RESEARCH ARTICLE

Does the pollution halo hypothesis exist in this "better" world? The evidence from STIRPAT model

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Abstract

Multinational corporation has changed their host countries. The new wave of FDI inflow attracted the interest of policymakers. FDI has significant effects on both productivity and carbon dioxide emissions. The host countries should carefully consider the advantages and disadvantages of FDI to their nation. The previous literature has not illustrated the global context's theoretical halo or haven pollution hypothesis. Using panel data of 96 countries between 2004 and 2014, our empirical results confirm the haven pollution hypothesis in both developing and developed countries. We employ the different general methods of moments (GMMs) to engage FDI in traditional STIRPAT theoretical frameworks. The empirical results contribute to the evidence of the EKC theory. The country's income level has been used to modify our models. The affluence of the economy, urbanization, FDI, and industrial sector would cause harmful effects on carbon dioxin emissions globally. The paper implies the two models which can be used for both developed and developing countries. The policymaker can use both short-run and long-run elasticities from those models to implicate their country's FDI inflow strategy.

Keywords Haven pollution hypothesis · Foreign direct investment · Urbanization · General method of moments · Stochastic impact by regression on population · Affluence · And technology · Carbon emissions

Introduction

Global climate change affects the global environment, the current issue worldwide. The United Nations Framework Convention on Climate Change (UNFCCC) committed to reducing greenhouse gas (GHG) emissions in 1992. Dangerous anthropogenic interference caused GHG emissions and damaged the climate system, which should be stopped. Historically, many global responses were generated to reduce GHG at country and corporation levels. At the global level,

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the 1997 Kyoto Protocol was established, with many countries agreeing to the commitment to reduce GHG emissions. Besides, investment in energy-efficiency technologies provided an efficient approach to reducing GHG and global warming at the corporation level. GHG emissions also set some global energy standards for firms. Energy service companies (ESCOs) can develop and design energy efficiency technology, which is generated to reduce GHG emissions (Council 2008; Ellis 2010; Fang et al. 2012; Linares and Labandeira 2010; Popp 2004, 2010; Vine 2005). Recently, sustainable development goals have been established by United Nations. There are 17 goals in total, integrating six goals on balancing economic and environmental sustainability. While the country's commitment to joining the SDGs, almost economic or environmental policies should be modified to reach SDGs standards before 2030. For example, the multinational corporations (MNCs), which ESCOs undertake, reduced GHG emissions in the host country's operation and transferred energy-efficiency technologies to reduce GHG emissions in other countries via their foreign direct investment (FDI). Besides that, the ISO 14001 also contributes to the green growth strategy of the firm in Pakistan (Abid et al. 2022). Significantly, MNCs from developed countries

can reduce GHG emissions in developing countries with their investments (He 2006; Hübler 2011; Saikawa and Urpelainen 2014; Yang et al. 2014). In previous studies, many researchers successfully captured the shreds of evidence that FDIs affect economic growth (Borensztein et al. 1998; Crespo and Fontoura 2007; Greenaway and Kneller 2007), have a spillover effect on productivity (De Mello 1999; Wei and Liu 2006), and prompt host country's entrepreneurship (Alfaro et al. 2004; 2009). Thus, many governments recently have specific strategies for observing FDI due to its importance towards economic growth. However, Phuc Nguyen et al. (2020) have failed to express the effect of FDI on pollution, while their study uses a tiny dataset only in emerging economies. At the same time, some other studies have reflected this significant hypothesis.

Furthermore, pollution halo and haven hypotheses are proposed to describe the causality relationship between pollution issues and FDI (Zhu et al. 2016). The host country's government has two options to justify a foreign investment. The government accepts the FDI and its low energy-intensive technology that can reduce harmful pollution situations in the host country, which is called well-known the pollution halo hypothesis (Mert and Bölük 2016; Zhu et al. 2016). Besides the above benefits, FDI can harm the host country's environment, called the pollution haven hypothesis. This phenomenon is proposed to appear under the context that the environmental issues are neglected or enforced under relaxed regulation by the government. Some studies indicate that FDI inflows harm the pollution situation in Vietnam, the Middle East North Africa (MENA) countries, other Southeast Asia countries, and the Middle East countries (Abdouli and Hammami 2017; Al-mulali 2012; Baek 2016; Tang and Tan 2015; Naz et al. 2019). Can FDI transfer and install an energy-efficient system for the host economy and reduce their CO_2 emissions level, or provide an opposite effect? According to recent literature, the empirical results are mixed and depend on the affluence of the economy, the choice of countries, or specific cities. They used fixed and random effects OLS regression, GMM methods, ARDL regression, and VECM (Abdouli and Hammami 2017; Al-mulali 2012; Baek 2016; Tang and Tan 2015; Naz et al. 2019). However, some studies support the hypothesis that FDI inflow helps host countries to reduce carbon dioxide emissions in Kyoto Annex countries and ASEAN countries by panel quantile regression and panel ARDL approach (Mert and Bölük 2016; Zhu et al. 2016; Zameer et al. 2020). Matthew et al. (2017) conclude that a consistent effect of the pollution haven hypothesis is hard to find due to certain countries and specific pollution-intensive sectors (precisely sample size). Recently, the interest of researchers in the linkage between FDI and pollution has increased. The necessary trend is a more and larger sample size, which is expected

to fulfill the understanding of researchers on existing phenomena. The last global events yield a new wave of FDI withdrawal from China.[1]

According to the government of ASEAN countries and Segis and Hauge (2020), due to the US-China trade war and unstoppable Covid-19 situation, the manufacturing FDI have runout China will be around 37%, which is known as the highest out-flow in recent 5 years. There is much academic and applied research on attracting FDI from firms looking for an alternative to China at this period. Even though the world is talking about the satellite imagery of an "unprecedented green China" resulting from industry imposed to halt the spread of Covid-19, the over-optimistic points of view emerge more and more in China's neighboring countries. The policymakers seemed to forget China's "Trade-offs" lesson two decades ago. The issue regarding FDI is predicted to happen in twofolds. First, MNCs in the USA, Japan, and South Korea will withdraw FDI from China, switching to neighboring countries. Moreover, the digital transformation era has promoted advanced manufacturing technologies such as AI, robots, and IoT and affected MNC's strategy (Tassey 2014). Automatic manufacturing factory reduces the competition of the FDI, hosting factory economics (Asia) and cheap labor (Szalavetz 2019). FDI factories can move from emerging countries to high advantage technological economies. Second, Chinese enterprises craving inflow of FDI expect to reinvest in a third country to reduce the export tariffs exposed by the USA through the country-of-origin regime. Previous studies on the Chinese context support the pollution halo hypothesis, which can be explained by the fact that the seriously damaged local environment forced residents, enterprises, and government to be concerned.

It should be noted that not all inflow of FDI will run out of China, which will lead to the pollution halo hypothesis. Carbon dioxide (CO_2) is recognized as the most important anthropogenic GHG by the International Panel on Climate Change (IPCC 2007) worldwide. The current study investigates the impact of inward FDI on emissions on a global scale. Testing this phenomenon can yield vital evidence about the trade-off between environmental conditions and economic growth. To test the halo or haven hypothesis, the effect of FDI on CO_2 emission can be looked at through four philosophies like positivism, post-positivism, post-empiricism, and interpretivism (Lor 2017). The number of publications on pollution, which imply the pollution

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[1] After the US-China trade war and Covid-19, ASEAN governments analyzed the political and economic situation in future to react to trade war and Covid-19. MNCs tend to shift their factories to China's neighbor. He (2006) directly addresses the haven pollution hypothesis and FDI-environmental regulation stringency in China, is the most recent. From Pao and Tsai (2011), researchers interested in the halo pollution hypothesis or EKC hypothesis.

halo hypothesis in China or other polluting industries, has increased in recent years.[2] The environmental perspective has changed from positivism to post-empiricism. Before, researchers reflected on the pollution phenomenon worldwide (pollution haven hypothesis) to analyze the antecedents of the pollution halo hypothesis (Zameer et al. 2020). Recently, the researchers usually refer to the empirical study with provinces data level, which includes the difference of the state's policy on environmental, even when those entities are in China and other Asian countries (He 2006; Gui et al. 2017; Liu et al. 2017; Huang et al. 2018; Zhang and Zhang 2018). After Matthew et al. (2017) review, empirical results truly convince the government based on recommendations with evidence from case studies, reflecting the unilateral pictures. Many researchers adopt positivism (quantitative) and interpretivism (qualitative) to investigate the causality between FDI and pollution. Thus, the limitations appear frequently in their dataset to explain case-oriented or variable-oriented, while the worldwide sample size data is available. Comparing the halo and haven phenomenon via developing and developed country data should be conducted.

Furthermore, does the pollution halo hypothesis be found in high-income countries? Moreover, does the pollution haven hypothesis be found in low-income countries? (Chang and Li 2019). Recent words-using also reflects this expectation. "The contradictory Pollution Haven Hypothesis" has appeared in the newest studies (Phuc Nguyen et al. 2020). The belief that FDI and its satellite factors can make up for the impact of "the pollution outsourcing hypothesis" is causing certain disturbs. In another context, policymakers should focus more on the cause of pollution issues rather than only on the reaction. Many improper decisions by policymakers are accused of lacking multidimensional empirical results, which can harm the host country's environment. This study aims to provide an effect of FDI on the haven pollution hypothesis that will alert policymakers to consider the influence of accepting FDI seriously. The system GMM is employed to generate the empirical results of an extensive version of the stochastic impact by regression on population, affluence, and technology model (Levine et al. 2000; Fang and Miller 2013). Contributing evidence contradicting the "Pollution Halo" hypothesis with a worldwide dataset. Our finding shows that the policymakers should treat the FDI as the factor that positively affects pollution. Their policy needs to be carefully built to exclude polluted MNCs and attract green technology investment. The affluence of the economy, urbanization, FDI, and industrial sector would cause harmful

effects on carbon dioxin emissions globally. FDI is a good factor that should be considered in extending the STIRPAT model. This new outlook of the STIRPAT model can explain both the domestic and foreign factors in an environmental study. Moreover, our findings also yield evidence on EKC theory which illustrates the inverted U-shape of the effect of household income on pollution.

Moreover, this article conducts empirical results with worldwide sample data that support the halo hypothesis in the global platform. A relevant literature review is discussed in the "Literature review" section, followed by data description and methodology in the "Research methodology" section. The empirical results are in the "Estimation results" section. Critical implications and conclusions are highlighted in the "Discussion" and "Conclusion" sections, respectively.

Literature review

In economic theory, Pao and Tsai (2011) yield the theoretical model for describing humanity's effect on the environment. Then the environmental impact (I) is defined by the well-known IPAT (or I = PAT) as the product of components: population size (P), the affluence of the economy (A), and existing technology (T). The Kaya identity applies the IPAT identity, which considers the four driving forces of global CO_2 emissions (Pao and Tsai 2011). The ImPACT, developed to predict total CO_2 emissions, is not derived from some underlying theoretical model (Waggoner and Ausubel 2002). Leaning the IPAT model and its relative to the pollution study is an essential requirement. Previous researchers claim those four factors cannot be excluded to avoid the omitted variable (Li et al. 2015; Zhang and Zhou 2016; Gui et al. 2017; Phuc Nguyen et al. 2020). Furthermore, urbanization has also been added-in to the IPAT model (Fang and Miller 2013). The lack of foreign factors made the scholars less interested in the IPAT model. Similar to the idea of moving from the closed economic model to the open economic model in any macroeconomic syllabus, the need for the foreign factor in the IPAT model extracts the researchers dig in this field.

The population factor implies all the human activities in the environment. Unfortunately, population growth and human behavior claim to be the main factor that positively impacts the environment. Ehrlich and Holdren (1971) mention that the population's elasticity of the environment should be near to one. For example, the higher population growth rate force using more fossil fuels to power is an example of their increasingly mechanized lifestyles. Recently, Zhang et al. (2017) found that human awareness can moderate the relationship between the population and the environment. Human activity and their living lifestyle

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support the explanation. For example, in countries where people are primarily medium or low income, cars are still luxury products, and many people tend to use one public vehicle. Those behavior causes reduce carbon dioxin levels. Researchers have found empirical results that consistently prove this point of view in developing countries (Rehman et al. 2021; Wu et al. 2021).

The researchers have noticed the relationship between household income and the environment from the beginning of UNFCCC commitment in the twentieth century. The affluence of the economy is claimed as a factor that can contribute to the diminishing returns on the harm of the environment before the thresholds (Tang and Tan 2015; Gökmenoğlu and Taspinar 2016). Besides that, Zhu et al. (2016) consider the environmental conditions as the inferior good in the household's basket for consumption. Individuals with low income can accept low welfare conditions based on their unaffordable budget constraints (Hotte and Winer 2012). Hence, scholars tend to look for the threshold that can separately observe the inverted U-shape in the relation between income and environmental conditions. In the past, scholars used GDP per capita and its square to measure this threshold (Lau et al. 2014; Muhammad et al. 2020). Using A and A^2 are famous for testing environmental Kuznets curve (EKC) theory (Balsalobre-Lorente et al. 2019).

Technology has affected almost aspect of human life. Hence, Pao and Tsai (2011) built the IPAT model toward this perspective and included the factor of existing technology. Any efficient way to cut off the harm to the environment from economic activities should be linked to existing technology. Zugravu-Soilita (2015) uses a regulatory environment to measure the government's efforts to reduce pollution. Even the nominal scale as the first-year countries allows ESCO company to start in the host country, which measures the dummy variable as the existing technology estimators (Fang et al. 2012). The most useful scale to measure the effect of the existing technology is the energy intensity level or the renewable energy consumption (Mert and Bölük 2016; Shahbaz et al. 2018; Ahmad et al. 2021; Yang et al. 2021); because it is roughly interested in investing the energy use directly with the other variables. Abid et al. (2020) described the causatively short-run relationship between the growth rate of carbon emission and non-renewable energy in Pakistan. Their study shows that the long-run positive effect of non-renewable energy on carbon emission still has a positive effect. At the global level, non-renewable energy is widely applied and used in life (Khan et al. 2022). Hence, the existing technology (energy intensive in the world development indicator) is assumed to affect carbon dioxin emissions positively.

Urbanization has contributed a significant effect on pollution. It is a crucial point of view when comparing the crowd of citizens between urban and rural areas in pollution studies. Many researchers consider urbanization an explaining variable to carbon emission (Fang and Miller 2013; Rehman et al. 2021; Wu et al. (2021). In general, pollution is higher in urban areas than in rural areas. For example, if the income level is affordable, the area shall have more cars when the cities have more citizens. Likewise, the scholar usually claims the positive effect of urbanization on most pollution indicators (Phuc Nguyen et al. 2020). However, the estimator of urbanization has been found as negative significant in the developing country contexts. Li et al. (2021a) and Li et al. (2021b) have found evidence that changing energy consumption can reduce pollution, such as moving from private transportation to public transportation and saving energy intensity. At the global level, the effect of urbanization on pollution is expectedly to have positive significance.

Foreign direct investment is used to clarify a factor that can affect the productivity of the host country (Alfaro et al. 2009). That is why the FDI always sticks with the citizen's income. The policymaker usually considers FDI the crucial factor contributing to the host country's income. For that reason, the effect of FDI on the environment should be comoved with household income. In other words, the public health condition is not their priority compared to the trade-off for income (Hotte and Winer 2012). Thus, the impact on the environment can also be assumed as inferior goods when the government in low-income countries chooses the FDI inflows or the national income level (GDP per capita). They tend to accept FDI-inflows without considering the impact on environments (Abdouli and Hammami 2017; Al-mulali 2012; Baek 2016; Tang and Tan 2015; Udemba 2020). Countries with a high level of pollution situations will prefer to attract the FDI within green technology spillover to reduce pollution situations (Huang et al. 2018; Hao et al. 2020; Horobet et al. 2021). Table 1 summarizes the relationship between FDI and the environment, conducted recently.

The research evidence is mixed in China, the most polluted globally regarding CO_2 emissions and air quality pollution (PM 2.5). At the city or province level, many types of research support the positive impact of inward FDI on the local environment in China (He 2006; Li et al. 2015; Xu et al. 2016). Besides, some articles support the Halo hypothesis that FDI inflows help reduce pollution in China. Yang et al. (2014) show that the increase in the R&D sector can decrease carbon dioxide emissions when FDI-inflows contribute an essential role in promoting the R&D sector. Following this direction, Auffhammer et al. (2016) conducted their research to confirm that the pollution halo hypothesis exerts more severe than the pollution haven hypothesis in Chinese cities. Again, the results confirm mixed implications among the pollution situations in each city or province in China. Balsalobre-Lorente et al. (2019) have also yielded evidence that FDI and environmental conditions have a nonlinear relationship in MINT countries. The two

Table 1 Previous studies that investigate the pollution halo or haven hypothesis

Authors	Related hypothesis	Model/methodology	No of variables	Developing	Developed	Specification of sample
He (2006)	Haven (negative: −)	GMM	9	v		China provinces
Al-mulali (2012)	Haven	Panel FMOLS/VECM	5	v	v	The Middle East countries
Lau et al. (2014)	Haven	EKC theory	5	v		Malaysia
Yang et al. (2014)	Haven	Fixed/random effects/2SLS	9	v		China Provinces
Li et al. (2015)	Haven	STIRPAT/PLS	7	v		Tian Jian City (China)
Tang and Tan (2015)	Halo (positive: +)	EKC theory/Granger VECM	5	v		Vietnam
Zugravu-Soilita (2015)	Haven	Fixed effect panel estimator	5		v	France-Germany-Sweden-UK
Auffhammer et al. (2016)	Halo	Decomposition/OLS	6	v		China Provinces
Baek (2016)	Haven	Pool OLS estimator	6	v	v	ASEAN countries
Gökmenoğlu and Taspinar (2016)	Haven	FMOLS/EKC theory	4		v	Turkey
Mert and Bölük (2016)	Halo	Pool OLS/ADRL	6		v	Kyoto Anmex countries
Zhu et al. (2016)	Halo	Fixed effect panel quantile regression	8	v	v	5 countries in ASEAN
Zhang and Zhou (2016)	Halo	STIRPAT/FGLS	7	v		China regions
Abdouli and Hammami (2017)	Haven	OLS/fixed and random effects/GMM	6	v	v	MENA countries
Gui et al. (2017)	Halo	STIRPAT/PLS regression	7	v		China
Liu et al. (2017)	Halo	OLS/Fixed effect/GMM	7	v		China
Huang et al. (2018)	Halo	Fixed effect/FGLS	8	v		China provinces
Shahbaz et al. (2018)	Haven	ADRL/CUSUM/CUSUMsq	6		v	France
Zhang and Zhang (2018)	Haven	ADRL/Granger causality	6	v		China
Balsalobre-Lorente et al. (2019)	Haven	FMOLS/DOLS/EKC theory	7	v		Mexico, Indonesia, Nigeria, Turkey
Dauda et al. (2019)	Halo	EKC theory/FMOLS/DOLS	8		v	Developed, MENA, BRICS
Hao et al. (2020)	Halo	SLM model/SEM	8	v		30 provinces of China
Muhammad et al. (2020)	Haven	EKC theory/2SLS	8	v	v	65 belt and road initiative countries
Phuc Nguyen et al. (2020)	Halo	STIRPAT model/panel Granger	11	v		33 emerging economies
Udemba (2020)	Haven	ADRL/Granger	4		v	Turkey
Ahmad et al. (2021)	Haven	ARDL/VECM	6	v		China
Horobet et al. (2021)	Haven/halo	VECM	7	v	v	24 European countries
Yang et al. (2021)	Haven/halo	Path LS	5	v		30 provinces of China

Several publications have concluded implications to the causality of FDI inflows on any kind of emission from Web of Science[a]

Year	Before 2016	2016	2017	2018	2019	2020	2021	Total
Halo pollution hypothesis (or contradict to "Haven")	03	06	06	09	20	18	30	92
Haven pollution hypothesis	09	05	11	07	17	20	42	111

[a]The metadata is analysis via advanced search on Web of Science by keywords as "FDI"; "Halo/Haven", and "emission". Authors do not count the paper with not concluding results

last factors are the industry and service sectors. By their natural characteristics, industrial production lines usually harm environmental conditions. The service sector seems to be more green (Fang et al. 2012.)

Research methodology

Research model

This study follows the equation system proposed by Fang et al. (2012). Concerning the empirical model, which allows hypothesis testing. York et al. (2003) take the derivative of the IPAT model to become stochastic impact by regression on population, affluence, and technology (STIRPAT) model, which is as follows:

$$I_i = aP_i^b A_i^c T_i^d e_i, \text{ or}$$
$$\ln I_i = \ln a + b \ln P_i + c \ln A_i + d \ln T_i + \varepsilon_i \quad (1)$$

The subscript i denotes the countries; a, b, c, and d are the parameters to be estimated; ε_i is the error term; and $\varepsilon_i = \ln e$. A simple model of CO_2 production is proposed to estimate equations like that of Eq. (1). First, assuming a simple Cobb–Douglas production function for CO_2 emissions as follows:

$$I_i = a_i E_i^\alpha e^{\varepsilon_i} \quad (2)$$

where $I = CO_2$ emissions; a_i is the technological, structural, and other effects; E is the energy use; e is the Euler's number, and ε_t is the error term.

The equation is further augmented by dividing both sides of this production function for CO_2 emissions by population (P), and real GDP (Y) is introduced as follows:

$$\left(\frac{I}{P}\right)_i = a_i \frac{E_i^\alpha}{P_i} e^{\varepsilon_i} = a_i \left(\frac{E}{P}\right)_i^\alpha \left(\frac{1}{P_i}\right)^{(1-\alpha)} e^{\varepsilon_i}$$
$$= a_i \left(\frac{E}{Y}\right)_i^\alpha \left(\frac{Y}{P}\right)_i^\alpha \left(\frac{1}{P_i}\right)^{(1-\alpha)} e^{\varepsilon_i} \quad (3)$$

Taking natural logarithms gives us the STIRPAT model

$$\ln I_i = \ln a_i + \alpha \ln P_i + \alpha \ln \left(\frac{Y}{P}\right)_i + \alpha \ln \left(\frac{E}{Y}\right)_i + \varepsilon_i \quad (4)$$

Equation (4) matches Eq. (1), where $b = c = d = \alpha$, $A_i = (Y/P)_i$ and $T_i = (E/Y)_i$. Equation (4) is a rather simple production function (for CO_2 in this case). Additional control variables can enter through the constant term as follows:

$$a_i = aX_i^g \text{ or } \ln a_i = \ln a + g \ln X_i \quad (5)$$

Panel data techniques are adopted in the practical implementations of the STIRPAT model to analyze the effects of population, affluence, energy intensity, industry share, service share, and urbanization on various environmental

effects (Shi 2003). The primary driving forces (i.e., population, per capita real GDP, and energy intensity) generate adverse environmental effects. Countries with a large share of service in GDP use less energy and produce fewer emissions; on the other hand, countries with a large share of manufacturing in GDP use more energy and produce higher CO_2 emissions. Urbanization is inevitable in development; thus, it positively affects CO_2 emissions. Many other works focus on an inverted-U relationship between environmental throwback and affluence. CO_2 emissions worsen in the early stages of growth (developing era), named the EKC curve; however, they eventually peak and start declining as the income passes a certain threshold level of the developed era (Kijima et al. 2010). An inverted-U relationship exists with the condition that the coefficient of the squared term is proved significantly negative and the estimated extreme point falls within the data range (Fang and Miller 2013). However, there has been no unanimous evidence supporting the inverted-U relationship. Total CO_2 emissions are focused on because it is directly associated with climate change and global warming. FDI-inflows can address these issues by developing high technological projects designed to improve energy efficiency. To examine the effect of FDI, a dynamic panel data model, which explicitly captures the adjustment in CO_2 emissions, is developed.

Nevertheless, it takes time to reach lower CO_2 emission targets like those in the Kyoto Protocol. In line with that, the previous evidence will be weak to convince policymakers to trust in better environmental conditions via good FDI. While both population and per capita income directly generate environmental pressure in either CO_2 emission in developing or low-income countries. This dependency suggests using a dynamic model to capture the lagged effect. The following estimation equation is used to assess the effect of FDI-inflows on CO_2 emissions:
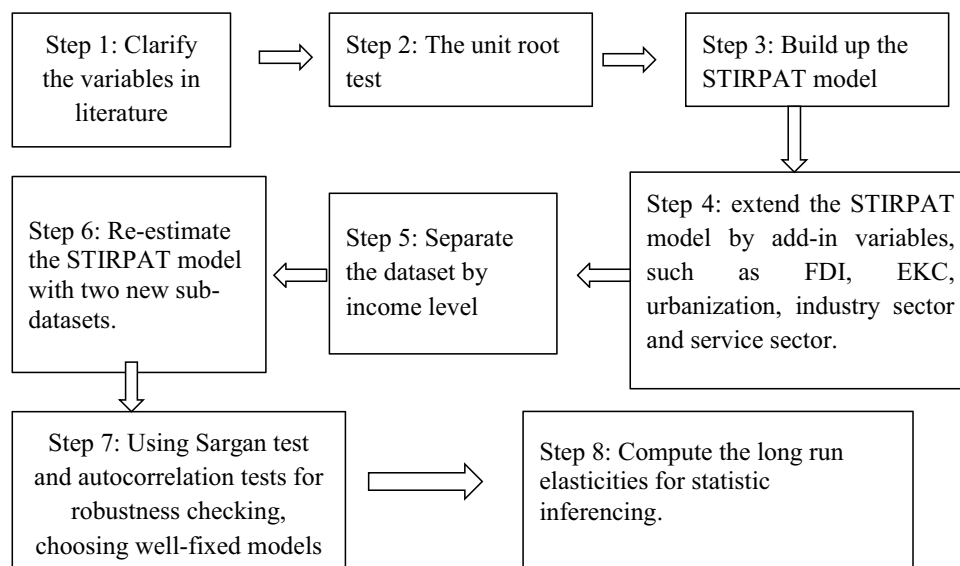
$$\ln I_{it} = \mu_i + \eta_i + b \ln I_{it-1} + c \ln P_{it} + d \ln A_{it} + e \ln T_{it} + f \ln X_{it} + \varepsilon_{it} \quad (6)$$

where the subscript t denotes the year. With panel data, $\ln a$ Eq. (5) becomes a country-specific fixed-effect μ_i, along with a year-specific fixed-effect η_t and the error term ε_{it}.

The dynamic panel data model $I_{it}(I_{it-1})$ denotes CO_2 emissions in country i at year emissions in kilotons. P_{it} denotes total population. A_{it} denotes real per capita GDP in PPP (purchasing power parity 2005 constant international dollars). T_{it} denotes energy intensity defined as energy use per unit of real GDP. X_{it} denotes a set of control variables: per capita GDP squared to test for the EKC hypothesis (Caviglia-Harris et al. 2009), the percentage share of industry (including manufacturing) and service sectors value-added in GDP (Shi 2003), the percentage of the total population living in urban areas (Martinez-Zarzoso and Maruotti, 2011) and the FDI-inflows, which aims to test pollution Halo or

Table 2 Descriptive statistic

Variables	Mean	Std. deviation	Maximum	Minimum	Explanation (indicator name)
ln I	10.4229	1.9068	16.1469	6.5411	CO_2 emissions (metric tons per capita)
ln P	16.5195	1.5486	21.0339	12.7925	Population, total
ln A	8.3515	1.3194	10.9496	4.9109	GDP per capital = GDP (current US$)/ Population, total
ln T	1.6895	0.5134	3.4004	0.4482	The energy intensity level of primary energy (MJ/$2011 PPP GDP)
ln FDI	21.4900	1.9165	27.3218	15.5905	Foreign direct investment, net inflows (BoP, current US$)
ln UB	15.9166	1.5084	20.4253	12.4787	Urban population
ln IN	3.0162	1.0938	4.3492	1.15164	Industry, value added (% of GDP)
ln SV	3.5900	1.2555	4.5338	2.93966	Services, etc., value added (% of GDP)

Fig. 1 The flowchart of the research structure

Step 1: Clarify the variables in literature → Step 2: The unit root test → Step 3: Build up the STIRPAT model

Step 4: extend the STIRPAT model by add-in variables, such as FDI, EKC, urbanization, industry sector and service sector.

Step 5: Separate the dataset by income level

Step 6: Re-estimate the STIRPAT model with two new sub-datasets.

Step 7: Using Sargan test and autocorrelation tests for robustness checking, choosing well-fixed models → Step 8: Compute the long run elasticities for statistic inferencing.

Haven hypothesis. The inclusion $\ln I_{t-1}$ leads to biased and inefficient OLS estimates due to the correlation between the lagged dependent variable and the error term. Moreover, from Eq. (6), two additional econometric problems may arise endogenous explanatory variables and correlation of country-specific effects with the explanatory variables. The system GMM estimators proposed in Levine et al. (2000) are employed to address these problems. This regression, which must pass two standard specification tests as Sargan and panel serial autocorrelation, is valid.

Data

The panel data of 96 countries from 2004 to 2014 with 1056 observations of CO_2 emissions and components are collected in world development indicators.[3] The world bank reports those indicators in yearly data. Our STIRPAT model includes the energy intensity level of primary energy, which

was stopped report in 2015. Hence, our data is the most updated track by the world bank (Table 2). All the variables are discussed in the literature review section. The analysis steps by steps will show in Fig. 1. In model 1, the original IPAT model in literature is presented. Model 2 is extended the effect of FDI (foreign technology) in the host environment. In model 3, the EKC hypothesis is estimated. By adding the effects of urbanization, industry, and service, models 4 and 5 continuously extend model 2. In models 6 and 7, the high-income threshold is set, which is also classified by the World Bank to separate the sample into developed countries sample as 297 observations (model 6) and 242 observations (model 8); developing and low-income countries sample as 759 observations (model 7) and 693 (model 9).[4]

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[3] Data come from the following source: https://data.worldbank.org/indicator?tab=all.

[4] The high-income thresholds are published by United Nation every year, respectively GDP per capital greater than U$D 10.065 in 2004 and then U$D 12.735 in 2014. The different number of observations are in model 6 and 8 (developed countries) or model 7 and 9 (developing countries), respectively the available data of preventative number of industrial value and service sector value on GDP in some countries have deleted in models 8 and 9.

Table 3 Panel unit-root test

Variables		$\ln I$	$\ln P$	$\ln A$	$\ln T$	$\ln FDI$	$\ln UB$	$\ln IN$	$\ln SV$
LLC test	I(0)	− 20.154[***]	− 4.577[***]	− 14.881[***]	− 20.888[***]	− 15.177[***]	− 14.530[***]	− 20.4837[***]	− 26.8857[***]
Im test	I(0)	− 5.864[***]	10.945	− 1.719[**]	− 6.158[***]	− 8.261[***]	− 9.4357	− 4.6207[***]	− 5.6676[***]
	I(1)		− 1.244[*]				− 0.234		

The Levin et al. (2002) and the Im et al. (2003) unit root tests consider the null hypothesis that all panels contain unit roots. *10% level; **5% level; ***1% level

Estimation results

The unit-roots test

Table 3 reports the results of the panel unit root tests. The data series used as inputs of the regression model should be stationary for solid robustness. The Im et al. (2003) and Levin et al. (2002) unit root tests are adopted to address this problem. The data series must pass one of the unit-roots tests and the evidence that the input values can use for GMM's regression. The logarithm forms of original data should be used.

Results of IPAT estimators

Table 4 reports the results from the system GMM estimator of Eq. (6). Under each variable coefficient is the coefficient's standard error in parenthesis. The Sargan test examines over-identification and AR(1) and AR(2) tests for first-order and second-order autocorrelation, respectively, with the p values in the parenthesis for each testing.

In model 1, CO_2 emission is regressed on the lagged CO_2 emission, total population, real GDP per capita, and the energy intensity level of primary energy. This baseline model incorporates the essential elements from the IPAT framework (Fang and Miller 2013). The results indicate that all four independent variables are statistically significant at the 1% significance level and are positive to the dependent variable. The lagged CO_2 emission variable makes up most of the CO_2 emission, supporting the dynamic specification. In the log–log specification, the estimators represent the long-run elasticities or the ratios of percent changes. The 1% change in the total population is associated with a 0.0641% increase in CO_2 emission. The 1% change in real GDP per capita brings the CO_2 emission up by 0.0754%. At the same time, a 1% change in technology leads to a 0.2752% increment in CO_2 emission.

Meanwhile, the long-run elasticities equal the estimators divided by one minus the coefficient of $\ln(I_{it-1})$ the lagged CO_2 emission variable. Therefore, the long-run elasticities equal 1.9663 for population, 2.319 for real GDP per capita, and 8.4117 for energy intensity, accordingly

to Eq. (1). The Sargan tests for over-identification do not reject the null at the 1% level but reject the null at the 5% significance level. The test for autocorrelation rejects the null of no first-order serial correlation, but it does not reject the null of no second-order serial correlation. The result of model 1 is not robust.

The extends of the STIRPAT model

First, the dynamic IPAT model is estimated, where FDI is included in model 2, on top of the estimators in model 1. The coefficient of the FDI variable proves significantly positive at a 1% significance level statistically. This outcome suggests that an increase in FDI results in higher CO_2 emissions. A 1% change in FDI is associated with a 0.0198% increase in CO_2 emission. The long-run elasticity is 0.7279 for FDI. All other diagnostic statistics match the baseline model (model 1). So, the robustness of model 2 is similar to model 1 as nonsignificant.

Second, model 3 adds squared real GDP per capita to model 2 to examine the existence of an inverted U-shape EKC. The estimate of the squared term proves significantly negative at the 1% level. The positive coefficient for real GDP per capita and the negative coefficient for squared real GDP per capita indicate that CO_2 emission shows evidence of the EKC hypothesis.

Third, in model 4, we expand the dynamic IPAT model by including the urbanization variable in model 3. The 1% significance positive FDI still holds when we accommodate the potential linkages between urbanization and CO_2 emission. This means a 1% increase in urbanization is associated with a 0.0551% increase in CO_2 emission. The inclusion of urbanization in the model does not revamp the models affecting the coefficients for the lagged dependent variable, total population, real GDP per capita, squared real GDP per capita, and FDI. Urbanization increases CO_2 emissions. However, the main thing that we need to pay attention to is the transformation of the real GDP per capita variable. It goes from being 1% positively significant in model 3 to being 1% negatively significant in model 4. This means that the 1% increase in population reduces the CO_2 emission by 0.3773% and suggests that in the long run, a 1% increase in FDI leads to a 0.1366% change in CO_2 emission. The change

Table 4 Estimation results

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
$\ln I_{t-1}$	0.9674***	0.9728***	0.9869***	0.8631***	0.7962***	0.5043***	0.9768***	−0.0232	0.9228***
	(0.1336)	(0.1480)	(0.0157)	(0.0249)	(0.0205)	(0.0288)	(0.0065)	(0.0591)	(0.0049)
$\ln P$	0.0641***	0.0367***	0.0306***	−0.3773***	−0.5078***	0.2288*	−0.1278***	3.4286*	−0.1865***
	(0.0092)	(0.0102)	(0.0100)	(0.6178)	(0.0581)	(0.1347)	(0.0324)	(1.7622)	(0.0298)
$\ln A$	0.0754***	0.0598***	0.3772***	0.3157***	0.4189***	−1.1647**	0.3839***	0.6143	0.4190***
	(0.0082)	(0.0092)	(0.0612)	(0.0578)	(0.0524)	(0.4516)	(0.0497)	(1.3366)	(0.0476)
$\ln T$	0.2752***	0.2758***	0.2927***	0.3607***	0.4581***	0.6948***	0.3189***	0.6153***	0.3476***
	(0.0197)	(0.0168)	(0.0163)	(0.0206)	(0.0240)	(0.0321)	(0.1717)	(0.0729)	(0.0151)
$\ln A^2$ (EKC test)			−0.0193***	−0.0159***	−0.0194***	0.0688***	−0.0214***	−0.0237	−0.0222***
			(0.0036)	(0.0033)	(0.0029)	(0.0233)	(0.0029)	(0.0708)	(0.0027)
$\ln FDI$		0.0198***	0.0199***	0.0187***	0.0187***	0.0188***	0.0200***	0.0231***	0.0155***
		(0.0031)	(0.0035)	(0.0034)	(0.0030)	(0.0035)	(0.0028)	(0.0048)	(0.0019)
$\ln UB$				0.5051***	0.6277**	0.1990	0.1915***	−1.8933	0.2569***
				(0.0739)	(0.0679)	(0.1343)	(0.3096)	(1.3167)	(0.0348)
$\ln IN$					0.0389***			−0.1213	0.0575***
					(0.0133)			(0.1316)	(0.0109)
$\ln SV$					0.0115			−0.2992	0.0068
					(0.0285)			(0.2706)	(0.0164)
No. of observations	1056	1056	1056	1056	935	297	759	242	693
No. of countries	96	96	96	96	85	27	69	22	63
Sargan test	74.0628	73.184	74.1677	73.7167	68.6840	20.6729	58.3050	10.6639	56.3119
(p value)	[0.0296]	[0.0345]	[0.0290]	[0.0314]	[0.0724]	[1.0000]	[0.2866]	[1.0000]	[0.3521]
AR (1)	−5.1786	−5.1223	−5.1205	−4.9504	−4.4705	−2.2788	−4.4090	−0.8566	−4.1550
(p value)	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0227]	[0.0000]	[0.3916]	[0.0000]
AR (2)	−1.5024	−1.5833	−1.6118	−1.5559	−1.5287	−1.1518	−0.6447	−1.0280	−0.6896
(p value)	[0.1330]	[0.1134]	[0.1070]	[0.1197]	[0.1263]	[0.2494]	[0.5191]	[0.3040]	[0.4904]

ln denotes the natural logarithms; the Sargan test examines over-identification. AR (1) and AR (2) test for the first-order and second-order autocorrelation, respectively. *10% level. **5% level. ***1% level

should come from mixed data, leading to model 4 bias. That is the main reason for this study to separate the sample into two datasets and re-estimate model 4 as models 6 and 7. The other diagnostic statistics from model 1 stay significant at the 1% level in models 3 and 4.

Fourth, model 5 covers all the variables included in model 4 and the industrial sector as percentage of GDP and service sector as percentage of GDP. Authors extend the theoretical model with a proposition by (Martinez-Zarzoso and Maruotti 2011; Shi 2003). The result indicates that the industrial sector estimator is significant at a 1% level while the service sector parameter is insignificant. The service sector may not affect emission levels. However, the inclusion of the two new estimators affects the significance of the urbanization variable, where the urbanization variable altered from being 1% significance to 5% significance. Hence, the author has also separated the sample into developing and developed datasets, different by income level. Because this study treats emission levels as inferior goods (Hotte and Winer 2012), citizens' perspective about the emission is also different in high- and low-income countries. Model 5 also passed the Sargan and autocorrelation tests, which implies its robustness. The square of real GDP per capita stays negatively significant at a 1% level in model 5, implying that this study's EKC hypothesis is confirmed using a large dataset.

The developing countries model and developed countries model

First, further check the model's efficiency when under two different groups of observation; the observations are divided into the developed and developing areas. Model 6 is model 4 applied to 297 observations over 10 years in developed countries (observations), whereas model 7 is model 4 applied to 759 observations over the 10 years in developing counties (observations). Models 6 and 7 show that Sargan's overidentifying restrictions are valid. AR(1) and AR(2) are valid in first-order and second-order autocorrelation tests. In model 6, the total population variable changes from a 1% negative significance to 10% positively significant. The changing of the population parameter is 0.2288, which implies the long-run emission level elasticity of the population is 0.4616. Unlike the study of Phuc Nguyen et al. (2020), our study does not ignore the population variable in the STIR-PAT model, which would support us in reaching the correct results. The omitted variable would be the main reason that causes the coefficient of correlation of FDI in their study to become nonsignificant (Phuc Nguyen et al. 2020). The emission level elasticity of the population is less than one that is reasonable in the scenarios of a good environment and a tiny increasing birth ratio in developed countries. The elderly population is a significant issue in developed countries. Because of the good environmental situation,

the change in emission level usually strikes high when the country increases its economic capacities. The real GDP per capita variable changes from the 1% positive significance to the 5% negative significance compared to model 4. In high-income countries, citizens may not accept a trade-off between public health conditions and income. Hence, even the increase of FDI or the other economic capacities should not be approved if it increases the emission level. So, the negative significance of income on the dependent variable is reasonable. This negative effect is also the proof of the EKC hypothesis and unnecessary to concern the square terms. The squared real GDP per capita in model 4 was 1% negative significance, but after the application to the developed countries group, it is now at 1% positively significance. The real GDP per capita had switched sign, so its square is also absolutely switched. The long-run elasticities equal 2.3095 and 1.4017, respectively, for real per capita GDP and energy intensity, which match closely the estimated 2.1412 and 1.7690 in Fang and Miller (2013), who include the same variables excepted FDI in their equations. It shows that our developed dataset is adequate to analyze the STIRPAT model as other studies (Phuc Nguyen et al. 2020). In model 6, we have confirmed that the long-run elasticity of FDI on emission is 0.0379 for high-income countries, inferring that the tiny change of harmful FDI will highly increase the emission. In addition, Wang et al. (2021) have caught up a positive signal of the effect of urbanization on emission intensity in OECD countries.

Furthermore, the urbanization estimator also has a tremendous change in model 6. It was at a 1% positive significance level, but now, according to model 6, it shows positive but insignificant. Model 7 closely follows model 4, where all seven variables stay significant at the 1% level, and all the signs stay the same without changes. In model 7, the estimator parameter of population level and emission intensity is negative, confirming the consistent signal in the recent studies about developing economies (Li et al. 2021a, 2021b; Rehman et al. 2021; Wu et al. 2021). No doubt, human population growth is a significant contributor to CO_2 emissions. Using fossil fuels to power is an example of their increasingly mechanized lifestyles. However, environmental awareness could reduce CO_2 emissions (Zhang et al. 2017). In addition, citizens' attention to highly polluted environments in developing countries that been enhanced dramatically. As living in a harmful environment and the spiritual civilization are elevated, people in urban areas tend to care more about environmental issues such as global warming. For that reason, the fostering of environmental awareness in developing countries is high. More than 60% of the population live in the metropolitan area but not rural, and then that group of people supports controlling the intensity of carbon dioxide levels in Pakistan (Rehman et al. 2021). Wu et al. (2021) have also found evidence of the population flow from

Western (rural) to Eastern (urban), supporting to reduce the growth of carbon emissions in China. This effect may easily explain as the high intensity of population can control and save fossil fuels used at one time. If we look at the carbon footprint, it will be easily recognized that countries with a larger carbon footprint usually have a smaller population size (Li et al. 2021a, b, c). For example, in countries where people are primarily medium or low income, cars are still luxury products, and many people tend to use one public vehicle. Those behavior causes reduce carbon dioxin levels. The result of models 6 and 7 shows us that the characteristics of the observations influence the outcome model heavily.

Furthermore, models 8 and 9 were modeled after model 5, where model 8 is to analyze the 242 developed countries (observations) and model 9 is to analyze the 693 developing countries (observations), similar to models 6 and 7, where the 1056 observations were divided into two groups. The number of observations in models 8 and 9 differs from models 6 and 7 because of the lack of data for industrial (ln IN) and service sector (ln SV) parameters. Model 8 is considerably disparate from model 5. In this model, six parameters have their property changed. They have started with the lagged variable where it was positively significant at the 1% level, and now the coefficient is negative where the parameter itself is insignificant. The total population parameter was negatively significant at the 1% level, and now the parameter is positively significant at the 10% level. Moreover, the real GDP per capita parameter and its squared change from significant at the 1% level to insignificant. In addition, the urbanization parameter goes from being 5% positively significant to negatively insignificant. Not only that, the application of model 5 in developed countries (observations) leads to the industrial sector parameter going from a 1% significance level to negatively insignificant. Different from model 8, model 9 closely follows model 5. The property of every parameter in model 5 stays the same for the parameters in model 9, other than the coefficient value itself since the data is not entirely the same.

Robustness test

Lastly, the Sargan test detects error cross-sectional dependency and over-identification. Model 8 does not reject the null hypothesis in AR(1) and AR(2) autocorrelation tests. The lagged dependent variable is not robust in models 1, 2, 3, 4, and 8 according to AR(1) autocorrelation test. Hence, the long-run estimators' parameters ($\ln I_{t-1}$) are also biased in those models. Models 5, 6, 7, and 9 show that overidentifying restrictions are valid. AR(1) and AR(2) are first-order and second-order autocorrelation tests. Model 5 is the baseline model with a global scale dataset. Model 6 is the only one that performs robustness with the developed country's dataset. Comparing models 7 and 9, this study uses the criteria proposed in the literature review of the SRITPAT model. Which model has the absolute value of long-run population elasticity of carbon emission as near the natural population ratio as 1, implying the better model (Ehrlich and Holdren 1971).

Computing long-run elasticity

From models 7 and 9, the coefficient of correlation for the population is -0.1278 and -0.1865, respectively. As for the long-run population elasticities, the values are calculated as 5.5086 and 2.4158. So, model 9 outperforms model 7 in terms of robustness with developing country's datasets. The industrial sector should be employed as an essential exogenous of emission. The authors compute the long-run elasticities of all the dependence variables from models 5, 6, and 9 in Table 5, contributing to the models of developed and developing countries, respectively.

In general, this study mainly focuses on the effect of FDI on CO_2 emission. The coefficient estimates prove positive and significant at the 1% level in all models. The results are consistent with the other study about foreign investment in Pakistan (Hussain and Rehman 2021). This study shows that FDI harms the CO_2 emission as a foreign investment component, confirming the haven hypothesis worldwide. In Table 5, it is crucial to notice that the coefficient estimate for FDI in model 6 (developed countries data) is less in model 9 (developing countries data). However, it is less than in model 5, where the coefficient estimate for FDI in global data worldwide. From models 5, 6, and 9, the coefficient of correlation for FDI is as follows: 0.0187, 0.0188, and 0.0155, respectively (Table 4). As for the long-run FDI elasticities, the values are calculated as follows: 0.09176,

Table 5 Computing long-run elasticities for developed and developing models

Long-run elasticities on CO_2 emission	ln P	ln A	ln T	ln A^2(EKC test)	ln FDI	ln UB	ln IN	ln SV
Baseline (global) model	−2.4917***	2.0554***	2.2478***	−0.0952***	0.0918***	3.0800***	0.1909***	0.0564
Developed country model	0.4616*	−2.3496**	1.4017***	0.1388***	0.0379***	0.4015		
Developing country model	−2.4158***	5.4275***	4.5026***	−0.2876***	0.2008***	3.3277***	0.7448***	0.0881

In the log–log specification, the estimators represent the long-run elasticities or the ratios of percent changes. Each elasticity equals their estimators divided by one minus the lagged CO2 emission variable coefficient in Table 4. The value is present as absolute value, where * denotes 10% level, ** denotes 5% level and *** denotes 1% level

0.0379, and 0.2008 (Table 5). We can see here that in model 9, the long-run elasticity for FDI with respect to CO_2 emission is at its highest level. Whereas in model 9, with the inclusion of FDI and squared real GDP per capita on the baseline model, FDI has the highest long-run elasticity value regarding CO_2 emission.

Discussion

The post-pandemic economy is a challenge that faces global climate change emissions. Because emissions should yield poverty worldwide and with poverty accompanied by war and violence, in Covid-19 scenarios, the manufacturer's global supply chain disruptions and closures will reduce pollution worldwide. The economic growth speed can recover faster as the environment is cleaned. Because the EKC hypothesis would be considered reducing harmful conditions. This study shows that the high-income level has significantly contributed to adverse CO_2 emissions. The long-run elasticity would be computed as -2.3496 respectively in developed countries. EKC hypothesis has also been confirmed in developing countries, and the long-run elasticity would be computed as -0.2876, respectively. The square variable of affluence of economic (A^2) represent the futural income level of developing countries; therefore, the countries that would gain from EKC theory should promote the income level consistently for many years. From that point of view, the policymaker should attend to the foreign technology interface and industrial policy, which are proven to support Malaysia and Chile cases, escaping the middle-income trap. The opportunity cost of economics is the environment. The people who live in the countries facing the haven hypothesis scenario are paying high costs for healthcare issues in the future. So, policymakers should provide suitable policies for assuring their people have been afforded a living environment to escape the middle-trap income. The GHG emissions were lowest in 2020. Suppose this criterion of emissions can be maintained every year until 2050. In that case, the UNFCCC expectation in 1992 will be reached to net-zero emission. However, the pandemic has expressed an emergency for the government to establish policies supporting a cleaner environment. The capital outflows from emerging market economies in the Covid-19 pandemic should be five times more than in the past crisis.[5] Foreign direct investment (FDI) is most concerned as the main factor that caused the pollution in China at the beginning of the twentieth century. The recent pandemic

forces the daily temperature to fall lower than the threshold of 30 °C. So the FDI-environmental regulation stringency in China at the most recent is becoming promising. For example, the ESCOs standard can be proposed as a critical condition for observing the FDI regime.

The other scenario that policymakers should be concerned about is after the US-China trade war and Covid-19, where there is significant FDI inflow. ASEAN governments analyzed the political and economic situation to react to trade war and Covid-19. FDI is one of the rich sources that countries can gain sovereign wealth funds (SWFs). Multinational corporations (MNCs) tend to shift their factories to China's neighbor. Hence, China's neighbors shall prepare well-developed policies to attract the green FDI and need to consider the pollution from MNCs deeply. Both India and Australia require prior government approval of the origin of MNCs. India invests in countries with shared borders to protect their domestic company vulnerabilities and carefully consider the applicant's historical business activities or the environmental causes. Australia attends the approval process on time, which will be extended from 30 days to 6 months during the pandemic. This regulation supports Australia's monetary system to protect national interests from lower profits to at least zero. In Western countries, the economy seems not to be highly restricted by FDI. Only the MNCs which want to develop, manufacture, producing vaccines or other medical equipment will become the target of the constraint policies. Spain, Germany, and France are confident about their monetary system and fiscal policy because they are not facing the liquidity trap. So eco-green FDI or not will be the only concentration. On the opposite side, Hungary, Italy, and Canada tend to protect the domestic economy from the recession due to the zero interest rate causing the deflation. However, even the need to protect national security interests is high or low. All developed countries should not trade off the long-term goal as an environment for the short-term target of economic recovery. Countries will protect the low level of CO_2 emissions in the period of present pandemics. Post-crisis, government actions and economic incentives will likely influence the global CO_2 emissions path for decades. For all the reasons above, the decision about the FDI regime is always extremely hard for decision-makers. Nevertheless, the FDI should not be traded off for environmental conditions, even in developed or developing countries.

Conclusion

For the FDI approvement, the host countries should be considered carefully to attract the unpolluted investment multinational corporations. Outsourcing capitalism can help recover the economy and reduce the pressure on the

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[5] The volume of capital outflow is recognized as -100 billion USD because of Covid-19, which is known as near -23 billion USD because of the Global financial crises in 2008/or the Taper Tantrum in 2013 and is known as -18 billion USD because of China stock market sell-off in 2015. Source: Jonathan Fortun, Institute of International Finance, Inc.; OECD.

nation's wealth of fiscal budget. Hence, the long-run steady-state can reach sustainability. This study uses GMM methods to successfully indicate the empirical results for developed and developing countries to understand better the effects of FDI on CO_2 emissions in line with the other macroeconomic variables. The policymaker shall base on the results to make better decisions.

Unfortunately, carbon dioxin emissions are the most severe issues, but not overall the pollution. Other pollution issues should be investigated, such as air quality pollution (PM 2.5), sulfur dioxin (SO), or the ecological footprint, that can use as dependent variables in the STIRPAT model. The existing technology factor sometimes can be measured by nominal scale as a dummy variable in a country or city context—for example, the country's new regulation for environmental conditions or the global standard energy in wide scale. Future studies can also look for the threshold conditions for the inverted U-shape of urbanization on carbon emission, which is expected to contribute a new lens to reduce pollution.

This study does not clarify the service sector's effect on carbon dioxin emission. Even the sub-dataset of developed countries has a higher share of the service sector in the economy and does not come out with a significant relationship. The limitation may come from the small observations. While energy-intensive is the best to measure the existing technology in global scenarios, the lack of observations remains. Our study has also failed to discuss renewable energy instead of non-renewable strategy. This limitation can be claimed on the small and disperse of the renewable dataset. In the future, the researchers can estimate the effect of renewable energy with others factors to enlarge the pollution knowledge.

Abbreviations AI: Artificial intelligence; ARDL: Auto regressive distributed lag; ASEAN: Association of Southeast Asian Nations; CO_2: Carbon dioxide; CUSUM: Cumulative sum control chart; DOLS: Dynamic ordinary least square; EKC : Environmental Kuznets curve; ESCOs: Energy services companies; FDI: Foreign direct investment; FGLS: Feasible generalized least squares; FMOLS: Full modify least square; GDP: Gross domestic product; GHG: Greenhouse gas emissions; GMM: General method of moments; ImPACT: The renovated IPAT identity; IoT: Internet of things; IPAT: Model of environmental impact_ IPAT identity; IPCC: International panel on climate change; OLS: Ordinary least square; MNCs: Multinational corporations; MENA: Middle East North Africa; PLS: Path least square; PM 2.5: Air quality pollution; STIRPAT: Stochastic impact by regression on population, affluence, and technology; UNFCCC: United Nations framework convention on climate change; VECM: Vector error correction model; 2SLS: Two simultaneous least square

Declarations

References

Abdouli M, Hammami S (2017) Economic growth, FDI inflows and their impact on the environment: an empirical study for the MENA countries. Qual Quant 51(1):121–146

Abid N, Wu J, Ahmad F, Draz MU, Chandio AA, Xu H (2020) Incorporating environmental pollution and human development in the energy-growth nexus: a novel long run investigation for Pakistan. Int J Environ Res Public Health 17:5154

Abid N, Ceci F, Ikram M (2022) Green growth and sustainable development: dynamic linkage between technological innovation, ISO 14001, and environmental challenges. Environ Sci Pollut Res 29(17):25428–25447

Alfaro L, Chanda A, Kalemli-Ozcan S, Sayek S (2004) FDI and economic growth: the role of local financial markets. J Int Econ 64(1):89–112

Alfaro L, Kalemli-Ozcan S, Sayek S (2009) FDI, productivity and financial development. The World Economy 32(1):111–135

Al-mulali U (2012) Factors affecting CO 2 emission in the Middle East: a panel data analysis. Energy 44(1):564–569

Ahmad M, Khan Z, Rahman ZU, Khattak SI, Khan ZU (2021) Can innovation shocks determine CO2 emissions (CO2e) in the OECD economies? A new perspective. Econ Innov New Technol 30(1):89–109

Auffhammer M, Sun W, Wu J, Zheng S (2016) The decomposition and dynamics of industrial carbon dioxide emissions for 287 Chinese cities in 1998–2009. J Econ Surv 30(3):460–481

Baek J (2016) A new look at the FDI–income–energy-environment nexus: dynamic panel data analysis of ASEAN. Energy Policy 91:22–27

Balsalobre-Lorente D, Gokmenoglu KK, Taspinar N, Cantos-Cantos JM (2019) An approach to the pollution haven and pollution halo hypotheses in MINT countries. Environ Sci Pollut Res 26(22):23010–23026

Borensztein E, De Gregorio J, Lee JW (1998) How does foreign direct investment affect economic growth? J Int Econ 45(1):115–135

Caviglia-Harris JL, Chambers D, Kahn JR (2009) Taking the "U" out of kuznets: a comprehensive analysis of the EKC and environmental degradation. Ecol Econ 68:1149–1159

Council W (2008) Energy efficiency policies around the world: review and evaluation. WEC, London

Crespo N, Fontoura MP (2007) Determinant factors of FDI spillovers–what do we really know? World Dev 35(3):410–425

Chang SC, Li MH (2019) Impacts of foreign direct investment and economic development on carbon dioxide emissions across different population regimes. Environ Resource Econ 72(2):583–607

Dauda L, Long X, Mensah CN, Salman M (2019) The effects of economic growth and innovation on CO2 emissions in different regions. Environ Sci Pollut Res 26(15):15028–15038

De Mello LR (1999) Foreign direct investment-led growth: evidence from time series and panel data. Oxf Econ Pap 51(1):133–151

Ellis J (2010) Energy service companies (ESCOs) in developing countries. International Institute for Sustainable Development, Manitoba, Canada

Ehrlich PR, Holdren JP (1971) Impact of population growth. Science 171(3977):1212–1217

Fang WS, Miller SM, Yeh C-C (2012) The effect of ESCOs on energy use. Energy Policy 51:558–568

Fang W, Miller SM (2013) The effect of ESCOs on carbon dioxide emissions. Appl Econ 45(34):4796–4804

Gökmenoğlu K, Taspinar N (2016) The relationship between CO2 emissions, energy consumption, economic growth and FDI: the case of Turkey. J Int Trade Econ Dev 25(5):706–723

Greenaway D, Kneller R (2007) Firm heterogeneity, exporting and foreign direct investment. Econ J, 117(517)

Gui S, Wu C, Qu Y, Guo L (2017) Path analysis of factors impacting China's CO2 emission intensity: viewpoint on energy. Energy Policy 109:650–658

Hao Y, Wu Y, Wu H, Ren S (2020) How do FDI and technical innovation affect environmental quality? Evidence from China. Environ Sci Pollut Res 27(8):7835–7850

He J (2006) Pollution haven hypothesis and environmental impacts of foreign direct investment: the case of industrial emission of sulfur dioxide (SO 2) in Chinese provinces. Ecol Econ 60(1):228–245

Horobet A, Popovici OC, Zlatea E, Belascu L, Dumitrescu DG, Curea SC (2021) Long-run dynamics of gas emissions, economic growth, and low-carbon energy in the European Union: the fostering effect of FDI and trade. Energies 14(10):2858

Hotte L, Winer SL (2012) Environmental regulation and trade openness in the presence of private mitigation. J Dev Econ 97(1):46–57

Hübler M (2011) Technology diffusion under contraction and convergence: a CGE analysis of China. Energy Econ 33(1):131–142

Huang J, Liu Q, Cai X, Hao Y, Lei H (2018) The effect of technological factors on China's carbon intensity: new evidence from a panel threshold model. Energy Policy 115:32–42

Hussain I, Rehman A (2021) Exploring the dynamic interaction of CO2 emission on population growth, foreign investment, and renewable energy by employing ARDL bounds testing approach. Environ Sci Pollut Res 1–11

Im KS, Pesaran MH, Shin Y (2003) Testing for unit roots in heterogeneous panels. Journal of Econometrics 115(1):53–74

International Panel on Climate Change (IPCC) (2007) Climate Change 2007: Synthesis Report. International Panel on Climate Change, New York

Khan H, Weili L, Khan I (2022) The role of institutional quality in FDI inflows and carbon emission reduction: evidence from the global

developing and belt road initiative countries. Environ Sci Pollut Res 1–28

Kijima M, Nishide K, Ohyama A (2010) Economic models for the environmental Kuznets curve: a survey. J Econ Dyn Control 34:1187–1201

Lau L-S, Choong C-K, Eng Y-K (2014) Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: do foreign direct investment and trade matter? Energy Policy 68:490–497

Levin A, Lin CF, Chu CSJ (2002) Unit root tests in panel data: asymptotic and finite-sample properties. J Econ 108(1):1–24

Levine R, Loayza N, Beck T (2000) Financial intermediation and growth: causality and causes. J Monet Econ 46(1):31–77

Li B, Liu X, Li Z (2015) Using the STIRPAT model to explore the factors driving regional CO2 emissions: a case of Tianjin. China Nat Hazard 76(3):1667–1685

Li C, Cong J, Yin L (2021a) Extreme heat and exports: evidence from Chinese exporters. China Econ Rev 66:101593

Li Y, Shen J, Xia C, Xiang M, Cao Y, Yang J (2021) The impact of urban scale on carbon metabolism–a case study of Hangzhou. China. J Clean Prod 292:126055

Li X, Zhang R, Chen J, Jiang Y, Zhang Q, Long Y (2021) Urban-scale carbon footprint evaluation based on citizen travel demand in Japan. Appl Energy 286:116462

Linares P, Labandeira X (2010) Energy efficiency: economics and policy. J Econ Surv 24(3):573–592

Liu Y, Hao Y, Gao Y (2017) The environmental consequences of domestic and foreign investment: evidence from China. Energy Policy 108:271–280

Lor PJ (2017) International and comparative librarianship. In Encyclopedia of Library and Information Sciences (pp 2404–2412). CRC Press

Martinez-Zarzoso I, Maruotti A (2011) The impact of urbanization on CO2 emissions: evidence from developing countries. Ecol Econ 70:1344–1353

Matthew AC, Robert JRE, Liyun Z (2017) Foreign direct investment and the environment. Annu Rev Environ Resour 42(1):465–487

Mert M, Bölük G (2016) Do foreign direct investment and renewable energy consumption affect the CO2 emissions? New evidence from a panel ARDL approach to Kyoto Annex countries. Environ Sci Pollut Res 23(21):21669–21681

Muhammad S, Long X, Salman M, Dauda L (2020) Effect of urbanization and international trade on CO2 emissions across 65 belt and road initiative countries. Energy 196:117102

Naz S, Sultan R, Zaman K, Aldakhil AM, Nassani AA, Abro MMQ (2019) Moderating and mediating role of renewable energy consumption, FDI inflows, and economic growth on carbon dioxide emissions: evidence from robust least square estimator. Environ Sci Pollut Res 26(3):2806–2819

Phuc Nguyen C, Schinckus C, Dinh Su, T. (2020) Economic integration and CO2 emissions: evidence from emerging economies. Climate Dev 12(4):369–384

Pao HT, Tsai CM (2011) Multivariate Granger causality between CO2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. Energy 36(1):685–693

Popp D (2004) Entice endogenous technological change in the DICE model of global warming. J Environ Econ Manag 48(1):742–768

Popp D (2010) Innovation and climate policy. Ann Rev Resour Econ 2(1):275–298

Rehman A, Ma H, Ozturk I, Ulucak R (2021) Sustainable development and pollution: the effects of CO2 emission on population growth, food production, economic development, and energy consumption in Pakistan. Environ Sci Pollut Res 1–12

Saikawa E, Urpelainen J (2014) Environmental standards as a strategy of international technology transfer. Environ Sci Policy 38:192–206

Segis A, Hauge J (2020) Foreign direct investments could contract by 40% this year, hitting developing countries hardest. World Economic Forum. https://www.weforum.org/agenda/2020/06/coronavirus-covid19-economics-fdi-investment-united-nations/. Accessed 20 June 2020

Shahbaz M, Nasir MA, Roubaud D (2018) Environmental degradation in France: the effects of FDI, financial development, and energy innovations. Energy Econ 74:843–857

Shi A (2003) The impact of population pressure on global carbon dioxide emissions, 1975–1996: evidence from pooled cross-country data. Ecol Econ 44:29–42

Szalavetz A (2019) Industry 4.0 and capability development in manufacturing subsidiaries. Technol Forecast Soc Chang 145:384–395

Tang CF, Tan BW (2015) The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam. Energy 79:447–454

Tassey G (2014) Competing in advanced manufacturing: the need for improved growth models and policies. J Econ Perspect 28(1):27–48

Udemba EN (2020) Ecological implication of offshored economic activities in Turkey: foreign direct investment perspective. Environ Sci Pollut Res 27(30):38015–38028

Vine E (2005) An international survey of the energy service company (ESCO) industry. Energy Policy 33(5):691–704

Xu J, Zhou M, Li H (2016) ARDL-based research on the nexus among FDI, environmental regulation, and energy consumption in Shanghai (China). Nat Hazards 84(1):551–564

Yang Y, Cai W, Wang C (2014) Industrial CO 2 intensity, indigenous innovation and R&D spillovers in China's provinces. Appl Energy 131:117–127

Yang T, Dong Q, Du Q, Du M, Dong R, Chen M (2021) Carbon dioxide emissions and Chinese OFDI: from the perspective of carbon neutrality targets and environmental management of home country. J Environ Manage 295:113120

York R, Rosa EA, Dietz T (2003) STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. Ecol Econ 46:351–365

Waggoner PE, Ausubel JH (2002) A framework for sustainability science: a renovated IPAT identity. Proc Natl Acad Sci (PNAS) 99:7860–7865

Wang WZ, Liu LC, Liao H, Wei YM (2021) Impacts of urbanization on carbon emissions: an empirical analysis from OECD countries. Energy Policy 151:112171

Wei Y, Liu X (2006) Productivity spillovers from RandD, exports and FDI in China's manufacturing sector. J Int Bus Stud 37(4):544–557

Wu L, Jia X, Gao L, Zhou Y (2021) Effects of population flow on regional carbon emissions: evidence from China. Environ Sci Pollut Res, 1–12

Zameer H, Yasmeen H, Zafar MW, Waheed A, Sinha A (2020) Analyzing the association between innovation, economic growth, and environment: divulging the importance of FDI and trade openness in India. Environ Sci Pollut Res 27(23):29539–29553

Zhang Y, Zhang S (2018) The impacts of GDP, trade structure, exchange rate and FDI inflows on China's carbon emissions. Energy Policy 120:347–353

Zhang C, Zhou X (2016) Does foreign direct investment lead to lower CO2 emissions? Evidence from a regional analysis in China. Renew Sustain Energy Rev 58:943–951

Zhang N, Yu K, Chen Z (2017) How does urbanization affect carbon dioxide emissions? A cross-country panel data analysis. Energy Policy 107:678–687

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

Zugravu-Soilita N (2015) How does foreign direct investment affect pollution? Toward a better understanding of the direct and conditional effects. Environ Resource Econ 66(2):293–338