The nexus between economic growth, healthcare expenditure, and CO2 emissions in Asia-Pacific countries: Evidence from a PVAR approach

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Abstract

In this study, a panel vector autoregressive (PVAR) model with system generalized method of moments (GMM) estimation is utilized to examine the dynamic causalities among economic growth, healthcare expenditure, and CO2 emissions in Asia-Pacific countries from 2000 to 2019. Results show that economic growth has a positive effect on government healthcare expenditure, with bidirectional causality observed with private healthcare spending. No significant long-term relationship is detected in the former case. These results emphasize the role of economic development in bolstering public health and reflect a later weakening of the level of government response as economies expand. Additionally, CO2 emissions negatively affect economic growth in a unidirectional manner. The impulse response analysis supports the presence of the environmental Kuznets curve (EKC). Furthermore, while a bidirectional causality exists between CO2 emissions and government healthcare spending, a long-standing correlation remains elusive. This result calls for a dual focus on enhancing healthcare services and reducing emission for health and environmental benefits. The results of variance decomposition highlight the significant contribution of government healthcare expenditure to economic growth and private healthcare spending, in addition to the important role of private healthcare spending in economic growth. These findings offer policymakers evidence-based insights to formulate strategies that balance economic growth, sustainable development, and healthcare provision.

Keywords Economic growth, Healthcare expenditure, CO2 emissions, System-GMM, PVAR, Asia-Pacific region

1 Introduction

This aim of this paper is to adopt an integrative framework to investigate the relationship between economic growth, healthcare expenditure and carbon emissions in the Asia-Pacific region. Carbon emissions pose global challenges due to their widespread repercussions for human health and the environment (Chaabouni and Saidi 2017; Yu and Qayyum 2022). The Asia-Pacific region, marked by densely populated countries experiencing rapid industrialization and urbanization, has witnessed a consequential surge in carbon emissions. Concurrently, economic growth requires increased healthcare spending to address the population's health needs. However, many countries face challenges related to inadequate healthcare practices and infrastructure. Consequently, examining the relationship between economic growth, healthcare expenditure, and carbon emissions in the Asia-Pacific area is crucial for promoting sustainable development, enhancing public health, and informing effective policymaking in the face of the dual challenges of climate change and economic progress.

The literature consists of three primary research strands. The first strand centres on the relationship between economic growth and healthcare expenditure. This discourse, rooted in endogenous growth theory (Romer 1986; Lucas 1988; Barro 1990), introduces human capital into the production function. Different from the neoclassical growth model (Solow 1956), the endogenous growth model emphasizes the influential role of internal factors in economic growth rather than relying solely on the exogenous factors of physical capital. Human capital components, encompassing knowledge, skills, experience, and innovative ideas, can be cultivated to impact economic growth through advancements in health, education, research and development, and technological progress (Romer 1986; Barro 1990; Barro and Sala 1992; Kurt 2015). Accordingly, healthcare expenditure plays a pivotal role in influencing the quality of human capital, with externalities and spillover effects on the overall economy.

The current research presents two major hypotheses regarding healthcare. One hypothesis suggests that healthcare is a luxury good, with the income elasticity of healthcare expenditure being greater than one (Newhouse 1977; Chaabouni and Saidi 2017; Akbar et al. 2021), positioning healthcare within market forces. Conversely, the second hypothesis assumes that healthcare is a necessity (Di Matteo and Di Matteo 1998; Baltagi and Moscone 2010; Boachie et al. 2014), where the income elasticity of healthcare expenditure is less than one, indicating that healthcare is an essential service requiring government support. Additionally, a few studies propose that healthcare has properties of both “luxury” and “necessity”, with income elasticity varying depending on the level of analysis (Getzen 2000). Empirical studies examining the relationship between healthcare expenditure and economic growth have yielded mixed findings, reporting positive correlations (Devarajan et al. 1996; Agénor 2010; Alshahrani and Alsadiq 2014; Boachie et al. 2014; Atems 2019; Rizvi 2019), negative correlations (Singh and Weber 1997; Nurudeen and Usman 2010; Yang 2020), and nonsignificant correlations (Devlin and Hansen 2001; Yang 2020).

The second research strand examines the interplay between economic growth and carbon emissions, with a primary focus on assessing the validity of the environmental Kuznets curve (EKC). The EKC hypothesis proposes an inverted U-shaped relationship between environmental degradation and economic development (Kuznets 1955; Grossman and Krueger 1991). Mapping the trajectory of environmental pollution alongside a nation’s income levels (Shafik and Bandyopadhyay 1992), the EKC suggests that environmental degradation intensifies during the early stages of income growth, reaches a threshold level, and then weakens in the later stages of income growth (Leal and Marques 2022). Numerous studies support the existence of the EKC (Halkos 2003; Dinda 2004; Omojolaibi 2009; Farhani et al. 2014; Twerefou et al. 2017; Olale et al. 2018), while others present empirical evidence contradicting this hypothesis (Holtz-Eakin and Selden 1995; Bimonte 2002; Akbostancı et al. 2009). Notably, this relationship involves complex bidirectional causalities (Kijima et al. 2010). Moreover, various studies emphasize the sensitivity of results to the selection of countries and periods (Grossman and Krueger 1991; Selden and Song 1994; Hill and Magnani 2002).

The third research strand centres on examining the relationship between carbon emissions and healthcare expenditure. The greenhouse effect caused by the emission of greenhouse gases, particularly carbon dioxide (CO_2), serves as a pivotal factor triggering global warming (Apergis et al. 2018; Wang et al. 2019; Ahmad et al. 2021). This phenomenon poses a threat to the environment and human health, including the incidence of chronic diseases, which may incur substantial costs, leading to a reduction in employee productivity (Erdogan et al. 2020). To address these health challenges and enhance overall population well-being, healthcare spending becomes essential. Therefore, it is imperative to examine the externalities of carbon emissions for total health expenditure. The prevailing body of research predominantly supports a positive and causal relationship between healthcare expenditure and carbon emissions, as indicated by Abdullah et al. (2016), Akbar et al. (2021), Boachie et al. (2014), Chaabouni and Saidi (2017), and Yazdi et al. (2014). However, some empirical evidence suggests nonsignificant correlations between these two variables (Yahaya et al. 2016; Alimi et al. 2020; Erdogan et al. 2020).

Nevertheless, the literature tends to overlook the interconnectedness of the three distinct research strands. Therefore, it is imperative to conduct research that effectively addresses this issue. This study distinguishes itself from previous studies in three ways. First, it addresses the aforementioned research gap by providing an integrative study of the dynamics and causal pathways connecting economic growth, healthcare expenditure, and carbon emissions. Second, this study employs a panel vector autoregressive (PVAR) model with system generalized method of moments (GMM) estimation to examine the dynamic causalities between economic growth, healthcare expenditure, and CO_2 emissions. This approach uses forward orthogonal deviations to remove individual-specific fixed effects, and it uses instrumental variables to alleviate endogeneity issues, generating consistent and robust estimators. Additionally, Granger causality tests are used to examine the direction and strength of the causal relationships, impulse response analysis is conducted to assess the dynamic effects of shocks over time, and forecast variance decomposition is used to evaluate the relative contributions of different shocks. Third, this study is the first of its kind to examine the nexus between these variables specifically in the Asia-Pacific region. This study offers policy implications for this region, which is facing escalating healthcare demands, environmental concerns, and economic growth.

The rest of the paper proceeds as follows. Section 2 presents the literature review. Section

3 describes the methodology and data. Section 4 presents the empirical results and discussion. Section 5 discusses the conclusions.

2 Literature review

Examining the intricate nexus between economic growth, healthcare expenditure, and carbon emissions holds great significance for informing policymaking and addressing real-world challenges. Although numerous studies have explored the relationships between any two of these variables, a consensus regarding their causality has yet to be reached. Moreover, there is a notable scarcity of research specifically focused on exploring the dynamics between all three variables simultaneously.

2.1 Economic growth and healthcare expenditure

The association between economic growth and healthcare expenditure involves not only a direct effect but also indirect or structural effects (Somé et al. 2019; Yang 2020; Li et al. 2022). The dynamics of this relationship remain complex and varied, and a clear consensus is lacking.

National income growth is considered a key factor influencing public healthcare expenditure (Newhouse 1977; Costa et al. 1987; Deno 1988). Boachie et al. (2014) investigated the determinants of public healthcare spending in Ghana (1970-2008) using the fully modified ordinary least squares (FMOLS) approach and found a positive long-term impact of real GDP on public healthcare expenditure. Atems (2019) employed the difference GMM estimation method to inspect the relationship between public healthcare expenditure and long-term growth in the U.S. using state-level data from 1963 to 2015. The study indicated a positive linkage between healthcare spending and economic growth. This result remains significant and robust even after accounting for the crowding-out effect of taxation and government budget constraints, supporting the positive effect of economic growth on healthcare expenditure.

Conversely, public healthcare spending can affect economic growth by influencing human capital, labour productivity, and individual discount factors (Agénor 2010; Piras and Marica 2018).

Maintaining good health enhances life expectancy, fostering personal savings and private investment and thus contributing to the development of human capital and increased productivity (Kurt 2015). Research by Şen et al. (2015) in Brazil and Mexico and by Rizvi (2019) in the developing countries in the Asia-Pacific region demonstrated a unidirectional positive influence of healthcare expenditure on economic growth. Additionally, some scholars have argued that productive government expenditure can stimulate economic growth, while nonproductive expenditure impedes it (Barro 1990; Kneller et al. 1999).

Amiri and Ventelou (2012) utilized a modified Granger causality introduced by Toda and Yamamoto (1995) to examine the causality between GDP and healthcare expenditure in 20 OECD countries (1970-2009). The results suggested a prevalent bilateral Granger causal relationship. Elmi and Sadeghi (2012) employed the panel cointegration method and vector error correction model (VECM) framework, confirming the bidirectional causality and a long-term relationship between GDP and healthcare expenditure in developing countries (1990-2009). Chaabouni and Abednnadher (2014) used the autoregressive distributed lag (ARDL) method to analyse the determinants of healthcare expenditure in Tunisia (1961-2008). Their findings supported the notion that healthcare is a necessity and demonstrated bidirectional causalities between healthcare expenditure and income in both the short run and the long run.

However, certain studies reveal nonpositive relationships and indirect impacts. In a study by Devlin and Hansen (2001), no Granger causal relationships were observed between aggregate healthcare spending and GDP in Denmark and Iceland. Similarly, Benos (2005) investigated 16 OECD countries (1970-1997) and found a hump-shaped relationship between healthcare spending and per capita growth, with the impact of healthcare spending on economic growth being weaker in poorer countries. Focusing on 21 developing countries (2000-2016), Yang (2020) employed a panel threshold model to investigate the moderating effects of varying levels of human capital on the relationship between national healthcare expenditure and economic growth. The findings presented an initial negative correlation, followed by an uncorrelated correlation, and ultimately, a positive association as human capital levels increase.

2.2 Economic growth and carbon emissions

The literature offers conflicting empirical evidence with four main hypotheses: growth, conservation, feedback, and neutrality (Chaabouni and Saidi 2017; Mirza and Kanwal 2017). The existence and direction of Granger causality between economic growth and carbon emissions are still inconclusive.

The growth and conservation hypotheses propose unidirectional causality. The growth hypothesis posits that economic growth determines carbon emissions, while the conservation hypothesis proposes the reverse. Fodha and Zaghdoud (2010) used cointegration analysis and time-series data from Tunisia (1961-2004) and found that carbon emissions had a monotonically increasing relationship with GDP, contradicting the EKC hypothesis. This study also indicated that income unidirectionally caused pollutant emissions in both the short term and the long term. Twerefou et al. (2017) used system GMM estimation across 36 Sub-Saharan African countries (1990-2013), verifying the positive effect of economic growth on environmental quality and supporting the EKC hypothesis. Similarly, Acheampong (2018) used system GMM, the PVAR model and a multivariate model to investigate the dynamic causality between economic growth, carbon emissions and energy consumption across 116 countries (1990-2014). Their findings demonstrated that carbon emissions positively affected economic expansion, whereas at the global and Caribbean-Latin America levels, economic growth exhibited unidirectional negative causality with carbon emissions.

The feedback hypothesis proposes bidirectional causalities between economic growth and carbon emissions. Ghosh (2010) applied ARDL bounds testing in India (1971-2006), suggesting bidirectional short-run causality between carbon emissions and economic growth but no long-run relationships, which contradicts the EKC hypothesis. Following Ghosh (2010)'s work, Mirza and Kanwal (2017) adopted ARDL, Johansen-Julius cointegration, and VECM methods to assess the dynamic causality between economic growth, energy consumption and CO_2 emissions in Pakistan (1971-2009). The results indicated bidirectional causalities between economic growth and carbon emissions based on the Granger long-run, short-run, and strong causality results.

Nonetheless, several studies support the neutrality hypothesis regarding the relationship between economic growth and carbon emissions. Soytas et al. (2007) examined the dynamic causality between GDP, energy consumption and carbon emissions in the U.S. (1960-2004), concluding that income growth did not Granger cause carbon emissions in the long run. Additionally, Zhang and Cheng (2009) discovered that neither carbon emissions nor energy consumption caused economic growth in China (1960-2007). Salahuddin and Gow (2014) found no significant relationship between economic growth and CO_2 emissions in their empirical study of Gulf Cooperation Council (GCC) countries.

2.3 Healthcare expenditure and carbon emissions

Many studies have examined the interaction between healthcare expenditure and carbon emissions. Yazdi et al. (2014) employed cointegration and ARDL methods to examine the impacts of environmental quality on healthcare expenditure in Iran (1967-2010). Sulphur oxide and carbon monoxide emissions were found to positively influence healthcare expenditure. Using the same approach, Abdullah et al. (2016) found a long-run positive effect of GDP, CO_2 emissions, nitrogen dioxide (NO_2) emissions and sulphur dioxide (SO_2) emissions on healthcare expenditure in Malaysia. Following prior studies, Akbar et al. (2021) adopted the PVAR approach to explore the causal association between healthcare expenditure, CO_2 emissions, and the human development index for OECD countries from 2006 to 2016. They identified bidirectional causality between healthcare expenditure and CO_2 emissions.

Nonetheless, certain studies suggest divergent outcomes. Alimi et al. (2020) utilized pooled ordinary least squares (OLS), fixed effects, and system GMM estimation to evaluate the causality between environmental quality and healthcare expenditure in 15 Economic Community of West African States (ECOWAS) countries (1995-2014). The results indicated that carbon emissions significantly and positively impacted both public and national healthcare expenditure but exhibited a nonsignificant relationship with private healthcare expenditure. In a separate study, (2020) employed a panel causality test to investigate the association between CO_2 emissions and healthcare spending in BRICS countries (2000-2006). Their findings indicated no significant relationship in Brazil, Russia, India, South Africa, and Turkey. However, for China, they found a unidirectional positive causal flow from carbon emissions to healthcare spending.

2.4 Economic growth, healthcare expenditure and carbon emissions

Few studies have integrated these three distinct research areas to explore the causal dynamics among economic growth, healthcare expenditure and carbon emissions. The scarcity of comprehensive empirical studies examining the nexus among these factors underscores the need for further research in this domain.

Wang et al. (2019) used the ARDL method to examine the dynamic interactions among CO_2 emissions, healthcare expenditure and economic growth in Pakistan (1995-2017). The results indicated a significantly positive bidirectional Granger causal relationship between healthcare expenditure and CO_2 emissions. Additionally, a significant negative bidirectional Granger causal relationship between healthcare expenditure and economic growth was identified. In the short run, unidirectional causality was observed from CO_2 emissions to healthcare expenditure. Li et al. (2022) further focused on BRICS countries and employed the Fourier ARDL model to explore the causality among CO_2 emissions, healthcare spending and economic growth. The study revealed long-run cointegration relationships in Brazil and China. Moreover, they discovered unidirectional negative causality running from healthcare expenditure to CO_2 emissions in India.

Chaabouni and Saidi (2017) examined the nexus among CO_2 emissions, healthcare spending and GDP growth across 51 countries (1995-2013) using dynamic simultaneous-equations models and GMM estimation. The findings revealed bidirectional causality between CO_2 emissions and GDP per capita. Additionally, unidirectional Granger causality was identified, indicating that CO_2 emissions causally affected healthcare expenditure in lower, upper middle-income, and middle-income countries. Ibukun and Osinubi (2020) used both static and dynamic (system GMM) approaches to examine the relationship among environmental quality, economic growth and healthcare expenditure across 47 African countries (2000-2018), finding that economic growth positively influenced healthcare expenditure. Furthermore, they discovered that the degradation of environmental quality, particularly the contribution of CO_2 emissions, significantly increased healthcare expenditure.

3 Methodology and data

In this study, the PVAR model proposed by Love and Zicchino (2006) and the GMM estimation method are used to examine the dynamic relationships among the variables of interest. The PVAR model combines the VAR model, treating all the variables in the system as endogenous, with the panel data approach, introducing fixed effects to allow for unobserved individual heterogeneity (Love and Zicchino 2006; Abrigo and Love 2016). By incorporating both temporal and cross-sectional dimensions, the PVAR model captures the interdependencies and synchronizations among variables, as each variable relies on its own historical values and the values of other variables (Adedoyin and Bekun 2020).

Building upon the insights of Alimi et al. (2020) and Bhat and Jain (2006), who elucidate the impacts of carbon emissions and economic growth on private healthcare expenditure, we extend them to encompass both public and private healthcare expenditure. This extension enhances our ability to glean more comprehensive and insightful information when exploring the relationships between healthcare expenditure and other variables.

Based on the practices of Acheampong (2018), Adedoyin and Bekun (2020), and Yu and Qayyum (2022), we examine the dynamic nexus between economic growth, healthcare expenditure and carbon emissions using the following PVAR model:

$$Z_{it} = \alpha_i + \Phi(L)Z_{it} + \delta_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where i and t denote the country and time, respectively; Z_{it} denotes the vector of GDP per capita in natural logarithmic form, $lnGDP_{i,t}$, government healthcare expenditure per capita in natural logarithmic form $lnGHE_{i,t}$, private healthcare expenditure per capita in natural logarithmic form $lnPHE_{i,t}$ and CO_2 emissions $CO2_{i,t}$; $\Phi(L)$ is a matrix of operators for the endogenous covariates; δ_i denotes the country fixed effect; λ_t represents the time fixed effect; and ε_{it} is the disturbance term.

Acheampong (2018) and Yu and Qayyum (2022) mentioned that the inclusion of country fixed effects and time fixed effects in equation (1) can lead to inconsistent OLS estimators. To mitigate this concern in our PVAR model, we apply the qth-order difference to equation (1), as indicated in the following equation:

$$\Delta Z_{it} = \Delta\alpha_i + \Phi(L)\Delta Z_{it-q} + \Delta\delta_i + \Delta\lambda_t + \Delta\varepsilon_{it} \quad (2)$$

where Δ is the difference operator and q is the autoregressive lag length. The OLS estimation of equation (2) is susceptible to inconsistency due to an endogeneity problem arising from the correlation between unobserved fixed effects and the lags of the independent variables in equation (2). To address this endogeneity issue and ensure consistent estimates, we employ GMM estimation with instrumental variables. Specifically, we utilize the forward orthogonal deviation or Helmert transformation technique proposed by Arellano and Bover (1995) to eliminate the panel-specific fixed effects (Abrigo and Love 2016). This transformation can effectively remove the influence of unobserved fixed effects and maintain the orthogonality between variables and their instruments. For the endogenous variables in equation (2), we use lagged levels with a minimum lag of two periods as valid instrumental variables. This approach helps account for the endogeneity bias and enhances the robustness of our estimation. Additionally, the applicability of dynamic panel GMM estimators has been established in "large N, small T" panel data settings (Arellano and Bond 1991; Blundell and Bond 1998), aligning with the data characteristics in this study.

The dataset in this research covers 2000 to 2019, including a total of 30 countries located in the Asia-Pacific region. The countries are Australia, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, Fiji, India, Indonesia, Japan, Kiribati, Korea, Rep., Lao PDR, Malaysia, the Maldives, the Marshall Islands, Mongolia, Myanmar, Nepal, New Zealand, Pakistan, Papua New Guinea, the Philippines, Singapore, the Solomon Islands, Sri Lanka, Thailand, Tonga, Vanuatu, and Vietnam. Economic growth (GDP) is proxied using GDP per capita in current US dollars. CO_2

emissions ($CO2$) are measured using CO_2 emissions (kg) per 2015 US dollar of GDP. Government healthcare expenditure (GHE) is proxied by domestic general government health expenditure per capita in current US dollars. Likewise, private healthcare expenditure (PHE) is proxied using out-of-pocket health expenditure per capita in current US dollars. These data are acquired from the World Bank's World Development Indicators.

Table 1 reports the descriptive statistics for all the variables in our strongly balanced panel dataset comprising 600 observations. In Table 2, the correlation coefficient matrix reveals significant negative correlations between carbon emissions and GDP, government healthcare expenditure, and private healthcare expenditure. Additionally, it reports a positive correlation at the 1% significance level between government healthcare expenditure and private healthcare expenditure, between government healthcare expenditure and GDP, and between private healthcare expenditure and GDP.

Table 1 Summary statistics

Variable	Mean	SD	Min	Max	N
CO2	0.51	0.37	0.11	2.36	600
lnGHE	4.17	1.99	-0.66	8.39	600
lnPHE	3.37	1.85	-2.46	7.10	600
lnGDP	8.06	1.43	4.88	11.13	600

Source: Data sourced from the World Bank's World Development Indicators. CO2: CO2 emissions (kg) per 2015 US dollar of GDP. GHE: Domestic general government health expenditure per capita in current US dollars. PHE: Out-of-pocket health expenditure per capita in current US dollars. GDP: GDP per capita in current US dollars. GDP, GHE, and PHE values are presented in logarithmic form for this analysis.

Table 2 Correlation matrix

	CO2	lnGHE	lnPHE	lnGDP
CO2	1.000			
lnGHE	-0.130***	1.000		
lnPHE	-0.055**	0.592***	1.000	
lnGDP	-0.149***	0.939***	0.761***	1.000

*, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

4 Empirical results and discussion

This section presents pre-estimation diagnosis, empirical results from the PVAR analysis, a

Granger causality test, impulse response function analysis and forecast error variance decomposition.

4.1 Pre-estimation diagnosis

We use several unit root tests to examine the stationarity of each variable: the Levin–Lin–Chu test, Im–Pesaran–Shin test, augmented Dickey–Fuller test, and Phillips–Perron test. Table 3 displays the unit root test results, confirming that all the series of the four variables are first-difference stationary. This result suggests that GDP, government healthcare expenditure, private healthcare expenditure and CO_2 emissions are integrated of order one or stationary at the first difference.

Table 3 Results of unit root tests

Method	lnGDP	dlnGDP	lnGHE	dlnGHE	lnPHE	dlnPHE	CO2	dCO2
Null hypothesis: common unit root process								
Levin–Lin–Chu t	0.66	-7.94***	-2.69***	-11.1***	-3.66***	-6.04***	-3.75***	-2.95***
Null hypothesis: individual unit root process								
Im–Pesaran–Shin t	0.87	-6.03***	0.28	-10.13***	-2.39***	-6.10***	-2.20**	-4.29***
ADF-Fisher chi-squared	2.18*	8.28***	-0.16	16.47***	5.38***	16.70***	1.21	9.34***
PP-Fisher chi-squared	-0.42	23.54***	2.35***	42.25***	-0.95	28.45***	1.28	25.01***

*, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

Moreover, we conduct the Kao test, Pedroni test and Westerlund test to examine the cointegration among the variables of interest in this study. As shown in Table 4, the results of the Kao test and Pedroni test reject the null hypothesis of no cointegration, confirming the presence of a long-run cointegration relationship among GDP, government healthcare expenditure, private healthcare expenditure and CO_2 emissions across the panels. The Westerlund test results also reject the null hypothesis, suggesting that some panels are cointegrated.

Table 4 Results of cointegration tests

Method	Statistic	p value
Kao cointegration test		
Modified Dickey–Fuller t	-15.36	0.0000
Dickey–Fuller t	-13.23	0.0000
Augmented Dickey–Fuller t	-10.99	0.0000
Unadjusted modified Dickey–Fuller t	-19.72	0.0000
Unadjusted Dickey–Fuller t	-13.96	0.0000
Pedroni cointegration test		
Modified Phillips–Perron t	1.87	0.0309
Phillips–Perron t	-9.63	0.0000
Augmented Dickey–Fuller t	-9.45	0.0000
Westerlund cointegration test		
Variance ratio	-1.65	0.0491

Table 5 reports the outcomes of the selection process for the optimal lag length q in the PVAR model. We determine the lag length by evaluating three information criteria: the modified Bayesian information criterion (MBIC) (Schwarz 1978), modified Akaike information criterion (MAIC) (Akaike 1969), and modified Hannan–Quinn information criterion (MQIC) (Hannan and Quinn 1979). The first-order lag exhibits the lowest values for all three criteria (MBIC, MAIC, and MQIC). Additionally, based on Hansen's J-statistic, the moment condition value of the first-order lag PVAR model exceeds that of alternative models, suggesting higher stability and greater reliability in capturing the relationships among the variables. Hence, the results suggest the selection of a lag length of one as the most appropriate choice for our PVAR model when using GMM estimation in this study.

Table 5 PVAR's optimal moment and selection order criteria

Lag	J	J p value	MBIC	MAIC	MQIC
1	74.934	0.165	-306.900	-53.066	-153.687
2	58.547	0.142	-227.828	-37.453	-111.919
3	36.537	0.266	-154.380	-27.463	-77.774
4	20.805	0.186	-74.654	-11.195	-36.361

4.2 PVAR analysis results

Table 6 presents the coefficients of PVAR analysis using GMM estimation with a lag of one period. Hansen's J chi-squared statistic of 261.71 with a p value of 0.16 confirms the validity of the instrumental variables in addressing the issue of endogeneity and omitted variable bias. First, the regression results indicate a statistically significant positive impact of economic growth on both government healthcare expenditure and private healthcare expenditure. A one percent increase in GDP leads to a 0.481% increase in government healthcare expenditure and a 0.353% increase in private healthcare expenditure. These empirical findings align with those of the studies by Atems (2019), Boachie et al. (2014), Costa et al. (1987), and Deno (1988), supporting the positive effect of national income on health expenditure. These results further suggest that healthcare is a necessity in the Asian-Pacific region, as evidenced by the income elasticity of healthcare expenditure.

Table 6 Results of panel vector autoregression

	Independent variables			
Dependent variables	$d\mathrm{CO2}_{t-1}$	$d\mathrm{lnGHE}_{t-1}$	dlnPHE_{t-1}	$d\mathrm{lnGDP}_{t-1}$
dCO2	-0.035 (0.03)	-0.028*** (0.01)	-0.074*** (0.01)	0.007 (0.02)
dlnGHE	0.400*** (0.09)	-0.315*** (0.03)	0.485*** (0.07)	0.481*** (0.07)
dlnPHE	-0.023 (0.08)	0.139*** (0.03)	0.310*** (0.05)	0.353*** (0.06)
dlnGDP	-0.129** (0.07)	-0.010 (0.02)	0.366*** (0.04)	0.299*** (0.05)

*, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively. Heteroskedasticity robust standard

errors are in parentheses.

Nonetheless, the results suggest that government healthcare expenditure has a nonsignificant impact on GDP. This finding is consistent with Devlin and Hansen (2001) and Yang (2020). In contrast, private healthcare expenditure exhibits a positive impact on GDP at the 1% level of significance. This result aligns with the empirical evidence provided by Beylik et al. (2022) and Lago-Peñas et al. (2013), further confirming the positive impact of enhanced human capital on economic growth, as suggested by endogenous growth theory (Romer 1986; Lucas 1988; Barro 1990).

Based on these findings, we discover a unidirectional causal relationship from economic growth to government healthcare expenditure. Additionally, there exists a bidirectional relationship between economic growth and private healthcare expenditure, which aligns with the conclusions drawn by Amiri and Ventelou (2012), Elmi and Sadeghi (2012), and Chaabouni and Abednnadher (2014).

Moreover, Table 6 suggests that GDP has a nonsignificant impact on CO_2 emissions, which is consistent with prior empirical studies conducted by Salahuddin and Gow (2014), Soytas et al. (2007), and Zhang and Cheng (2009), indicating that economic growth does not necessarily lead to increased CO_2 emissions. Thus, economic growth might be achieved without degrading the environment in the Asia-Pacific region. Conversely, the results indicate that CO_2 emissions negatively affect economic growth. A one percent increase in CO_2 emissions correlates with a 0.129% decrease in GDP at the 5% level of significance. This finding aligns with the empirical findings of Azam et al. (2016), Borhan et al. (2012), and Ejuvbekpokpo (2014), revealing the detrimental effect of carbon emissions on economic prosperity.

Therefore, the results indicate a unidirectional causal relationship running from carbon emissions to economic growth, supporting the conservation hypothesis proposed by Acheampong (2018) and Fodha and Zaghdoud (2010). These findings emphasize the economic consequences of pollutant emissions and highlight the necessity of sustainable development strategies in the Asia-Pacific region.

Furthermore, the results show bidirectional causalities between government healthcare expenditure and CO_2 emissions and unidirectional causality between private healthcare expenditure and CO_2 emissions. Government healthcare expenditure responds positively to CO_2 emissions at the 1% level of significance, with a one percent increase in CO_2 emissions corresponding to a 0.4% increase in government healthcare expenditure. This result aligns with findings from Abdullah et al. (2016), Akbar et al. (2021), Boachie et al. (2014), Chaabouni and Saidi (2017), and Yazdi et al. (2014). Notably, an increase in CO_2 emissions does not significantly reduce private healthcare spending, possibly due to increased public subsidies for healthcare, which alleviate the burden of individual out-of-pocket healthcare spending.

An intriguing and rarely discussed result emerges. Both government healthcare expenditure and private healthcare expenditure negatively influence CO_2 emissions. A one percent increase in government healthcare expenditure leads to a 0.028% decrease in CO_2 emissions, and a one percent increase in private healthcare expenditure causes a 0.074% decrease in CO_2 emissions.

Additionally, the analysis reveals a bidirectional positive relationship between government healthcare expenditure and private healthcare expenditure. A one percent increase in private healthcare expenditure leads to a 0.485% increase in government healthcare expenditure. This result helps explain why increased CO_2 emissions do not significantly impact private healthcare expenditure but stimulate a significant increase in government healthcare expenditure. Consequently, government health expenditure is highly responsive to private health expenditure, allowing healthcare expenses to be promptly covered by the government. This partially explains why private health spending is not significantly affected by carbon emissions.

Conversely, a one percent increase in government healthcare expenditure leads to a smaller 0.139% increase in private healthcare expenditure. This finding underscores the mutual influence between government and private healthcare expenditure and suggests that an increase in private healthcare expenditure stimulates public healthcare expenditure to a greater extent than the reverse relationship; this indicates the importance of considering the dynamic relationship between the two sectors when formulating healthcare policies and resource allocation strategies.

4.3 Companion matrix eigenvalues

Fig. 1 presents the roots of the companion matrix, suggesting that the eigenvalues lie inside the unit root circle. This observation is important because the stability condition is satisfied in a VAR model when all eigenvalues of the companion matrix are strictly less than one (Abrigo and Love 2016). Consequently, based on this stability criterion, we can conclude that our PVAR model is stable.

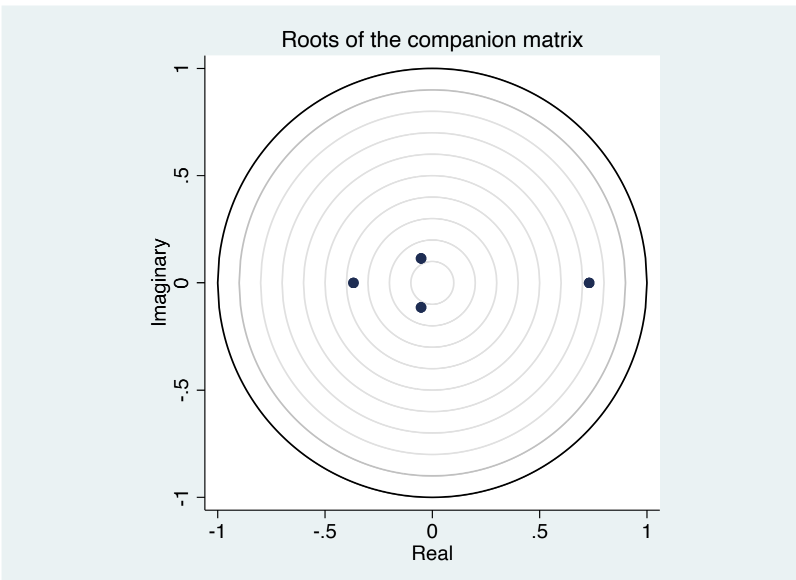

Fig. 1 Eigenvalue stability condition graph

4.4 Granger causality test

To validate the robustness of our Table 6 results, we conduct Wald tests of Granger causality for the PVAR model to examine the existence and direction of Granger causality among our variables of interest. As presented in Table 7 and Fig. 2, there is unidirectional causality running from GDP to government healthcare expenditure. However, the table reveals a bidirectional causal relationship between economic growth and private healthcare expenditure. Additionally, CO_2 emissions demonstrate a unidirectional causal impact on GDP, while private healthcare expenditure exhibits unidirectional causality towards CO_2 emissions. Notably, we observe bidirectional causality between CO_2 emissions and government healthcare expenditure.

Furthermore, a bidirectional causal relationship is observed between government and private healthcare expenditure. These results align with the findings obtained from our PVAR causality analysis, further strengthening our conclusions from Table 6 and providing additional evidence of the causalities among our variables of interest.

Table 7 Wald tests of Granger causality for the PVAR model: Null hypothesis of no causality

Excluded	Chi-squared	Degree of freedom	Probability	Decision
Dependent variable: dCO2				
dlnGHE	8.427	1	0.004	Reject
dlnPHE	26.155	1	0.000	Reject
dlnGDP	0.169	1	0.681	Accept
ALL	83.116	3	0.000	Reject
Dependent variable: dlnGHE				
dCO2	18.942	1	0.000	Reject
dlnPHE	52.737	1	0.000	Reject
dlnGDP	46.252	1	0.000	Reject
ALL	245.793	3	0.000	Reject
Dependent variable: dlnPHE				
dCO2	0.093	1	0.760	Accept
dlnGHE	30.055	1	0.000	Reject
dlnGDP	40.030	1	0.000	Reject
ALL	81.143	3	0.000	Reject
Dependent variable: dlnGDP				
dCO2	3.882	1	0.049	Reject
dlnGHE	0.197	1	0.657	Accept
dlnPHE	103.106	1	0.000	Reject
ALL	120.011	3	0.000	Reject

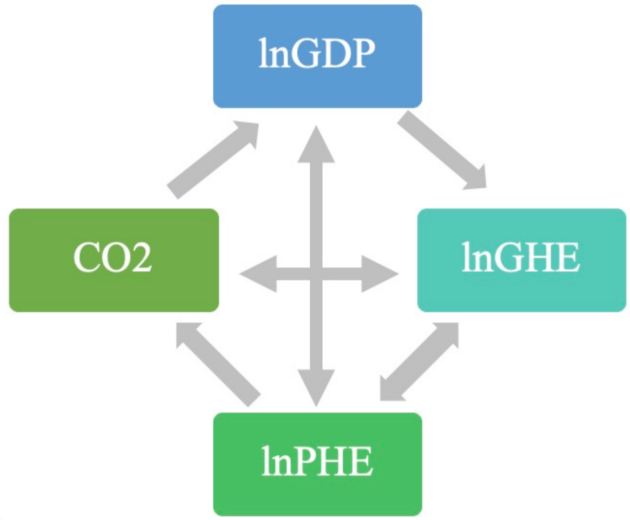

Fig. 2 Causal relationships among variables of interest. Bidirectional arrows represent bidirectional causality and unidirectional arrows represent unidirectional causality

4.5 Impulse response analysis

We perform an impulse response analysis using Monte Carlo simulation with 2000 repetitions to enhance the robustness of our findings. Fig. 3 presents the impulse response functions (IRFs) and corresponding 95% confidence interval band. We estimate orthogonalized IRFs to eliminate contemporaneous correlations, ensuring that the impulse response of each variable to a specific shock represents the unique contribution of that shock to the variable.

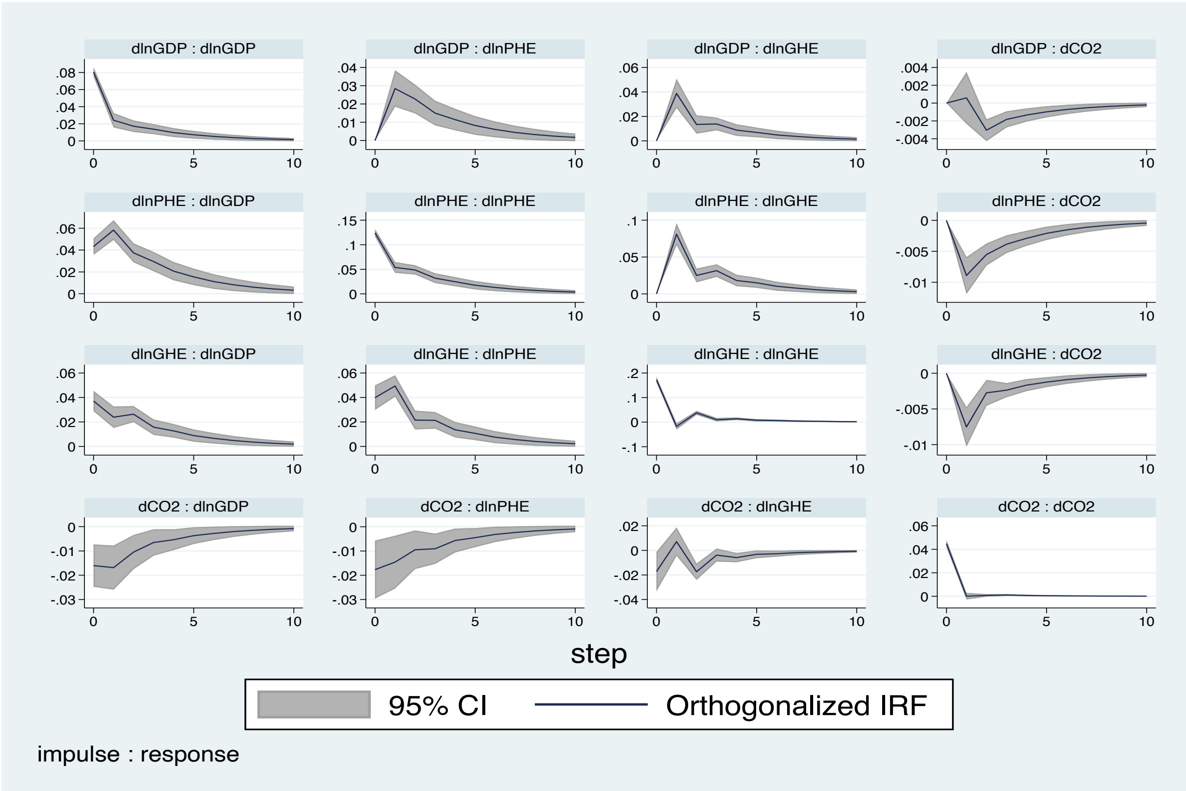

Fig. 3 Impulse response functions

In the first row of Fig. 3, we observe positive responses of $lnGDP$ to a one standard deviation shock to $lnPHE$ during the initial years, gradually reverting to equilibrium by the tenth year. Similarly, $lnGDP$ responds positively to a one standard deviation shock to $lnGHE$ in the first year, which diminishes and becomes zero by the tenth year. These findings indicate that both public and private healthcare expenditure contribute to GDP growth. Regarding the responses of $lnGDP$ to a one standard deviation shock to $CO2$, an initial positive response is observed in the first year. However, entering the second year, $lnGDP$ responds negatively to the shock to $CO2$, gradually approaching zero thereafter. These findings suggest a short-term positive impact of carbon emissions on GDP, followed by a negative impact in the long term.

In the second row of Fig. 3, $lnPHE$ responds positively to a one standard deviation shock to $lnGDP$ throughout the examined period, gradually reaching equilibrium by the end. This result indicates the positive impact of economic growth on private healthcare expenditure. Similarly, the responses of $lnPHE$ to a shock to $lnGHE$ follow a similar pattern. In contrast, $lnPHE$

continuously responds negatively to a one standard deviation shock to $CO2$ over the examined period, gradually returning to equilibrium, which suggests a stabilization of the relationship between $lnPHE$ and $CO2$ in the long run.

In the third row of Fig. 3, we examine $lnGHE$'s responses to various shocks. $lnGHE$ responds positively to a one standard deviation shock to $lnGDP$ throughout the examined period, gradually reaching equilibrium by the end. This finding reveals the positive impact of economic growth on public expenditure. Similarly, $lnGHE$'s responses to a shock to $lnPHE$ follow a comparable pattern, indicating that increased personal spending prompts the government to boost public subsidies. Conversely, $lnGHE$ responds negatively to a one standard deviation shock to $CO2$ during the initial three years. Beyond this period, the responses revert to equilibrium and remain stable for the remaining examined period. These findings indicate a slight short-term decrease in government healthcare expenditure due to CO_2 emissions, with no evident long-term relationship.

In the fourth row of Fig. 3, we observe the responses of $CO2$ to shocks to the other variables. $CO2$ consistently responds negatively to a one standard deviation shock to $lnGDP$ during the examined period, ultimately converging to zero. This finding suggests that economic development promotes emission reduction, supporting the EKC hypothesis. Similarly, $CO2$ responds negatively to a shock to $lnPHE$. However, the responses of $CO2$ to a one standard deviation shock to $lnGHE$ show a different pattern. There is an initial positive response in the first year, but entering the second year, $CO2$ exhibits a significant negative response. The response approaches zero in the third year and gradually returns to equilibrium thereafter. These results imply that in the short run, government health expenditure leads to an increase in CO_2 emissions, while in the long run, it causes a decrease in CO_2 emissions.

These findings highlight the dynamic relationships between $lnGDP$, $lnGHE$, $lnPHE$ and $CO2$, with responses evolving over time and ultimately returning to their long-term equilibrium levels.

4.6 Forecast error variance decomposition

Table 8 reports the forecast error variance decomposition results. The own shocks to $CO2$ explain over 89% of its own variance throughout the period. $lnGHE$ contributes less than 4% of the variation in $CO2$ variance, while $lnPHE$ explains a larger percentage but still less than 7% of the variation in the variance in CO_2 emissions. In contrast, $lnGDP$ explains only 0.02%, 0.66%, and 0.74% of the $CO2$ variations in the second, fifth, and tenth years, respectively. These results suggest that carbon emission fluctuations are mainly influenced by their own shocks and healthcare expenditure dynamics.

Table 8 Forecast error variance decomposition

	Impulse variable			
Response variable	dCO2	dlnGHE	dlnPHE	dlnGDP
dCO2				
0	0	0	0	0
1	1	0	0	0
2	0.9365	0.0263	0.0370	0.0002
3	0.9163	0.0292	0.0501	0.0044
4	0.9066	0.0314	0.0562	0.0058
5	0.9013	0.0325	0.0596	0.0066
6	0.8985	0.0330	0.0614	0.0070
7	0.8971	0.0333	0.0624	0.0072
8	0.8963	0.0335	0.0629	0.0073
9	0.8959	0.0336	0.0631	0.0074
10	0.8956	0.0336	0.0633	0.0074
dlnGHE				
0	0	0	0	0
1	0.0099	0.9901	0	0
2	0.0091	0.7811	0.1708	0.0391
3	0.0159	0.7677	0.1754	0.0410
4	0.0157	0.7464	0.1936	0.0443
5	0.0163	0.7399	0.1984	0.0454
6	0.0164	0.7353	0.2021	0.0462
7	0.0165	0.7333	0.2037	0.0465
8	0.0166	0.7321	0.2047	0.0467
9	0.0166	0.7315	0.2051	0.0468
10	0.0166	0.7311	0.2054	0.0469

dlnPHE				
0	0	0	0	0
1	0.0180	0.0916	0.8904	0
2	0.0222	0.1700	0.7737	0.0341
3	0.0227	0.1655	0.7630	0.0488
4	0.0241	0.1710	0.7513	0.0536
5	0.0244	0.1717	0.7476	0.0563
6	0.0247	0.1725	0.7452	0.0576
7	0.0248	0.1728	0.7441	0.0582
8	0.0248	0.1730	0.7435	0.0586
9	0.0249	0.1731	0.7432	0.0588
10	0.0249	0.1732	0.7430	0.0589
dlnGDP				
0	0	0	0	0
1	0.0257	0.1376	0.1870	0.6497
2	0.0365	0.1312	0.3555	0.4768
3	0.0376	0.1523	0.3851	0.4250
4	0.0371	0.1549	0.4049	0.4044
5	0.0372	0.1572	0.4111	0.3944
6	0.0372	0.1582	0.4152	0.3894
7	0.0372	0.1587	0.4172	0.3868
8	0.0372	0.1590	0.4183	0.3854
9	0.0372	0.1592	0.4189	0.3847
10	0.0372	0.1593	0.4192	0.3843

Regarding $lnGHE$, its own shocks explain 99% of the variance in the first year, with this amount decreasing to 73.1% in the tenth year. $CO2$ contributes only 1% to the fluctuations in $lnGHE$ initially, with the amount rising to 1.7% in the tenth year. Additionally, $lnPHE$'s contribution to the variation in $CO2$ increases from 17.1% in the second year to 20.5% in the tenth year. Shocks to $lnGDP$ do not significantly impact the fluctuations in $CO2$ initially, but they account for 4.5% and 4.7% of the variation in $lnGHE$ in the fifth and tenth years, respectively. These findings indicate the greater impact of private healthcare expenditure and GDP growth on government healthcare expenditure compared to the impact of CO_2 emissions.

Regarding $lnPHE$, the analysis shows that in the first year, 89% of the variance is explained by its own shocks; this amount decreases to 74.3% in the tenth year. $CO2$ contributes only 1.8% to the fluctuations in $lnPHE$ initially, but the contribution increases to 2.5% in the tenth year. $lnGHE$'s contribution to the variation in $lnPHE$ rises from 9.2% in the first year to 17.3% in the tenth year. Shocks to $lnGDP$ have no effect on the fluctuations in $lnPHE$ initially, while $lnGDP$ explains 5.6% and 5.9% of the change in $lnPHE$ in the fifth and tenth years, respectively. These results emphasize the important contribution of government healthcare spending and GDP growth to private healthcare spending.

For $lnGDP$, its own shocks explain 65% of the variance in the first year, with this amount decreasing to 38.4% in the tenth year. $CO2$ accounts for only 2.6% of the variance in $lnGDP$ initially, and the amount increases to 3.7% in the tenth year. $lnGHE$'s contribution to the variation in $lnGDP$ shows a slight increase from 13.8% in the first year to 15.9% in the tenth year. Shocks to $lnPHE$ explain 18.7% of the variance of $lnGDP$ in the first year, while $lnPHE$ explains 41.1% and 41.9% of the variation in $lnGDP$ in the fifth and tenth years, respectively. These results underscore the role of private healthcare expenditure in economic growth.

5 Conclusions

This study presents pioneer research on the dynamic causality among economic growth, public and private healthcare expenditure, and carbon emissions using 2000-2019 panel data covering 30 Asia-Pacific countries and employing a PVAR model. The key findings can be summarized as follows: First, economic growth unidirectionally stimulates government healthcare expenditure while exhibiting bidirectional positive causality with private healthcare expenditure. This result emphasizes the role of economic development in bolstering public health, necessitating increased government support as economies expand. Second, carbon emissions negatively affect economic growth in a unidirectional manner. This result implies that increased carbon emissions hamper economic growth, while economic growth does not necessarily lead to increased environmental pollution. These results emphasize the importance of fostering economic growth alongside implementing carbon reduction measures, aligning with the EKC hypothesis. Finally, there exists a bidirectional causal relationship between carbon emissions and government healthcare expenditure. Carbon emissions raise government healthcare expenditure, while government healthcare expenditure reduces carbon emissions. This result calls for a dual focus on enhancing healthcare services and implementing emissions reduction measures for economic and environmental benefits.

In summary, the findings offer policymakers evidence-based insights to develop strategies for promoting economic growth, sustainable development, and healthcare resource allocation. This research contributes to addressing the intricate nexus between economic development, healthcare delivery, and environmental conservation, facilitating the development of holistic and integrated policies for the Asia-Pacific region.

The methodology employed in this study has a limitation in fully capturing the individual heterogeneity of countries. While panel data analysis provides a broad perspective across countries and time, it may not offer in-depth insights into specific country-level dynamics. Additionally, the scope of this paper is limited to the Asia-Pacific region, necessitating further research on a global scale to validate its conclusions.

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