

Planetary health issues in the developing world: Dynamics between transportation systems, sustainable economic development, and CO2 emissions

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Highlights

Exploring the interface between institutional quality, transportation, economic growth and CO2.

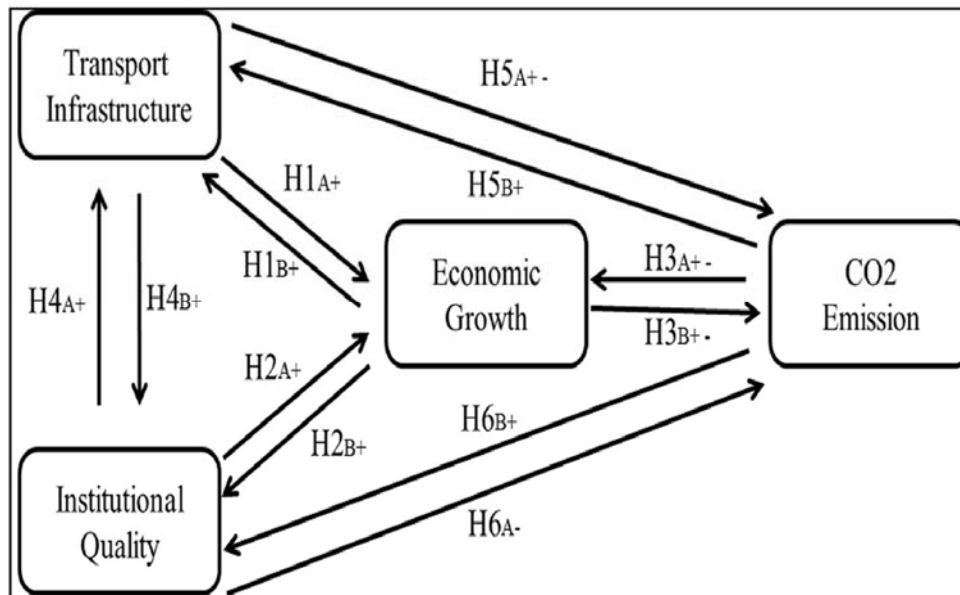
The sample comprises developing countries from 2005 to 2022.

The study uncovers uni- and bidirectional nexus between these variables.

Abstract

The earth is experiencing unprecedented global warming and this has an adverse impact on the health of the planet, people and economies. A major contributor to the degradation of planetary health is CO2 emissions that are contributed by the transportation sector. The brunt of the environmental degradation is experienced by developing countries, where the transportation sector is dependent on cheaper fossil-fuels. This study examines the causal interface between transportation infrastructure development, economic growth, institutional quality, and CO2 emissions in 79 developing countries over the period 2005 to 2022. A quantile-on-Quintile regression (QQR) and vector error-correction model (VECM) are deployed to study the causal relationships between the above-mentioned variables. The empirical findings show strong endogenous relationships between the variables in the short-run and long-run. The concerning trend is that, while the transportation sector and improvement in the institutions contribute positively to the economic growth of these countries, CO2 emissions (from the transportation sector) have a detrimental, and perhaps larger, impact on economic growth. A key insight from these findings is that there is a need to reduce CO2 emissions by ensuring greater use of renewable energy to power the transportation sector. A more environmentally-friendly transportation sector will be critical in enabling these countries to transition towards sustainable economic growth trajectories.

Graphical abstract



Keywords

Planetary health; Institutional quality transportation infrastructure; CO2 emissions; Economic growth; Developing economies; Sustainable development goals (SDG-7, SDG-11 and SDG-13); QQR; VECM

JEL classification

O16; O43; E31; E44

1. Introduction

The earth is undergoing rapid changes due to global warming and changes in weather patterns. Scientific studies show that rapid economic development post-industrial revolution have adversely impacted the biodiversity of natural habitats and, increasingly impacted climate systems across the globe (Fanning et al., 2022; Dasgupta, 2021; Steffen et al., 2011). A major contributor to climate change and global warming is the use of fossil fuels, especially as a source of energy to power the transportation sector. The transport sector is the second highest contributor of greenhouse gas, after energy use for electricity & heat – it contributes close to 15 percent of the greenhouse gas (Centre for Climate and Energy Solutions, 2023).¹

At the 27th Conference of the 198 Parties of the United Nations Convention (UNC) on Climate Change (recognised as COP27) in Egypt in November 2022, United Nations Secretary-General Antonio Guterres advised the global community that “the planet is heading toward irreversible climate chaos” and that there is a need for all stakeholders to take concerted efforts to reduce greenhouse gas (GHG) emissions (Guterres, 2022). He warned that “we are

in a life-or-death struggle for our own safety today and our survival tomorrow ... The world can't wait ... Emissions are at an all-time high and rising” (United Nations, 2022).

Transportation and its related infrastructure have both direct and indirect impacts to economic development through numerous channels such as employment, industrial activity, productivity, competitiveness, property values, and tax revenues. For example, Litman (2010) concludes that some transportation policies, especially ones that provide options to consumers, improve affordability, and improve producer transport (e.g. freight services) often have positive impacts on economic development. Similarly, Zhang and Cheng (2023) find that transportation infrastructure (comprising roadways, railways, seaports, and airport) development is essential for economic growth both directly and indirectly. Effectively, transportation infrastructure adds to economic growth in numerous ways: growth of capital and labour productivity (see, Pradhan and Bagchi, 2013; Pradhan, 2019); lessening travel time and increasing transportation efficiency (e.g., passenger and freight transporters openly gain from both time and cost savings); influencing the economy by changing aggregate market demand; and increasing the development of the housing sector which stimulates relocation of the population due to greater mobility of people and goods. Numerous studies have shown the positive contribution of transportation to the economy (see, for example Pradhan and Bagchi, 2013); Pradhan (2019); Lenz et al. (2018); Mohmand et al. (2016); Hong et al. (2011); and Gunasekera et al. (2008)). It is estimated that, through the year 2040, an investment of more than USD 2 trillion is needed to fund transport infrastructure and thus drive global economic development (Milani et al., 2021). Hence, discovering the drivers of economic growth from the perspective of transportation infrastructure is a significant driver of development policy.

While the transportation system is an important driver of economic growth, a significant portion of the transportation systems across the globe, especially the developing world, are still dependent on fossil fuels. Globally, only 3.7% of the transportation sector uses renewable energy; the remaining 96.3% are non-renewable energy sources (IRENA, 2021). Fossil fuels such as gasoline and diesel that are used in the transportation system release carbon dioxide (CO₂). CO₂ emissions are an important contributor to the GHG that cause global warming (see, the United States Environmental Protection International Energy Agency, 2022). In the USA, the transportation sector contributes close to 27% of GHG (United States Environmental Protection International Energy Agency, 2022). Globally, the transport sector contributed to 37% of CO₂ emissions in 2021 (International Energy Agency, 2022). Increasing CO₂ and its ‘knock-on’ effect on global warming has a negative impact on the health of the people, industries, and the planet (IPCC, 2023, 2003; NOAA, 2019). CO₂ emissions have an adverse impact on the health and well-being of people, as they increase incidences of zoonotic diseases, pollution-related ailments and deaths, and natural disasters such as floods, droughts, wildfires and hurricanes (Akdis and Nadeau, 2022; Sipari et al., 2022; Cappelli et al., 2021).

The primary focus of the present study is to explore the dynamics between transportation infrastructure, CO₂ emissions, economic growth, and institutional quality in developing economies. The reason for selecting developing countries is that 19 of the top 30 countries,

with respect to CO₂ emissions, are classified as developing countries (Mott et al., 2021). The top emitter of CO₂ from 1960 to 2020 is China, followed by the US and India (Mott et al., 2021). One of the major contributors to CO₂ emissions in the developing world is fossil-fuel driven transportation systems. There is also evidence that developing countries might “suffer disproportionately from damaging physical impacts of climate change due to a wide range of factors that create a specific set of vulnerabilities for each of them” (Hamwey, 2021). Some of these vulnerabilities include their geography, distances to major trade centres, being either landlocked or surrounded by water, contending with limited physical infrastructure, high transportation costs, and a lack of economic diversification. As such, international policies aimed at targeting reduced emissions (e.g., COP21) might create additional challenges for developing countries compared with developed nations. Additionally, there is no organization that can enforce these agreements, even if they are not potentially detrimental to developing nations (Santos, 2017). Other studies that discuss transportation infrastructure and emissions in developing countries include Berg et al. (2017), Zhu (2023) and Foster et al. (2023).

Here, we examine if institutions matter in ensuring that developing countries effectively manage their transportation systems to enhance economic development, and, at the same time, reduce CO₂ emissions. It is postulated that countries with sound institutions will ensure that effective transportation infrastructure development initiatives are undertaken to stimulate economic growth without harming the environment (i.e., increasing CO₂ emissions). The inter-relationships between these variables are evaluated in developing countries. A key contribution of this work is that it examines the co-development policies and strategies concerning institutional reforms, transportation infrastructure development, and a strong push towards reducing CO₂ emissions (due to the reduction of fossil fuels in the transportation system) to safeguard sustained economic growth in these economies. This is an important gap in the transportation infrastructure development literature which this study endeavours to close.

The rest of the paper is presented as follows. In Section 2, the contextual literature and hypothesis formulation are provided. In Section 3, we present the sample and the empirical methodology deployed in this study. In Section 4, a discussion of the outcomes of the study is provided. In Section 5, policy implications based on the short- and long-run dynamics between the variables are discussed. Final remarks are also given in this section of the paper.

2. Contextual literature and hypothesis formulation

This section reviews studies linking transportation infrastructure development, CO₂ emissions, institutional quality, and economic growth, particularly with locus to the Granger causality procedure. Our study reviews six distinct relationships, namely the relationship between: transportation infrastructure development and economic growth; economic growth and institutional quality; CO₂ emissions and economic growth; transportation infrastructure development and institutional quality; transportation infrastructure development and CO₂ emissions; and CO₂ emissions and institutional quality.

The discussion that follows, in addition to highlighting previous empirical work, also considers the complexities among and between the relationships. These complexities add to the challenges that policymakers face as they attempt to balance the need for economic growth and strong transportation infrastructure with the concerns of further environmental degradation. For example, there is evidence that, with regards to the relationships between economic growth and CO₂ emissions, the impact of growth can have both positive and negative effects on emissions. This is evidenced in the Environmental Kuznets Curve where, at first, economic growth has a detrimental impact on environmental health. However, at a certain point, resources can be diverted into innovations and technologies that can reduce environmental damage. Better understanding the dynamics among these variables will provide additional insight to assist policymakers in promoting sustainable development while also contributing positively to environmental health.

2.1. Transportation infrastructure development and economic growth

In this section, the prior literature focuses on the associations between economic growth and transportation infrastructure. There are two ways to address this nexus. First, is the hypothesis where transportation infrastructure Granger causes economic growth (the SLH¹-*supply-leading hypothesis*). The justification for this relationship is that sound transportation enables efficient mobility of goods and services and people. Furthermore, investments in modern transportation networks that use environmental-friendly energy sources will reduce harm to the health of the planet, lower healthcare costs and increase worker productivity to the economies of the developing world. The cost savings from healthcare cost can be channelled to more productive economic endeavours. These are critical for stimulating business activity, creating employment and stimulating economic growth (see, for instance, Zhang and Cheng, 2023; Zhu et al., 2022; Arvin et al., 2021a; Alam et al., 2021; Shahbaz et al., 2015).

Second, is that economic growth Granger causes transportation infrastructure (*demand-following hypothesis* - DFH¹). The justifications for this relationship are that increased economic growth will lead to increased income levels among firms and/or people. This will increase the demand for both travel and the movement of goods and services. This, in turn, increases transportation infrastructure development and investments, especially in transportation systems that use environmentally-friendly energy sources (see, for instance, Nguyen, 2023; Pradhan et al., 2021; Vlahinić Lenz et al., 2018; Yousif, 2023; Arvin et al., 2015).

Further, if both hypotheses exist, we call it the *feedback hypothesis* (FBH¹), where economic growth and transportation infrastructure reciprocally Granger cause one another (see, for instance, Pradhan et al., 2023a; Zhu et al., 2022; Pradhan, 2019; Beyzatlar et al., 2014; Yetkiner and Beyzatlar, 2020; Shahbaz et al., 2015; Pradhan and Bagchi, 2013). Finally, if there is no evidence of Granger causality, we call it the *neutrality hypothesis* (NEH¹), where neither transportation infrastructure nor economic growth Granger causes one another (see, for instance, (Mohmand et al., 2021; Pradhan and Bagchi, 2013).

Grounded on the above discussion, we test the following hypothesis for the sample of developing countries.

H1A, B. Economic growth Granger-cause (positively) transportation infrastructure, and vice versa.

2.2. Economic growth and institutional quality

There are two ways to address this nexus. First, is the institutional quality Granger causes economic growth hypothesis (*supply-leading hypothesis* – SLH²). The motivation for this line of reasoning is that sound institutions will result in the efficient allocation of resources, which enhances economic growth. Quality institutions will develop effective and efficient policies and strategies to create an exciting, business-friendly and sustainable business ecosystem. These include ensuring that pro-planetary health initiatives are core the to all development initiatives, including developing sustainable environmentally-friendly transportation systems. These policies will positively contribute to economic development (see, for instance, Pradhan et al., 2023a, Pradhan et al., 2023b, Pradhan et al., 2023c, Pradhan et al., 2023d; Huo et al., 2023; Chomen, 2023; Arvin et al., 2021b; Silve and Plekhanov, 2018; Angeles, 2010; Aron, 2000; Acemoglu and Robinson, 2010; Djankov et al., 2002; Knack and Keefer, 1995; La Porta et al., 1999).

Second is the economic growth Granger causes institutional quality hypothesis (*demand-following hypothesis* – DFH²). The rationalisation for this line of argument is that, as nations experience economic richness, they will improve institutional quality to ensure their economies remain resilient and competitive. This includes having the required resources to incorporate the best technology, governance systems and talent to improve the quality and resilience of the institutions to power a more decarbonised economy (see, for instance, Pradhan et al., 2023c, Pradhan et al., 2023d, Pradhan et al., 2023e, Pradhan et al., 2023f; Nair et al., 2021; Silve and Plekhanov, 2018; Angeles, 2010; Aron, 2000; Acemoglu and Robinson, 2010; Djankov et al., 2002; Knack and Keefer, 1995; La Porta et al., 1999).

Further, if there is evidence that two main hypotheses exist, we call it the *feedback hypothesis* (FBH²), which means that both institutional quality and economic growth Granger cause each other in turn (see, for instance, Pradhan et al., 2022). Finally, if there is no confirmation of Granger causality between economic growth and institutional quality, we call it the *neutrality hypothesis* (NEH²).

Grounded on this literature, the following hypothesis is tested in this study.

H2A, B. Economic growth Granger causes (positively) institutional quality and vice versa.

2.3. CO2 emissions and economic growth

In this section, we evaluate associations between CO2 emissions and economic growth. There are two primary ways to address this nexus. First, is that CO2 emissions Granger causes economic growth (*supply-leading hypothesis* – SLH³). The rationale for this relationship is that the transportation systems in the developing world use fossil fuels, which are cheaper than renewable energy. Hence, increasing CO2 emissions are attributed to the high use of a fossil-fuel driven transportation system and industrial activities. This increased industrial activity

leads to higher economic growth in developing economies. On the other hand, higher CO₂ emissions have the potential to increase environmental pollution. This will have an adverse impact on worker productivity and increase healthcare costs. High healthcare cost due the environmentally-related diseases will crowd out investments into productive sectors of the economy. All of which will reduce economic growth.

Second, is that economic growth Granger causes CO₂ emissions (*demand-following hypothesis* – DFH³). The rationalisation for this hypothesis is that increasing economic growth in a fossil-fuel-dependent economy will lead to increasing CO₂ emissions in the short-run. Increasing economic growth will provide economies with additional resources to invest in renewable energy sources and environmentally-friendly transportation systems. These investments will reduce CO₂ emissions over a longer period of time. In essence, it is postulated that the relationship between economic growth and CO₂ emissions follows an inverted “U-shaped” curve² known as the Environmental Kuznets Curve (Katsoulakos et al., 2016).

Further, if both the main hypothesis co-exists, we call it the *feedback hypothesis* (FBH³), where CO₂ emissions and economic growth Granger cause one another. Again, if both of the main hypotheses do not co-exist, we call it the *neutrality hypothesis* (NEH³), where these two variables do not Granger cause each other. Works that have surveyed the dynamics between these two include Foster et al. (2023), Arvin et al. (2022), Nair et al. (2021), Umar et al. (2020), Danish et al. (2018), Saidi and Mbarek (2016) and Jebli and Youssef (2013).

Established on the above discussions, the following hypothesis is tested in this study.

H3A, B. CO₂ emissions Granger causes (positively or negatively) economic growth and vice versa.

2.4. Transportation infrastructure and institutional quality

In this section, we examine the associations between transportation infrastructure and institutional quality. There are two primary ways to address this nexus. First, is that transportation infrastructure Granger causes institutional quality (*supply-leading hypothesis* – SLH⁴). The validation for this theme is that a sound transportation system will lead to greater mobility of people and goods. This will attract talent and people with diverse skills into developing countries (especially in rural areas where there is an extension of the transport network). Wider and deeper penetration of transportation networks into many of the localities in developing countries will create increased wealth effects in these localities. Increasing wealth in these localities will enable them to invest in improving their institutions and governance systems (see, for instance, Esfahani and Ramirez, 2003). It is postulated that improvement in the overall governance system will enhance efficiency in the transportation system, including greater use of environmentally-friendly energy sources in the transportation system.

Second, is that institutional quality Granger causes transportation infrastructure (*demand-following hypothesis* – DFH⁴). The rationale for this relationship is that improving institutional

quality will enable better governance of the transportation infrastructure. These include increasing transportation networks across the country using renewable and environmentally-friendly energy sources. These will not only reduce CO2 emissions, but the expansion of the transportation network will have a major economic spillover across the country, especially in underserved and rural areas.

Further, if both the main hypotheses hold true, we call it the *feedback hypothesis* (FBH⁴), where transportation infrastructure and institutional quality reinforce each other. Finally, if neither of the main hypotheses hold true, we call it the neutrality hypothesis (NEH⁴), where both variables are completely independent. Studies that have shown the link between the quality of institutional supremacy and the development of transportation infrastructure include those of Chen et al. (2022), Zergawu et al. (2021), Danish et al. (2020), Crescenzi et al. (2016) and Kenny (2009).

Based on the discussions above, we test the following hypothesis.

H4A, B. Transportation infrastructure Granger causes (positively) institutional quality and vice versa.

2.5. Transportation infrastructure and CO2 emissions

In this section, we focus on the associations between the CO2 emissions and transportation infrastructure. There are two diverse means to address this nexus. First, the transportation infrastructure Granger causes the CO2 emissions (*supply-leading hypothesis* – SLH⁵). The motivation for this hypothesis is that in many developing countries, the transportation sector is dependent on fossil fuels. As such, increased expansion of fossil-fuel-driven transportation systems will result in an increase in CO2 emissions in these economies (Umar et al., 2020; Danish and Baloch, 2018; Danish et al., 2018; Wang et al., 2017, 2018; Yang et al., 2015; Churchill et al., 2021). If developing countries invest in environmentally friendly transportation systems, the emissions of CO2 will be reduced over time. Some studies have found that, whether transportation has a negative or positive impact on emissions is dependent on the particular form of transportation, such as railways compared to airlines (Ali et al., 2022; United States Environmental Protection Agency – EPA, 2022).

Second is that CO2 emissions Granger cause transportation infrastructure (*demand-following hypothesis* – DFH⁵). The rationalisation for this particular hypothesis is that increasing CO2 emissions leads to climate change and other planetary health issues. This will force countries in the developing world to intensify transportation infrastructure that leverages on clean energy sources. These actions are due to the fact the increased CO2 emissions will have an adverse impact on the environment and health of people in these countries. This will increase the cost of environmental degradation and healthcare in the sample countries. Further, increasing use of fossil-fuels for industrial production will result in many of the products and services from the sample countries being unable to access more advanced markets that have strict adherence to environmental, social and governance (ESG) standards. To reduce environmental cost and adhere to global ESG standards, it is envisaged that many of

developing countries will increase investments in transportation system that uses renewable energy.

Further, if both the main hypotheses are valid, we call it the *feedback hypothesis* (FBH⁴), where transportation infrastructure and CO2 emissions Granger cause equally. Finally, if neither of the main hypotheses hold, we call it the neutrality hypothesis, where both variables are independent of each other. Studies that show the link between transportation infrastructure development and CO2 emissions include Song et al. (2023), Alatas (2022), Mohmand et al. (2021) and Arvin et al. (2015).

Based on the discussions above, we test the following hypothesis.

H5A. Transportation infrastructure Granger causes (positively or negatively) CO2 emissions.

H5B. CO2 emissions will Granger cause (positively) CO2 transportation infrastructure.

2.6. CO2 emissions and institutional quality

In this section, we consider the relationship between CO2 emissions and institutional quality. There are two different ways to address this nexus. First, is that institutional quality Granger causes CO2 emissions (*supply-leading hypothesis* - SLH⁶). The justification for this particular hypothesis is that as developing countries improve their institutions, they will invest in renewable energy sources and sustainable transportation systems to ensure that economic development will go in tandem with the reduction of CO2 emissions (Haldar and Sethi, 2021; Ibrahim and Law, 2016).

Second, is that CO2 emissions Granger cause institutional quality (*demand-following hypothesis* - DFH⁶). The motivation for this line of reasoning is that an upward trend in CO2 emissions will result in increased degradation of planetary health, human health and economic productivity. These will result in key stakeholders (firms, consumers and the general public) pressuring governments to be stricter in the enforcement of CO2 emissions. These also include intensifying environmental awareness campaigns and providing financial benefits (tax incentives and subsidies) for firms and consumers to transition towards a more environmentally-friendly transportation system.

Further, if the two main hypotheses co-exist, we call it the *feedback hypothesis* (FBH⁶), where both CO2 emissions and institutional quality Granger cause each other. Finally, if there is no Granger causality, we call it the neutrality hypothesis (NLH⁶), where both variables are completely independent. Studies that have shown these relationships include Nair et al. (2021) and Karim et al. (2022).

Centred on the above discussions, we test the particular hypothesis.

H6A. Institutional quality Granger causes (negatively) CO2 emissions.

H6B. CO2 emission Granger cause (positively) institutional quality.

2.7. Contributions of the study

Appendix A summarises numerous studies evaluating these six key relationships in terms of whether they find evidence of the supply-leading, demand-following, feedback, or neutrality-hypotheses. Based on the above literature review, we find that the evidence with regards to the direction of causality for the six hypotheses are rather mixed and unclear in the literature.

The present study endeavours to determine the causal interface between institutional quality, transportation infrastructure, CO₂ emissions and economic growth from the perspective of developing countries. The nexus between these variables is important in determining planetary health development initiatives in developing countries. We attempt to address the gap in the literature by simultaneously considering the role of CO₂ emissions, transportation infrastructure, and institutional quality on economic growth. We examine this particular gap in the literature using a panel Granger causality method to ascertain the short-term and the long-term dynamics between the variables. Additionally, past studies mostly focus on institutional quality and transportation infrastructure as measured by one proxy. However, we consider a large pool of proxies for both transportation infrastructure and institutional quality. An important contribution of the present study is the insights into the co-development planetary health policies pertaining to the variables used in the study. The relationships between these variables will enable developing countries to design policies that will ensure more sustainable economic growth in these countries aligned to global planetary health practices.

3. Sample, variables, hypotheses and methodology

3.1. Sample

We deploy a panel of 79 developing countries³ (DCs) that includes countries from Africa, Asia, and the Americas. The sample includes the yearly data for the period from 2005 to 2022. We acquired our data from the *WDI database*, put forth by the World Bank.

3.2. Definition of variables

The variables utilized in this work⁴ are transportation infrastructure (TRA), institutional quality (INQ), CO₂ emissions (CO₂), and per-capita economic growth (GPG). Specifically, CO₂ is a measurement of CO₂ emissions from transport (% of total fuel combustion). This variable measures emissions from the combustion of fuel for all transport activity, with the exception of international marine bunkers and international aviation. Consequently, domestic aviation; domestic navigation; and road, rail and pipeline transport are included in this measure. GPG is measured as the percentage change in per capita gross domestic product.

TRA involves six different transportation indicators, which are goods transported in railways (TR1), passengers carried in railways (TR2), rail lines (TR3), freight in air transport (TR4), passengers carried in air transport (TR5), and registered carrier departures worldwide in air transport (TR6). Each measure will be used individually as six different cases in our panel Granger causality tests.

INQ involves eleven different institutional indicators measured through various Country Policy and Institutional Assessment (CPIA) variables. The eleven individual indicators are listed in Appendix B. Rather than estimate Granger causality results for each of the eleven indicators, we constructed a composite index of institutional quality (*CIQ*) by means of principal component analysis (PCA). The results of the PCA are not provide here to conserve space. However, it is available upon request from the authors.

Table C.1 (see, Appendix C) highlights the summary statistics and the correlations for each of the variables employed in our empirical process.

3.3. Hypotheses

The present study focuses on the link between institutional quality, transportation infrastructure, CO2 emissions and economic growth. The hypotheses that we tested are:

H1A, B: Transport infrastructure development Granger causes (positively) economic growth and vice versa.

H2A, B: Institutional quality Granger causes (positively) economic growth and vice versa.

H3A, B: CO2 emissions Granger cause (positively or negatively) economic growth and vice versa.

H4A, B: Institutional quality Granger causes (positively) transport infrastructure and vice versa.

H5A: Transport infrastructure Granger causes (positively or negatively) CO2 emissions and vice versa.

H5B: CO2 emissions Granger cause (positively) transportation infrastructure.

H6A: Institutional quality Granger causes (negatively) CO2 emissions.

H6B: CO2 emission Granger cause (positively) institutional quality.

In Fig. 1, we present a visual representation of the six above-mentioned hypotheses. Each hypothesis with the possible direction of causality is presented.

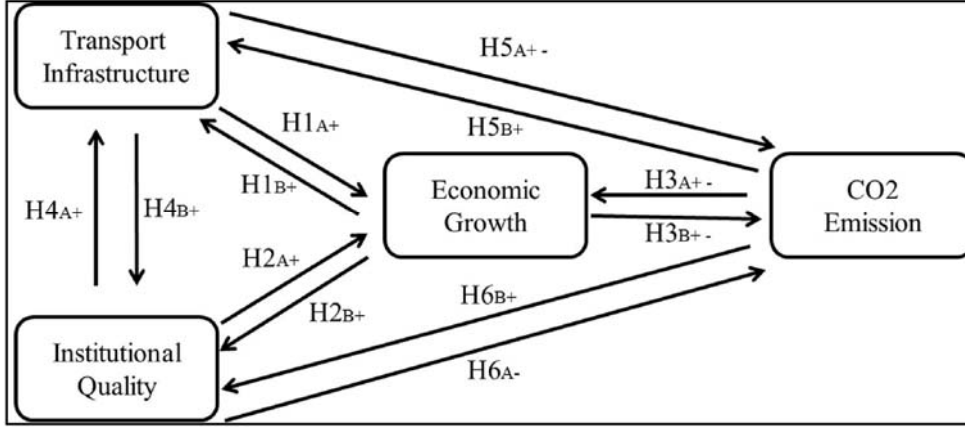


Fig. 1. Possible Causal Relationships between the Variables

Notes: The notation “+” and “-” represents positive and negative causal relationships, respectively.

3.4. Methodology

In this section of the paper, we outline the empirical model, and econometric methodology used to capture the dynamics between the development of the transportation systems, institutions, trends in CO emissions and economic growth in developing countries.

3.4.1. The econometric methodology

We used the following equation to assess the relation between institutional quality, CO2 emissions, transportation infrastructure development, and economic growth.

$$GPG_{i,t} = \delta_0 GPG_{i,t} + \delta_1 GPG_i TRA_{i,t} + \delta_2 GPG_i INQ_{i,t} + \delta_3 GPG_i CO2_{i,t} + \xi_{GPG_{i,t}} [1]$$

where *GPG* denotes per capita economic growth, *TRA* denotes transportation infrastructure, *INQ* denotes institutional quality, and *CO2* denotes CO2 emissions. Equation (1) can be taken further by using other selected variables (*TRA* or *INQ* or *CO2*) as a substitute for the predicted variable. This allows for the likelihood that causation might drift in other directions. The parameters δ_j signify the long-term elasticity assessments of *GPG* with response to *TRA*, *INQ* and *CO2* emissions.

3.4.2. The estimation techniques

The empirical model below is used to study the dynamic relationships between economic growth, transportation infrastructure, CO2 emissions, and institutional quality.

$$\begin{aligned}
\begin{bmatrix} \Delta GPG_{i,t} \\ \Delta TRA_{i,t} \\ \Delta INQ_{i,t} \\ \Delta CO2_{i,t} \end{bmatrix} &= \begin{bmatrix} \delta_{01PEGj} \\ \delta_{02FMSj} \\ \delta_{03FMOj} \\ \delta_{04INNj} \end{bmatrix} \\
&+ \sum_{k=1}^s \begin{bmatrix} \delta_{11GPGi,k}(L) & \delta_{12GPGi,k}(L) & \delta_{13GPGi,k}(L) & \delta_{14GPGi,k}(L) \\ \delta_{21GPGi,k}(L) & \delta_{22GPGi,k}(L) & \delta_{23GPGi,k}(L) & \delta_{24GPGi,k}(L) \\ \delta_{31GPGi,k}(L) & \delta_{32GPGi,k}(L) & \delta_{33GPGi,k}(L) & \delta_{34GPGi,k}(L) \\ \delta_{41GPGi,k}(L) & \delta_{42GPGi,k}(L) & \delta_{43GPGi,k}(L) & \delta_{44GPGi,k}(L) \end{bmatrix} \begin{bmatrix} \Delta GPG_{i,t-k} \\ \Delta TRA_{i,t-k} \\ \Delta INQ_{i,t-k} \\ \Delta CO2_{i,t-k} \end{bmatrix} \\
&+ ECT_{i,t-1} \begin{bmatrix} \mu_{1GPGi} \\ \mu_{2GPGi} \\ \mu_{3GPGi} \\ \mu_{4GPGi} \end{bmatrix} + \begin{bmatrix} \xi_{1GPGi,t} \\ \xi_{2GPGi,t} \\ \xi_{3GPGi,t} \\ \xi_{4GPGi,t} \end{bmatrix} \tag{2}
\end{aligned}$$

where *TRA* is transportation infrastructure, which is measured via six indicators, namely TR1 - TR6; *INQ* is institutional quality, which is used as a composite index (CIQ); *GPG* is economic growth; and *CO2* is CO2 emissions. ECTs indicate error-correction terms, representing the long-term oscillation.

The use of this model depends upon the inherent features of the variables and their association, particularly with reference to an order of integration (the unit root) and cointegration. Hence, the first step is to obtain the order of integration of all deployed variables. We utilized two-panel unit root tests, specifically the IPS test⁵ and BRE test,⁶ to determine the order of integration.

The next step after ascertaining the variables' order of integration is to examine the actuality of cointegration between *GPG*, *INQ*, *CO2* and *TRA*. In this paper, we engaged the Pedroni cointegration test to ascertain the co-integrating vectors between the variables of interest in Equation (2).

If we find a cointegration association between these variables, the third step is estimating long-term per capita economic growth elasticities. This study applied four different estimation techniques, namely, dynamic ordinary least squares (DOLS), fully modified OLS (FMOLS), generalised method of moments (GMM), and quantiles-on-quantile regression (QQR) to guarantee the robustness of the long-term estimated results. Finally, we used the VECM⁷ technique to probe the path of Granger causality among *GPG*, *INQ*, *CO2* and *TRA*. In the VECM estimation, the choice of optimum lags is crucial. This work deployed the widely-engaged Akaike Information Criterion to establish the optimum lags.

Quantile-on-quantile regression (QQR) is an econometric method proposed by Sim and Zhou (2015) to determine how the quantile of a variable is dependent on the quantile of another variable. This technique uses quantile regressions⁸ with nonparametric estimations, which provides a more robust estimation of capturing the underlying complex relationships between variables used the regression models. The results obtained from this approach is also robust against structural breaks in the data series. Sim and Zhou (2015) argue that this

modelling approach can be used in a wide range of macroeconomic and finance studies. This econometric method has been utilized in the macroeconomic literature by authors such as Duan et al. (2021) Mallick et al. (2019), Shahzad et al. (2019), and Shahbaz et al. (2018, 2017).

4. Results and discussion

In this section, we report the results from the panel unit root test, panel cointegration test, and the short-run and long-run relationships between the variables used in this study.

4.1. Panel unit root test results

We tested the null hypothesis of a unit root by using two diverse panel unit root tests (IPS and BRE) on the developing countries' panel. Table C.1 in Appendix C presents the results of these two-unit root tests on these variables utilized in this study (GPG, CIQ, CO₂, TR1, TR2, TR3, TR4, TR5, and TR6). Based on the test outcomes, we reject the null hypothesis of unit root at a 1% probability level. The findings confirmed that, in general, at the normal-level data, all the variables are non-stationary, but they are stationary at the first-difference. That is, they are integrated of order one, I [1].

4.2. Panel cointegration test results

Given the findings regarding the panel unit root tests, we deployed the Pedroni panel cointegration test to examine any long-term association between GPG, TRA, CO₂ and CIQ. We examined six cases, that differed based on the use of the six different proxies of TRA (TRA1 – TRA6). For each case, the three common variables are GPG, CO₂ and CIQ. Table 1 provides the summary of the panel cointegration test. The results are presented in Table 1 and it shows that we reject the null-hypothesis of no cointegration. This suggests the existence of cointegration relationship between institutional quality, transportation infrastructure development, CO₂ emissions, and economic growth. That is, transportation infrastructure, CO₂ emissions, institutional quality, and economic growth are co-moving in the long term. We present the short-run and long-run dynamics between the variables below.

4.3. Vector error-correction model results

Since we found the variables to be non-stationary and co-integrated, we estimated a panel vector error-correction model to ascertain the short-term and long-term causal relationships between institutional quality, transportation infrastructure development, CO₂ emissions, and economic growth. Table 2 provides the findings regarding the VECM. Based on the VECM estimation, we discuss the short-term and long-term dynamics between the variables.

Table 1. Panel cointegration test results.

Part A: Pedroni Cointegration Test								
	Within Dimension				Between Dimension			Decision on
Cases	A	b	c	d	e	f	g	Cointegration Exists
1	-2.14	1.87	-4.84*	-0.90	4.04	-3.18*	-8.88*	Yes
2	-2.35	1.93	-5.30*	-1.59**	4.13	-8.47*	-1.22***	Yes
3	-1.56	1.67	-4.38*	-0.83	4.33	-4.09*	-1.71**	Yes
4	-1.59	2.56	-8.89*	-4.13*	4.39	-9.27*	-2.08**	Yes
5	-1.61	2.39	-8.05*	-3.27*	5.24	-7.42*	-2.44*	Yes
6	-1.52	2.54	-8.99*	-3.40*	5.44	-8.42*	-2.65*	Yes

Note 1: GPG is per capita economic growth, CIQ is a composite index of institutional quality, CO2 is CO2 emissions, TR1 is goods transported in railways, TR2 is passengers carried in railways, TR3 rail lines, TR4 is freight in air transport, TR5 is passengers carried in air transport, and TR6 is registered carrier departures worldwide in air transport.

Note 2: Case 1- GPG, CIQ, CO2 and TR1; Case 2- GPG, CIQ, CO2 and TR2; Case 3- GPG, CIQ, CO2 and TR3; Case 4- GPG, CIQ, CO2 and TR4; Case 5- GPG, CIQ, CO2 and TR5; and Case 6- GPG, CIQ, CO2 and TR6.

Note 4: *, **, *** significant at 1%, 5%, and 10% respectively.

Note 5: *a-d* are within-dimension statistics, while *e-g* are between-dimension statistics.

Table 2. Panel Granger causality test results.

Predictand Variable	Explanatory variables and ECT ₋₁									
	Case 1: TR1					Case 2: TR2				
	Δ GPG	Δ CIQ	Δ CO2	Δ TR1	ECT ₋₁	Δ GPG	Δ CIQ	Δ CO2	Δ TR2	ECT ₋₁
Δ GPG	–	1.73	8.12*	0.99	–0.84*	–	1.42	7.32*	0.96	–0.83*
Δ CIQ	0.07	–	1.40	0.32	–0.21	0.11	–	1.86	4.06***	–0.04
Δ CO2	5.47**	1.74	–	1.21	–0.37	5.15**	2.95	–	6.70*	–0.19
Δ TRA	10.1*	0.55	1.73	–	–0.10	5.25**	0.13	1.67	–	–0.01
Inferences: CO2 $\Rightarrow$ GPG; GPG $\Rightarrow$ TR1						Inferences: CO2 $\Rightarrow$ GPG; GPG $\Rightarrow$ TR2; TR2 $\Rightarrow$ CIQ; TR2 $\Rightarrow$ CO2				
	Case 3: TR3					Case 4: TR4				
	Δ GPG	Δ CIQ	Δ CO2	Δ TR3	ECT ₋₁	Δ GPG	Δ CIQ	Δ CO2	Δ TR4	ECT ₋₁
Δ GPG	–	1.37	5.16**	0.14	–0.71*	–	0.31	4.51***	14.2*	–0.91*
Δ CIQ	0.04	–	0.28	2.63	–0.04	0.09	–	1.45	4.90***	–0.10
Δ CO2	4.55***	1.96	–	0.67	–0.19	1.09	1.33	–	4.23***	–0.03
Δ TRA	4.87***	0.22	1.12	–	–0.01	0.08	0.03	3.55	–	–0.26
Inferences: CO2 $\Rightarrow$ GPG; GPG $\Rightarrow$ TR3						Inferences: CO2 $\Rightarrow$ GPG; TR4 $\Rightarrow$ GPG; TR5 $\Rightarrow$ CIQ; TR4 $\Rightarrow$ CO2				
	Case 5: TR5					Case 6: TR6				
	Δ GPG	Δ CIQ	Δ CO2	Δ TR5	ECT ₋₁	Δ GPG	Δ CIQ	Δ CO2	Δ TR6	ECT ₋₁
Δ GPG	–	0.14	4.56***	5.63*	–0.91*	–	0.15	4.39***	13.1*	–0.91*
Δ CIQ	0.02	–	1.16	4.33***	–0.07	0.05	–	1.11	5.24**	–0.10
Δ CO2	0.53	1.41	–	1.85	–0.02	0.51	1.54	–	1.16	–0.02
Δ TRA	2.51	0.72	12.4*	–	–0.03	2.47	0.57	9.12*	–	–0.01
Inferences: CO2 $\Rightarrow$ GPG; TR5 $\Rightarrow$ GPG; TR5 $\Rightarrow$ CIQ; TR5 $\leq$ CO2						Inferences: CO2 $\Rightarrow$ GPG; TR6 $\Rightarrow$ GPG; TR6 $\Rightarrow$ CIQ; TR6 $\leq$ CO2				

Note 1: TRA stands for transportation infrastructure and indicates TR1, TR2, TR3, TR4, TR5, or TR6.

Note 2: Case 1 presents the link between GPG, CIQ, CO2, and TRA 1; Case 2 presents the link between GPG, CIQ, CO2, and TRA 2; Case 3 presents the link between GPG, CIQ, CO2, and TRA 3; Case 4 presents the link between GPG, CIQ, CO2, and TRA 4; Case 5 presents the link between GPG, CIQ, CO2, and TRA 5; and Case 6 presents the link between GPG, CIQ, CO2, and TRA 6.

Note 3: *, **, *** significant at 1%, 5%, and 10% respectively.

4.3.1. Short-term dynamics

Based on Table 2, we observe the short-term dynamics based on the coefficients of the first difference of the explanatory variables for all six cases of the transportation variable. If the coefficients were found to be statistically significant, we accept that there are causal relationships between the variables. The short-term relationships were found to be complex and varied for each of the six cases. Several of the hypotheses are supported in the short-run analysis. The relationships between the four variables are discussed below for the six different transportation systems.

• *Case 1 for TR1 (goods transported by railways) – refer to Fig. 2a:*

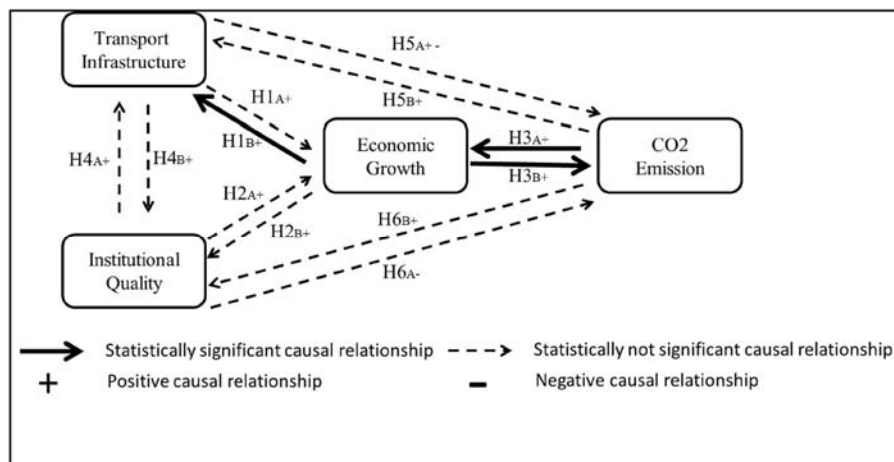


Fig. 2a. Short-run Analysis – TR1

(Goods transported via railways – in 1 million ton - kilometres).

There were positive bi-directional causal relationships between CO2 emission and economic growth. The analysis also shows that economic growth has a positive causal impact on TR1. This suggests that economic growth contributes positively to CO2 emissions. This is not surprising that much of the industrial activities in these countries rely on fossil-fuels as an energy source. An increase in economic growth will increase the demand for railway services for transporting goods. The increased cost of CO2 emissions will force governments to look at alternate rail systems that use renewable energy sources. This will increase spending in the eco-friendly transportation sector, contributing to new jobs and economic growth.

- *Case 2 for TR2 (passengers carried via railways) – refer to Fig. 2b:*

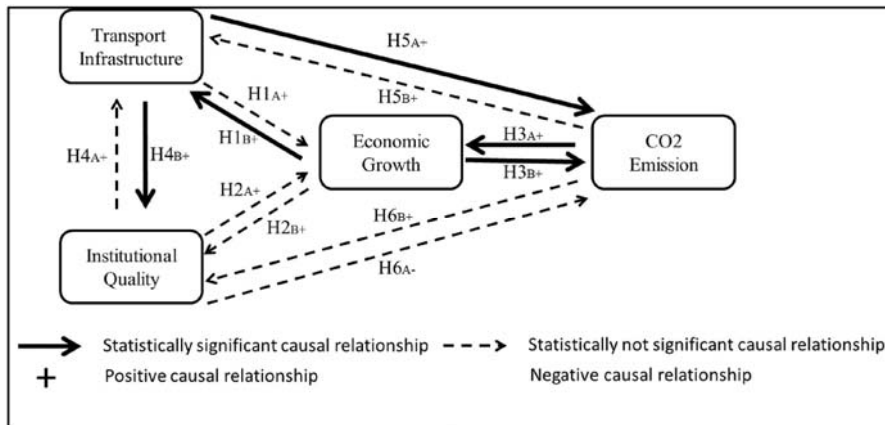


Fig. 2b. Short-run Analysis – TR2

(Passenger transported via railways – in 1,000,000 passengers-kilometres).

There were positive bi-directional causal relationships between CO2 emission and economic growth. Economic growth was also found to have a positive causal impact on TR2; TR2 has a positive impact on institutional quality. Similar to the discussion in Case 2, increasing the use of railways to transport people will lead to increased economic growth and CO2 emissions. The latter is due to the high use of fossil-fuels to power the train systems in developing countries. Increasing mobility of people via train was found to improve the quality of institutions in the country. Increase in transportation infrastructure will also increase CO2 emissions.

- *Case 3 for TR3 (rail lines) – refer to Fig. 2c*

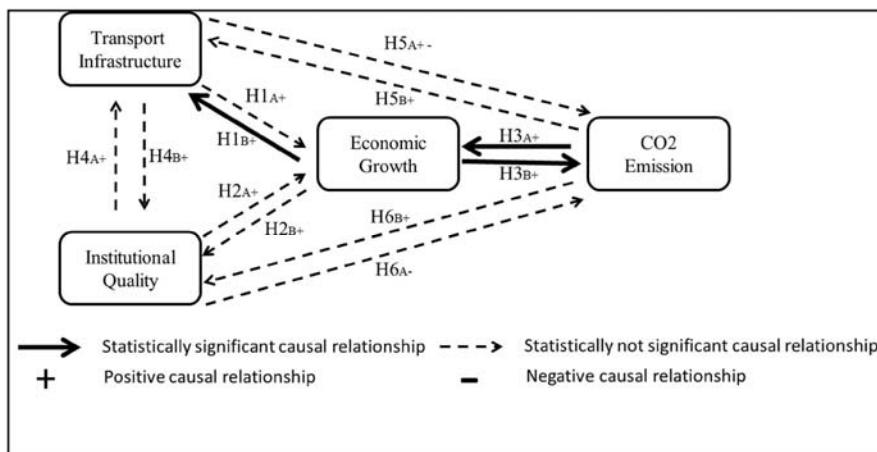


Fig. 2c. Short-run Analysis – TR3

(Rail lines – total route in kilometres).

There were positive bi-directional causal relationships between CO2 emission and economic growth. Economic growth was also found to have a positive causal impact on the transport infrastructure, TR3. As in the previous two cases, the rail system is seen as important for development in these sample countries. Increasing economic growth in these countries will increase CO2 emissions.

•Case 4 for TR4 (freight air transport) – refer to Fig. 2d

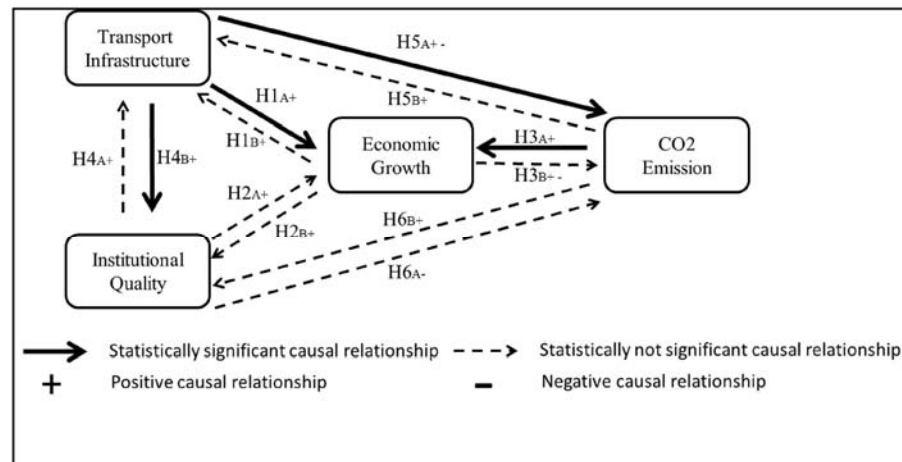


Fig. 2d. Short-run Analysis – TR4

(Freight by air transport – 1,000,000 ton-kilometres).

There were positive causal relationships from CO2 and transport TR4 to economic growth. The empirical analysis also shows a positive relationship from TR4 to CO2 emissions and to institutional quality. The rationale for these relationships is that increased freight air transport will raise economic growth and improve the quality of the institutions. However, an increase in freight air transport will also raise CO2 emissions.

•Case 5 for TR5 (freight by air transport) – refer to Fig. 2e

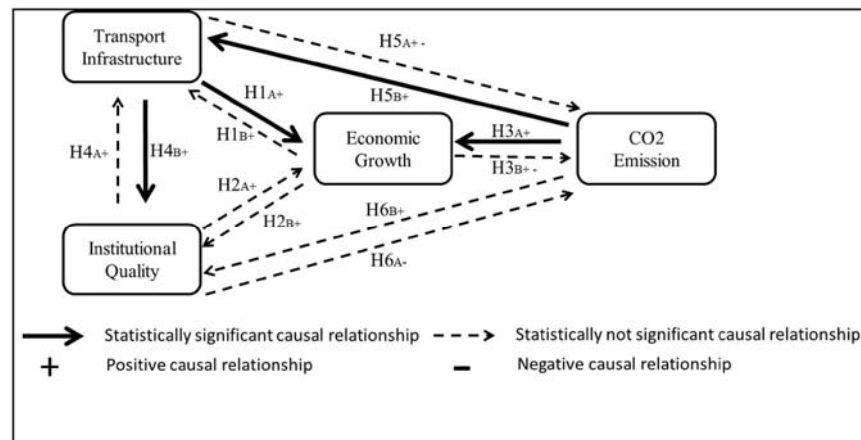


Fig. 2e. Short-run Analysis – TR5

(Passengers carried by air transport in 1,000,000).

There were positive causal relationships from CO2 emissions and transport TR5 to economic growth. TR5 was also found to have a positive causal impact on institutional quality. The rationale for this short-term relationship is similar to that of Case 4. High CO2 emission will also increase investment in transportation infrastructure TR5 (more eco-friendly transportation system).

• *Case 6 for TR6 (registered freight by air transport) – refer to Fig. 2f*

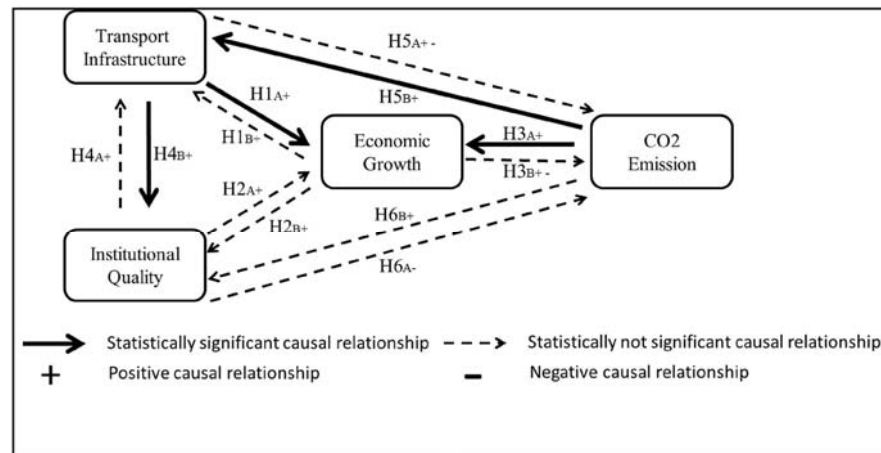


Fig. 2f. Short-run Analysis – TR6

(Registered carrier departures worldwide in air transport – in 1,000,000).

There were positive causal relationships from CO2 emissions and transport TR6 to economic growth. TR6 was also found to have a positive causal impact on institutional quality. CO2 was found to have a positive impact on TR6. This suggests that while TR6 contributes positively to economic growth and institutional development; increasing CO2 emissions will lead to more pressure for these countries to increase investments towards more eco-friendly air transportation systems in developing countries.

4.3.2. Long-term dynamics

Statistically significant ECT_{-1} coefficients for the VECM estimation in Table 2 indicate that there exist long-run associations between the deployed variables. The lagged ECT figures were found to be negative and significant at a 1% level. This endorses the view that there is a stable long-term affiliation between these variables. Additionally, the lagged ECT coefficients varied between -0.71 and -0.91, which indicates that any departure from the long-term path after a short-term change in the explanatory variables will be re-adjusted back by between 71% and 91% after each year.

Given that there exist long-term associations between these variables, we estimated Equation (1) to obtain the long-term elasticities of economic growth with respect to transportation infrastructure, CO2 emissions, and institutional quality. The study used QQR, GMM, FMOLS, and DOLS to evaluate the long-term elasticities of per capita economic growth. Table 3 details the QQR results. Table D.1 (in Appendix D) provides the results of GMM, FMOLS, and DOLS.

Table 3. Quantile-on-quantile regression (QQR) results.

Predictand Variable: GPG									
IVs:	10th	20th	30th	40th	50th	60th	70th	80th	90th
Estimate 1: with TR1									
CIQ	0.01*	0.01*	0.01*	0.01*	0.01*	0.04*	0.03*	0.04*	0.05*
CO 2	-0.03**	-0.03**	-0.03*	-0.02*	-0.02*	-0.02*	-0.03*	-0.02*	-0.03*
TR1	0.01*	0.004**	0.01*	0.01*	0.01*	0.01*	0.04*	0.01*	0.04*
C	1.84*	1.86*	1.87	1.86	1.86	1.87	1.88	1.88	1.87
QL R	8.32*	21.3*	34.1*	141.2*	39.7*	31.7*	21.6*	13.5*	10.8*
Estimate 2: with TR2									
CIQ	0.01*	0.01*	0.01*	0.01*	0.01*	0.05*	0.04*	0.05*	0.07*
CO 2	-0.03**	-0.03**	-0.03*	-0.02*	-0.02*	-0.02*	-0.03*	-0.03*	-0.03*
TR2	0.01*	0.001**	0.01*	0.01*	0.01*	0.01*	0.04*	0.04*	0.02*
C	1.83*	1.86*	1.86	1.86	1.86	1.87	1.88	1.90	1.92
QL R	12.1*	25.8*	43.8*	50.9*	168.9*	38.4*	27.9*	16.8*	13.0*
Estimate 3: with TR3									
CIQ	0.01*	0.01*	0.01*	0.01*	0.01*	0.002*	0.001*	0.001*	0.001*
CO 2	-0.02** *	-0.02**	-0.03*	-0.02*	-0.02*	-0.02*	-0.02*	-0.03*	-0.03*
TR3	0.01*	0.004**	0.003* *	0.002*	0.002* *	0.002* *	0.002* *	0.01*	0.002*
C	1.81*	1.83*	1.84	1.85	1.86	1.86	1.87	1.91	1.91
QL R	10.9*	14.2*	31.4*	36.5*	31.6*	24.8*	16.1*	12.2*	10.2*
Estimate 4: with TR4									
CIQ	0.01*	0.01*	0.01*	0.01*	0.01*	0.04*	0.03*	0.01*	0.01*
CO 2	-0.01** *	-0.01** *	-0.01*	-0.014 *	-0.012 *	-0.014 *	-0.02* *	-0.024 *	-0.023 *
TR4	0.004*	0.001**	0.002* *	0.001* *	0.001*	0.001*	0.001*	0.004*	0.003*
C	1.81*	1.83*	1.84	1.85	1.85	1.86	1.87	1.89	1.90
QL R	14.9*	7.98*	26.3*	24.1*	28.4*	23.7*	25.5*	21.9*	17.1*
Estimate 5: with TR5									
CIQ	0.01*	0.01*	0.01*	0.01*	0.01*	0.04*	0.03*	0.02*	0.02*
CO 2	-0.01**	-0.011* *	-0.01*	-0.015 *	-0.012 *	-0.012 *	-0.018 *	-0.021 *	-0.023 *
TR5	0.004*	0.002**	0.003*	0.002*	0.001*	0.001*	0.001*	0.003*	0.005*

C	1.78*	1.82*	1.82	1.84	1.85	1.86	1.88	1.91	1.93
QL R	11.9*	7.67**	16.4*	25.7*	31.3*	32.9*	26.5*	213.5*	17.3*
Estimate 6: with TR6									
CIQ	0.01*	0.01*	0.01*	0.01*	0.01*	0.04*	0.03*	0.01*	0.03*
CO 2	-0.01**	-0.012* *	-0.01*	-0.02*	-0.012 *	-0.011 *	-0.017 *	-0.02*	-0.03*
TR6	0.01*	0.02***	0.003*	0.002*	0.001*	0.001*	0.002*	0.004*	0.008*
C	1.78*	1.82*	1.82	1.84	1.85	1.86	1.88	1.90	1.93
QL R	14.7*	8.22**	34.1*	24.7*	30.9*	32.7*	25.9*	23.2*	19.5*

Note: *, **, *** significant at 1%, 5%, and 10% respectively.

The coefficients of transportation infrastructure, CO₂ emissions, and institutional quality were found to be significant at a 1% significance level. This advises that economic growth increases when there is an increase in transportation infrastructure and institutional quality. The positive interface between economic growth and transportation infrastructure development and institutional quality confirms the supply-leading hypothesis and this was found to be true for all of the six cases (TR1, TR2, TR3, TR4, TR5, and TR6). On the other side, economic growth decreases when CO₂ emissions increase in the sample countries.

The long-run results were found to be robust for all the cases. This implies that the interaction between CO₂ emissions, transportation infrastructure development, and institutional quality has an impact on the long-run economic growth trajectory of the sample developing countries, as shown in Fig. 3. All the transportation systems were found to contribute positively to economic growth. Improvement of institutional quality also was found to enhance economic growth in these countries. On the other hand, an increase in CO₂ will reduce economic growth. Interestingly, in the case of GMM and DOLS estimations, the magnitude of the negative impact of CO₂ emission was found to be significantly higher (for some of the TR variables) than the positive impact of improvement in the transportation systems and institutions of governance in the sample countries. This suggests that policymakers in the sample countries should give careful attention to addressing CO₂ emissions, as degradation of the health of the planet may stifle economic growth in these countries over a longer period of time.

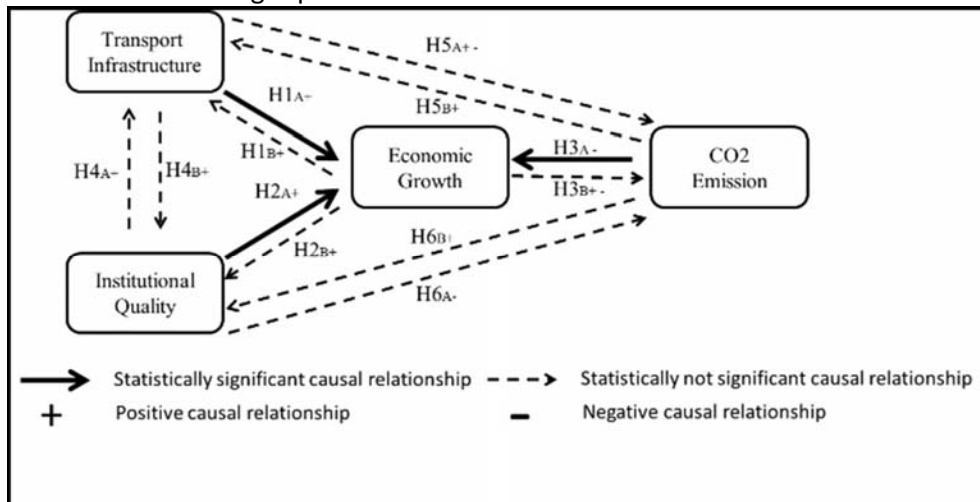


Fig. 3. Long-term dynamics.

4.3.3. *The inter-play between the short-term and long-term dynamics*

The empirical analysis in this paper unpacks the complex dynamics between the development of the different transportation systems, CO₂ emissions, institutional quality and economic growth in selected developing countries. The analysis shows that the current transportation systems in these countries contribute to economic growth, and institutional development (due to the mobility of goods, services, and people, especially skilled workforce). The short-run analysis also shows that the current transportation systems which rely on fossil-fuel will increase CO₂ emissions, and there will be pressure for these countries to invest in modernising their transportation systems towards more eco-friendly energy sources. The latter is reinforced by the long-run analysis which shows that, while the development of transportation systems and institutions in these countries contribute to positive economic growth, increasing CO₂ emissions will have an adverse impact on economic growth in the long run.

4.4. Checking for the robustness of results

We have conducted additional tests to assess the robustness of the estimated results. First, we have examined the nexus between institutional quality (at the individual level) along with transport infrastructure, CO₂ emissions and economic growth. The findings are uniform to the original analysis. These supplementary results are not presented here due to space constraints. Second, we employed generalised impulse response functions to see how any shocks to these variables shake the remaining variables. These results are reported in Figures E.1-E.6 (see Appendix E) for Cases 1–6, particularly with reference to different indicators of transport infrastructure (TR1-TR6). These findings are consistent with the estimated results.

5. Discussion, concluding remarks, and policy implication

This paper examines causal associations between institutional quality, transportation infrastructure development, CO₂ emissions, and economic growth in 79 developing economies over the period 2005–2022. The study shows that, in the short run, we observe a strong endogenous relationship between transportation infrastructure, CO₂ emissions, institutional quality and economic growth. In the short-term, increases in the development of the current transportation networks, which utilise cheaper fossil fuels, will increase economic growth. However, in the long-run, increased emissions of CO₂ will have an adverse impact on the economic growth of these countries. In the long run, both transportation infrastructure and institution quality have a positive effect on economic growth, whereas CO₂ emissions have a negative influence on economic growth.

Unpacking the complex relationships between the variables highlights that for developing economies to achieve sustainable economic growth, policy-makers must ensure that sound institutional reforms are undertaken to ensure that investment in modernising the transportation infrastructure to promote economic growth must take into consideration climate change and planetary health issues.⁹ That is, policy makers need to ensure that

transportation infrastructure plans mitigate risks associated with CO₂ emissions by having a comprehensive energy transition program from fossil-fuels to renewable energy.

In this paper, we propose several important co-development policies to ensure sustainable development of the transportation system and economic development in the sample developing countries. First, the institutional and infrastructure development initiatives in these countries must have a provision for transitioning from a fossil-fuel transportation system to an environmentally friendlier transportation system that uses renewable energy sources. A study by IRENA (2021) shows that there is significant scope for the various transportation systems to use renewable energy sources. The study states that 3% of the global transportation system used ethanol and biodiesel for road transportation system in 2018, and around 9% of the inter-city railways use renewable electricity in 2015. In the shipping sector, the study states that progress has been made in the use of bio-fuels, hydrogen-based electricity, as well as in wind and solar propulsion technology. However, the use of these energy sources is relatively low. In the case of electric and hybrid-electric ferries, the study found that these technologies are utilized in many advanced countries. However, they are scarce in developing countries. In the airline industry, biofuels have been blended with traditional jet fuels to reduce CO₂ emissions. However, the use of these energy sources is not widespread in the industry. The study also highlights that other environmental propulsion technologies have emerged in the aviation industry, such as solar energy, synthetic fuels and green hydrogen. These technologies are in the early stages of adoption.

Greater use of electric vehicles and other renewable energy sources in the transportation system in the developing world will go a long way to address the increasing CO₂ emissions in these countries. To ensure a smooth transition towards renewable energy sources in the transportation sector, there is a need to re-examine and refine the supply-side and demand-side policies and strategies. On the supply-side, taxation and subsidy systems in these countries can be used to encourage greater development and adoption of alternate fuels such as electricity, battery technology, biodiesel, ethanol, hydrogen, nuclear and other renewable energy to power the transportation systems in the developing emerging world. Clear policies and mandates must be in place on the energy mix for the various transportation modes. Others strategies include putting in place restrictions on fossil-fuel based vehicles and eventual removal of environmental polluting vehicles from the transportation system. In this context, urban planning, and township development in developing countries must put in place long-term smart infrastructure development plans that utilise renewable energy.

On the demand-side initiatives, there needs to be a greater impetus for people to use environmentally friendly transportation modes. These include the use of public transportation systems (bus, trams, subway systems, trains and bus rapid transport networks) in these countries. An affordable public transportation system will be key to encourage people to use this mode of transportation. Other initiatives include transitioning people towards non-motorised transportation modes such as walking and cycling. In this context, in major townships, investments are needed to build safe walkways and cycling lanes to encourage these modes of transportation. Further, preferred parking (with discounted rates) for car sharing and increasing parking spots near public transportation systems can reduce

traffic congestion and air pollution in many of the city centres in the developing world. Another key demand side analysis strategy includes undertaking community engagement and public awareness (CEPA) campaigns to educate the population and firms on the benefits of using clean energy sources for transportation. Clearly articulated CEPA messages on the reduction of cost of transportation (i.e, lower cost inputs for businesses) and health benefits due to the use of renewable energy will encourage more firms and consumers to make the transition towards environmentally friendly transportation systems.

For example, the transportation system in China was dependent on fossil fuels, which contributed to air pollution and greenhouse gas emissions in major cities in China. To overcome this challenge, a concerted effort was undertaken to transition the nation towards environmental-friendly transportation modes. The Chinese government incorporated a series of supply and demand strategies as part of their green transportation and urban planning agenda. These included investing in metropolitan transportation systems with high-speed rail networks, intensifying the production of electric vehicle (EV) and EV charging infrastructure networks across the country (Ding and Liu, 2023). To increase the take-up of electric cars, public transportation system and other environmentally friendly transportation modes, a combination of regulatory changes (including the introduction of tax incentives, subsidies and access to electric charging infrastructure) were introduced. The other factor that increased the use of environmentally friendly transportation modes is ensuring sustainable and steady power supply. These required significant investments in energy storage technologies, renewable energy infrastructure and grid management systems. These developments had a significant positive spill over impact on China - they created strong domestic renewable energy market, high-tech EV sector and one of the largest EV transportation industries globally (Fang, et al., 2022).

Further, a pilot project of switching all the buses to electric vehicles in the city of Shenzhen was undertaken, where at the end of 2017 the entire bus fleet in the city was powered by electricity from renewable energy sources. It was the first city in the world with a fully electrified bus system, which increased its ridership by 48% from 2013 to 2018 (Berlin et al., 2020). To intensify the initiative, the central government of China provided the city a subsidy of USD490 million for the deployment of the electric busses and charging stations (Dixon, 2017). This bus system was found to use close to 73% less energy than the diesel-powered busses, and was found to release approximately 48% less carbon in the atmosphere (IRENA, 2021). This initiative also reduced harmful particles such as nitrogen oxides, hydrocarbons and other hazardous materials in the atmosphere (ITDP (2018)). The city also reported that it substituted close to 366,000 tonnes of coal with 345,000 tonnes of renewable energy – thus, reducing its dependence on coal energy source for its public transportation services (Dixon, 2017).

Second, most of these developing countries do not have the financial resources or expertise to make the transition towards environmentally friendly transportation systems. In this context, foreign aid provided by more developed countries to the developing world must include the provision to help these countries make the transition towards environmentally friendly transportation systems. These include providing adequate support for transportation

infrastructure development, capability development and developing a transparent transportation governance system that reduces the dependence on fossil fuels. The latter is important to prevent rent-seeking behaviour that undermine the transition of the transport sector to a more environmentally friendly sector. Pradhan et al. (2023c, 2023e) show that foreign aid can be used as incentives for less developed economies to improve the quality of institutions, develop innovative technologies and introduce innovative financial instruments for enhancing productive endeavours that contribute to economic development. In this context, foreign aid in the form of financial resources, capability development and institutional reforms can help these countries transition towards building a sustainable and affordable environmentally friendly transportation systems. These will have significant long-term impacts on reducing greenhouse gasses and improving the health of the planet.

Third, in many of the developing economies, resources are scarce to modernise the transportation system. One of the strategies to transition from a fossil fuel-based transportation architecture to an environmentally friendly transportation system is through private sector investment into the transportation sector. To encourage domestic and foreign investments into the transportation system, there is a need to improve governance, transparency, and to reduce red-tape and rent-seeking behaviours in these economies. Business-friendly policies and attractive taxation for investors in the transportation sector will also encourage inflow of financial resources and expertise in the transportation sector. The domestic and foreign investments into the transportation sector will enable the transportation and logistics supply chain in the sample countries to modernise and adopt clean energy sources. The push towards the use of renewable energy in the transportation sector will enhance domestic innovation and restructure the industrial structure of the sample developing countries. Hence, the development of the smart and sustainable transport supply chain has the potential to create high-income jobs, reduce the cost of fuel (cost of doing business), and potentially spawn next-generation industries in the transport, logistics and renewable energy sectors in these countries. All these factors can stimulate economic growth in these countries, while contributing towards improving the quality of the environment and reducing the risk of global warming.

In summary, carefully curated reforms to enhance the quality of the transportation governance systems and infrastructure will result in the development of sustainable and planet-friendly transportation sectors in the developing world. These have the potential to reduce CO₂ emissions and help these countries transition to higher sustainable economic growth trajectories. Collective action by developing countries towards reducing dependence on fossil-fuels for their transportation sector will enhance the health of the planet, people, and economies.

CRedit authorship contribution statement

Rudra P. Pradhan: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Mahendhiran S. Nair:** Conceptualization, Investigation, Methodology, Project administration, Resources,

Supervision, Validation, Visualization, Writing – review & editing. **John H. Hall:** Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – review & editing. **Sara E. Bennett:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of Competing interest

We declare that the authors have no conflict of interest with respect to the Funding **Source Declaration, Author Agreement, and Permission Note** for the submission paper “**Planetary Health Issues in the Developing World: Dynamics between Transportation Systems, Sustainable Economic Development, and CO2 Emissions**” by *Rudra P. Pradhan, Mahendhiran Nair, John H. Hall, and Sara E. Bennett* to the possible inclusion in ‘**Journal of Cleaner Production**’.

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Appendix A. Summary of Extant Literature

Table A. 1. Selected Studies on the Possible Nexus between Transportation Infrastructure, Institutional Quality, CO2 Emissions and Economic Growth

Authors	Study	Time	Major
	Area	Frame	Findings
Part A: Studies focusing on Links between Transportation Infrastructure Development and Economic Growth			
Zhang and Cheng (2023)	UK	1970–2017	F ¹
Zhu et al. (2022)	China	1980–2015	F ¹
Pradhan and Bagchi (2013)	India	1970–2010	F ¹
Beyzatlar et al. (2014)	EU-15	1970–2008	F ¹
Yetkiner and Beyzatlar (2020)	18- countries	1970–2017	F ¹
Meersman and Nazemzadeh (2017)	Belgium	1979–2012	D ¹
Mohmand et al. (2021)	Pakistan	1971–2017	F ¹
Vlahinic Lenz et al. (2018)	CEMS countries	1996–2016	D ¹
Part B: Studies Focusing on Links between Institutional Quality and Economic Growth			
Pradhan et al. (2023a)	Developing countries	2005–2019	D ² , S ² , F ²
Nair et al. (2021)	Developing countries	2005–2018	D ² , S ² , F ²
Law et al. (2013)	60 countries	1990–2008	S ² , F ²
Arvin et al. (2021b)	Middle-income countries	2005–2019	F ²
Part C: Studies Focusing on Links between CO2 Emissions and Economic Growth			
Nair et al. (2021)	Developing countries	2005–2018	D ³ , S ³ , F ³
Saidi and Mbarek (2016)	Developed countries	1990–2013	D ³
Jebli and Youssef (2015)	North African countries	1971–2008	D ³ , S ³ , F ³
Umar et al. (2021)	USA	1981–2019	S ³
Part D: Studies focusing on Links between Transportation Infrastructure and Institutional Quality			
Zergawu et al. (2020)	99 countries	1980–2015	D ⁴
Part E: Studies focusing on Links between Transportation Infrastructure and CO2 Emissions			
Mohmand et al. (2021)	Pakistan	1971–2017	D ⁵ , S ⁵
Part F: Studies on the Link between Institutional Quality and CO2 Emissions			
Nair et al. (2021)	Developing countries	2005–2018	D ⁶ , S ⁶ , F ⁶
Karim et al. (2022)	SSA countries	2000–2021	S ⁶

Note 1: D stands for demand-following hypothesis; S stands for Supply-leading hypothesis; F stands for feedback hypothesis; N stands for neutrality hypothesis.

Note 2: D¹: Granger causality from transportation infrastructure development to economic growth only; S¹: Nexus from economic growth to transportation infrastructure only; F¹: Bidirectional Granger causality between transportation infrastructure development and economic growth; and N¹: No causality between transportation infrastructure development and economic growth.

Note 3: D²: Granger causality from institutional quality to economic growth; S²: Granger causality from economic growth to institutional quality only; F²: Bidirectional Granger causality between economic growth and institutional quality; and N²: No causality between institutional quality and economic growth.

Note 4: D³: Granger causality from CO2 emissions to economic growth only; S³: Granger causality from economic growth to CO2 emissions only; F³: Bidirectional Granger causality between CO2 emissions and economic growth; and N³: No causality between CO2 emissions and economic growth.

Note 5: D⁴: Granger causality from institutional quality to transportation infrastructure only; S⁴: Granger causality from transportation infrastructure to institutional quality only; F⁴: Bidirectional

Granger causality between transportation infrastructure and institutional quality; and N⁴: No causality between transportation infrastructure and institutional quality.

Note 6: D⁵: Granger causality from CO2 emissions to transportation infrastructure only; S⁵: Granger causality from transportation infrastructure to CO2 emissions only; F⁵: Bidirectional Granger causality between transportation infrastructure and CO2 emissions; and N⁵: No causality between transportation infrastructure and CO2 emissions.

Note 7: D⁶: Granger causality from institutional quality to CO2 emissions only; S⁶: Granger causality from CO2 emissions to institutional quality only; F⁶: Bidirectional Granger causality between CO2 emissions and institutional quality; and N⁶: No causality between CO2 emissions and institutional quality.

Appendix B. Countries and Variables Details

Table B.1. Definition of Variables

Notation	Definition
GPG	Per capita economic growth: % change in per capita (PC) gross domestic product (GDP).
CO2	CO2 emissions from transport (as a % of total fuel combustion).
CIQ	Composite Index of institutional quality (the weighted average of eleven institutional indicators, formed with the help of principal component analysis).
TR1	Goods transported in railways (in 1,000,000 ton-km).
TR2	Passengers carried in railways (in 1,000,000 passengers-km)
TR3	Rail lines (total route-km)
TR4	Freight in air transport (1,000,000 ton-km)
TR5	Passengers carried in air transport (in 1,000,000)
TR6	Registered carrier departures worldwide in air transport (in 1,000,000)

Note 1: All variables are well-described in *the WDI database*, the World Bank.

Note 2: The detailed discussion of the construction of CIQ is not available here. It is available upon request.

Appendix C. Summary Statistics

Table C.1. Descriptive, Cross Section Dependence, Unit Root, and Correlation Matrix

Variable	Descriptive Statistics							Unit Root Statistics			
	1	2	3	4	5	6	7	IPS		BRE	
								I (0)	I(1)	I (0)	I(1)
Part A: Descriptive, Cross-Section Dependence, Unit Root											
GPG	1.84	1.99	1.70	0.03	0.18	7.90	310*	-1.31	-6.96*	0.47	-4.12*
CIQ	0.51	1.44	0.00	0.65	0.49	1.25	51.9*	0.48	-2.97*	0.23	-3.09*
CO2	1.28	1.86	0.74	0.23	-0.09	2.76	11.9*	-0.50	-4.67*	3.57	-5.52*
TR1	3.90	6.47	1.41	1.04	0.70	3.36	26.5*	0.39	-1.90*	-1.34	-3.98*
TR2	3.44	6.06	-0.41	1.11	0.15	3.58	5.87*	2.40	-6.87*	-0.14	-1.44**
TR3	3.62	4.93	2.39	0.57	0.59	3.04	17.8*	-0.55	-3.61*	-0.07	-6.65*
TR4	1.44	4.25	-3.39	1.33	-0.38	3.92	18.4*	-0.46	-8.64*	1.23	-2.78*
TR5	6.43	8.59	4.18	0.81	0.41	2.87	8.98*	-0.06	-3.85*	1.20	-5.31*
TR6	4.53	6.53	2.62	0.73	0.50	2.93	13.1*	1.19	-4.53*	2.07	-2.46*
Part B: Correlation Matrix											
	GPG	CIQ	CO2	TR1	TR2	TR3	TR4	TR5	TR6		
GPG	1.00	0.17**	-0.24*	0.24*	0.20*	0.20*	0.20*	0.10	0.12		
CIQ		1.00	0.10	-0.26*	-0.19*	-0.37*	-0.18*	-0.31*	-0.33*		
CO2			1.00	-0.62*	-0.46*	-0.49*	-0.19*	-0.22*	-0.21*		
TR1				1.00	0.80*	0.87*	0.48*	0.57*	0.60*		
TR2					1.00	0.86*	0.63*	0.74*	0.75*		
TR3						1.00	0.60*	0.72*	0.75*		
TR4							1.00	0.88*	0.86*		
TR5								1.00	0.99*		
TR6									1.00		

Note 1: GEG is per capita economic growth, CIQ is composite index of institutional quality, CO2 is CO2 emissions, TR1 is good transported in railways, TR2 is passengers carried in railways, TR3 rail lines, TR4 is freight in air transport, TR5 is passengers carried in air transport, and TR6 is registered carrier departures worldwide in air transport.

Note 2: 1 is maximum, 2 is minimum, 3 is mean, 4 is standard deviation, 5 is Kurtosis, 6 is skewness, 7 is Jarque-Bera statistics, PCD: Pesaran cross-section dependent test statistics, CIPS: the mean of individual cross-sectionally augmented ADF statistics (CADF), CIPS*: the mean of truncated individual CADF statistics, and I [1] signifies integration of order one.

Note 3: *, **, *** significant at 1%, 5%, and 10% respectively.

Appendix D. GMM, FMOLS, and DOLS Estimates

Table D.1. GMM, FMOLS and DOLS Estimation Results

	Dependent Variable: GPG					
IVs:	TR1	TR2	TR3	TR4	TR5	TR6
Estimate 1: with GMM						
CIQ	0.10/0.04	0.10/0.05	0.09/0.04	0.09/0.05	0.09/0.03	0.09/0.03
	[0.04]	[0.00]	[0.00]	[0.10]	[0.01]	[0.00]
CO2	-0.83/0.05	-0.94/0.05	-0.55/0.08	-0.11/0.04	-0.49/0.05	-0.60/0.06
	[0.04]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
TRA	0.19/0.02	0.15/0.02	0.30/0.03	0.08/0.03	0.17/0.01	0.20/0.02
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
J-statistic	20.68*	24.88*	22.84*	21.88*	31.55*	29.49*
Estimate 2: with FMOLS						
CIQ	0.16/0.09	0.10/0.01	0.28/0.01	0.23/0.07	0.12/0.05	0.16/0.06
	[0.09]	[0.02]	[0.05]	[0.01]	[0.01]	[0.00]
CO2	-0.08/0.03	-0.13/0.03	-0.10/0.04	-0.12/0.09	-0.37/0.08	-0.45/0.09
	[0.08]	[0.00]	[0.06]	[0.00]	[0.00]	[0.00]
TRA	0.17/0.03	0.20/0.01	0.77/0.54	0.10/0.04	0.19/0.02	0.24/0.03
	[0.00]	[0.00]	[0.05]	[0.01]	[0.00]	[0.00]
Estimate 3: with DOLS						
CIQ	0.08/0.02	0.10/0.03	0.08/0.02	0.09/0.03	0.09/0.02	0.10/0.02
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
CO2	-0.83/0.02	-0.92/0.03	-0.60/0.04	-0.11/0.02	-0.40/0.03	-0.50/0.03
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
TRA	0.18/0.01	0.17/0.01	0.28/0.54	0.10/0.01	0.19/0.03	0.24/0.01
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]

Note 1: All variables are demarcated earlier.

Note 2: Parentheses direct the probability level of significance.

Appendix E. The Generalised Impulse Response Functions Predicts

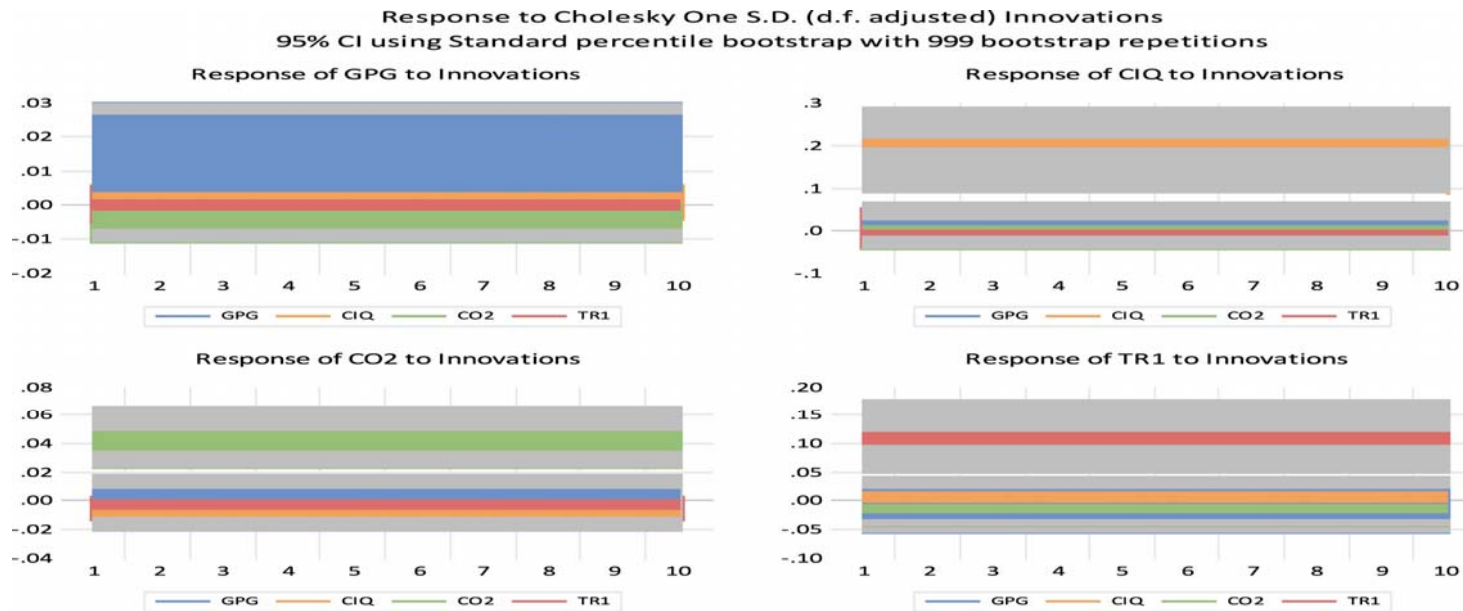


Fig. 1. Between GPG, CIQ, CO2, and TR1.

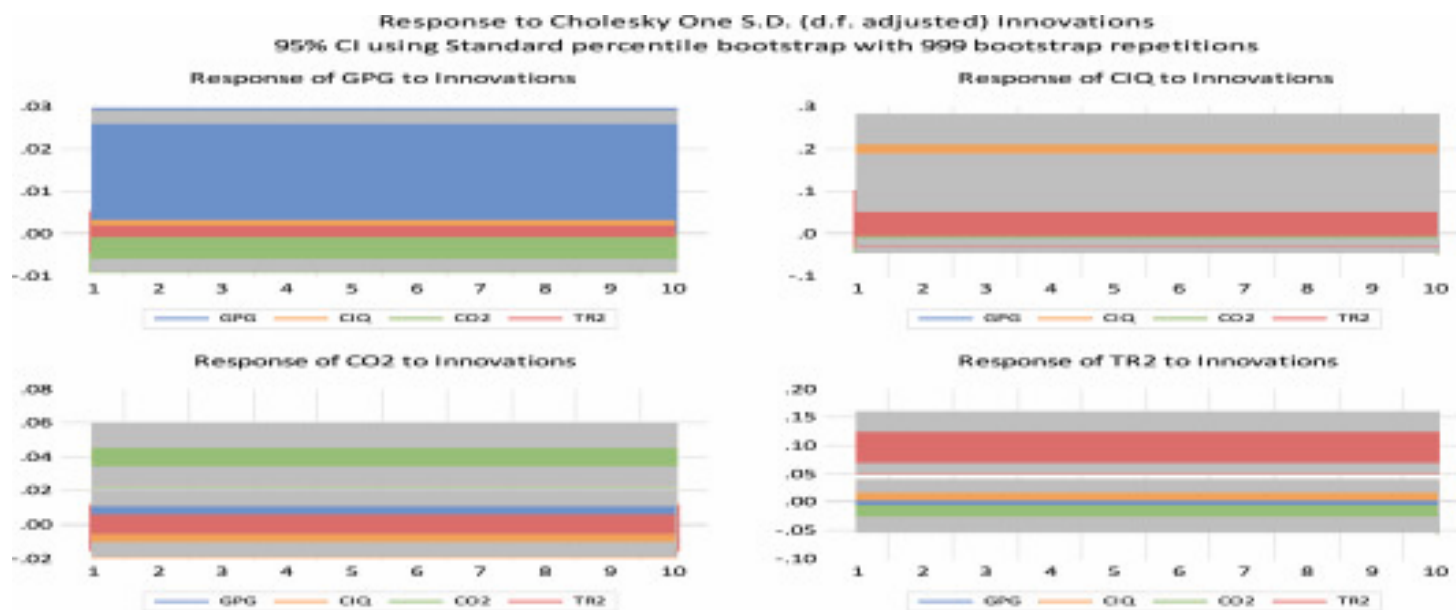


Fig. 2. Between GPG, CIQ, CO2, and TR2.

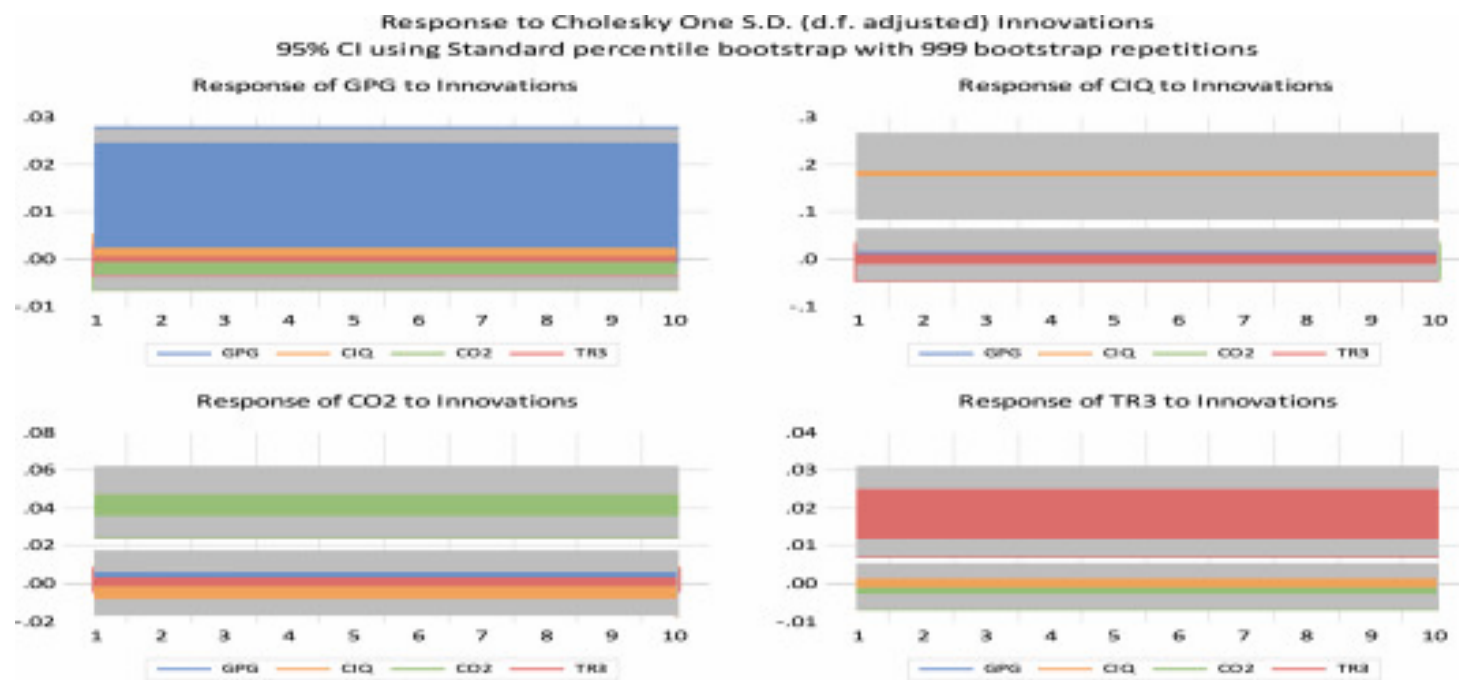


Fig. 3. Between GPG, CIQ, CO2, and TR3.

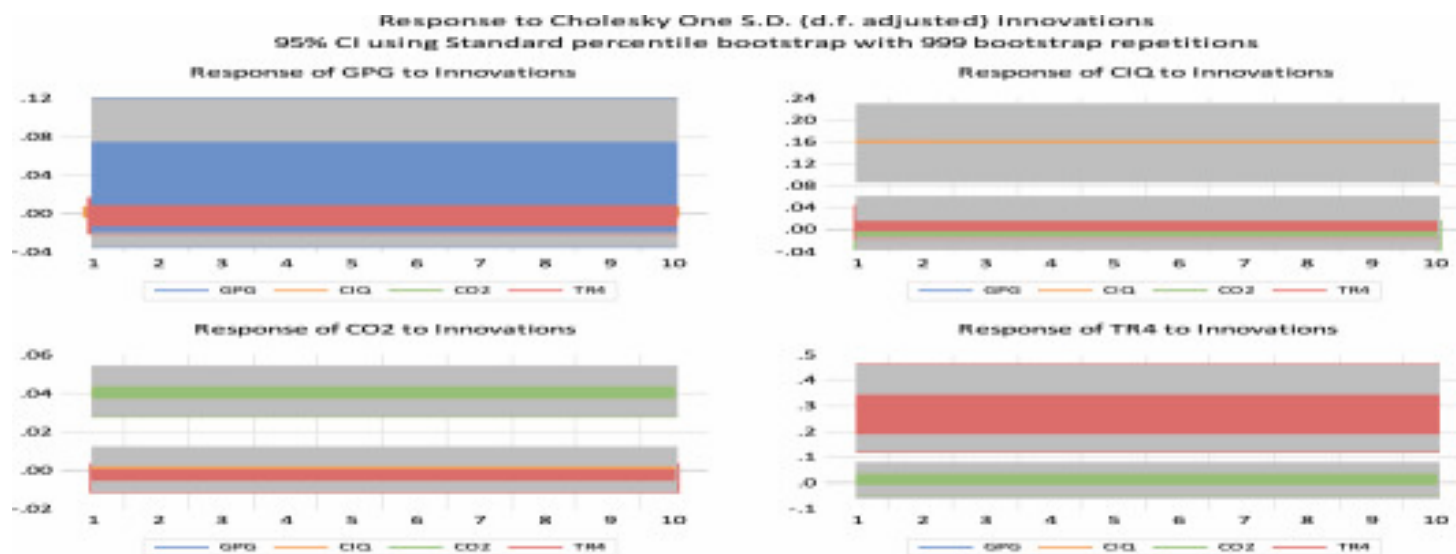


Fig. 4. Between GPG, CIQ, CO2, and TR4.

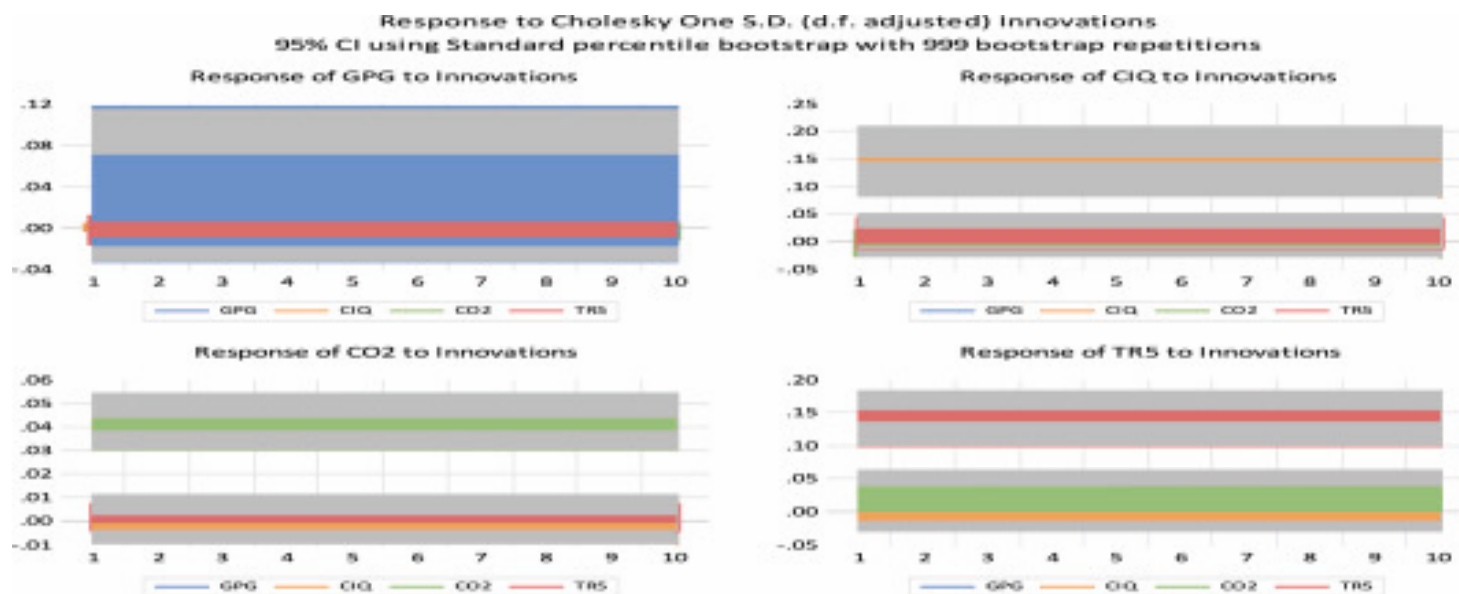


Fig. 5. Between GPG, CIQ, CO2, and TR5.

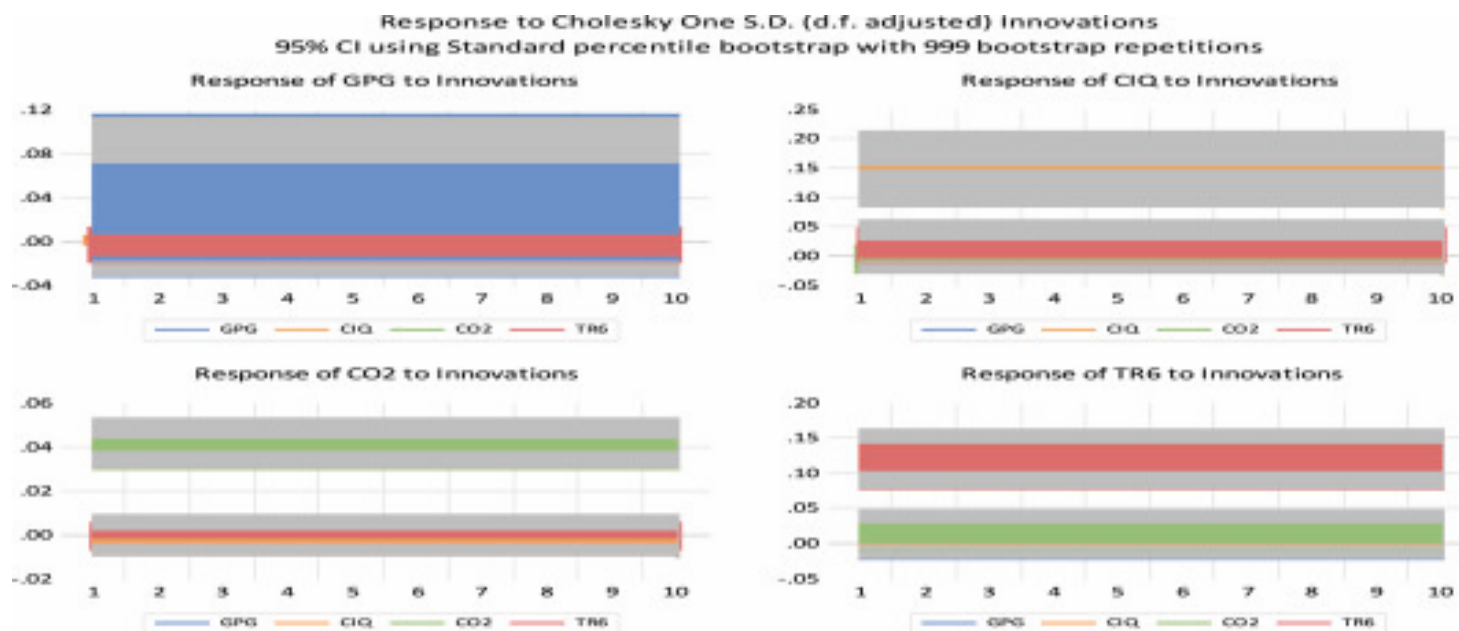


Fig. 6. Between GPG, CIQ, CO2, and TR6.

Data availability

Data will be made available on request.

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