the non-linear term of trade openness in model 4 is statistically significant. This finding is not aligned with the results obtained by Shahbaz et al. (2017) who found that at initial stage trade openness has detrimental effects on environmental quality, whereases after a certain threshold level of trade openness, it starts to have a beneficial effect. However, results from the other two pollutants in Tables 3 and 4 and find are quite different results to those of determinants affecting CO_2 emissions.

The results presented in Table 3 shows the impact of trade openness and potential determinants on nitrous oxide (NO) emissions. We rely on both the Arellano-Bond test and Hansen *J* test to select appropriate lag orders. As can be seen in Table 3, the second lag is applied on the basis of these tests. The results also base on Windmeijer's errors correction for a finite sample size to obtain more consistent estimators. In most of the regressions, we found that trade openness exerts a statistically insignificant effect on NO emissions. This result is not in line with Frankel and Rose (2005) that trade tends to moderately significantly decrease NO emissions. However, this result is aligned with the finding from Cole and Elliott (2003), in which

Table 3 The contribution of determinants to ln(NO emissions per capita)

Indicators	Models				
	(1)	(2)	(3)	(4)	(5)
Ln(NO_x emissions) (− 1), lagged	0.8033*** (0.1835)	0.8426*** (0.1629)	0.7822*** (0.1871)	0.7047*** (0.1971)	0.6939*** (0.2559)
Ln(Energy consumption)	0.1276 (0.1609)	0.0959 (0.1442)	0.16658 (0.17907)	0.01371 (0.1282)	0.0942 (0.1768)
Trade openness	− 0.0019 (0.002)	-	-	− 0.00404 (0.0037)	− 0.0009 (0.0022)
Trade openness ^{2}	-	-	-	9.63e−06 (0.00001)	-
Export share GDP	-	− 0.003 (0.0032)	-	-	-
Import share GDP	-	-	− 0.00368 (0.00372)	-	-
Ln(GDP per capita)	0.0087 (0.1663)	− 0.00913 (0.1533)	0.06766 (0.1764)	− 0.0375 (0.0773)	0.01901 (0.0472)
Ln(GDP per capita) ^{2}	− 0.0038 (0.0111)	− 0.00213 (0.01014)	− 0.00795 (0.0125)	-	-
Foreign direct investment	0.0083 (0.0097)	0.0056 (0.0078)	0.0091 (0.01061)	0.0006 (0.0141)	0.0035 (0.0112)
Industrialization	0.00127 (0.0035)	0.0025 (0.0039)	− 0.0008 (0.00404)	0.0035 (0.0042)	0.0005 (0.0044)
Urbanization	− 0.0010 (0.0052)	− 0.0004 (0.0048)	− 0.0021 (0.00543)	0.00077 (0.0085)	− 0.01094 (0.0113)
Population growth	− 0.0156 (0.0337)	− 0.0154 (0.0322)	− 0.01527 (0.0334)	− 0.0247 (0.0777)	− 0.0127 (0.0398)
IQ1—democracy	0.0010 (0.0045)	0.00036 (0.0038)	0.00144 (0.0047)	0.00178 (0.0046)	0.00085 (0.0053)
IQ2—autocracy	− 0.0012 (0.0044)	− 0.00036 (0.0036)	− 0.00155 (0.0047)	− 0.00223 (0.0043)	0.0026 (0.0056)
IQ1 × Trade openness	-	-	-	-	0.00002 (0.0002)
IQ2 × Trade openness	-	-	-	-	− 0.00008 (0.00014)
Landlocked	0.2202 (0.2809)	0.1939 (0.2728)	0.2217 (0.2716)	0.3126 (0.3001)	0.20029 (0.3231)
Constant	− 0.7501 (1.1012)	− 0.5597 (0.9901)	− 1.1111 (1.3048)	0.00242 (0.5497)	− 0.4103 (0.8293)
Observations	2082	2082	2082	2082	2082
No. countries	66	66	66	66	66
Hansen *J* (*p* values)	11.07 (0.438)	11.54 (0.399)	10.74 (0.466)	16.71 (0.117)	11.21 (0.511)
Arellano-Bond test for AR (*p* values)	1.25 (0.210)	1.25 (0.210)	1.25 (0.212)	1.20 (0.228)	1.28 (0.201)

Robust standard errors corrected for finite sample using Windmeijer's correction are reported in parentheses; empirical results based on collapsed instruments the second lag of the endogenous variables as valid instruments based on Arellano-Bound test and Hansen *J* test being greater than 10% and estimation is from unbalanced panel of 66 developing countries covering the period 1971–2012. ***$p < 0.01$; **$p < 0.05$; and *$p < 0.1$

Table 4 The contribution of determinants to ln($PM_{2.5}$)

Indicators	Models				
	(1)	(2)	(3)	(4)	(5)
Ln(PM2.5) (− 1), lagged	1.1443*** (0.1182)	1.095*** (0.13197)	1.1893*** (0.1151)	1.0012*** (0.0470)	0.9795*** (0.0448)
Trade openness	0.00213 (0.0013)	-	-	0.00284 (0.0018)	− 0.00039 (0.00068)
Trade openness^2	-	-	-	− 6.78e−06 (4.43e−06)	-
Export share GDP	-	0.00302 (0.0035)	-	-	-
Import share GDP	-	-	0.00438** (0.00206)	-	-
Ln(GDP per capita)	− 0.9457 (1.4552)	− 1.3692 (1.9562)	− 0.70258 (1.3624)	− 0.0168 (0.0444)	− 0.03050 (0.0549)
Ln(GDP per capita)^2	0.05411 (0.0848)	0.07815 (0.1152)	0.04189 (0.08034)	-	-
Foreign direct investment	− 0.0021 (0.0054)	0.00091 (0.0065)	− 0.00511 (0.00434)	− 0.0008 (0.0012)	0.00157 (0.0029)
Industrialization	− 0.00061 (0.0042)	− 0.0016 (0.00578)	0.00055 (0.00323)	− 0.0002 (0.0013)	0.00106 (0.0017)
Urbanization	0.00127 (0.0074)	0.0027 (0.0072)	− 0.00164 (0.00594)	0.0045 (0.0024)	0.00419 (0.0031)
Population growth	− 0.0047 (0.0272)	− 0.0023 (0.02329)	− 0.01419 (0.02327)	− 0.01624 (0.0108)	− 0.00551 (0.01723)
IQ1—democracy	− 0.0104 (0.0120)	− 0.01104 (0.01486)	− 0.00979 (0.01311)	− 0.0008 (0.0050)	− 0.01266 (0.0080)
IQ2—autocracy	0.01367 (0.01557)	0.01523 (0.02087)	0.01199 (0.01493)	− 0.0017 (0.0054)	0.00076 (0.01964)
IQ1 × Trade openness	-	-	-	-	0.00015* (0.00008)
IQ2 × Trade openness	-	-	-	-	− 0.00005 (0.00021)
Landlocked	0.00974 (0.0999)	0.02761 (0.1173)	− 0.01186 (0.08873)	0.0589 (0.0487)	0.02644 (0.0507)
Constant	3.4292 (5.9668)	5.4092 (8.0737)	2.27136 (5.63005)	− 0.2299 (0.4431)	0.10268 (0.3888)
Observations	390	390	390	390	390
No. countries	65	65	65	65	65
Hansen *J* (*p* values)	7.59 (0.668)	7.64 (0.664)	6.81 (0.744)	4.39 (0.928)	9.76 (0.552)
Arellano-Bond test for AR (*p* values)	0.01 (0.988)	− 1.23 (0.220)	− 1.49 (0.137)	− 1.04 (0.297)	− 0.70 (0.486)

Robust standard errors corrected for finite sample using Windmeijer's correction are reported in parentheses; all of equations are used lag(2 2) as valid instruments, yet in columns 3, 7 and 8, we employed lag (3) as instruments due to autocorrelation and invalid instruments from Hansen *J* and Arellano-Bound tests being higher than 10% and estimation is from unbalanced panel of 65 developing countries covering the period 2010–2016, excepting Venezuela due to data availability. ***$p < 0.01$; **$p < 0.05$; and *$p < 0$

trade intensity as a measurement of trade openness has no significant impact on NO emissions. The reason for this might result from the role of the transport sector affecting No emissions (Cole and Elliott 2003) Furthermore, the other relevant factors in our study also exert an insignificant impact on NO emissions. However, the empirical results confirm that there is inertia in NO emissions. In other words, NO emissions in the next period would be resulted from NO emissions in the previous period. Specifically, a 1% increase in NO emission in the previous period leads to approximately 0.8% rise in NO in the future. However, we do not find any evidence that the remaining factors affecting NO emissions. These findings are inconsistent with Hove and Tursoy (2019) who found that industrialization contributes to increasing nitrous oxide emissions. Moreover, we do not find any evidence of an inverted U-shaped relationship between income and nitrous oxide emissions, which has been confirmed by the previous study of Hove and Tursoy (2019).

In Table 4, ambient particulate matter ($PM_{2.5}$) air pollution is the dependent variable. Results from the Arellano-Bond and Hansen *J* tests for appropriate lags indicate that there are no autocorrelation and valid instruments. Therefore, the selected optimal lagged lengths are appropriate instrument variables. The result reveals that a 1% increase in $PM_{2.5}$ in the previous period leads to around 1.1443% increase in $PM_{2.5}$ in the coming year at a 1% level of significance. It is suggested that air quality in future period would result from $PM_{2.5}$ in the previous period. Another surprising result that can be drawn from Table 4 is that 0.438% increase in $PM_{2.5}$ could be resulted from a 1% rise in import share GDP, while trade openness and export share GDP exert no statistically significant effect on $PM_{2.5}$. Results are aligned with the results obtained from Frankel and Rose (2005) suggesting that there is no statistically significant relationship between trade and particulate matter. To test whether does country with better institutional quality accelerate the impact of trade openness on the environment, we use the interaction terms between trade openness and institutional quality following Tamazian and Rao (2010). However, there is no evidence of a country with better-institutionalized autocracy government impacts on trade-environment nexus. An interesting finding is that the interaction term between trade openness and institutionalized democracy government is significant at the conventional level of significance with a positive sign.

This sign suggests that a country with higher institutionalized democracy government might accelerate the effect of trade openness on $PM_{2.5}$ air pollution. We now explain the results of the remaining variables in Table 4. Results reveal that there is no statistically significant relationship between financial development, urbanization, industrialization, population growth, institutional quality, landlocked and income and $PM_{2.5}$ air pollution. Results are partly consistent with the findings from Ouyang et al. (2019) in which there is no significant relationship between FDI and $PM_{2.5}$ concentrations while urbanization and GDP per capita have a significantly negative impact on $PM_{2.5}$. However, our results are inconsistent with the findings of Ji et al. (2018) who indicate the relationship between $PM_{2.5}$ and urbanization and income followed an inverted U-shaped curve, in which $PM_{2.5}$ pollution goes up at a low level of income and urbanization then goes down at a high level of income and urbanization.

Conclusions and policy implications

The economic literature emphasizes the importance of international trade in assisting developing economies to foster economic development. However, an expansion of exchange activities and energy-intensive industries resulted from trade openness is considered as the potential source of pollutant emissions. The present research has investigated the effects of trade openness on air quality in the presence of potential determinants of pollutants a case of 66 developing countries in controlling for the endogeneity of the explanatory variables. These results, which consider three main air quality recently attracted a number of scholars and employ appropriate estimation techniques, provide new insights of the relatively ambiguous question of whether trade openness impedes environmental quality in controlling other factors. Results reveal a statistically positive sign for the coefficient of trade openness, suggesting that a 1% increase in trade openness leads to around 0.2% rises in CO_2 emissions. The obvious reason for this is developing countries have to rely on dirty industries, which release pollutants (Grossman and Krueger 1995). This suggests that trade policy towards an expansion trade openness may be harmful for the environment. Energy consumption also is a major contributor to carbon emissions. Therefore, developing countries should consider this in strictly using environment-friendly technologies to produce cleaner products. Moreover, the existence of an environment Kuznets curve in the case of developing countries is valid in this study. However, the empirical results vary and depend on the use of indicators and pollutants mainly due to different time dimensions. Another, interesting observation of our finding is that an increase in air pollutants in the previous period significantly leads to rising in pollutants in the future. It implies that if there is no action to reduce the amount of air pollutant in the previous period, the environmental quality is worse off in the future. However, the findings have failed to convince that urbanization, population growth and institutional quality impact on the environment.

The result suggests several policy implications for developing countries. The findings obtained in this research provide evidence to convince that decreasing energy consumption as measured emission reduction policy leads to reduce emissions. Since developing countries might consider reducing carbon emissions yet remain economic growth prospects via promoting energy green consumption instead. In this sense, supporting the application and development of new technologies that consume fewer energy sources leads to less carbon dioxide emissions. Furthermore, we argue with regard to financial development and environmental quality foreign direct investment directly contributes to carbon emissions. This implies that policies related to attracting financial development in developing countries increase emissions; thus, controlling dirty industries' investments is the other strategy of improving environmental quality. In addition, our findings have failed to provide evidence that institutional quality influences environmental quality. However, our study is limited to not provide the analysis of how environmental policies could motivate countries to use more efficient technologies in tackling environmental issues. Furthermore, the other research also could be extended the empirical results by employing different econometric approaches to account for cross-sectional dependence. Hopefully, these issues will be addressed in other research by the authors in the future.

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