RESEARCH ARTICLE

Environmental quality, healthcare and research and development in Saudi Arabia

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Abstract
While global warming and climate change associated with increasing carbon dioxide are widely seen to be one of the most serious worldwide dangers to population health, little is known regarding "how" country alters the linkage between increasing CO2 emissions and population health outcomes. Current literature on the health effects of CO2 emissions recommends various factors that may establish a more robust link, including health expenditure and research and development. Therefore, the purpose of this inquiry is to examine the effectiveness of health expenditure and R&D in improving health outcomes through reducing CO2 emissions. Using data for Saudi Arabia over the period 2000–2018, the dynamic ordinary least squares (DOLS) technique shows that (i) health and R&D expenditures decrease infant mortality and increase life expectancy; (ii) health and R&D expenditures reduce CO2 emissions in all the estimated models; (iii) health and R&D expenditures can improve health outcomes through reducing CO2 emissions; and (iv) health and R&D expenditures have both direct and indirect effect on health outcomes. Policy implications and limitations are also discussed.

Keywords Health expenditure · Research and development · Health outcomes

Introduction

CO_2 emissions are the main culprits of environmental degradation which negatively influences human health in diverse manners, such as skin contact, inhalation, and ingestion through eye contact, even resulting in carcinogenic

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impacts with long-term exposure (World Health Organisation 2020) documents that during the period 2030–2050, climate change, induced by the increase of CO_2 emissions, is expected to cause about 250,000 added deaths annually, from malnutrition, malaria, diarrhea, and heat stress. According to the same source, 7,000,000 deaths were previously caused by air pollution. In global CO_2 emissions, Saudi Arabia is ranked among the top world's 10 largest emitter since its economy still depends on fossil fuel production and use, causing negative effects on health outcomes (Ahmed et al. 2016). Therefore, reducing CO_2 emissions becoming a growing difficult task in the country, as economic growth is principally depending on fossil fuels. For this reason, the decision-makers in Saudi Arabia target, through the vision 2030, low emissions in the areas of the strategic goals of national industrial development and the national transformation agenda, designed to provide a healthy and satisfying life (Kingdom of Saudi Arabia, 2019). The role of health expenditure and R&D in mitigating such issues has been emerged as a subject of some debates in policy and scholarly circles (Gupta and Baghel 1999; Li and Wang 2017; Rahman et al. 2018; Petrović and Lobanov 2020; Abid et al. 2022). Our study contributes to this debate by examining the role of R&D and health expenditure in improving the health

outcomes through reducing CO_2 emissions in Saudi Arabia over the period 2000–2018. To validate this objective, we use the three-step approach suggested by Baron and Kenny (1986). The following strands of literature justify each step of this approach.

The first step focuses on the direct effects of health expenditure and R&D on human health outcomes. According to Nketiah-Amponsah (2019), financing the healthcare, whether public or private, remains vital to improving the state of health of individuals. Yet, despite the worldwide expansion in health expenditures, the WHO found that health expenditures received little attention in government budgets in developing countries. However, according to the statistics of the World Bank, the Saudi's health sector is the third-largest beneficiary behind the army and education, which is the most important in the Middle East. The allocated social and health budget outlines an 8% increase in 2019 ($46 billion) compared to the year 2018 ($42.4 billion), which equates to about 15% of total government expenditures, estimated at $260 million. Indeed, there is a multitude of studies that connect health outcomes to health expenditure and many of which confirm the positive impacts of health spending on different selected health outcomes (Gupta and Baghel 1999; Bokhari et al. 2007; Rahman et al. 2018; Nketiah-Amponsah 2019; Mladenovic et al. 2021). Despite the indispensable role of health expenditure in improving health outcomes, R&D has been also seen a key determinant of health outcomes. For instance, Paruk et al. (2014) argue that the increase of spending on R&D leads to better chance of achieving general goals in the health sector and supporting the improvement of the country's health outcomes. In the same vein, Callaghan et al. (2019) argue that the differences in R&D investment improve healthcare inequality between nations. Accordingly, we predict a direct positive impacts of health expenditure and R&D on the improvement of health outcomes.

The second step justifies the contributions of health expenditure and R&D on reducing CO_2 emissions (mediation variable). Indeed, previous literature also shows the key roles of health expenditure and R&D in improving environmental quality. On the one hand, recently, specifically after the COVID-19, research on health-environment nexus has become extremely important (World Health Organisation 2020). However, while most of the existing studies on this nexus have mainly focused on the health expenditure impact of environmental quality, little attention has been paid to the environmental impact of health expenditure. Safi and Hassen (2017); Apergis et al. (2018); Ganda (2021) confirm the effectiveness of health expenditure in improving environmental quality. On the other hand, some other scholars show a positive association between R&D and reducing CO_2 emissions (Gerlagh 2007; Lee and Min 2015; Ahmed et al. 2016; Henriques and Borowiecki 2017; Costantini et al.

2017; Zhang et al. 2017; Petrović and Lobanov 2020; Abid et al. 2022). Therefore, we expect that health expenditure and R&D reduce CO_2 emissions.

The third step focuses on the relationship between CO_2 emissions and health outcomes. CO_2 emissions are widely seen as one of the most serious global dangers to population health (Costello et al. 2009). The problem of linking health outcomes to environmental degradation, specifically CO_2 emissions, is critical for developing countries, particularly those with weak environmental policies and weak share of green energy in the global energy mix (Kiross et al. 2020; Martins et al. 2018; Omri and Belaïd 2021). Environmental degradation may affect the health of the population by creating heat stress and negative changes in food production, causing water source diseases and the spread of diseases, such as malaria, dengue, aerobic allergens, and other diseases (Majeed and Ozturk 2020). There is a consensus in previous literature that human activities increase emissions that deteriorate human health outcomes (Seppänen et al. 1999; Sirag et al. 2017; Erdoğan et al. 2019; Majeed and Ozturk 2020; Shobande 2020). So, we expect that a reduction in CO_2 emissions improves population health outcomes.

In light of the above-discussed strands of literature, it is assumed that health expenditure and R&D may improve health outcomes through reducing CO_2 emissions. Accordingly, this study contributes to the existing literature in the following ways. First, there are shortcomings in prior literature regarding how R&D, health expenditure, and environmental quality could improve human health outcomes. Research in this tendency is relatively so far sparse in previous literature. Second, previous studies have focused mainly on the direct relationship between either health expenditure and/or R&D on health outcomes (Bokhari et al. 2007; Rahman et al. 2018; Callaghan et al. 2019; Faria et al. 2021), health expenditure and/or R&D on CO_2 emissions (Petrović and Lobanov 2020; Abid et al. 2022), or CO2 emissions and health outcomes (Erdoğan et al. 2019; Majeed and Ozturk 2020; Shobande 2020); whereas, to our knowledge, no study has examined the mechanisms relating them. For this reason, this study seeks to investigate the possibly indirect effects of health expenditure and R&D on human health through the reduction of CO2 emissions. Third, in terms of results, this study confirms the direct and indirect effects of R&D on improving human health through reducing CO_2 emissions in Saudi Arabia.

The remainder of the paper is organized as follows. The "Literature review" section presents the literature review. The "Methodology and data" section discusses the data and methodology, while the "Results and discussion" section presents and discusses the results. Finally, the "Conclusion and policy implications" section concludes the study and discusses some policy implications and future research directions.

Literature review

To theoretically justify the indirect effects of both health expenditure and R&D on health outcomes through reducing CO_2 emissions, we present and discuss here prior studies following the steps suggested by Baron and Kenny (1986). The first step focuses on the direct effects of health expenditure and R&D on human health outcomes ("Impacts of health expenditures and R&D on health outcomes (step 1)".). The second one justifies the contributions of health expenditure and R&D on reducing CO_2 emissions ("Impacts of health expenditure and R&D on CO2 emissions (step 2)"). The third step focuses on the relationship between CO_2 emissions and health outcomes. We conclude this section by suggesting a conceptual model of the study.

Impacts of health expenditures and R&D on health outcomes (step 1)

There exists a growing interest in the prior studies on the relevance of health expenditure and R&D in improving human health. These studies could be divided into strands of research. The first stand focuses on the impact of health expenditure on health outcomes. For instance, by using a specific data on healthcare spending for 20 countries of the Organization for Economic Cooperation and Development (OECD) over the period 1960−1992, Berger and Messer (2002) show that any enhancement in healthcare expenditures will reduce the mortality rates. Similarly, Bokhari et al. (2007) investigate the effect of healthcare expenditures and per capita income on maternal mortality and child under-five mortality as health outcomes. Using instrumental variables techniques (GMM-H2SL), they find that both variables are essential determinants of health outcomes. They add that increased government spending on health will not necessarily lead to improved health outcomes unless theses raise is accompanied by policies, tools, and institutions that properly characterize intra- and inter-sectoral needs and appropriately allocate funds. In the same vein, Rahman et al. (2018) also investigate the association linking healthcare expenditures and three health outcomes: life expectancy, infant mortality, and death rate. Their results show that healthcare expenditure improves health outcomes. Private and public healthcare expenditures reduce infant mortality, and only private healthcare expenditure reduces the death rates. The authors explain the un-meaningful effect of public healthcare expenditure on the crude death rate by the inefficient use of these funds due to inappropriate governance and corruption. Recently, Mladenovic et al. (2021) investigate the determinants of life expectancy of eighty-five Russian

geographical districts during 15 years. This study uses variable neighborhood programming to solve the symbolic regression model based on a recent "promising automatic programming technique." They also confirm that healthcare expenditure significantly increases life expectancy. However, Filmer and Pritchett (1997) show that public health expenditure does not have a significant effect on reducing child mortality. However, the study results found that other factors can significantly influence this health outcome, such as women's education and income inequality. Filmer et al. (1998) and Musgrove (1996) confirm that the effect of health expenditure on child mortality and maternal mortality is statistically less significant.

Despite the key role of health expenditure in enhancing health outcomes, some other scholars have shown the significance of R&D in improving health outcomes (Blaya et al. 2010; Paruk et al. 2014; Tsai et al. 2018; Callaghan et al. 2019). For instance, Paruk et al. (2014) focus on the appropriate funds devoted to R&D health care in South Africa and they show that more funds allocated for R&D health care promote achieving general healthcare goals. They suggest to build a transparent and realistic plan of health goals and the necessary R&D expenditures to achieve these goals. Similarly, Callaghan et al. (2019) confirm that divergence in R&D investments boosts disparity of healthcare conditions across countries. Many reasons make this disparity evident between developed and developing countries. The most important reason is the capability of developed countries to invest more and more in healthcare R&D compared to developing countries. The research also confirms that the success of healthcare R&D outcomes in developed countries would not necessarily provide the same achievements as hoped when applied to developing countries. The authors argue that increasing healthcare R&D in developing countries and allocating more funds for R&D expenditure will improve health outcomes. Recently, Faria et al. (2021) show that R&D in medical schools plays an important role and has a significant positive effect on R&D in hospitals. The research also indicates that improving general healthcare outcomes in the country has a close relationship with healthcare R&D. The presented studies in this area commonly indicate that investment in R&D plays a vital role in improving the general health status and protecting the population against environmental degradation worsening in the last decades.

The above-discussed studies confirm the ability of health expenditure and R&D in improving the health outcomes (infant mortality and life expectancy). Thus, we propose the following hypotheses:

Hypothesis 1a. Health expenditure and R&D decreases infant mortality in Saudi Arabia.

Hypothesis 1b. Health expenditure R&D increases life expectancy in Saudi Arabia.

Impacts of health expenditure and R&D on CO_2 emissions (step 2)

The nexus between CO_2 emissions, R&D, and health attracts more and more empirical and theoretical research studies. On the one hand, a large number of studies have focused on the impact of CO_2 emissions on health expenditure (Narayan and Narayan 2008; Boachie et al. 2014; Yahaya et al. 2016; Yazdi and Khanalizadeh 2017; Alimi et al. 2020); however, fewer studies have interest in examining the impact of health expenditure on CO_2 emissions (Safi and Hassen 2017; Apergis et al. 2018; Gündüz 2020; Ganda 2021). Among these fewer studies, Safi and Hassen (2017) examine the relationship between private health expenditure and environmental quality and they show that increasing private health expenditures leads to higher levels of capital accumulation and environmental quality. Similarly, Apergis et al. (2018) apply a panel methodological approach to examine the relationship between CO_2 emissions, per capita GDP, renewable energy consumption, and health expenditure for a panel of 42 sub-Saharan Africa countries over the period 1995–2011. Their long-run estimates show that both health expenditure and renewable energy decrease CO_2 emissions. They call these countries to continue their growth and increase investment in the renewable energy and health sectors, which will allow them to take advantage of their abundant wealth in renewable energy resources, enhance human health outcomes, and combat climate change. In the same direction, Bilgili et al. (2021) use a quantile regression model to examine the impacts of health expenditure and economic growth on CO_2 emissions in a selected Asian country over the period 1991–2017. Their findings reveal that both private and government expenditures reduce CO_2 emissions and that the contribution of private health expenditure on reducing emissions is greater than that of the government health expenditure. They suggest that policymakers aiming for sustainable economic growth should augment the spending on health for improving and protecting the environment. For the case of BRICS countries, Ganda (2021) investigate the influence of health expenditures on environmental quality using the Fully Modified Ordinary Least Square (FMOLS), the Vector Error Correction Model (VECM), and Granger causality test. Their findings also show that the aggregate level of health expenditures is negatively connected with CO_2 emissions. The country-specific results show that health expenditure in China, India, and South Africa significantly reduces CO_2 emissions, whereas it has a negative and an insignificant effect in the case of Brazil.

On the other hand, some other studies have recommended R&D as a key determinant in reducing CO_2 emissions (Gerlagh 2007; Ang 2009; Smulders and Maria 2012; Lee and Min 2015; Ahmed et al. 2016; Henriques and Borowiecki 2017; Costantini et al. 2017; Yang and Li 2017; Zhang et al. 2017; Churchill et al. 2019; Petrović and Lobanov 2020; Abid et al. 2022). For example, Gerlagh (2007) confirms that R&D progress reduces CO_2 abatement costs by lowering the price of carbon and learning income in R&D. By applying ARDL techniques to estimate the determinants of China's environmental quality over the period 1953–2006, Ang (2009) shows that R&D activities and technology transfer significantly reduce CO_2 emissions. Relying on a sample of Japanese manufacturing firms for the period 2001–2010, Lee and Min (2015) also exhibit that green R&D activities reduce companies' CO_2 emissions and enhance their financial performance. Ahmed et al. (2016) also apply an ARDL technique on a sample of twenty-four European economies over the period 1980–2010 and they confirm that R&D helps to reduce CO_2 emissions in the long run. Similarly, Henriques and Borowiecki (2017) make an international comparison between twelve countries over a long-run period 1800–2010 and they show that R&D is one of the main drivers which curbs long-run CO_2 emissions. For France, Shahbaz et al. (2018) show that R&D negatively affects carbon dioxide emissions, and that investments in energy innovation have a strong positive effect on improving environmental quality. Using data for sixteen OECD countries, Petrović and Lobanov (2020) analyze the impact of R&D on CO_2 emissions over the period 1981–2014 and they find a 1% increase in R&D investment reduces emissions by 0.09–0.15% on average. They call the decision-makers in OECD countries to focus their efforts on strengthening R&D programs, such as those in Germany and the USA, which focus squarely on mitigating emissions and increasing their use.

In light of these studies, it is clear that health expenditure and R&D could be used as solution to reduce CO_2 emissions. Therefore, we formulate the following two hypotheses:

Hypothesis 2. Health expenditure and R&D positively contribute to CO_2 emissions reduction in Saudi Arabia.

CO_2 emissions and health outcomes (step 3)

The significant increase in the number of cars, manufacturing companies, and the need for electricity generation worldwide causes environmental pollution and the emissions of harmful gases in large quantities. Many recent studies link environmental quality to human well-being. There is a consensus that human activities cause a massive increase in air pollution that deteriorates health outcome indicators (Majeed and Ozturk 2020). In this context, many recent studies focus on this phenomenon to

provide some practical recommendations (Seppänen et al. 1999; Issaoui et al. 2015; Sirag et al. 2017; Alola and Kirikkaleli 2019; Azad et al. 2018; Erdoğan et al. 2019; Shobande 2020). For example, based on a proportional hazards regression model, Cao et al. (2011) show that air pollution increases mortality rate significantly for a sample composed of 70947 China's middle-aged people. In addition, Issaoui et al. (2015) use a sample of 10 MENA countries over 1999–2010 to investigate the effect of CO_2 emission on many variables, such as life expectancy and welfare and they show that CO_2 emissions destroy life expectancy meaningfully in both the short and long-term over the studied 10 years. Applying FMOLS and DOLS methods, Sirag et al. (2017) confirm that emissions destroy health outcome indicators for 35 African economies over 1995–2012. In the same tendency, Erdoğan et al. (2019) use turkey's observations from 1971 to 2016 and they show that emissions significantly decrease life expectancy and increase mortality rates. To reduce this effect, the authors suggest more investments in renewable energy sector. Based on a global study for 180 economies from 1990 to 2016, Majeed and Ozturk (2020) show that CO_2 emissions ruin health outcomes, especially mortality and life expectancy. They suggest that health-related reforms should be consistent with policies that ensure a clean environment. Shobande (2020) uses a sample of 23 African countries over 1999–2014 and he confirms that more energy use catalyzes pollution and enhances infant mortality. As a solution, he suggests using clean energy sources, which help improving health outcomes through reducing emissions. In the same direction, Urhie et al. (2020) show that economic growth is a significant factor that enhances air pollution and destroys Nigerians' health outcomes. Their study also confirms that public health expenditure reduces this negative effect but does not diminish air pollution.

The research recommends using environment-friendly technologies that improve environmental quality and support health outcomes.

In light of the above-discussed studies, we formulated the following hypothesis:

> **Hypothesis 3**a. CO_2 emissions increase infant mortality in Saudi Arabia.
>
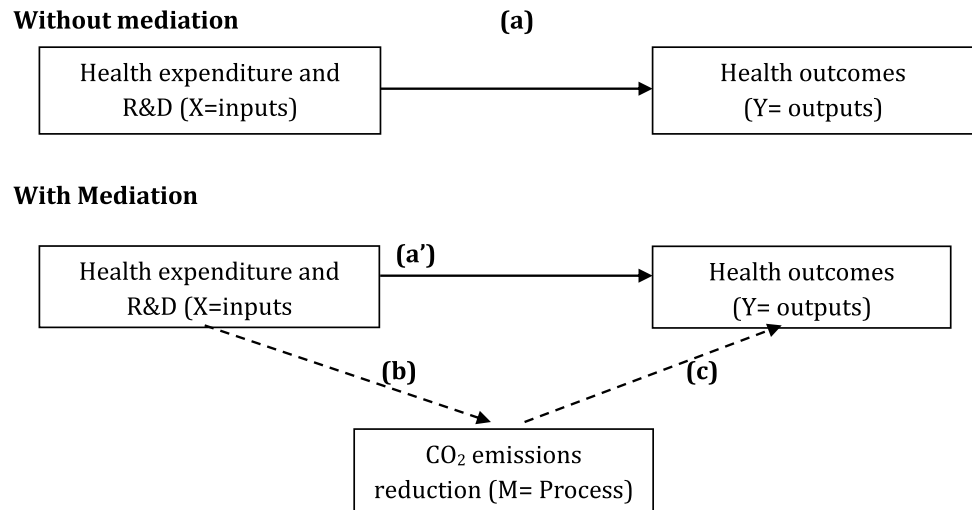> **Hypothesis 3**b. CO_2 emissions decrease life expectancy in Saudi Arabia.

Mediating effects

In light of the above-discussed studies, we can argue that an increase in health expenditure and R&D may reduce CO_2 emissions, which, in turn, improves health outcomes. In other words, both health expenditure and R&D may contribute to improve health outcomes through reducing CO_2 emissions. Compared to previous literature, this study proposes a mediational model that contains as inputs health expenditure and R&D, CO_2 emissions as a process, and health outcomes (infant mortality and life expectancy) as outputs. To validate the direct and indirect effects of health expenditure and R&D on health outcomes, we propose to use the three-step approach of Baron and Kenny (1986). Therefore, we suggest the following hypothesis:

> **Hypothesis 4**. Health expenditure and R&D improves health outcomes through reducing CO_2 emissions.

To validate this hypothesis, we employed the three-step approach suggested by Baron and Kenny (1986) (see Fig. 1), who argue that three steps are required to show the mediation effect of a variable *M* in the manner that the independent variables *X* affect the dependent variable *Y*.

Fig. 1 Description of the mediation effects

Without mediation **(a)**

Health expenditure and R&D (X=inputs) → Health outcomes (Y= outputs)

With Mediation

Health expenditure and R&D (X=inputs **(a')** → Health outcomes (Y= outputs)

(b)

(c)

CO_2 emissions reduction (M= Process)

The first step should justify the significant direct impacts of the independent variables on the dependent variable when M is not incorporated in the model. The second one should justify the significant impact of independent variables on M when the dependent variable is not incorporated in the model. The last step should justify, after incorporating M together with the independent variables, that M significantly affects the dependent variable, while the significant effects of the independent variables on the dependent variable (demonstrated in step 1) must decrease or become insignificant.

Based on the above arguments, we suggest to validate the following conceptual model composed of inputs (health expenditure and R&D), process (CO_2 emissions reduction), and outputs (infant mortality and life expectancy). Figure 2 presents this model.

Methodology and data

Methodology

To validate this conceptual model, we used the three-step approach suggested by Baron and Kenny (1986). A large number of studies have used this approach to identify the mediating effect of a variable (Omri and Ayadi-Frikha 2014; Omri et al. 2015; Giarratana and Mariani 2014; Dhahri and Omri 2020). As mentioned above, this approach considers that three steps are required to identify a mediation effect. The first step should justify the significant direct impacts of the independent variables on the dependent variable

on the dependent variable when M is not incorporated in the model. The second one should justify the significant impact of independent variables on M when the dependent variable is not incorporated in the model. The last step should justify, after incorporating M together with the independent variables, that M significantly affects the dependent variable, while the significant effects of the independent variables on the dependent variable (demonstrated in step 1) must decrease or become insignificant. If all these steps/requirements are verified and the effects of the independent variables become insignificant when including the mediator in the estimated model, these effects are said to be fully mediated by M; whereas, if all these steps are verified, but the significances of the independent variables only diminish, these effects are said to be "partially" mediated by M. If one of these steps is not verified, we can say no mediation by the variable M (Baron and Kenny,1986).

Regarding these procedures, Baron and Kenny (1986) suggest estimating three-regression models: model 1 to estimate the direct effects of the independent variables (health expenditure and R&D) and other control variables on the dependent variable (health outcomes: infant mortality and life expectancy), model 2 to estimate the effects of independent variables (health expenditure and R&D) and other control variables on the mediator variable (CO_2 emissions reduction), and model 3 to estimate the effects of the independent variables (health expenditure and R&D), (CO_2 emissions reduction), and other control variables on the dependent variables (health outcomes: infant mortality and life expectancy).

Fig. 2 Conceptual model of the study
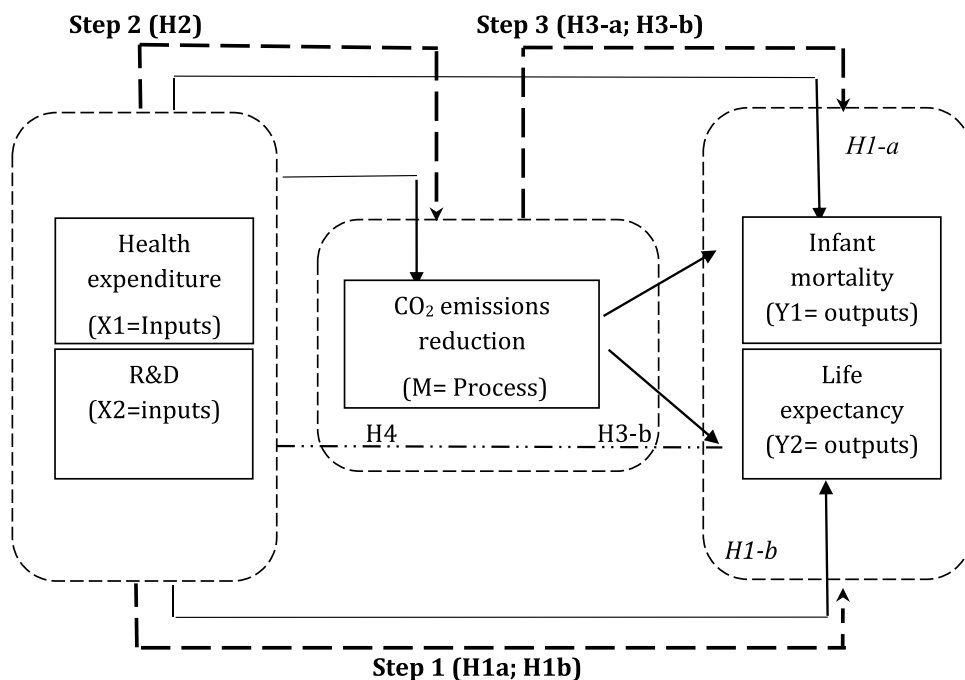
Model 1 is econometrically specified as follow (step 1)

$$lnH_t = \alpha_0 + \alpha_1 Hexp_t + \alpha_2 R\&D_t + \sum_{j=1}^{K} \lambda_j Z_{jt} + \varepsilon_t \qquad (1)$$

where t ($t = 1,\ldots,n$) denotes the time period (1990–2018), ln is the natural logarithm, H is the health outcomes measured by infant mortality and life expectancy, $Hexp$ is public health expenditure, $R\&D$ is research and development, and Z is the vector of control variables (economic growth, education). A large number of empirical studies have interest on the relationship between education and human health and most of them show that education improves health outcomes, regardless of whether the focus is at country or individual levels (Grossman 2006; Dursun et al. 2018). Some other scholars, such as Majeed and Gilani (2017), Majeed and Ozturk (2020), also argue that economic growth increases individual's income, which allows them a better diet, housing, educations, and health facilities that lead to improve human health outcomes.

We then check the second step, i.e., estimate the effects health expenditure and R&D and other control variables on CO_2 emissions. Formally, model 2 has the following econometric specification:

$$lnCO_t = \alpha_0 + \alpha_1 Hexp_t + \alpha_2 R\&D_t + \sum_{j=1}^{K} \lambda_j X_{jt} + \varepsilon_t \qquad (2)$$

where t ($t = 2000,\ldots,2018$) denotes the time period, ln is the natural logarithm, CO is CO_2 emissions, $Hexp$ is public health expenditure, $R\&D$ is research and development, and X is the vector of control variables (economic growth, energy consumption, and trade openness). We expect that these control variables increase CO2 emissions (Ben Youssef et al. 2016; Omri et al. 2021; Kahia et al. 2021; Omri and Saidi 2022).

To check the third step, in which, we test the impacts of health expenditure, R&D, and CO_2 emissions on health outcomes, we followed the health production function proposed by Grossman (1972) and the extension made by of Fayissa and Gutema (2005). The extended health production function is structured as follows:

$$lnH_t = \alpha_0 + \alpha_1 Hexp_t + \alpha_2 R\&D_t + \alpha_3 CO_t + \sum_{j=1}^{K} \lambda_j Z_{jt} + \varepsilon_t \qquad (3)$$

where H is the matrix of the outputs (infant mortality and life expectancy). The $Hexp$, $R\&D$, and CO are the main inputs (health expenditure, research and development, and CO_2 emissions). Z is matrix of the control variables (includes GDP per capita as measure of economic growth, and education). The coefficients α_1, α_2 and α_3 are the long-run estimated coefficients of $Hexp$, $R\&D$, and CO.

Before estimating Eqs. (1), (2), and (3), we first check the stationarity of the used variables. We then run the long-run

equilibrium relationships between our variables. Finally, we employ the dynamic ordinary least squares (DOLS) technique to estimate these equations and to check the three-step approach suggested by Baron and Kenny (1986). Dols takes leads and lags and of the first-difference regressors to deal with the endogeneity bias (Omri et al. 2019).

Data

As argued above, this study aims to examine the direct and indirect effects of health expenditure and R&D on infant mortality and life expectancy for Saudi Arabia over the period 2000 to 2018. This periodicity has been chosen based on the availability of data on the two selected measures of R&D. Infant mortality (Imo) is measured by infant mortality rate in per thousand live births. Life expectancy (LE) is measured by total life expectancy at birth in years. Health expenditure (HE) is measured by domestic general government health expenditure in percent of GDP. Two indicators of R&D are included in the three-estimated models: research & development expenditures (RDexp) in percent of GDP and the number of patents environmental-related technologies (PET)—environmentally related R&D. The data this later is collected from the OECD Statistics online database. Four indicators of CO_2 emissions, namely CO_2 emissions per capita (COpc), CO_2 emissions from electricity and heat production (COelhp), CO_2 from liquid fuel consumption (COlfc), and CO_2 intensity (COint), are included in the analysis to show which types of emissions that affect infant mortality rates and life expectancy. Regarding the control variables, economic growth (Y) is measured by GDP per capita in constant 2010 US$, education (Edu) is measured by gross enrollment rate in tertiary education, energy consumption (EC) is measured by energy use in kilogram of oil equivalent per capita, and trade openness (Tr) is measured by the sum of exports and imports of goods and services measured as a percent of GDP. All these indicators, with the exception of PET, were sourced from the World Bank Indicators (WDI) online database published by the World Bank.

Results and discussion

Before estimating our empirical model, we first check the stationary of the used variables using two-unit root tests, namely Augmented Dickey-Fuller (Dickey and Fuller 1981; ADF) and Philippe and Perron (Philips and Perron 1988; PP). The results of these unit root tests in both levels and first differences are stated in Tables 1, 2, which shows that, except CO2 intensity, all of the variables are non-stationary at their level forms; however, they become all stationary at the first differences, meaning that the used variables are

Table 1 Results of unit root tests

Variables	ADF		PP	
	Level	1st difference	Level	1st difference
Imo	1.774	−3.667*	1.774	−3.360 *
LE	−1.974	−3.554 *	−0.832	−2.219*
HE	−1.174	−5.855*	−1.073	−5.715*
RDexp	−0.709	−2.685**	−0.709	−2.685**
PET	−0.503	−2.334**	−1.681	−6.389*
COpc	−1.911	−3.100*	1.645	−2.892*
COehp	−1.740	−3.365*	−2.479	−3.359*
COlfc	−1.095	−4.426*	−1.095	−4.887*
COint	−3.796**	−7.728*	−3.796**	−8.176*
Edu	−0.286	−6.346*	−0.076	−6.346*
Y	−1.096	−3.873*	−0.870	−4.650*
EC	−0.771	−8.550*	−0.546	−7.496*
Tr	−0.950	−3.850*	−1.350	−4.828*

* and ** show the significance at 1% and 5% levels, respectively. PP and ADF are, respectively, the tests of Phillips and Perron (1988) and Augmented Dickey-Fuller (1981)

Table 2 Johansen's cointegration test (step 1)

Step 1: H =f(HE, RDexp, PET, GDP, Edu)

Rank = 0*	Infant mortality (Imo)		Life expectancy (LE)	
	Trace test	Critical value (5%)	Trace test	Critical value (5%)
0	184.836	95.75	196.376	95.75

* denotes rejection of the null hypothesis at 5% significance level

Table 3 Johansen's cointegration test (step 2)

Step 2: CO =f(HE, RDexp, PET, GDP, EC, Tr)

Rank = 0*	COpc		COehp		COlfc		COint	
	Trace test	Critical value (5%)	Trace test	Critical value (5%)	Trace test	Critical value (5%)	Trace test	Critical value (5%)
0	182.662	95.75	199.2728	95.75	175.276	95.75	179.268	95.75

* denotes rejection of the null hypothesis at 5% significance level

Table 4 Johansen's cointegration test (step 3)

	Step 3: H =f(HE, RDexp, PET, CO, GDP, Edu)				
	Rank = 0*	Infant mortality (Imo)		Life expectancy (LE)	
		Trace test	Critical value (5%)	Trace test	Critical value (5%)
COpc	0	174.523	125.62	203.387	125.62
COehp	0	186.023	125.62	192.401	125.62
COlfc	0	201. 924	125.62	188.226	125.62
COint	0	171.177	125.62	194.38	125.62

* denotes rejection of the null hypothesis at 5% significance level

integrated of order one, which, therefore, allows us to test the long-run equilibrium relationships among variables using the Johansen's (1988) cointegration test. Tables 2, 3, and 4 present the results of this test for the models relative to each step discussed above and clearly show that the trace statistics are superior to critical values at rank = 0, confirming that all models do not reject the hypothesis of cointegration. Therefore, we can run the long-run estimates in the next step using the DOLS technique. The long-run estimates of the three steps (Eqs. 1, 2, and 3) are reported in Tables 5 and 6.

Regarding the first step, it is clear from these tables that government health expenditure has negative (−0.206) and positive (0.366) impacts on infant mortality and life expectancy, respectively. These magnitudes indicate that a 1% increase in health expenditure decreases the rate of infant mortality by around 0.21% and increases life expectancy by around 0.37%. This result is in line with Rahman et al. (2018) who investigate the association linking healthcare expenditures and three health outcomes (life expectancy, infant mortality, and death rate) for 15 SAARC-ASEAN countries. Their results also show that healthcare expenditure improves health outcomes. Private and public healthcare expenditures reduce infant mortality, and the effect of private sector was greater than that of public sector. Mladenovic et al. (2021) also confirm that healthcare expenditure significantly increases life expectancy for eighty-five Russian geographical districts. However, it contradicts the findings of and Musgrove (1996), Filmer and Pritchett (1997), and Filmer et al. (1998), among others, who find that public health expenditure does not have a significant effect on reducing child mortality. Moreover, these tables also show

Table 5 Long-run results of the three steps for infant mortality (Imo)

	Step 1	Step 2				Step 3	
	Imo	COpc	COehp	COlfc	COint	Imo	Imo
HE	−0.206* (0.000)	−0.126** (0.034)	−0.141* (0.002)	−0.119*** (0.059)	−0.102*** (0.070)		−0.161*** (0.055)
RDexp	−0.177* (0.000)	−0.150* (0.004)	−0.129*** (0.063)	−0.138** (0.025)	−0.125** (0.010)		−0.099** (0.023)
PET (a)	−0.102 (0.116)						
COpc						0.149** (0.013)	−0.094 (0.159)
COehp						0.098** (0.044)	−0.077 (0.124)
COlfc						0.159* (0.000)	−0.114 (0.110)
COint						0.138** (0.019)	−0.102 (0.130)
Edu	−0.311* (0.000)					−0.293* (0.000)	−0.244* (0.000)
Y	−0.305* (0.000)	0.476* (0.000)	0.398* (0.000)	0.418* (0.000)	0.504* (0.000)	−0.246* (0.000)	−0.294* (0.000)
EC		0.616* (0.000)	0.556* (0.000)	0.579* (0.000)	0.497* (0.000)		
Tr		0.327* (0.000)	0.282* (0.000)	0.338* (0.000)	0.360* (0.000)		
constant	0.657 (0.000)	4.306* (0.000)	9.455* (0.000)	7.621* (0.000)	3.882* (0.000)	1.803 (0.000)	3.567 (0.000)

(a) We did not include PET in steps 2 and 3 because its impact is not significant in the first step

Table 6 Long-run results of the three steps for life expectancy (LE)

	Step 1	Step 2				Step 3	
	LE	COpc	COehp	COlfc	COint	LE	LE
HE	0.366* (0.000)	−0.096** (0.021)	−0.122** (0.030)	−0.142** (0.010)	−0.152* (0.000)		0.144** (0.011)
RDexp	0.149* (0.008)	−0.144** (0.004)	−0.120** (0.042)	−0.158* (0.003)	−0.093*** (0.068)		0.074*** (0.023)
PET (a)	0.134 (0.110)						
COpc						−0.209* (0.000)	0.123 (0.118)
COehp						−0.187* (0.004)	0.102 (0.156)
COlfc						−0.189** (0.027)	0.072 (0.209)
COint						−0.186** (0.035)	0.105 (0.1325)
Edu	0.284* (0.000)					0.224* (0.000)	0.303* (0.000)
Y	0.298* (0.000)	0.340* (0.000)	0.389* (0.000)	0.329* (0.000)	0.387* (0.000)	0.197* (0.000)	0.197* (0.000)
EC		0.469* (0.000)	0.384* (0.000)	0.470* (0.000)	0.392* (0.000)		
Tr		0.291* (0.000)	0.330* (0.000)	0.279* (0.000)	0.322* (0.000)		
constant	1.293 (0.000)	3.852* (0.000)	4.029* (0.000)	5.933* (0.000)	9.288* (0.000)	4.362* (0.000)	7.102* (0.000)

(a) We did not include PET in steps 2 and 3 because its impact is not significant in the first step

that only R&D expenditure has significant impacts on infant mortality and life expectancy. The magnitude of −0.177 means that a 1% increase in spending on R&D reduces infant mortality by around 0.1%. Tang (2019) argues, in this context, that R&D has invariably enabled the growth of disease control protocols, high-level health material, and elimination methods that have synergistically reduced infant mortality rates. He also documents that R&D increases innovation in treatment and care as well as the development of advanced medical tools and material that will enhance the control of the present therapeutic intervention and procedures measures. The magnitude of 0.149 indicates that 1% increase in spending on R&D increases life expectancy by around 0.15%. Faria et al. (2021) argue, in this context, that improving general healthcare outcomes in the country has a close relationship with R&D and more investments in R&D play are vital for improving the general health status and protecting the population against environmental degradation worsening in the last decades. For South Africa, Paruk et al. (2014) also argue that increasing healthcare R&D in developing countries and allocating more funds for R&D expenditure will increase life expectancy and reduce the mortality rates. The positive contributions of health expenditure and R&D on improving health outcomes confirm the first step and our first two hypotheses (H1a and H1b), i.e., health expenditure and R&D have direct positive impacts on health outcomes in Saudi Arabia. For the control variables, Tables 5 and 6 clearly show that education level improves health outcomes (increases life expectancy and decreases infant mortality) as educated people can avoid unhealthy diets and habits (Majeed and Khan 2019). Similarly, we find that economic growth is a key determinant for improving health outcomes. In other words, when the income is high in an economy, the government has more resources to spent on enhancing the health quality of their residents, via augmenting the income, and will have more resources to offer better shelter, food, and healthcare facilities (Majeed and Ozturk 2020).

Regarding the second step, Tables 5 and 6 show that health expenditure has significant impacts on reducing CO_2 emissions, ranging from −0.096% for the model of the CO_2 emissions per capita (COpc) to −0.152% for CO_2 intensity (CO_2). These results confirm the findings of Apergis et al. (2018) who find that both health expenditure decreases CO_2 emissions for 42 sub-Saharan Africa countries over the period 1995–2011, and they call these countries to continue their growth and increase investment in the renewable energy and health sectors, which will allow them to take advantage of their abundant wealth in renewable energy resources, enhance human health outcomes, and combat climate change. In the same vein, Bilgili et al. (2021) show that both private and government expenditures reduce CO_2 emissions and that the contribution of private health expenditure

on reducing emissions is greater than that of the government health expenditure. They suggest that policymakers aiming for sustainable economic growth should augment the spending on health for improving and protecting the environment. Our results also show that R&D expenditure has significant impacts on reducing emissions, ranging from −0.093 for the CO_2 intensity (COint) model to −0.158 for the CO_2 from liquid fuel consumption (COlfc). The positive contribution of R&D expenditure on reducing CO_2 emissions is in line with some fewer studies, such as Gerlagh (2007) who confirms that R&D progress reduces CO_2 abatement costs by lowering the price of carbon and learning income in R&D. Similarly, Henriques and Borowiecki (2017) make an international comparison between twelve countries and they show that R&D is one of the main drivers of curbing long-run CO_2 emissions. The positive contributions of health expenditure and R&D on reducing CO_2 emissions confirm the second step and our second hypothesis, i.e., health expenditure and R&D positively contribute to CO_2 emissions reduction in Saudi Arabia. Tables 5 and 6 also show that, in all the estimated models, the three control variables (per capita GDP, energy consumption, and trade openness) have significant and positive impacts on the four indicators of CO_2 emissions. These results are in line with those of Kahia et al. (2020, 2021); Omri et al. (2021), Omri and Saidi (2022).

In the third step, we included the mediation variable (CO2 emissions) as explanatory variable in the models of infant mortality (Imo) and life expectancy (LE). We first find that all the indicators significantly increase infant mortality and decrease life expectancy. The negative impacts of CO2 emissions on the health outcomes is in line with the findings of Sirag et al. (2017) who confirm that emissions destroy health outcomes indicators for 35 African economies over 1995–2012. In the same direction, Erdoğan et al. (2019) also show that emissions significantly decrease life expectancy and increase mortality rates. To reduce this effect, the authors suggest more investments in renewable energy sector. However, when we included CO2 emissions with the other explanatory variables (health expenditure and R&D) in the infant mortality and life expectancy models, their impacts on the two dependent variables become insignificant. We also find that the reduction of CO2 emissions plays a mediation role between health expenditure and both infant mortality and life expectancy since the significance level of health expenditure decreased from 1% in step 1 to 10% for the model of infant mortality and to 5% in the model of life expectancy in the third step. This result indicates that CO2 emission reduction partially mediates the relationship between health expenditure and health outcomes. Therefore, we can argue that policymakers in Saudi Arabia are called to increase their spending in healthcare to reduce emissions, which, in turn, enhance health outcomes. In this direction, Apergis et al. (2018) call the Sub-Sabsaharan countries to

continue their growth and increase investment in the renewable energy and health sectors, which will allow them to take advantage of their abundant wealth in renewable energy resources, enhance human health outcomes, and combat climate change. Moreover, compared to the results of the first step 1, we find that CO_2 emissions partially mediate the relationship between R&D expenditure and the two indicators of health outcomes since the significance level of R&D expenditure decreased from 1% in step 1 to 5% for the model of infant mortality and to 10% in the model of life expectancy in the third step. This result indicates that CO_2 emissions reduction partially mediate the relationship between R&D expenditure and health outcomes, i.e., R&D expenditure reduces CO2 emissions, which, in turn, improve health outcomes. Therefore, we can argue that policymakers in Saudi Arabia are called to spending more in R&D to reduce the incidence of CO_2 emissions on health outcomes. These results confirm our last hypotheses, i.e., health expenditure and R&D improves health outcomes through reducing CO_2 emissions. The practical significance of this result is reflected in the fact that it directs policymakers to redirect their efforts to the promotion of the R&D programs, such as those in Germany and the USA, which are directly focused on reducing CO_2 emissions and increasing the use thereof (Petrović and Lobanov 2020), which, in turn, enhances health outcomes (Erdoğan et al. 2019).

Conclusion and policy implications

This study contributes to the previous literature by examining the effectiveness of health expenditure and R&D in improving health outcomes through reducing CO2 emissions. As mentioned above, the health production function of Grossman (1972) was extended by including CO_2 emissions reduction as a meditator variable through which health expenditure and R&D could improve health outcome in Saudi Arabia over the period 2000 to 2018. Using DOLS estimator, we find that (i) health expenditure and R&D expenditure decreases infant mortality and increases life expectancy; (ii) health expenditure and R&D expenditure reduce CO_2 emissions in all the estimated models; (iii) health expenditure and R&D could improve health outcomes through reducing CO_2 emissions; (iv) health expenditure and R&D expenditure have direct and indirect effect on health outcomes.

These findings allow us to suggest some policy and practical implications for the Saudi's policymakers. First, since the results highlight the significance of health expenditure in improving health outcomes, the Saudi's government should increase and review health expenditure to effectively mitigate CO_2 emissions, and to promote a healthy environment. Moreover, in the structure of health and environmental expenditures, it should also augment the volume of the environmental research, environmental health education, create a favorable external environment for increasing economic growth, and offer full play to the positive impact of environmental public spending on establishing a kindly external technological innovation environment and improving human health. Second, R&D is also found to have a significant impact on reducing emissions and then improving health outcomes. The Saudi's government should, therefore, prioritize R&D initiatives that strategically reduce CO_2 emissions. This could be realized by providing incentives as well the adoption of obligatory regulations in crucial fields to improve disclosure and accountability. The intensity and efficiency of R&D activities should be enhanced to avoid unnecessary spending on environmentally unsound areas. Within the framework of environmental protection, the efforts of public authorities must be strictly focused on the support and promotion of R&D programs aimed directly at reducing CO_2 emissions and increasing their use. Finally, effective R&D operations require considerable collaboration among researchers from different areas. For instance, to be maximally productive, investments in health R&D domains require to include investments in many other relevant fields, such as information and communication technologies, physical sciences, biology, chemistry, and economics.

This paper is subject to limitations. The first limitation is related to the choice of the measures of health outcomes. Infant mortality and life expectancy are measures of quantity of life that do not consider the quality of life. Carbon emissions also affect mental health whereas our study only focuses on physical health. The current study uses two measures of health outcomes because of the limitations of data. Future studies can focus on other measures of health outcomes. The above-discussed findings are specific to Saudi Arabia. Therefore, the findings shown during this period can be generalized neither to other countries nor to this country at a different period.

Author contribution Anis Omri: conceptualization, methodology, project administration; Bassem Kahouli: formal analysis, software; Hatem Afi: investigation, data collection; Montassar Kahia: formal analysis, software.

Data availability The data are available upon demand by request to the corresponding author.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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