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Economic growth and health expenditures relationship between OECD countries

Edited by
Dilaver Tengilimoğlu, Maye Abu Omar, Aysu Zekioglu, Maria Johann and Mustafa Z. Younis

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Economic growth and health expenditures relationship between OECD countries

Topic editors

Dilaver Tengilimoğlu — Atılım University, Türkiye
Maye Abu Omar — University of Leeds, United Kingdom
Aysu Zekioglu — Trakya University, Türkiye
Maria Johann — Warsaw School of Economics, Poland
Mustafa Z. Younis — Jackson State University, United States

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Table of contents

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Hai Fang,
Peking University, China

*CORRESPONDENCE
Dilaver Tengilimoğlu
✉ dilaver.tengilimoglu@gmail.com

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Editorial: Economic growth and health expenditures relationship between OECD countries

Dilaver Tengilimoğlu*

Department of Business, School of Business, Atilim University, Ankara, Türkiye

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Editorial on the Research Topic
Economic growth and health expenditures relationship between OECD countries

Countries need to increase the welfare and the wellbeing of their population. Countries' health systems are naturally essential in sustaining and increasing welfare and wellbeing. Furthermore, health systems are financed through health expenditures. Therefore, increasing health expenditures may positively impact the performance of health systems. Thus, increasing health expenditures in a country may increase the population's welfare and wellbeing.

A healthy population has many benefits, and potentially increasing economic growth is one of its most important benefits. Economic growth is vital for countries, so the relationship between economic growth and health expenditure must be carefully analyzed. Furthermore, the Organization for Economic Cooperation and Development (OECD) is one of the most prominent organizations in the world. In this context, this Research Topic focused on the relationship between economic growth and health expenditures among OECD countries. There were valuable contributions to the Research Topic, and nine articles were chosen.

Celik et al. analyze the relationship between health expenditures and economic growth with the convergence hypothesis and non-linear unit root tests in their contributed article titled "*Convergence of economic growth and health expenditures in OECD countries: evidence from non-linear unit root tests*". They use data from 22 OECD countries from 1976 to 2020 and find that health expenditure convergence had significantly contributed to growth convergence. Beylik et al. analyze the same relationship with the Driscoll-Kraay standard error approach in their contributed article titled "*The relationship between health expenditure indicators and economic growth in OECD countries: a Driscoll-Kraay approach*". They use data from 21 OECD countries and find that increasing health expenditures may increase economic growth.

Sustainability must accompany economic growth because countries cannot keep increasing their economic growth if it harms the population's health and the planet. Manzoor et al. find that innovation is critical for economic stability in their contributed article titled "*Sustainability-oriented innovation system and economic stability of the innovative countries*", and they emphasize the importance of sustainability-oriented innovation. Their study obtains data from the 12 most innovative countries from 2011 to 2021 and uses fixed-effect methods.

Health outcomes are considered among the important indicators of the welfare and wellbeing of the population. Anwar et al. use the system generalized method of moments (GMM) in their contributed article titled "*Government health expenditures and health outcome nexus: a study on OECD countries*" and analyze the impact of health expenditures on health outcomes in the OECD countries. They find that health expenditures have a positive impact on life expectancy and a negative impact on infant mortality.

Treatable mortalities are very significant because they highlight the importance of health expenditures and economic growth. Countries with higher health expenditure and economic growth are more likely to have better and more effective health systems than countries with lower health expenditure and economic growth. As a better and more effective health system has a higher chance of treating treatable mortalities, higher health expenditure and economic growth can lower treatable mortality rates. Ivankova et al. investigate the relationships between health spending, treatable respiratory mortality, and GDP in OECD countries in their contributed article titled "*Understanding the relationships between health spending, treatable mortality and economic productivity in OECD countries*". Their data covers the 1994–2016 period, and they find a negative relationship between health spending and treatable respiratory mortality in their regression analysis.

Food insecurity is another major issue that needs to be considered, as a healthy population depends on nutrients. Yılmaz and Günal evaluate food insecurity risk among 14 OECD countries in their contributed article titled "*Food insecurity indicators of 14 OECD countries in a health economics aspect: a comparative analysis*". They find that food insecurity could be reduced by promoting economic growth.

Global pandemics such as the COVID-19 pandemic create a public health security issue that challenges health systems and disrupts the global economy. Fu et al. analyze the spatial linkage mechanism of public health security, better health status, and economic climate in their contributed article titled "*The spatial linkage mechanism: medical level, public health security, and economic climate from 19 OECD EU countries*". They use data from 19 OECD European Union countries and find that increasing the medical level may reduce the negative impact of public health security issues on the economy.

Increasing health expenditures is beneficial, but only if it is effective. Therefore, analyzing the effectiveness of health expenditures is very important and necessary. The effectiveness of health expenditures becomes an even more significant concern during pandemics. Boduroglu et al. examine the effectiveness of health expenditures in 5 OECD countries during the COVID-19 pandemic in their contributed article titled "*Phase and wave dependent analysis of health expenditure efficiency: a sample of OECD evidence*". They conduct unit root tests and find that the countries started to control the number of COVID-19 cases in the relaxation phase and at the beginning of the second wave of the COVID-19 pandemic by taking adequate measures, thereby increasing the effectiveness of health expenditures.

Furthermore, while increasing health expenditures is important and beneficial, it is also fundamental because it can financially ruin poor households, which is a big problem for the entire health system, especially in the long run. This is called catastrophic health expenditure. Söyük conducts a regression analysis with data from OECD countries for the 2003–2019 period and analyzes the impact of the pre-paid financing model implementations, such as those based on taxation, on the risk of catastrophic health expenditure in their contributed article titled "*The impact of public health expenditure and gross domestic product per capita on the risk of catastrophic health expenditures for OECD countries*". They find that pre-paid financing models can reduce the risk of catastrophic health expenditure.

It is hoped that this Research Topic and these highlights stimulate further research about the relationship between economic growth and health expenditures.

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EDITED BY
Dilaver Tengilimoğlu,
Atilim University, Turkey

REVIEWED BY
Shah Fahad,
Leshan Normal University, China
Wasi Ul Hassan Shah,
Zhejiang Shuren University, China
Narendra N. Dalei,
Central University of Himachal Pradesh, India

*CORRESPONDENCE
Umit Cirakli
umit.cirakli@bakircay.edu.tr

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The relationship between health expenditure indicators and economic growth in OECD countries: A Driscoll-Kraay approach

Umut Beylik[1], Umit Cirakli[2]*, Murat Cetin[3], Eyyup Ecevit[4] and Osman Senol[5]

[1]Department of Health Management, Gulhane Health Sciences Faculty, Health Sciences University, Istanbul, Turkey, [2]Department of Health Management, Faculty of Health Sciences, Izmir Bakircay University, Izmir, Turkey, [3]Department of Economics, Faculty of Economics and Administrative Sciences, Tekirdag Namik Kemal University, Tekirdag, Turkey, [4]Department of Economics, Faculty of Economics and Administrative Sciences, Erciyes University, Kayseri, Turkey, [5]Department of Health Management, Faculty of Health Sciences, Karadeniz Technical University, Trabzon, Turkey

Introduction: The main purpose of the study is to examine the relationship between health expenditure indicators and economic growth in OECD countries.

Methods: In this context, health expenditures and economic indicators data of 21 OECD countries were analyzed by the Driscoll-Kraay standard error approach within the scope of panel data analysis. While Gross Domestic Product (GDP) and income per capita were used as dependent variables, the amount of out-of-pocket health spending, per capita health expenditure, the amount of public health expenditure, the ratio of drug expenditures to gross domestic product, the share of current health expenditures in GDP were used as independent variables.

Results: According to the results, in the model (Model 1) where real GDP level was used as the dependent variable, all health expenditure indicators were positively related to the economic growth. When the estimation results of Model 1 are examined, it is predicted that there will be an increase of 0.09% in GDP in case of a 1% increase in the share allocated to health services from GDP. In case of a 1% increase in the amount of out-of-pocket spending on healthcare, it is foreseen that there may be an increase of 0.04% in the real GDP. In the model (Model 2) where the per capita income variable is the dependent variable, it is seen that the increase in out- of-pocket health spending has a decreasing effect on the per capita income level, while the increase in public expenditures has an increasing effect on the per capita income level. From the findings of Model 2, it was found that if a 1% increase in the share of current health expenditures in GDP, there may be an increase of 0.06% in the amount of per capita income.

Discussion: Concludingly, it is possible to say that that public resources allocated to health services play an important role in the economic growth.

KEYWORDS

health expenditures, economic growth, OECD countries, Driscoll-Kraay standard error approach, panel data analysis

Introduction

Researchers and policy makers are particularly interested in achieving and sustaining economic growth and the factors affecting it. Solow (1) and Swan (2) focus on the neo-classical growth model of labor and capital, as well as the contribution of technological progress to economic growth. Following these authors, Nelson and Phelps (3) first mentioned the role of education in developing human capital to be able to apply new technologies. Romer (4) attaches importance to the development of human capital as a critical input in the generation of new ideas. While defining human capital, Shultz (5) sees health and education as the basic components of human capital and states that the development of human capital can be achieved with better education and health. Becker (6) points out that the main determinant of a country's development is how the country's individuals successfully utilize their talents, knowledge and health. In this context, the reason why health investments are important for the economic development of the country is related to the fact that these investments reduce the levels of disease and death and minimize human capital losses. According to the main argument of Bloom et al. (7); When health is considered as an important component of human capital, it also becomes a critical determinant of economic growth. Healthy individuals become physically and mentally more energetic and stronger. They can work more efficiently and earn more. They rarely leave their jobs due to illness.

Bloom et al. (8) demonstrate that a healthier and more productive workforce is important in the creation, adoption and application of new technologies, thereby supporting economic growth. The authors also point out that when health is neglected, investigating the relationship between human capital and economic growth cannot provide multifaceted results. Barro (9) investigates the effect of health capital on economic growth by adding health to the neo-classical growth model and draws a theoretical framework. Schultz (10) claims that health expenditures have a significant impact on productivity. Agenor (11) studies the optimal allocation of public health expenditures within the framework of an endogenous economic growth model. Here, it is explained in the theoretical framework that infrastructure and health have an impact on labor productivity and household utility. Due to these effects of health on the economy, especially on economic growth, it is also the subject of empirical studies in the health economics literature (12–17). However, since the findings are quite complex and not in harmony with each other, the investigation of this subject still continues as an important area of interest. In this study, the effect of health expenditure indicators on economic growth in OECD countries is analyzed. There are important reasons behind the selection of OECD countries. Namely:

When the empirical studies in the health expenditures-growth literature are examined, a type of health expenditure is generally taken as an independent variable and its effect on economic growth is analyzed. For example, Aboubacar and Xu (18) and Piabuo and Tieguhong (19) take per capita health expenditure as a measure of health expenditure, Wang (20) the share of health expenditure in GDP, and Zaidi and Saidi (21) total health expenditure as a measure of health expenditure. The most important difference of our study from the literature is that it analyzes the effects on economic growth in detail by including various types of health expenditures (such as per capita health expenditure, public health expenditure, out-of-pocket expenditure, share of health expenditures in GDP, and share of pharmaceutical expenditures in GDP) into the model. Thus, it will be able to present comprehensive empirical findings. Another contribution of the study to the literature is that it uses both per capita income and total GDP variables as a growth model, so that the effects on economic growth can be analyzed more soundly. The study uses second generation panel tests. The CADF test is used in unit root analysis, and the Driscoll-Kraay standard error approach is used in the estimation of long-term coefficients. Since the effects on economic growth are investigated by constructing two different regression models, it will be possible to obtain robust (soundly) results. In addition, comprehensive empirical findings on health expenditures will be able to make comprehensive recommendations for policies that will accelerate economic growth in OECD countries.

The main purpose of this research is to determine the effects of health expenditures on economic growth, both at the country level and at the individual level. In this direction, in accordance with the purpose of the research, individual and national health expenditures were included in the model as independent variables, while economic indicators at both individual and national levels were included in the models as dependent variables. This study may provide important contributions to literature. First, it includes both national and individual level indicators of health expenditures and economic growth, and this may provide better understanding of link between them. On the other hand, the method used in this study can make an important contribution to the literature related to the health expenditures and economic growth relationship. Because the Driscoll-Kraay estimator used in the study provides more robust results in the models with problems of cross-sectional dependence, autocorrelation and heteroscedasticity.

The following parts of the study can be stated as follows: The second part is a literature review. In the third part, the aim and scope of the empirical research, the model and the data set will be discussed. The fourth part includes the methodology used in the study and presents the findings. The study ends with a conclusion and policy recommendations.

Literature review

Health is one of the important dimensions of human capital (22). A healthy population, in addition to being seen as the basis of national economic productivity and the assurance of economic growth, is an effective factor on labor supply and productivity by affecting the physical and mental conditions of employees. In the context of education and health, human capital is directly involved in the production function as a production input, as well as indirectly affecting other sources of economic growth such as technological development and physical capital accumulation (23). According to the report World Health Organization (24), the increase in health expenditures is a factor supporting the economic growth of both developing and developed countries. Poor health levels of individuals will cause a loss in workforce and productivity. This situation may negatively affect economic growth (25).

Another factor in explaining the relationship between health expenditures and economic growth is the effect of health on savings and investments. Good health can increase life expectancy and encourage individuals' motivation to save and invest in entrepreneurs. This may positively affect economic growth (8).

Health expenditures are seen as one of the top priority issues evaluated with different aspects in the health economics literature (13, 26–29). The literature primarily focuses on the determinants of health expenditures. Hitiris and Posnett (30) analyze the data of 560 countries and focus on the determinants of health expenditures. The findings indicate that the main determinant of health expenditures is economic growth. Thus, Ozturk and Topcu (31) identify a causality running from economic growth to health expenditures. Jack (32) shows that labor productivity is important to human capital investments, especially the physical and mental abilities of the workforce. Strauss and Thomas (33) prove the existence of a positive relationship between health and labor productivity. Toor and Butt (34) explore the issue for the Pakistani economy. The authors find that the main determinants of health expenditures are economic growth, urbanization, schooling rate, crude birth rate and foreign aid. On the other hand, Khan et al. (35) investigates the Malaysian economy with ARDL technique and concludes that health protection expenditures are determined by economic growth, population structure and population growth.

Behera and Dash (36) addresses the role of tax revenues and financial transfer as determinants of health expenditures. In this study, in which panel regression analyzes were performed, it is revealed that both variables have a positive effect on health expenditures. According to Abbas et al. (37) explores the socio-economic determinants of health quality for the Pakistani economy. The results of the research reveal that the quality of bureaucracy and accountability, health expenditures positively affect the quality of health, while the risk of population growth, socio-economic conditions, protectionism and out-of-pocket health payments decrease the quality of health.

Grossman (27) argues that a positive change in health investments will positively affect health outcomes in any society. Findings of Oladosu et al. (38) supports this view of Grossman. Oladosu et al. (38) analyze the impact of public health spending on health outcomes (such as infant mortality, malaria mortality, and maternal mortality) for Nigeria and Ghana. Contrary to the findings for Ghana, there is a positive relationship between public health expenditures and health outcomes in Nigeria.

Secondly, the literature explores the relationship between health expenditures and macroeconomic indicators (economic growth, productivity, etc.) (12, 14–16, 19, 21, 39–45).

Nobel laureate Fogel (12, 46), who investigated the effects of health on economic growth with a series of studies, found that three-thirds of economic growth could be explained by changes in health. Gyimah-Brempong (39), analyzing the relationship between health protection expenditures and economic growth in African countries, shows the existence of a positive correlation between the two variables. By analyzing the health-led growth hypothesis empirically, Bloom and Canning (13) show that the said hypothesis is valid and that there is a positive effect in the opposite direction, that is, from growth to health. Mayer (14) applies the Granger causality test to Latin American countries, indicating a causality from health expenditures to economic growth. Bloom et al. (7) investigates the effect of health on economic growth and shows the existence of a positive relationship between the two variables. Wang (42) examines the relationship between health protection expenditures and economic growth with panel regression analysis and panel quantile regression analysis for 31 countries. Research findings indicate that health protection expenditures increase economic growth in these economies. Chaabouni and Abdennadher (47) find a bidirectional causality between health expenditures and economic growth for the Tunisian economy with the help of Granger causality test.

Pradhan (41) focuses on the relationship between health spending and economic growth in 11 OECD countries. The results obtained from the panel data analysis indicate that there is a cointegration between the variables and a bidirectional causality. Eggoh et al. (15) examines the relationship between education, health and economic growth for African countries. According to the GMM estimation results, public education and health expenditures are in a negative relationship with economic growth. Using the panel GMM estimation technique, Chaabouni et al. (44) analyzes the relationship between health expenditures, CO_2 emissions and economic growth for 51 countries. Empirical findings are that health expenditures are positively related to economic growth in the long run. This finding is similar to the findings of Narayan et al. (48) for 5 Asian countries and Hartwig (49) for 21 OECD countries. Applying the adaptive neuro-fuzzy technique, Mladenovic et al. (50) tries to estimate the

impact of health protection expenditures on economic growth. The findings show evidence that the most influential factor in economic growth forecasts is health protection expenditures.

Çetin and Ecevit (51) investigates the link between health expenditures and economic growth for 15 OECD countries. Panel regression analysis reveals that there is no statistically significant relationship between health expenditures and economic growth. Piabuo and Tieguhong (19) focuses on African countries. Evidence from the OLS, DOLS and FMOLS estimates is that health expenditures are positively associated with economic growth in the long run. Applying ARDL model, Haseeb et al. (52) indicates that health expenditures are positively related with economic growth in the long run and there is a causal relationship from economic growth to health expenditures. Gok et al. (53) examines the impact of health expenditures on economic growth in emerging economies. Findings reveal a positive relationship between the variables. Erçelik (54) investigates the relationship between health expenditures and economic growth with the ARDL model in the Turkish economy. The study identifies a positive relationship between health expenditures and economic growth in the long run. Using panel ARDL and panel VECM causality tests, Zaidi and Saidi (21) explores the relationship between health expenditures, environmental degradation and economic growth for SSA countries. Panel causality analysis identifies a running causality running from health expenditures to economic growth.

Yang (16) analyzes the relationship between health expenditures, human capital and economic growth with the help of the panel threshold regression model for 21 developing country economies. Empirical findings, health expenditures affect economic growth negatively in developing countries with low level of human capital, health expenditures affect economic growth positively in developing countries with medium level of human capital, and health expenditures affect economic growth positively in developing countries with high level of human capital. Using ARDL bounds test and Toda-Yamamoto causality method for Australia, Kumar et al. (55) investigates the links among health expenditures, energy consumption and economic growth. Empirical findings show a u-shaped relationship between health expenditures and economic growth. Applying a panel GMM approach for selected African economies, Modibbo and Saidu (56) dwells on the relationship between health expenditures and economic growth. They find that health expenditures have a positive effect on economic growth. Raghupathi and Raghupathi (45) empirically examine the relationship between health protection expenditures and economic performance for the USA. Research findings indicate the existence of a positive correlation between health protection expenditures and economic growth and labor productivity.

Selvanathan et al. (57) analyzes the relationship between different government expenditures and economic growth for the Sri Lankan economy in the context of Wagner and Keynesian approaches. Findings from the ARDL approach indicate that health expenditures support economic growth in the long run. Yang et al. (58) examines the relationship between industrialization, economic growth, environmental degradation and health expenditures within the framework of the STIRPAT model. Panel causality test results provide evidence for bidirectional causality between health expenditures and economic growth. Ahmad et al. (17) analyzes the interrelationships between urbanization, health expenditures, environmental pollution and economic growth for the Chinese economy. In the study with the help of the system GMM approach, the existence of a mutually positive relationship between health expenditures and economic growth draws attention. Matahir et al. (59) intensifies on the links among energy efficiency, health expenditures and economic growth for Malaysia. VECM Granger causality analysis indicates that health expenditures and economic growth cause each other. Li et al. (60) explores the links between CO_2 emissions, health expenditures and economic growth for BRICS countries. The study reveals that there is a causality running from economic growth to health expenditures for Brazil and South Africa. Applying a bootstrap ARDL technique for Saudi Arabia, Ageli (61) shows that there is a bi-directional causality between health expenditures and economic growth. Wu et al. (62) examines the link between health expenditures and economic growth in Asian countries by applying panel quantile technique. The results do not guarantee the existence of a positive relationship between the variables.

Materials and methods

Purpose of the research

The main purpose of this study is to examine the relationship between health expenditure indicators and economic growth in 21 OECD countries. In order to clearly reveal the relationship between the health expenditure indicators and the economic indicators, both individual and country level indicators were used in the analysis.

Estimation strategy

The created panel data can be micro or macro according to the time they cover. Baltagi (63) stated in his study that panels up to 20 periods should be considered micro, and macro for panels with more than 20 periods. Since the time dimension of the variables considered within the scope of the research is 20 periods or more and falls into the macro panel class, the cross-sectional dependency states of the variables were first examined. The cross-sectional dependence states of the variables

were tested with Breusch-Pagan CDLM1 and Pesaran CDLM2 and CDLM tests.

The stationarity of the series lies at the basis of the panel data analysis. Therefore, unit root tests are performed to examine the stationarity of the series. Second generation panel unit root tests should be used if data have cross-sectional dependence, whereby all units in the same cross-section are correlated. Cross-sectionally Augmented Dickey-Fuller (CADF) test of Pesaran (64) is one of the most preferred second generation panel unit root tests. The most preferred secondary generation unit root tests are Pesaran's cross-section augmented ADF (CADF) test and Im, Pesaran and Shin (CIPS) tests. In this study, CADF statistical values were calculated for unit root control in variables.

Findings obtained from models that do not provide basic assumptions are not free from errors. In this context, the first thing is to check whether there is a variable in the model that can cause multicollinearity problem. As stated by Gujarati (65), having multicollinearity problem in a model will cause incorrect predictor coefficients to be calculated. If there is such a problem in the model, corrective actions should be taken. Different tests and methods have been developed to detect this problem. One of these methods is the calculation of the Variance Inflation Factor (VIF) values of the variables. the VIF values of each variable are calculated using the formula (1/1-R2) (66). In the literature, it has been stated that acceptable VIF values can be accepted up to 4 in some studies, 5 and even 10 in some studies (67).

According to Joshi et al. (68), preliminary analyzes should be made about what the panel data model will be to be selected among the pooled model, fixed model and random model. F-test is conducted to select between the fixed-effect model and the pooled ordinary least square model in panel data analysis. Then, the Hausman test is used to determine the final model between fixed and random effect models (68).

Since the panel data have repetitive observations over time, there may be problems of cross-sectional dependence, heteroscedasticity and serial correlation. The inferences drawn from the panel data are not conclusive and the statistical result is completely biased if the presence of cross-sectional dependence in the model. Therefore, diagnostic controls about the problems of the cross-sectional dependence, heteroscedasticity and serial correlation in the model should made to check the model's validity (68). Tests applied for diagnostic controls in this study are Bhargava et al. Durbin-Watson and Baltagi-Wu LBI tests for autocorrelation, Modified Wald Test for heteroscedasticity, Breusch-Pagan LM Pesaran Scaled LM and Pesaran CD test for cross-sectional dependence.

In the case of autocorrelation, heteroscedasticity (changing variance), and cross-section dependence in a panel data analysis model, robust estimators should be used to overcome these problems. Joshi et al. (68) states that the White (1980) estimator, the Rogers (1993) estimator and the Driscoll and Kraay (69) estimator can be considered as the appropriate estimators to draw a conclusive result. However, as stated by Joshi, et al. (68) the Driscoll and Kraay estimator gives strong conclusive empirical results, and removes the deficits of the White and Rogers approach which produces inappropriate estimation when the cross-sectional dependence is present in the panel data set. Since it eliminates the effects of cross-sectional dependence problem, autocorrelation problem and heteroscedasticity problems in the developed models and enables us to reach more accurate estimator values, the Driscoll and Kraay estimator was used to estimate models.

TABLE 1 Explanations of variables.

Variables	Symbol
Real gross domestic product	GDP
Per capita Income	PcINC
Per capita health expenditure	PcHEx
Public health expenditure	PHEx
Out-of-pocket health spending	OPHS
Share of current health expenditures in GDP	SCHEx
Ratio of drug expenditure in GDP	DEx

Model and data

Within the scope of the study, two dependent variables and five independent variables were used. The dependent variables are GDP and per capita income. The independent variables are the amount of out-of-pocket expenditure, per capita health expenditure, the amount of public health expenditure, the ratio of drug expenditures to gross domestic product, the share of current health expenditures in GDP. The type of data used is annual. The time dimension of the variables covers the periods 1990–2019. The data were obtained from the OECD database. In order to further generalize the results, all countries whose data can be accessed in line with the selected variables were tried to be included in the analysis. However, due to the availability of data, 21 countries were included in the study. The variables to be used in the model are shown in Table 1.

Descriptions and justifications of variables are given below:

Real Gross Domestic Product (GDP): It is an inflation-adjusted measure that reflects the value of all goods and services produced by an economy in a given year. Real GDP is expressed in base-year prices. GDP is the most used economic indicator when comparing incomes between countries. This indicator also has a positive effect on individual and social health status.

Per Capita Income: It is the most important economic indicator showing the level of development of a country. It is the value obtained by dividing the gross domestic product of the country by the population. Values are calculated in US dollars. As the per capita income level increases in a country, many

social indicators, especially health indicators, show positive developments both at the individual and societal level. As Hu and Mendoza (70) stated, having a high per capita income level makes it easier to access health services. A higher income level allows individuals to spend more on their own health. A healthier individual can also participate in the workforce at an efficient level.

Health Expenditure Per Capita: It is one of the most important health indicators of a country. Health expenditure per capita is the amount of health expenditure per capita in US dollars. While economic developments at the individual and national level have an increasing effect on the amount of health expenditure per capita, individuals' spending on their own health has a positive effect on both labor productivity and general health level.

Public Health Expenditure: It is the amount of public expenditure in total health expenditures. The increase in public health expenditures facilitates people's free access to health services and enables them to meet their health needs more easily.

Out-of-Pocket Health Spending: It represents the direct payments made by individuals while receiving health services. However, the increase in the amount of out-of-pocket health expenditures creates an extra burden on households and increases inequality in the society.

Share of Current Health Expenditures in GDP: This ratio gives information about the amount of resources allocated to health services, according to other areas of use. By looking at the current health expenditure level of a country, it can be commented on its priority in the economy and the level of importance given to health.

Ratio of Drug Expenditure in GDP: This amount includes final expenditure on pharmaceuticals, wholesale and retail margins, and value added tax. Pharmaceutical expenditures, which have a significant share in total health expenditures, are in a mutual relationship with economic indicators. It is important to examine the relationship between pharmaceutical expenditures, which has a substantial proportion in total health expenditures, and economic indicators.

In the research, two different models will be obtained because each of the dependent variables will be produced separately. In the model, natural logarithmic transformation was applied in series with high numerical value. The equations of the models can be expressed as follows:

Model 1:

$$LNGDP_{it} = C + \sum_{j=1}^{pi} \lambda_{ij} LNPcHEx_{i,t-j} + \sum_{j=0}^{qi} \delta_{ij} LNPHEx_{i,t-j} + \sum_{j=0}^{qi} \varphi_{ij} LNOPHS_{i,t-j} + \sum_{j=0}^{qi} O_{ij} SCHEx_{i,t-j} + \sum_{j=0}^{qi} O_{ij} DEx_{i,t-j} + \gamma_1 LNPcHEx_{i,t-1} + \gamma_2 LNPPHEx_{i,t-1} + \gamma_3 LNOPHS_{i,t-1} + \gamma_4 LNSCHEx_{i,t-1} + \gamma_5 DEx_{i,t-1} + \varepsilon_{it}$$

Model 2:

$$LNPcINC_{it} = C + \sum_{j=1}^{pi} \lambda_{ij} LNPcHEx_{i,t-j} + \sum_{j=0}^{qi} \delta_{ij} LNPHEx_{i,t-j} + \sum_{j=0}^{qi} \varphi_{ij} LNOPHS_{i,t-j} + \sum_{j=0}^{qi} O_{ij} SCHEx_{i,t-j} + \sum_{j=0}^{qi} O_{ij} DEx_{i,t-j} + \gamma_1 LNPcHEx_{i,t-1} + \gamma_2 LNPPHEx_{i,t-1} + \gamma_3 LNOPHS_{i,t-1} + \gamma_4 LNSCHEx_{i,t-1} + \gamma_5 DEx_{i,t-1} + \varepsilon_{it}$$

The left sides of the equations represent the dependent variable. On the right side of the equations, "c" represents the constant variable, "α" represents the estimator coefficients of the independent variables, the "ε" represents the error term, "i" represents the cross-section, "Δ" represents differencing operator, "LN" represents logarithmic transformation and finally "t" represents the information about the period.

Analysis results and discussions

The created panel data can be micro or macro according to the time they cover. Baltagi (53) stated in his study that panels up to 20 periods should be considered micro, and macro for panels with more than 20 periods. Since the time dimension of the variables considered within the scope of the research is 20 periods or more and falls into the macro panel class, the cross-sectional dependency states of the variables were first examined. The cross-sectional dependence states of the variables were tested with Breusch-Pagan CDLM1 and Pesaran CDLM2 and CDLM tests.

According to the results shown in Table 2, the H_0 hypothesis that there is no cross-sectional dependence on variables has been rejected. In other words, there is cross-sectional dependence in variables. CADF test, which is one of the second generation unit root tests that take into account cross-sectional dependence, will be used test unit root in the series.

In this study, CADF statistical values were calculated for unit root control in variables. According to the results of CADF test in the Table 3, it is understood that the series are stationary. After the stationary conditions of the variables are determined, the Variance Inflation Factor (VIF) values of the variables will be calculated to se whether there is multicollinearity problem in data.

As seen in Table 4, each variable in the model was made a dependent variable once and the value of R^2 was obtained. The VIF values of the variables were calculated using the specified formula and the values in the table were obtained. The most critical value of the variables is the coefficient of 5. Since the VIF value of the variables used in the research < 5, there is no variable in the model that can cause multicollinearity problem. The next step in the panel data is to determine which approach the model will be determined by. Within the three basic panel

10.3389/fpubh.2022.1050550

TABLE 2 Cross-sectional dependency results of variables.

Variables	Breusch-Pagan		Pesaran scaled LM		Weigh CD	
	Statistics	Probability	Statistics	Probability	Statistics	Probability
Real GDP	5458.01	0.000	255.05	0.000	73.76	0.000
Per capita income	2139.32	0.000	93.11	0.000	42.80	0.000
Per capita health Expenditure	2540.29	0.000	112.68	0.000	47.98	0.000
Public health expenditure	1665.86	0.000	70.01	0.000	35.83	0.000
Out-of-pocket health spending	290.80	0.000	2.91	0.003	5.71	0.010
Share of current health expenditures in GDP	3101.48	0.000	140.06	0.000	46.41	0.000
Ratio of drug expenditure in GDP	1082.85	0.000	18.63	0.000	13.94	0.000

TABLE 3 CADF panel unit root test.

Variables	t-bar	Cv10	Cv5	Cv1	Z(t-bar)	P
Real GDP	−1.342	−2.070	−2.150	−2.300	1.907	0.972
Per capita income	−1.905	−2.040	−2.110	−2.230	−2.971	0.001
Per capita health expenditure	−2.785	−2.060	−2.150	−2.350	−7.268	0.000
Public health expenditure	−2.966	−2.070	−2.150	−2.300	−5.355	0.000
Out-of-pocket health spending	−3.216	−2.070	−2.150	−2.300	−6.8550	0.000
Share of current health expenditures in GDP	−2.258	−2.070	−2.150	−2.300	−2.374	0.009
Ratio of drug expenditure in GDP	−1.959	−2.070	−2.150	−2.300	−0.979	0.169

t-bar test, N, T = (21, 26); Obs = 523, Augmented by 2 lags (average).

TABLE 4 VIF values for variables.

Variables	R^2	VIF value
Real GDP	0.43	1.75
Per capita income	0.60	2.50
Per capita health expenditure	0.34	1.51
Public health expenditure	0.29	1.40
Out-of-pocket health spending	0.47	1.88
Share of current health expenditures in GDP	0.25	1.33
Ratio of drug expenditure in GDP	0.17	1.20

data analysis approaches, it is necessary to determine which model to be developed is the most appropriate. Results of the panel data model determination tests are shown in Table 5.

First, the validity of the pooled model was tested by F test, the H_0 hypothesis was rejected, and the fixed effects approach was found to be valid. In the next step, it is necessary to determine whether the fixed effects approach or the random effects approach is valid in the model. In order to make this determination, the Hausman test was performed. The results of the Hausman tests shows that the most appropriate approach for Model 1 (GDP) was the fixed effects approach. On the other hand, the random effects approach is valid for Model 2 (PcINC). After determining the approach with which the models will be predicted, autocorrelation, heteroscedasticity and cross-sectional dependency tests should be checked in the models to see whether there are problems in the basic assumptions of panel data. If there are problems, then corrective robust estimators will be used to solve them.

To reach the most accurate results in the model developed in the panel data modeling studies, the first factor to be considered is to check whether there is an autocorrelation problem in the model. According to the results of the autocorrelation test in Table 6, it was found that there is an autocorrelation problem in the Model 1 since the test values are less than 2. On the other hand, In Model 2, the autocorrelation coefficients > 2 indicate no autocorrelation problem in the Model 2.

Another aspect that needs to be tested in the model is the control of the changing variance state (heteroscedasticity).

TABLE 5 Panel data model identification tests.

	Model 1(GDP)		Model 2 (Per capita Income)	
	Statistic	**p**	**Statistic**	**p**
F- Fixed Effects	43.89	0.000	27.34	0.000
Hausman Test	17.64	0.003	6.83	0.23

TABLE 6 Results of autocorrelation, heteroscedasticity, and cross-sectional dependence tests.

	Tests	**Model 1 (GDP)**		**Model 2 (per capita income)**	
Autocorrelation tests	Bhargava et al.	0.32		2.27	
	Durbin-Watson				
	Baltagi-Wu LBI	0.46		2.31	
Heteroscedasticity test	Modified Wald Test	**Chi^2**	***p***	**Chi^2**	***p***
		3462.14	0.000	2506.18	0.000
Cross-sectional dependence tests		**Statistic**	**p**	**Statistic**	**p**
	Breusch-Pagan LM	3145.17	0.000	2493.18	0.000
	Pesaran Scaled LM	256.39	0.000	157.82	0.000
	Pesaran CD	31.89	0.000	19.73	0.000

Modified Wald test used to test heteroscedasticity problem. From the results of Modified Wald test, it is seen that there is a problem of variance changing in the models. Therefore, this problem needs to be corrected by using robust estimators.

Another assumption that should be considered in the panel data models is to check whether there is a cross-sectional dependency problem in the models. Cross-sectional dependency states of the models were checked with three different test types. In all three test types, it is seen that the models have the cross-sectional dependency problem and need to be corrected by using robust estimators. In this context, Driscoll-Kraay standard error approach, which provides solution to previously mentioned problems, was used to estimate panel data.

When the situation of meeting the basic assumptions of the developed models is examined, it is seen that there are problems of correlation, changing variance (heteroscedasticity) and cross-sectional dependence in the Model 1. Panel data model identification tests were revealed that the most appropriate approach for the Model 1 was the fixed effects approach, while the most appropriate approach for the Model 1 was the random effects approach for the Model 2. For Model 2, it is seen that although there is not autocorrelation problem, there are changing variance and cross-sectional dependency problem in the model. Therefore, the Driscoll Kraay Standard Error estimator was used to eliminate errors that may occur due to these problems. Estimation results for the models are shown in Table 7.

According to the estimation results of Driscoll-Kraay Standard Error shown in Table 7, it is seen that the Model 1 is significant at the level of 1% significance. When R^2 is examined, it can be said that In the Model 1, the percentage of independent variables explaining the dependent variable is 27%, and this level of explanation is sufficient.

When the estimation results of Model 1 are examined, it is seen that the share of current health expenditures in GDP is positively correlated with GDP. In other words, the share of current health expenditures in GDP increases economic growth. This can be interpreted that there will be an increase of 0.097% in economic growth in case of a 1% increase in the share allocated to health services from GDP. The results indicate that out-of-pocket health spending is positively affects GDP. This means that that out-of-pocket health spending encourages economic growth. In case of a 1% increase in the amount of out-of-pocket spending on healthcare, it is foreseen that there may be an increase of 0.041% in economic growth. The results also indicate that public health expenditure is positively related to GDP. This implies that public health expenditure stimulates economic growth. From the results, it is detected that if there is an increase of 1% in the amount of public health expenditure, it is foreseen that there may be an increase of 0.078% in economic growth. The coefficient of health expenditure per capita is positive and statistically significant at 1% level. This means

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TABLE 7 Estimation results of Driscoll-Kraay standard error.

Period:1990–2019, cross section: 21, total number of observations: 541

	Variable	Coefficient	Drisc/Kraay	*t*	*p*
Model 1 (GDP)	Share of current health expenditures in GDP	0.097	0.017	4.47	0.000
R^2: 0.27	Ratio of drug expenditure in GDP	0.868	0.236	1.01	0.322
F-statistic: 15.37	Out-of-pocket health spending	0.041	0.012	3.46	0.002
Prob (F-Statistic): 0.000	Public health expenditure	0.078	0.007	3.79	0.001
	Per capita health expenditure	0.047	0.009	5.00	0.000
	C	24.220	0.385	62.87	0.000
Model 2 (Per capita Income)	Share of current health Expenditures in GDP	0.066	0.001	14.05	0.000
R^2: 0.34	Ratio of drug expenditure in GDP	−0.258	0.006	−1.23	0.218
F-statistic: 6.32	Out-of-pocket health spending	−0.270	0.001	−7.26	0.000
Prob (F-Statistic): 0.000	Public health expenditure	0.036	0.0003	9.24	0.000
	Per capita health expenditure	−0.023	0.001	−23.41	0.000
	C	2.507	1.539	6.82	0.000

that health expenditure per capita raises economic growth. If there is a 1% increase in the amount of health expenditure per capita, it is predicted that there may be an increase of 0.047% in economic growth. Finally, it is found that the coefficient of drug expenditure is positive but no statistically significant. This implies that there is no statistically significant relationship between the amount of drug expenditure and economic growth. As can be seen from the results of estimation for the Model 1, all independent variables are positively related to GDP level. In other words, the realization of increases in independent variables (health expenditure indicators) supports the country's growth by contributing positively to the country's economy.

When the findings related to the Model 2 are examined, it is found that the rate of GDP allocated to health services is positively correlated with GDP. This implies that the rate of GDP allocated to health services raises economic growth. If a %1 increase in the rate of GDP allocated to health services occurs, there may be an increase of 0.066% in economic growth. In this model, the coefficient of the ratio of drug expenditures in GDP is negative but no statistically significant. This means that there is no statistically significant relationship between the ratio of drug expenditures in GDP and economic growth. The findings reveal that out-of-pocket health expenditure is negatively related to GDP. This implies that out-of-pocket health expenditure decreases economic growth. In other words, it is foreseen that if there is an increase of 1% in the amount of out-of-pocket health expenditure, there may be a decrease of 0.270% in economic growth. The findings also reveal that public health expenditure is positively affects GDP. This means that public health expenditure increases economic growth. In other words, it is estimated that an increase of 1% in the amount of public health expenditure may result in an increase of 0.036 % in economic growth. It is detected that the coefficient of health expenditure per capita is negative and statistically significant at 1% level. This implies that health expenditure per capita reduces economic growth. In the event of an increase of 1% in the amount of health expenditure per capita, it is foreseen that there may be a decrease of 0.023% in economic growth.

Our finding is that there is a positive relationship between public health expenditure and economic growth coincides with the result of Eggoh et al. (15). This study reveals that public health expenditure encourages economic growth. Our finding does not coincide with the results of Yang (16). This study shows both positive and negative relationship between the variables. Our finding proving the positive relationship between health expenditure per capita and economic growth is similar to the findings of Chaabouni et al. (43) and Aboubacar and Xu (18). The authors find that health expenditure per capita is positively related to economic growth. Our finding on the positive relationship between the share of health expenditure in GDP and economic growth is compatible with the results of Wang (20) and Narayan et al. (48). These papers indicate a positive link between the variables.

Conclusion and recommendations

The main purpose of this study was to examine the relationship between health expenditure indicators and economic growth in 21 OECD countries. In this context, annual data of health expenditure indicators and economic indicators between 1990 and 2019 of 21 OECD countries were analyzed

using Driscoll-Kraay Standard Error approach within scope of panel data analysis. In the study, variables of the GDP and per capita income were used as the dependent variables, while the variables of the amount of out-of-pocket expenditure, per capita health expenditure, the amount of public health expenditure, the ratio of drug expenditures to gross domestic product, the share of current health expenditures in GDP were used as the independent variables. Two different models have been developed for two dependent variables.

From the estimation results for Model 1, it was found that the variables of the share of current health expenditures in GDP, out-of-pocket spending on healthcare, public health expenditure, health expenditure per capita were significantly positively related to GDP. On the other hand, it was found that there was no significant relationship between drug expenditure and GDP. Although there are different factors that increase economic growth, these results for Model 1 (GDP) show that increase in the health expenditures both at the individual level and at the national level will contribute to the economic growth at national level. In other words, it is seen that expenditures on health services have a positive increasing effect on economic growth.

In the Model 2 where the per capita income is the dependent variable, it is seen that the increase in individual level expenditures has a decreasing effect on the per capita income level, while the increase in public expenditures has an increasing effect on the per capita income level. This result can be interpreted as that public health expenditures have a significant supportive effect on economic growth. When examined in general, it is seen that each resource allocated to health services is seen as an investment and that these expenditures indirectly support economic growth. It is thought that the comparison of the results by examining these indicators on other country groups will contribute to the literature.

Individual and national public health expenditures also have an impact on economic growth, especially on the general health level of the society. As the amount of spending on health services in a society increases, infant mortality decreases, the average life expectancy increases, and the society can be healthier and more productive. On the other hand, investing in the public expenditures for health programs also function as macroeconomic stabilizers. Of course, although the increase in health expenditures does not always mean better health, it can be expected that the increase in the health expenditures, especially governmental health expenditures, may contribute to improving the health of vulnerable people. As a result, healthy people will contribute more to the growth of the economy by being more productive. In this context, this study shows that that investments in health services support economic growth.

This study has some limitations. First, only countries whose data are available within OECD countries are included in the sample. Therefore, it is not possible to generalize the results to all OECD countries. Secondly, due to the insufficient level of data on the variables, the time dimension of the research had to be limited. Third, apart from health expenditures, there are many factors affecting economic growth. Thus, the results are valid under the assumption of other factors ceteris paribus. As a suggestion within the scope of the research, new models can be produced by adding different indicators to models. Results can be compared across different country groups under similar indicators. In order to reveal how and at what level health expenditures affect the income levels of the countries, research can be done with dynamic panel data threshold models.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: https://stats.oecd.org/.

Author contributions

UC, EE, and MC organized and provided feedback on the writing of the manuscript. All authors contributed to the conception and design of the study, wrote the first draft of the manuscript, wrote sections of the manuscript, contributed to manuscript revision, read, and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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EDITED BY
Dilaver Tengilimoglu,
Atilim University, Turkey

REVIEWED BY
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University of Primorska, Slovenia
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Vahit Yigit,
Süleyman Demirel University, Turkey

*CORRESPONDENCE
Beata Gavurova
✉ gavurova@utb.cz

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Understanding the relationships between health spending, treatable mortality and economic productivity in OECD countries

Viera Ivankova[1], Beata Gavurova[2]* and Samer Khouri[1]

[1]Institute of Earth Resources, Faculty of Mining, Ecology, Process Control and Geotechnologies, Technical University of Košice, Košice, Slovakia, [2]Center for Applied Economic Research, Faculty of Management and Economics, Tomas Bata University in Zlín, Zlín, Czechia

Introduction: Population health is one of the highest priorities for countries, which can translate into increased economic prosperity. This encourages research on health in an economic context.

Methods: The objective was to assess the relationships between health spending, treatable respiratory mortality, and gross domestic product (GDP) in countries of the Organization for Economic Co-operation and Development (OECD). The research was conducted with respect to health systems (tax-based, insurance-based) and gender differentiation of the productive population (aged 25–64 years). Descriptive analysis, regression analysis, and cluster analysis were used to achieve the main objective. The data covered the period from 1994 to 2016.

Results: The results of the regression analysis revealed negative relationships between health spending and treatable respiratory mortality in countries with a tax-based health system for male and female working-age populations, as well as in countries with an insurance-based health system for male population. This means that higher health spending was associated with lower treatable respiratory mortality. Also, lower treatable mortality was associated with higher GDP, especially in the male productive population from countries with an insurance-based health system. In this study, countries with a tax-based health system were characterized by higher health spending, lower rates of treatable mortality from respiratory system diseases, and higher GDP compared to countries with an insurance-based health system. Males reported a higher mortality rate than females. Among the countries with a tax-based health system, the United Kingdom and Latvia showed less positive outcomes, while Italy and Iceland were the countries with the most positive outcomes. Among the countries with an insurance-based health system, Hungary and Slovakia reported poor outcomes, while France, Switzerland and Luxembourg were characterized by very positive outcomes. The United States showed a high mortality rate despite its high economic outcomes, i.e., health spending and GDP.

Discussion: Health care financing in particular is one of the instruments of health policy. It seems that the leaders of countries should ensure a

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sufficient level of health financing, as higher health spending can contribute to lower mortality rates in a country. This may translate into higher productivity. Especially countries with underfunded health systems should increase their health spending.

KEYWORDS

treatable mortality, respiratory diseases, health spending, GDP, health systems, OECD, productive population

1. Introduction

Population health is of great importance for the economic life of countries and is therefore constantly at the center of social, professional and political debates. Moreover, the coronavirus disease 2019 (COVID-19) pandemic reinforces this fact. Population health is in itself a great motivator for action to improve it, but the economic power of health is another driver for country leaders to make appropriate efforts. That is why public officials and experts strive every day to improve the health of a population, using a variety of tools to do so. Health spending is a common element of high-quality health care, adequate accessibility and efficient delivery of health services. It is health spending, that enables all these attributes of health systems to be achieved. In a health-economic context, health spending is considered growth-enhancing because it can increase both the quantity and productivity of labor by ensuring prolonged good health (1–3). All these facts encourage research on health in an economic context. If health systems are well designed, they should generate comparable results, and it is therefore possible to assess health indicators and confront them with economic indicators across countries (4, 5). One useful health indicator is treatable mortality, which reflects the effectiveness of health care and allows comparisons between countries and their applied health systems, suggesting the high economic potential of this indicator (6). Nevertheless, this indicator is still poorly understood and there is a clear need for research to examine the significant factors associated with treatable mortality in order to reduce the number of deaths and obtain potential health and economic benefits (7, 8).

The previous findings were the motivation for conducting this study, which focuses on examining the relationships between health spending, treatable mortality from respiratory system diseases among productive males and females, and gross domestic product (GDP) in countries of the Organization for Economic Co-operation and Development (OECD). This research was driven by the undeniable importance of the issue, as evidenced by the excessive health and economic losses worldwide. In addition, the current era is characterized by medical practices, knowledge and innovation which, if health systems and their financing are properly set up, should prevent premature deaths of productive people contributing to GDP. The COVID-19 pandemic highlighted these facts. This disease is mentioned several times in the study, as the research topic deals with treatable mortality from respiratory diseases. COVID-19 is an infectious disease that can lead to severe respiratory disease with the possibility of death. During the COVID-19 pandemic, many people died from treatable diseases, and at the same time, there was a disaster in health systems.

The issue of the relationship between health spending, treatable mortality, and economic productivity is still unclear, despite several studies that have been conducted. The originality of the paper lies in the fact that it examines all 37 OECD countries divided according to the applied health system. The presented research offers a comprehensive view of this issue in the OECD. In addition, COVID-19, which mainly affects the respiratory system, has increased the attention of researchers to this diagnosis group. This paper takes into account not only the applied health system but also gender differentiation and, in addition, focuses exclusively on treatable mortality from diseases of the respiratory system in the working-age population. To the best of our knowledge, such a perspective has not been used in any research.

2. Literature review

In general, treatable mortality is a health indicator that includes those causes of death that are expected to be averted through effective medical interventions in the form of appropriate treatment and secondary prevention (9). Such deaths can usually be averted by the age of 75 years. Evidence shows that treatable mortality contributes significantly to both overall and premature mortality despite its declining trend (8, 10). This was also confirmed by Nolte and McKee (11), who examined treatable mortality in 16 high-income countries and found that deaths from treatable diseases accounted for 24% of mortality in the population aged under 75 years. For these reasons, many studies have examined treatable mortality as a whole or within selected diseases (12–19). These studies confirm the fact that treatable mortality is widely recommended as an indicator of health systems performance over time, and, in combination with other indicators, is able to identify areas of the health system that need improvement. Comparative analyses using this indicator have the power to quantify differences in

health system performance between geographical locations and to show whether these differences diminish over time (20).

Following the above-mentioned findings, it is possible to point out large differences in treatable mortality between countries, but also between their regional areas. This was confirmed by Weber and Clerc (10), who focused their research on the countries of the European Union. Similar findings were revealed by Jarčuška et al. (21), who found an explicit difference in treatable mortality rates between more developed countries of Western, Northern and Southern Europe and less developed countries of Central and Eastern Europe. Nolte and Mckee (16) highlighted differences in treatable mortality between the United States and three European countries (France, Germany, and the United Kingdom) and concluded that the United States has a relatively high treatable mortality rate and lags behind the other three countries in terms of a slower decline. Differences among 32 OECD countries were also confirmed by Gianino et al. (18). At this point, it should be noted that significant differences can be observed not only at the geographical level, but also at the societal level (13, 22, 23). Gender differences in avoidable mortality, which includes treatable mortality, were confirmed in several studies (24, 25), with the results showing that males face a higher risk of death from avoidable diseases compared to females (26, 27). All these findings underline the need to take into account the variety of countries with different health systems, as well as gender considerations, when examining treatable mortality.

It is understandable that the objective of any country's health system is to eliminate treatable mortality, as this effort can translate into health and economic gains (28, 29). In this context, Jarčuška et al. (21) found a strong negative relationship between treatable mortality and life expectancy at birth in the European Union. The findings of Verstraeten et al. (30) also indicated that reductions in treatable mortality may lead to gains in life expectancy. This can translate into longer working lives for individuals and higher productivity for countries, resulting in economic benefits. From the opposite perspective, it can be pointed out that poor health status in a country may be reflected in other socio-economic areas such as reduced employment, reduced productivity of a population, increased need for social protection, or reduced economic performance or competitiveness, and these are the attributes that underpin developed countries. As the productivity of small and medium-sized enterprises in particular depends on a healthy working-age population in a country, the economic importance of health is indisputable (31, 32). Alkire et al. (33) argued that the unjustifiability of treatable deaths brings economic losses in the form of a decline in the GDP of countries. The authors also revealed that treatable deaths can cause a cumulative loss of economic output of $11.2 trillion in low- and middle-income countries between 2015 and 2030. At the same time, it is possible to develop the idea that treatable mortality contributes significantly to overall mortality, and thus a reduction in treatable mortality could also be reflected in overall mortality. In this context, reductions in population mortality have been shown to improve the attributes of countries' economic life, not least GDP and economic development (34, 35). It is for these findings that special attention should also be paid to treatable mortality and its reduction. In other words, reductions in treatable mortality are desirable from both a health and an economic point of view. Based on the above, there is an assumption about the relationship between treatable mortality from various causes and GDP.

Health care financing, represented by health spending, appears to play an important role in the issue of reducing treatable mortality. This is supported by the findings from Heijink et al. (36), which showed a statistically significant negative relationship between health spending and avoidable mortality, which includes treatable mortality in addition to preventable mortality. According to the authors, most countries with above-average growth in health spending also show an above-average reduction in avoidable mortality. Currie et al. (37) took a different perspective on the issue and also highlighted that increasing health care financing for deprived areas can contribute to a significant reduction in treatable mortality inequalities and can thus help to converge health outcomes between rich and poor areas. In terms of mortality as such, it also appears that health spending, together with other social factors, can contribute to improving the health status of the population. Based on the above, there is an assumption about the relationship between health spending and treatable mortality from various causes.

Mortality from diseases of the respiratory system is undoubtedly considered a health burden. This is evidenced by the fact that respiratory diseases accounted for 7.5% of all deaths in the European Union in 2016 (38). These diseases are also one of the major causes of avoidable premature mortality (39), with asthma and chronic obstructive pulmonary disease (COPD) being a worldwide public health problem (40, 41). Thus, the impact of respiratory diseases is considerable, which is why international organizations call for increased attention to be paid to the respiratory health of populations as a priority in public health decision-making (42). To make matters worse, COVID-19, caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has exacerbated already critical conditions (43). All of this can lead to huge economic losses, either in terms of significant costs for health services or in terms of lost production for businesses in general.

At this point, fragmented evidence should be pointed out. In terms of the economic nature of treatable mortality, the literature lacks a comprehensive view of respiratory disease mortality in the working-age population in OECD countries. Therefore, until this time, claims about relationships have been mere conjecture. Based on the current literature, the authors of this study set out to answer research questions focused on the diagnosis group of respiratory diseases. From

the above-mentioned findings, it can be concluded that aspects such as health spending, GDP, as well as health systems may play an important role in the issue of treatable mortality. It is also necessary to distinguish between male and female mortality. On this basis, the following research has taken all these aspects into account when examining treatable mortality from respiratory system diseases in the productive population (aged 25–64 years).

3. Methodology

3.1. Research objective

The main objective was to assess the relationships between health spending (HS), treatable mortality from respiratory system diseases (RSP) and gross domestic product (GDP) in OECD countries. The research was conducted with respect to the health systems applied in the countries, as well as gender differentiation.

With respect to the main objective, the following research questions were formulated:

- RQ1: Are there statistically significant relationships between HS and male/female RSP in OECD countries with a tax-based health system?
- RQ2: Are there statistically significant relationships between HS and male/female RSP in OECD countries with an insurance-based health system?
- RQ3: Are there statistically significant relationships between male/female RSP and GDP in OECD countries with a tax-based health system?
- RQ4: Are there statistically significant relationships between male/female RSP and GDP in OECD countries with an insurance-based health system?

3.2. Research data

International databases, namely those of the OECD and WHO, provided economic and health data for research purposes. These data covered the period from 1994 to 2016, and were collected for all available years (i.e., for each year in which a country reported a value). The study period was chosen based on the availability of a data base sufficient for the analysis. As it was data on the specific number of deaths for specific treatable diagnoses of the respiratory system individually for working-age females and males, the published data were limited. This type of data is updated with little regularity. This was included among the limitations of the research.

The analyses included two economic variables obtained from the OECD database. First, health spending (HS) as a total share (%) of GDP capturing final consumption of health care goods and services, including personal health care (curative care, rehabilitative care, long-term care, ancillary services and medical goods) and collective services (prevention and public health services, health administration), but excluding investment spending (44). Second, gross domestic product (GDP) representing economic activity in terms of the added value generated by production in a country in a given year. This variable was expressed in US dollars per capita (economy-wide PPPs) (45).

The only health variable was treatable mortality from respiratory system diseases (RSP) collected from the WHO database (46). This group of diagnoses was selected because of its frequent occurrence in the population. The variable captured deaths from respiratory causes that can be avoided by early and effective health interventions, including secondary prevention and treatment (after the onset of respiratory diseases to reduce mortality) (9). According to the OECD and Eurostat list, the following diagnoses were included in the group of treatable respiratory causes of death, identified by the International Classification of Diseases (ICD-10) codes: J00–J12, J15–J20, J22–J47, J80–J81, J85–J90, J93–J94, J98 (9). These mortality data were provided separately for each age and gender category, and the research presented in this study was on the productive population aged 25–64 years. Taking into account gender differentiation, the collected mortality data were recalculated per 100,000 females aged 25–64 years as well as per 100,000 males aged 25–64 years. Data on population were obtained from the United Nations database as part of the "World Urbanization Prospects" report (47).

3.3. Research subjects

The research covered all 37 OECD countries. These countries were selected on the assumption that they have a well-developed health system that provides both primary and specialized (secondary and tertiary) health care. Their common feature is the overcoming of various challenges, which may include the economic nature of health as an output of the efficiency of health systems aimed at improving the health status of the population. Each of the countries provides health care to different degrees, which may be reflected in the health status of the population, but the essence of each OECD country is to ensure a better life for the population while improving the prospects for stronger and more equitable economies and societies.

OECD countries divided into two groups based on their applied health system:

- Countries with a tax-based health system: Australia (AU), Canada (CA), Denmark (DK), Finland (FI), Iceland (IS), Ireland (IE), Italy (IT), Latvia (LV), Norway (NO), New Zealand (NZ), Portugal (PT), Spain (ES), Sweden (SE), the United Kingdom (GB);

- Countries with an insurance-based health system: Austria (AT), Belgium (BE), Chile (CL), Colombia (CO), the Czech Republic (CZ), Estonia (EE), France (FR), Germany (DE), Greece (GR), Hungary (HU), Israel (IL), Japan (JP), Korea (KR), Lithuania (LT), Luxembourg (LU), Mexico (MX), the Netherlands (NL), Poland (PL), Slovakia (SK), Slovenia (SI), Switzerland (CH), Turkey (TR), the United States (US).

In 14 countries the health system was tax-based and in 23 countries the health system was insurance-based. Latvia changed its health system from insurance-based to tax-based in 2011; therefore, only the most recent data were included in the analyses.

The classification of OECD countries in terms of health systems was based on criteria from surveys of health system characteristics in OECD countries in 2008, 2009, 2012, and 2016 (48, 49), on criteria from the Country Health Profiles in 2017 and 2019 (50, 51), as well as on data provided on the websites of the ministries of health of each of the analyzed countries. These criteria are offered in the original surveys and reports.

3.4. Statistical analysis

In the first statistical step, a descriptive analysis offered a first look at the data using measures such as arithmetic mean, median, standard deviation, quartiles, minimum and maximum, skewness and kurtosis. In the second statistical step, the significance of the relationships between HS, RSP and GDP was assessed by a panel regression analysis, in which robust methods were used to estimate the coefficients (HC3). The study used robust panel regression models with fixed or random effects. The Arellano method (fixed effects models) and the White 2 method (random effects models) were used to assess the significance of the coefficients. The relationships were analyzed in four variants of the models as follows: "One-way (individual) effect Fixed effect model" (Arellano), "One-way (individual) effect Random effect model" (White 2), "Two-ways effects Within (fixed) effect model" (Arellano), "Two-ways effects Random effect model" (White 2). Prior to this analysis, panel diagnostics was performed to select an appropriate regression model. The *F*-test for the presence of individual effects (or time effects) and the Hausman test were chosen to test the assumptions. In the last third statistical step, a cluster analysis was used to provide a multivariate view of the relationships. The silhouette method (52) was chosen to estimate the optimal number of clusters, and the Partitioning Around Medoids (PAM) method and the Manhattan distance (53) were chosen to determine individual clusters. Prior to conducting this analysis, male/female mortality data (RSP) were averaged over the observed period for each country. The economic variables (HS, GDP) were also averaged, but gender differentiation was not applied. Subsequently, the averaged variables were standardized on a scale of 0–1, with 1 meaning the most positive score and 0 meaning the least positive score. After this step, the score of the economic variables were averaged again to form one economic score for each country. This helped to create two variables evaluating economic variables and a mortality variable against which countries were assessed in the cluster analysis. In this way, the cluster maps enabled the classification of countries.

The analytical processing was performed in the programming language R v 4.1.1 (RStudio, Inc., Boston, MA, USA).

4. Results

This section presents the main results of descriptive analysis, regression analysis, and cluster analysis. All these analyses respected the classification by health systems and gender.

Table 1 presents the results of the descriptive analysis of the analyzed economic and health indicators. With a focus on HS, it can be concluded that countries with a tax-based health system reported a higher level of spending on health care (Mean = 8.68; Median = 8.69) compared to countries with an insurance-based health system (Mean = 7.98; Median = 7.13). In a tax-based health system, a minimum level was 5.40%, and this was the case for Latvia in 2013. Among countries with an insurance-based system, Korea showed a minimum level of 3.35% in 1995. From the opposite perspective, Sweden, as a country with a tax-based health system, reported a maximum level of 10.98% in 2014. In an insurance-based health system, a maximum level was 16.71%, which was reported by the United States in 2015. In terms of economic productivity, countries with a tax-based health system showed a higher level of GDP (Mean = 35,565.12; Median = 34,198.62) than countries with an insurance-based health system (Mean = 28,591.40; Median = 26,585.63). Among countries with a tax-based health system, a minimum level of 19,887.83 USD per capita was identified for Latvia in 2011, while Norway reported a maximum level of 66,956.29 USD per capita in 2013. In an insurance-based health system, a minimum level of 6,554.63 USD per capita was identified for Colombia in 1999 and a maximum level of 103,787.97 USD per capita for Luxembourg in 2015.

Table 1 also shows descriptive statistics for RSP as an indicator of treatable mortality in the productive population. In this case, in addition to classification by the health system, classification by gender was also applied. A first look at the results revealed that countries with an insurance-based health system reported a higher mean mortality rate for both males and females (Mean: males = 17.77; females = 8.05) compared to countries with a tax-based health system (Mean: males = 11.5; females = 7.98). From a gender point of view, males showed higher mortality rates than females in both health systems. In other words, males were disadvantaged in terms of RSP. In a

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TABLE 1 Descriptive statistics of economic indicators and treatable mortality from respiratory system diseases classified by gender and health system.

	Tax-based health system				Insurance-based health system			
	HS	GDP	RSP-M	RSP-F	HS	GDP	RSP-M	RSP-F
n	216	216	216	216	389	406	406	406
Miss	0	0	0	0	17	0	0	0
Mean	8.68	35,565.12	11.50	7.98	7.82	28,591.40	17.77	8.05
Median	8.69	34,198.62	9.64	7.13	7.15	26,585.63	16.23	7.67
St Dev	1.07	9,402.50	5.66	4.06	2.45	16,312.20	9.89	3.94
Skew	−0.25	0.80	2.28	1.05	1.16	1.51	1.33	0.99
Kurt	0.55	0.78	8.56	0.77	1.76	3.63	1.95	1.24
Min	5.40	19,887.83	3.49	2.35	3.35	6,554.63	2.76	1.82
Max	10.98	66,956.29	42.87	21.42	16.71	103,787.97	62.25	25.31
Q1	8.02	28,704.91	8.01	5.26	6.08	16,451.52	10.35	4.82
Q3	9.32	41,523.52	15.07	9.64	9.55	35,896.24	21.39	10.12

HS, health spending in % of GDP; GDP, gross domestic product per capita; RSP-M, treatable mortality from respiratory system diseases per 100,000 males aged 25–64 years; RSP-F, treatable mortality from respiratory system diseases per 100,000 females aged 25–64 years; n, number of observations; Miss, missing values; St Dev, standard deviation; Skew, skewness; Kurt, kurtosis; Min, minimum; Max, maximum; Q1, first quartile; Q3, third quartile.
Source own calculations based on available data (44–46).

tax-based health system, males reported an average of 3.52 more deaths per year due to respiratory diseases compared to females. A maximum rate was 42.87 deaths per 100,000 males aged 25–64 years, which was observed in Latvia in 2013. On the other hand, Iceland in 2015 showed a minimum rate of 2.35 deaths per 100,000 females aged 25–64 years. Focusing on countries with an insurance-based health system, males reported an average of 9.72 more deaths per year due to respiratory diseases than females. This also indicates that countries with an insurance-based health system were characterized by a larger gender gap in terms of RSP. Lithuania was identified as a country with a maximum mortality rate of 62.25 deaths per 100,000 males aged 25–64 years in 2007, while Korea reported a minimum rate of 1.82 deaths per 100,000 females aged 25–64 years in 2009.

Based on the above-mentioned results, it was possible to assume that there was a relationship between economic and health indicators, as countries with a tax-based health system that showed higher levels of economic indicators (HS, GDP) also showed lower mortality rates (RSP). On the other hand, countries with an insurance-based health system showed lower levels of economic indicators, but also higher mortality rates. The following regression analysis focuses on examining the significance of the relationships between HS, RSP and GDP, respecting the classification by health system and gender. However, prior to conducting the regression analysis, assumption testing was performed to select an appropriate regression model. The results of the test statistics are shown in Table 2.

Based on the results in Table 2, it can be stated that a one-way fixed effects model was preferred to assess the relationship between HS and RSP in a tax-based health system, as evidenced by the results of the *F*-tests indicating statistically significant effects only in the country structure and the results of the Hausman test indicating the choice of a fixed effects model (p-value < 0.05). In contrast, a one-way random effects model was recommended to assess the relationship between HS and RSP in an insurance-based health system, with the results of the *F*-tests showing statistically significant effects only in the country structure and the results of the Hausman test favoring the choice of a random effects model (p-value > 0.05).

When focusing on the relationships between RSP and GDP in a tax-based health system, the preference inclined toward a two-ways fixed effects model, as these cases showed statistically significant effects in the data structure for both countries and years, and their results of the Hausman test recommended a preference for a fixed effects model (p-value < 0.05). On the other hand, a two-ways random effects model was preferred to assess the relationships between RSP and GDP in an insurance-based health system, as the *F*-tests revealed statistically significant effects in the data structure for both countries and years, and the results of the Hausman test supported the choice of a random effects model (p-value > 0.05).

The following Table 3 provided the main results of panel regression models with fixed or random effects evaluating the significance of the relationships. It should be noted at this point that the authors' first intention was to show all of the original results of the panel regression models used, but in their interpretations the authors only considered the results of the recommended model, which was appropriate based on the

10.3389/fpubh.2022.1036058

TABLE 2 Testing the assumptions for the selection of regression models.

		F-test—countries (*p*-value)	*F*-test—years (*p*-value)	Hausman test (*p*-value)	Model
Tax-based health system					
Male	HS→ RSP	133.829 (<0.001)	1.065 (0.388)	4.759 (0.029)	One-way fixed
	RSP→ GDP	9.020 (<0.001)	7.417 (<0.001)	6.504 (0.011)	Two-ways fixed
Female	HS→ RSP	129.632 (<0.001)	1.311 (0.168)	8.578 (0.003)	One-way fixed
	RSP→ GDP	13.963 (<0.001)	5.960 (<0.001)	9.357 (0.002)	Two-ways fixed
Insurance-based health system					
Male	HS→ RSP	104.373 (<0.001)	0.346 (0.998)	0.026 (0.871)	One-way random
	RSP→ GDP	57.540 (<0.001)	3.757 (<0.001)	0.026 (0.871)	Two-ways random
Female	HS→ RSP	101.935 (<0.001)	0.344 (0.998)	0.229 (0.632)	One-way random
	RSP→ GDP	64.463 (<0.001)	3.955 (<0.001)	0.259 (0.611)	Two-ways random

HS, health spending in % of GDP; RSP, treatable mortality from respiratory system diseases per 100,000 males/females aged 25–64 years; GDP, gross domestic product per capita. Source own calculations based on available data (44–46).

testing of assumptions for the selection of the regression models. Their results were accepted.

In each analyzed case, the balance statistics of the panel regression models argued in favor of considering a balanced model. This was supported by the acquired values of gamma (γ) and nu (ν). The closer their value was to 1, the more balanced the panel seemed. In terms of countries with a tax-based health system, the values were $\gamma = 0.8463299$ and $\nu = 0.9060825$ when evaluating all the relationships. In terms of countries with an insurance-based health system, the values were $\gamma = 0.7470208$ and $\nu = 0.9352060$ when evaluating the relationships between HS and RSP, and $\gamma = 0.7376557$ and $\nu = 0.9380606$ when evaluating the relationships between RSP and GDP. The coefficients of determination (R2) were informative only and did not need to be considered in terms of model strength. The low value was due to the relatively low number of observations as a result of the classification structure of the panel data.

The results of the regression models provided in Table 3 revealed several significant relationships between the analyzed variables. Focusing on the recommended models in assessing the relationships, it can be concluded that HS was associated with RSP in both health systems and both gender categories.

Statistical significance at the level of $\alpha < 0.05$ and negative coefficient estimates can be observed in countries with a tax-based health system in the population of males and females of productive age. This indicates that in these countries higher HS was associated with lower RSP, and vice versa. On this basis, it can be expected that in a country with a tax-based health system, the number of treatable deaths from respiratory system diseases in the productive population would decrease with an increase in HS.

In countries with an insurance-based health system, the situation was different. In the population of productive males, a significance of the relationship between HS and RSP was confirmed at the level of $\alpha < 0.001$, and the coefficient estimate was again negative. In the population of productive females, statistical significance was confirmed at the level of $\alpha < 0.05$, but in this case the coefficient estimate was positive. As mentioned above, a negative coefficient indicates that higher HS was associated with lower RSP, and vice versa. Conversely, a positive coefficient is indicative of the fact that in countries with an insurance-based health system, lower HS was observed along with lower RSP in the female productive population, and vice versa.

Either way, HS played an important role in RSP, especially for the productive population in countries with a tax-based health system and the population of productive males in countries with an insurance-based health system.

A significant relationship between RSP and GDP was confirmed only for productive males in countries with an insurance-based health system, with statistical significance at the level of $\alpha < 0.01$. In this case, RSP was negatively associated with GDP. This means that fewer treatable deaths from respiratory system diseases among productive males were associated with higher GDP, and vice versa. This was true in countries with an insurance-based health system.

Looking at the results, it is possible to speculate that time explains changes in countries' economic productivity (GDP) to a greater extent than RSP. It can be assumed that the treatment of respiratory diseases requires high spending, thus draining resources in the economy, and this burden may also be reflected in the relationship between RSP and GDP.

The following cluster analysis was conducted to point to homogeneous groups of countries based on their economic (HS, GDP) and health (RSP) outcomes. In addition, this made it possible to assess each country in comparison with

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TABLE 3 Panel regression analysis—relationships between economic and treatable mortality indicators classified by gender and health system.

			One-way random	One-way fixed	Two-ways random	Two-ways fixed
Tax-based health system						
Male	HS→ RSP	R^2	0.166	0.122	0.120	0.029
		α	19.67***		19.65**	
		β	−0.81***	**[−0.76*]**	−0.81	−0.55
	RSP→ GDP	R^2	0.096	0.084	0.142	0.064
		α	44707.60***		30632.46***	
		β	−789.75***	−1148.59**	80.08	**[362.37]**
Female	HS→ RSP	R^2	0.129	0.132	0.001	0.037
		α	13.14***		12.70***	
		β	−0.61***	**[−0.62*]**	−0.53*	−0.43**
	RSP→ GDP	R^2	0.085	0.118	0.008	0.021
		α	44408.84***		30925.14***	
		β	−1213.82***	−1747.85**	100.05	**[298.54]**
Insurance-based health system						
Male	HS→ RSP	R^2	0.032	0.026	0.082	0.001
		α	23.07***		22.18***	
		β	**[−0.75***]**	−0.72	−0.63***	0.14
	RSP→ GDP	R^2	0.110	0.099	0.198	0.026
		α	39654.84***		30004.27***	
		β	−633.19***	−622.65*	**[−176.19**]**	−147.37
Female	HS→ RSP	R^2	0.015	0.011	0.035	0.001
		α	6.27***		6.50***	
		β	**[0.20*]**	0.19	0.17	0.02
	RSP→ GDP	R^2	0.005	0.001	0.028	0.001
		α	28548.15***		27040.36***	
		β	7.24	63.79	**[−28.50]**	−14.18

Sig.: ***p-value < 0.001, **p-value < 0.01, *p-value < 0.05, · p-value < 0.1.
HS, health spending in % of GDP; RSP, treatable mortality from respiratory system diseases per 100,000 males/females aged 25–64 years; GDP, gross domestic product per capita.
The accepted results are highlighted in bold and brackets [].
Source own calculations based on available data (44–46).

other countries applying the same health system. This health-economic assessment also respected gender differentiation, as males were more vulnerable in terms of mortality. It should be noted that the change in a country's position was driven by mortality outcomes separately for males and females, as the economic outcomes were the same for the entire population of a country. The upper right quadrant represents the most positive position, while the lower left quadrant represents the least positive position in terms of the assessment of countries.

With a focus on the cluster maps presented in Figure 1, it can be stated that two clusters were recommended by the silhouette method to assess countries with a tax-based health system based on their economic outcomes (HS, GDP) and mortality outcomes (RSP) in the female population, and three clusters in the male population. Regarding the left cluster map, which took into account economic outcomes and female mortality, countries such as Denmark, the United Kingdom, Latvia and New Zealand were included in the second cluster with less positive assessment positions. On the other hand, Italy, Iceland, but also other countries were the countries in the first cluster that showed the most positive positions.

Focusing on the right cluster map, which covered the male population, only Latvia was in the third cluster. This country showed the least positive economic and mortality outcomes.

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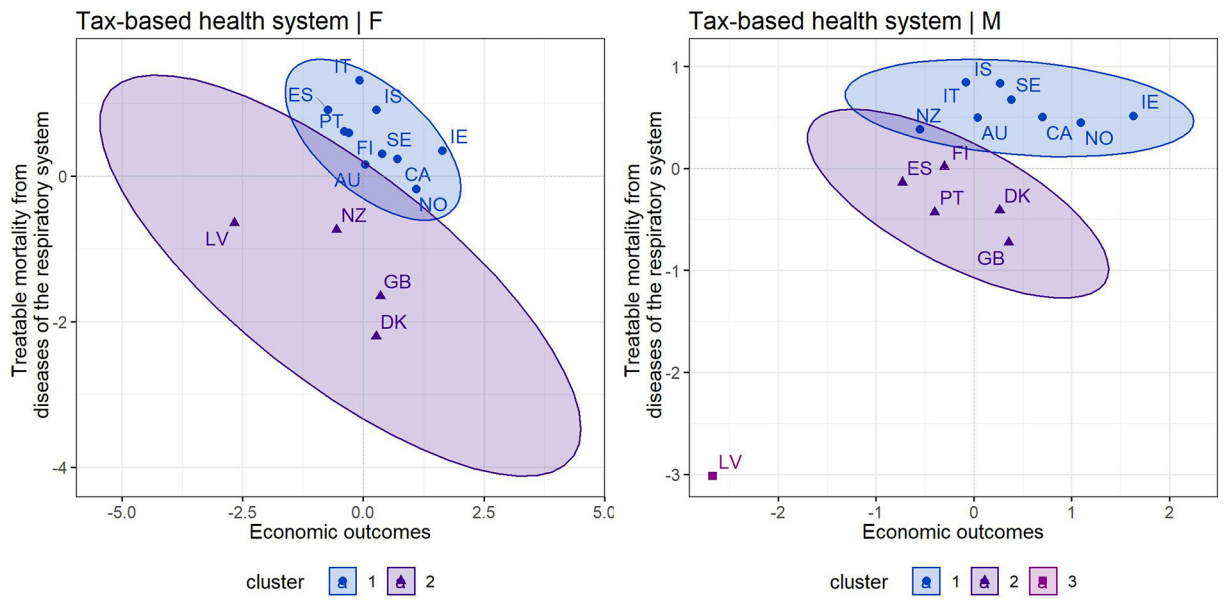

FIGURE 1
Cluster maps of countries applying a tax-based health system [left—female population, right—male population) [Source own processing based on available data (44–46)].

The second cluster included the United Kingdom, Denmark, Portugal, Finland and Spain. The most positive positions were represented by the countries in the first cluster, namely Iceland, Italy, Sweden, Canada, Norway, Ireland, but also New Zealand and Australia. At this point, several findings should be emphasized. In addition to the least positively assessed Latvia, developed countries such as Denmark and the United Kingdom also showed less positive outcomes, especially in terms of mortality outcomes in both male and female populations. Interestingly, while Spain, Portugal and Finland were among the more positive countries in terms of female mortality, they were among the poorer countries in terms of male mortality. The opposite situation was observed in New Zealand. Overall, countries such as Ireland, Norway, Canada, Sweden, Iceland and Italy were very positive from a health-economic perspective.

Figure 2 shows the cluster maps for countries that apply an insurance-based health system. It can be noted that six clusters were identified for the assessment of economic outcomes (HS, GDP) and female mortality outcomes (RSP), while two clusters were identified for the assessment of economic outcomes and male mortality outcomes. With a focus on the left cluster map, which took into account the female population, attention should be paid to the United States (cluster 6), which reported a high mortality rate despite high economic outcomes, i.e., HS and GDP. This cannot be considered positive. Hungary (cluster 5) also showed a very poor position, indicating lower economic outcomes as well as a high mortality rate. Other less positive countries with an insurance-based health system were Colombia, Mexico or Slovakia. On the other hand, countries such as France, Switzerland, Luxembourg and Austria were among the countries with the most positive assessment positions.

Looking at the right cluster map covering the male population, countries such as Lithuania, Hungary, Estonia and Slovakia from the second cluster had the least positive positions, i.e., they showed the least positive economic and mortality outcomes. The first cluster included the countries with the most positive outcomes, in particular France, Switzerland, Luxembourg, Austria, but also others. The United States was considered an outlying country. In this case, given the high economic outcomes, a more positive mortality rate was expected.

5. Discussion

It goes without saying that developed countries consider the health of their populations to be one of their highest priorities and adjust their financing accordingly. It is clear from public databases that health spending has been growing in most OECD countries and, moreover, some countries have shown that their health spending has consistently grown faster than the rate of GDP growth (44). This study revealed that countries with a tax-based health system reported higher health spending than countries with an insurance-based health system. At the same time, countries with a tax-based health system showed lower rates of treatable mortality from respiratory system diseases compared to countries with an insurance-based health system.

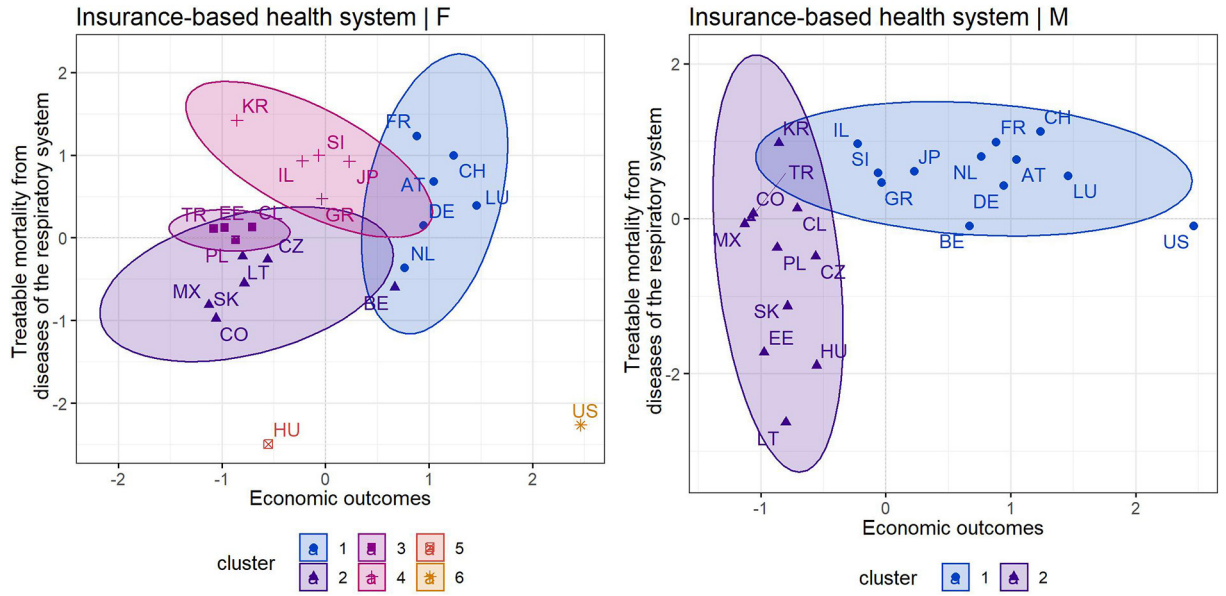

FIGURE 2
Cluster maps of countries applying an insurance-based health system [left—female population, right—male population) [Source own processing based on available data (44–46)].

Finally, in terms of economic productivity, countries with a tax-based health system showed higher GDP than countries with an insurance-based health system. All of this contributes to understanding the economic perspective of treatable mortality (6). The findings also point to the wellknown fact that males face a higher risk of death from avoidable diseases compared to females (26, 27). In general, even Kim (54) agreed that the survival probability of males is disadvantaged compared to the survival probability of females. According to this author, socioecological factors play an important role in the issue of life expectancy and humans' survival probability of becoming centenarians. The different habits and health behaviors of males should also be emphasized. In this way, they are characterized by delaying seeking health care, non-adherence to treatment, premature discontinuation of treatment, as well as ignoring and downplaying health problems (55). Thus, the gender aspect should not be overlooked when designing effective interventions aimed at reducing treatable mortality in the productive population.

The study demonstrated that health spending is one of the important factors that should be considered when addressing treatable mortality from respiratory system diseases in the productive population. Comparable negative relationships were observed in countries with a tax-based health system for male and female populations, as well as in countries with an insurance-based health system for male population. This means that higher health spending was associated with lower treatable mortality. However, a positive relationship was found in countries with an insurance-based health system for the female population. In any case, diseases and acute inflammations of the upper and lower respiratory tract or pneumonia are widespread in the whole population; therefore, special attention should be paid to this group of diagnoses. The year 2020, in which the COVID-19 pandemic was in full force globally, is the year when it became clear that these diseases with viral infections can be very critical to health. At the same time, the pandemic showed the important role of health spending, as it made it possible to provide the necessary health care at a time when it was more than needed (56, 57). The results of the presented study also contribute to the understanding of this issue. In general, it can be agreed that health spending can help to reduce mortality and increase life expectancy, which is consistent with other studies (58–61). According to Makuta and O'Hare (62), public spending on health has a significant impact on health outcomes. Thus, public spending on health improves health outcomes. The findings of Budhdeo et al. (63) showed that a 1% decrease in health spending, measured as a share of GDP, was associated with a significant increase in all mortality metrics. This was confirmed in the short and long term. Therefore, policy measures taken in response to the pandemic should focus on health care financing in order to avoid a deterioration in the health status of the population. Lest it be forgotten, there are various health care resources, including health care facilities, a number of health professions, vaccinations, which may play an important role along with health spending (64).

In fact, every country should strive to reduce treatable mortality using all available tools, including health spending. These efforts lead to other beneficial consequences. According

to Kiadaliri (65), reductions in avoidable (treatable and preventable) mortality can be clearly reflected in life expectancy. This may also bring economic benefits such as longer productive life and increased productivity of the population. The importance of this is underlined by the statements of international organizations that healthy populations are drivers of economic life, whether in terms of their higher productivity, longer working lives, or reduced burden of health and social spending (66, 67). Last but not least, health is a source of comparative economic development of countries (68). In the light of the results of this study, lower treatable mortality from respiratory system diseases was associated with higher GDP, especially in the male productive population from countries with an insurance-based health system. This is consistent with the findings of Fantini et al. (69), who also found a negative relationship between mortality and GDP per capita. In addition, Alkire et al. (33) emphasized that economic losses, such as a decrease in GDP, can be expected due to treatable mortality. In other words, reductions in mortality can be reflected in economic benefits (34). All of these findings suggest that public policy-makers need to recognize that if premature and treatable deaths did not occur, productive populations could continue to generate economic gains (35).

Population health should be a central social, professional and political issue, and general efforts should focus on improving it, which can bring economic additional benefits. Treatable mortality indicates the extent of a health system's contribution to population health, and it is important to look at this indicator when assessing health systems that vary by funding model (6). This study showed that countries within a single health system can be further sorted into several clusters, distinguishing between countries with less positive outcomes and countries with more positive outcomes. In this context, the United Kingdom and Latvia were among the countries with a tax-based health system that showed less positive outcomes. On the other hand, Italy and Iceland were the countries with the most positive outcomes. Among the countries with an insurance-based health system, Hungary and Slovakia had poor outcomes, while France, Switzerland and Luxembourg were characterized by very positive outcomes. The United States showed a high mortality rate despite its high economic outcomes, i.e., high health spending and GDP. The results clearly showed that countries vary from each other despite implementing the same health system, and they can be compared with other studies that have examined a similar problem (16, 18, 21, 70).

The difficult current period requires active efforts to improve the health status of the productive population, including a reduction in treatable mortality. To achieve this, the development and implementation of successful health policies and continuous improvement of health systems with sustainable and adequate health care financing are essential.

5.1. Implications for public policies

It is desirable for policy makers to use evidence on the relationship between population health and the economic life of countries. The presented study offers this evidence and supports the strengthening of health systems, which can translate into better population health and increased economic prosperity. This is both the objective and the challenge of every public health system. Health spending appears to be an aspect that can contribute to some extent to good health translating into the productivity of the economy. With a focus on the research presented in this study, treatable mortality is an important health indicator on which many surveys comparing countries and their health systems are based. The study contributes to the formulation of health policies and provides a supportive approach to the development of strategic plans with respect to particular diagnosis groups and gender specificities. Health care financing in particular is one of the instruments of health policy, and policy makers are in a unique position to adopt and promote evidence-based measures in an effort to improve population health, increase health system efficiency, as well as enhance economic productivity, which is linked to the competitiveness of countries in international comparisons. It seems that the leaders of countries should ensure a sufficient level of health financing, as higher health spending can contribute to lower mortality rates in a country. This may translate into higher productivity. Especially, countries with underfunded health systems should increase their health spending.

5.2. Limitations

Limitations of the study include the fact that it focuses only on OECD countries with two models of health systems and therefore its results cannot be generalized to other less developed countries or countries with different health systems. The unbalanced structure of the panel data can also be considered a limitation. This may have been due to the specific focus on a particular group of diagnoses, with not all countries publishing their health outcomes in detail. On the other hand, the study includes all available country-reported data. Regarding the limitations of the models, causality was not examined; therefore, the relationships revealed in the study cannot be seen as causal. All results can only be considered in terms of associations, and reasoning about causal relationships can be misleading. As it was data on the specific number of deaths for specific treatable diagnoses of the respiratory system individually for working-age females and males, the published data were limited. This type of data is updated with little regularity. As this was an overall view of the situation in the OECD across several classifications, it was not possible to filter the data further. Another limitation is that only health spending was considered. It is necessary to recognize that health spending is not the

only important factor of treatable mortality that is related to the health system. There are many factors that the study did not account for. Future research should focus on other factors such as quality and accessibility of health care, qualifications of doctors, working conditions, equipment of health facilities, availability of medicines, and management of health facilities. At the same time, other socio-economic and environmental determinants of health should also be considered.

6. Conclusion

Deaths from respiratory system diseases that can be averted through health care need increased attention, especially in the context of the COVID-19 pandemic. This study emphasizes an economic perspective of this problem. The main objective was to assess the relationships between health spending, treatable mortality from respiratory system diseases and GDP in OECD countries, with the productive population as the focus of the research. The research was carried out taking into account the health systems implemented in these countries as well as gender differentiation. The main finding highlighted the important role of health spending in treatable mortality in countries with both tax- and insurance-based health systems. In this way, higher health spending can be expected to lead to lower treatable mortality from respiratory system diseases. Lower treatable mortality was associated with higher economic prosperity (GDP), especially in the male productive population from countries with an insurance-based health system. On this basis, the leaders of countries should ensure a sufficient level of health financing. Higher spending on health could help countries from both a health and economic point of view, and this should not be forgotten in the creation of public policies. In particular, countries with underfunded health systems should increase their health spending. In this study, countries with a tax-based health system were characterized by higher health spending, lower rates of treatable mortality from respiratory system diseases, and higher GDP compared to countries with an insurance-based health system. The results of the study provide a closer look at the health systems applied in OECD countries. In this context, the consideration of health systems is undoubtedly beneficial for future research efforts.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://data.oecd.org/healthres/health-spending.htm#indicator-chart, https://data.oecd.org/gdp/gross-domestic-product-gdp.htm, https://www.who.int/data/data-collection-tools/who-mortality-database?fbclid=IwAR2gVBBqbMEUf6Y1g505FjN_hg77TkINf_VWGO3-efYrTr-J9sC7_Wkpy7Q, https://www.oecd.org/health/health-systems/Avoidable-mortality-2019-Joint-OECD-Eurostat-List-preventable-treatable-causes-of-death.pdf, https://population.un.org/wup/.

Ethics statement

Ethical approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

VI: conceptualization, methodology, formal analysis, investigation, resources, writing—original draft preparation, visualization, writing—review and editing, and supervision. BG: conceptualization, visualization, writing—original draft preparation, writing—review and editing, supervision, project administration, and funding acquisitions. SK: data curation, writing—original draft preparation, visualization, writing—review and editing, supervision, and funding acquisitions. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Aysu Zekioglu,
Trakya University, Türkiye

REVIEWED BY
Limei Jing,
Shanghai University of Traditional Chinese Medicine, China
Fahd Jarad,
Cankaya University, Türkiye

*CORRESPONDENCE
Elif Boduroglu
✉ bodurogluelif@gmail.com

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Phase and wave dependent analysis of health expenditure efficiency: A sample of OECD evidence

Elif Boduroglu[1]*, Kazim Baris Atici[2] and Tolga Omay[3]

[1]Business Department, Atilim University, Ankara, Türkiye, [2]Department of Business Administration, Hacettepe University, Ankara, Türkiye, [3]Economics Department, Atilim University, Ankara, Türkiye

Introduction: Health expenditures are a factor that reflects the government's public health policy and contributes to the protection of national health. Therefore, this study focuses on measuring the effectiveness of health expenditures in order to evaluate and improve the public health system and policy during the pandemic period.

Method: In order to examine the effectiveness of health expenditures, the behaviors of the pandemic process were analyzed in two stages. The number of daily cases is analyzed in the first stage by dividing it into waves and phases according to the transmission coefficient (R). For this classification, the discrete cumulative Fourier function estimation is used. In the second stage, the unit root test method was used to estimate the stationarity of the number of cases in order to examine whether the countries made effective health expenditures according to waves and phases. The series being stationary indicates that the cases are predictable and that health expenditure is efficient. Data consists of daily cases from February 2020 to November 2021 for 5 OECD countries.

Conclusion: The general results are shown that cases cannot be predicted, especially in the first stage of the pandemic. In the relaxation phase and at the beginning of the second wave, the countries that were seriously affected by the epidemic started to control the number of cas es by taking adequate measures, thus increasing the efficiency of their health systems. The common feature of all the countries we examined is that phase 1, which represents the beginning of the waves, is not stationary. After the waves fade, it can be concluded that the stationary number of health cases cannot be sustainable in preventing new waves' formation. It is seen that countries cannot make effective health expenditures for each wave and stage. According to these findings, the periods in which countries made effective health expenditures during the pandemic are shown.

Discussion: The study aims to help countries make effective short- and long-term decisions about pandemics. The research provides a view of the effectiveness of health expenditures on the number of cases per day in 5 OECD countries during the COVID-19 Pandemic.

KEYWORDS

COVID-19 daily cases, OECD, health expenditure efficiency, wave and phase dependency, cumulative Fourier transform, unit root testing

1. Introduction

Increasing the effectiveness of health systems during pandemics that leave severe problems in economic and social welfare at the global level will increase the level of resistance against the health shocks that countries have to manage (1). It has therefore led to an examination of the capacities and capabilities of national economies worldwide to prevent, detect, and rapidly respond to the emergence of infectious diseases and other acute forms of public health hazards. Health systems that can respond effectively to such health threats also have a significant advantage in reducing their adverse health, social and economic consequences (2).

The effectiveness of health expenditures is the evaluation of expenditures made by the health system by considering factors such as efficiency, usefulness, and quality. Effective health expenditures aim to be achieved with the minimum cost to provide the highest possible quality of service (3). During epidemics, the importance of health expenditures increases to provide the necessary tools and services to contain the epidemic and prevent the spread of the disease. In addition, health expenditures can increase the capacity to protect and treat the diseases caused by the epidemic and allow society to respond healthily (4). The effectiveness of health expenditures during epidemic periods is significant in preventing the spread of the disease and maintaining a healthy society (5).

For this reason, there are many studies on the effectiveness of health expenditures. In the literature, studies on the effectiveness of health expenditures have been examined with parametric and non-parametric methods. Among non-parametric methods, Data Envelopment Analyse (DEA), free disposal hull (FDH) technique and Malmquist efficiency index were frequently used; parametric methods are OLS, COLS, stochastic frontier approach (SFA), correlation and regression analysis, tobit model, global generalized directional distance function, spatial Durbin model, panel models, econometric models such as unit root tests (1, 6–13). From all this literature, we evaluated that there is no consensus on the theoretical or statistical criteria that should be explicitly used to conduct empirical analyses with short- or long-term data to measure the effectiveness of health expenditures (14). Each method has its advantages and disadvantages, and which is most appropriate may vary depending on the problems and objectives being measured.

Unlike the methods used in the literature, this study presents an indirect test method to measure the efficiency of health expenditure or investment during the COVID-19 period. We derived the equation to indirectly test health expenditure efficiency based on the statistical structure of the series of COVID-19 cases and proved this hypothesis in the proceeding sections. This methodological procedure offers a different approach to testing health expenditure efficiency and is a candidate to contribute to this literature. A new constraint is imposed on the Fourier ADF test using wave structure. Therefore, we have proposed a new approach to the cumulative Fourier ADF tests. Therefore, the results of this study show the efficiency of health expenditure during the COVID-19 epidemic.

Examining the pandemic process from February 2020 to November 2021, this study analyses new daily cases using the Cumulative Fourier function. The study split the country's case numbers into waves and phases according to the contagion coefficient (R). Then, it applies a unit root test to investigate the stationarity of the phases. The results show the effectiveness of health expenditures in waves and phases where case numbers are stationary. The results show that the onset of waves (Phase 1) is unpredictable and a unit root process. However, as expected, the daily cases process is becoming predictable, resulting from stationarity. Therefore, we are in a position to determine the health expenditure efficiency by using only daily cases. This computationally easy result is emerging from our proposed theoretical foundation proposition 1. In proposition one, we have shown that we can test whether the health expenditure efficiency can be checked from the daily COVID cases predictability.

The results of this study can help determine the direction of studies to increase the health expenditure efficiency of countries. In addition, this method does not have to be used only for testing the health expenditure efficiency of the COVID-19 outbreak. It may also be a suitable approach for future epidemics or diseases. At the same time, the applicability of these methods to evaluate productive investments in other sectors, such as the energy, agriculture, or tourism sectors, can be explored.

In conclusion, this study offers a new and unique method to test whether health expenditures are efficient or not. This method uses a unit root test that considers the phase and wave structure. Thus, it shows that the unit root test indirectly measures health expenditures' efficiency using the daily COVID cases. The study points out the importance of efficient use of health expenditures and contributes to previous studies.

2. Data and methodology

2.1. Data

The effectiveness of health systems in OECD countries is analyzed based on data presented in the Systematic dataset of the COVID-19 policy Report published by Oxford University (2022). Country COVID-19 data are taken from the public website of The Oxford COVID-19 Government Response Tracker (OxCGRT). The start dates of the new case data used in the study differ according to the countries. As seen in Table 1, the initial dates of the data start according to the case reporting date of the countries in February 2020. The data expiry date also differs from country to country. The expiry date of the data ends in November 2021. This end-day differs for some reason, such as the start of the Omicron variant, the relaxation of the stiffness index measures on a country-by-country basis, or changes in testing policies. For the sample, Australia (AUS), Canada (CAN), Germany (DEU), France (FRA), and America (USA) are countries within the group of advanced economies, among the top 10 in the human development index (2020–2021), and relatively high populations among OECD countries have been selected. Thus, it is aimed to create a homogeneous sample by considering developed countries in the study.

TABLE 1 Data statistics.

Country	Date range	Observations
AUS	26.01.2020–2.11.2021	646
CAN	26.01.2020–3.11.2021	647
DEU	27.01.2020–4.11.2021	647
FRA	24.01.2020–30.09.2021	615
USA	22.01.2020–10.11.2021	658

2.2. Hypothesis and the theoretical fundamentals

Daily COVID-19 case data was used to indirectly measure the effectiveness of health expenditure. There are studies in the literature in which many different methods use health expenditure data. In the literature, inpatient beds, medical technology indicators, and health employment are often examined to measure the effectiveness of health expenditures, while variables of the human development index (Life expectancy, infant mortality, infection deaths, etc.) and economic indicators (GDP, Health Expenditure per Capita, etc.) used in many studies (7, 15–17). As can be seen, the variables that measure the effectiveness of the health system examined in the literature generally have annual data. The annual data review does not allow a short-term strategy to contain such a pandemic period. In the non-annual studies conducted for the COVID period, a specific date range was taken, and comparisons were made between countries. In country comparisons made within a specific date range, since countries are caught in waves at different times, simultaneity cannot be obtained, and this makes it difficult for countries to compare their efficiency (1, 18–20). Our methodological approach preserves sample homogeneity when considering the abovementioned methodologies.

However, the point where these studies have the most difficulty and cannot reach the data is the absence of daily health data or the fact that daily health expenditures affect the data later and show effectiveness in these data in the long term. One of the significant problem encountered in the studies conducted to examine the COVID-19 period and its effects arises as being faced with a data set that is very difficult to measure in monetary terms. Moreover, the measurement of economic losses and indirect health expenditures due to daily closures also seems problematic. It is impossible to reach health expenditure data due to the implicit nature of many health expenditures, at least within the framework of the COVID-19 period. In order to overcome these measurement limitations, the hidden information in the number of daily cases of the COVID-19 was utilized in the study. If the number of cases can be brought under control or reduced, a structure emerges that we can call health expenditures effective or ineffective. The stability or controllability of data can be checked from the stochastic properties of that data. If the data we are interested in is stationary, that means that the data is under control. Data that is under control can be predicted for the long term. If the long-term can be predicted, then health expenditures can be changed accordingly, and efficiency can be increased. This chain of actions can show different dynamics in each wave and the phase of each wave. If covariance stationarity can be achieved in each wave's phase, then the case numbers in that case are under control. We can express this more formally as follows:

Lemma 1. Let y_t be the number of cases per day. The number of cases per day is an indicator of health expenditure.

Proof

$$HE = f(S, V, ...)$$

Health expenditure depends on many variables (stringency: S and vaccine: V). The same variables are also function of the number of COVID-19 cases $C = f(S, V, ...)$. As we know from the SIR models, the contamination coefficient R, especially $R = f(S, V)$, is a function of these two variables. As the stringency S and vaccine V increase, the contamination coefficient R decreases. We have come to the point where we can only show the daily number of cases from the transmission or contamination coefficients. In addition to this, health expenditure also contains the same data in its functional structure with a positive relationship, contrary to the number of cases. Since the relationship is as follows $HE = f(R) \nearrow\rightarrow C = f(R) \searrow$, health expenditure efficiency can be detected following this relationship. Hence, decreasing number of daily cases indicate the health expenditure efficiency.

Proposition 1. Let y_t is the daily COVID-19 cases where y_t satisfies these conditions $y_t \rightarrow E(y_t) = \mu$, $E(y_t^2) = \sigma^2$, and $E(y_{t-s}, y_{t-j}) = \sigma$, s $\neq$ j $\rightarrow$ hence, this condition provides the health expenditure efficiency independent of other conditions.

Proof

It has shown that the $C = f(R)$ in Lemma 1. The contamination rate R is calculated from the two consecutive day, hence, $R \cong f\left(\frac{y_t - y_{t-1}}{y_{t-1}}\right)$. If this ratio is 1, $\frac{y_t - y_{t-1}}{y_{t-1}} = 1$, then one person contaminated only one another person. If this ratio decreases then the contaminated one person contaminated less than one person and vice versa. Let us consider the contamination coefficient α for equal and less than case $\frac{y_t - y_{t-1}}{y_{t-1}} \leq \alpha$. Now multiply both side of the inequality with y_{t-1}; $y/_{t-1}\frac{y_t - y_{t-1}}{y/_{t-1}} \leq \alpha y_{t-1}$. And more over including the stochastic error term to this deterministic relation, we obtained this equation $y_t - y_{t-1} \leq \alpha y_{t-1} + u_t$. With some algebra, we can obtain this form $\Delta y_t \leq \alpha y_{t-1} + u_t$ which is very well-known Dickey and Fuller unit root test (21). If the ADF test result showed that the null hypothesis was rejected or the alternative hypothesis accepted $\alpha \leq 0$ then this means that y_t satisfies the following conditions, $y_t \rightarrow E(y_t) = \mu$, $E(y_t^2) = \sigma^2$, and $E(y_{t-s}, y_{t-j}) = \sigma$, s $\neq$ j. By using this proof for Proposition 1 and the proof from Lemma 1 showing that the stationarity of daily cases provides the health expenditure efficiency result.

Corollary 1. The conditions in Proposition 1 of daily case numbers with waves and phases can only be met by each phase or demanded series by cumulative Fourier function.

Proof

Let the cases estimated by the following function $y_t = \beta_1 + \alpha y_{t-1} + WP_t + u_t \rightarrow WP_t = \phi(t)$. By using Fourier Representation Theorem that the cumulative Fourier functions estimated or approach to the wave and phases one to one $\phi(t) = \alpha_0 + \sum_{i=1}^{n} \alpha_i \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \beta_k \cos\left(\frac{2\pi kt}{T}\right)$. By using stochastic difference equation or simply a regression analysis we can find the best

approximating n value for the cumulative Fourier transform where the n shows the number of cumulating. By using residual sum of square value $u_t^2 = f(\beta)$ where $\beta = (\alpha_0, \alpha_1, ..., \alpha_n, \beta_1, \beta_2, ..., \beta_n)$ we find the best fitting n. Ordinary least square (OLS) $\beta = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\mathbf{Y}$ is the optimization algorithm for finding the $\min_{\beta}(u_t^2)$ $y_t^* = y_t - \alpha_0 + \sum_{i=1}^{n}\alpha_i \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n}\beta_k \cos\left(\frac{2\pi kt}{T}\right) \rightarrow y_t^* = u_t$. Shortly we can demonstrate by this equation $y_t^* = \alpha^* y_{t-1}^* + u_t^*$. Hence the condition in Proposition 1 is satisfied. The condition now is satisfied with demeaned data, fortunately we can also divide the sample in to phase and wave by using the cumulative Fourier function and hence the conditions are also satisfied for each wave's phase as well. When we take the first derivative with respect to time and equating it to zero $\frac{d\phi(t)}{dt} = 0$ we will obtain the optimum points of cumulative Fourier trend. The condition which we know from differential equation can be obtained by difference equation as follows: $\Delta\phi(t) = \alpha_0 + \sum_{i=1}^{n}\alpha_i \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n}\beta_k \cos\left(\frac{2\pi kt}{T}\right) - \alpha_0 + \sum_{i=1}^{n}\alpha_i \sin\left(\frac{2\pi k(t-1)}{T}\right) + \sum_{k=1}^{n}\beta_k \cos\left(\frac{2\pi k(t-1)}{T}\right) = 0$. In a more compact form $\Delta\phi(t) = \left(\sum_{i=1}^{n}\alpha_i(\sin_t - \sin_{t-1})\right) + \left(\sum_{i=1}^{n}\beta_i(\cos_t - \cos_{t-1})\right) = 0$. Taking the second derivative with respect to time then will give the inflection points $\frac{d^2\phi(t)}{dt^2} = 0$. These inflection points are helping us to divide the sample into phases. Therefore, the first derivative will give the peak points of wave and from the second derivative we will find the phases. Thus, we satisfied the condition which we obtained in Proposition 1 for the phases as well.

2.2.1. Technical remark

Similar types of efficiency studies are also found in the finance literature. The most well-known of these is the efficient market hypothesis. The efficient market hypothesis says that the markets are unpredictable and that investors will not provide returns above the index's return. ADF test is used again to test this hypothesis, and it is tested that the null hypothesis shows the efficient market hypothesis, that is, that the series diverges and is unpredictable. On the contrary, in the alternative hypothesis, the market will be predictable, and above-index returns can be achieved. While the understanding of effectiveness comes from the unpredictability of the series here, predictability in the structure we propose shows the effectiveness of health expenditure: $\Delta P_t = \alpha P_{t-1} + u_t$. The null hypothesis applied to the equation leads to the result of market efficiency, while the alternative hypothesis leads us to the result of market inefficient; $H_0 : \alpha = 0$ $H_a : \alpha \neq 0$.

2.3. Econometric modeling

Recent studies by Becker et al. (22), Enders and Lee (21, 23), Rodriques and Taylor (24), and others have used Flexible Fourier Transforms to represent smooth breaks. The Fourier approach has several benefits, such as being able to capture the behavior of a deterministic function of unknown form even if the function itself is not periodic, performing better than dummy variable methods whether the breaks are instantaneous or smooth, and not having to worry about choosing the dates, number, and type of breaks (21–24). All of these papers made the point that to avoid the over-filtration issue; the structural break assessment should be done using the single frequency component of the Fourier Transforms. Becker et al. (22) used the Fractional Frequency Flexible Fourier Form (FFFFF) for the Trig-test, a structural break test. They try to demonstrate why their approach is superior to the widely used break tests.

Moreover, the newly proposed Omay (25) test follows Becker et al. (22) and Enders and Lee (21) and combines their methodologies to obtain the FFFFF ADF test. However, our study uses cumulative frequency to investigate wave and phase-dependent unit root testing, which is a deviation from the previous studies. The previous studies concentrate on the single frequency to determine the smooth break, but we are searching for the wave and phase of the data-generating process.

For this purpose, we are using **Corollary 1** to introduce a new constraint on cumulative frequency. Therefore, this new constraint lets us determine the exact number of the cumulative frequency apart from Enders and Lee (21) and Omay (25). These studies assume the cumulative frequency to be a maximum of 5. However, we introduce a new condition for obtaining the correct timing of waves and phases. This new methodology enables us to find the correct number of cumulative frequencies and hence proper testing of the data, which covers wave and phase-dependent data-generating processes. As we know from the previous literature, the upper limit of cumulative frequency determination is not possible due to the goodness of fit measure of the residual sum of squares getting better and better with the increasing number of cumulative frequencies. Thus, it is impossible to stop increasing the cumulative frequency at a reasonable number of frequencies. Finally, we solve this problem for this specific data-generating process by using **Corollary 1.**

The following Dickey–Fuller test is considered;

$$y_t = d(t) + \phi_1 y_{t-1} + \lambda t + \varepsilon_t \tag{1}$$

in this equation, ε_t is a stationary disturbance with variance, while is a deterministic function of t. Omay (25) assume that the initial value is fixed, and ε_t has weak dependence, similar to Enders and Lee (21, 23). According to Enders and Lee (21, 23), if the functional form of $d(t)$ is known, it is feasible to estimate Eq. (1) and evaluate the null hypothesis of a unit root. Any test for is difficult if $d(t)$ is misidentified when the form of $d(t)$ is unknown. Omay (25) test and Enders and Lee (21, 23) tests are predicated on the notion that by using the Fourier expansion, one can approximate by $d(t)$:

$$d(t) = \alpha_0 + \alpha \sin\left(\frac{2\pi kt}{T}\right) + \beta_k \cos\left(\frac{2\pi kt}{T}\right) \tag{2}$$

where T is the total number of observations and k is a specific frequency. When there is no non-linear trend, all $\alpha_k = \beta_k = 0$ values result in the DF test, a specific case of the test. Use of a large number of cumulative frequencies is unsuitable for a variety of reasons. Specific frequency $k = 1$ is frequently a good approximation to a model with structural change, as advised in the

literature. However, we concentrate on the cumulative frequency and estimate the n for the best-fitting wave and phase-dependent non-linearity. Therefore, using Corollary 1 leads us to obtain the sharp type of change in the data correctly. Until now, we have explained all the details of Fourier type of unit root testing. Nevertheless, from now on, we are considering only Corollary 1 to proceed in the empirical part.

$$\Delta y_t = \rho y_{t-1} + c_1 + c_2 t + \sum_{i=1}^{n} c_{3,i} \sin\left(\frac{2\pi kt}{T}\right) + \sum_{i=1}^{n} c_{4,i} \cos\left(\frac{2\pi kt}{T}\right) + e_t \quad (3)$$

Now we can proceed with economic intuition behind the testing equation. With the number of daily cases, regardless of the health investments of the countries, the pandemic process is indirectly determined by the number of cases. In a similar study, Mulligan (26) and Barasa et al. (3) assumed that in the presence of infectious disease, the costs of infection were proportional to the number of infected people and stated that they were proportional to the number of interactions, that is, to the transmission coefficient. They control the dramatic results of the epidemic with the number of new cases per day measured depending on the number of tests valid for both the transmission stage and the diagnosis and treatment stage. Their study revealed that countries prepare for such a crisis differently regarding the organization and leadership of the health system (27). These differences have also caused differences in the pandemic process of countries. Therefore, this affects the wave and phase lengths and the contamination coefficients. Based on these studies and our Proposition 1, the behavior of the pandemic process was examined in two stages. Due to the lack of monthly and daily data on health expenditure, the indirect method proposed in Section 2.2 is used. The number of daily cases in the first stage was divided into waves and phases according to the contamination coefficient with the Cumulative Fourier function. In the second stage, COVID-19 cases' stationarity is examined to investigate whether the countries make effective health expenditures according to waves and phases. The study aims to help countries make effective short- and long-term decisions. The research presented an opinion on the effectiveness of health expenditures indirectly over the number of daily cases in 5 OECD countries during the COVID-19 Pandemic. The sample start date was chosen as each country's first case notification day.

3. Empirical study and discussion

In the first stage of the study, the new daily cases taken until November in the pandemic process, which started with the detection of the first cases in February 2020, were estimated with the cumulative Fourier function. As can be seen from Table 2, Australia and Germany had three waves, while Canada, France, and America had four waves. While Canada, Germany, and France experienced the pandemic process with similar movements in almost the same period, Australia separated from these countries after the Second Wave. After the First Wave, all other countries except America were in the pivotal region where the number of cases (not fluctuating) remained stable until the beginning of the 2nd Wave. It has an interim period of about two months, which we can describe as, throughout the pilot region, countries were able to keep the number of cases stable. While Australia and America completed their second Wave in the 3rd quarter of 2020, other countries experienced the 2nd Wave until the 1st quarter of 2021. Australia managed to keep the number of cases at a reasonable level for about 10 months after the 2nd Wave. With this analysis, it has been shown that countries experience different conditions of the pandemic at different times. A similar study; is the study of Al-Saidi et al. (27), who found that countries respond differently to the pandemic process due to different readiness.

For this reason, to compare the effectiveness of their countries' health systems, they are examined by dividing them into waves and phases according to the contagion coefficient. The predictability of the number of cases means that the cases are under control and the process is managed effectively. Therefore, stationarity means that health expenditures are also carried out effectively. The related cumulative Fourier estimation results can be seen below in Table 2:

In the second stage of the study, the unit root test was applied to investigate the stationarity of the phases. The results show waves and phases where case numbers are stationary. According to the results obtained by using the intercept and trend model (W1P1), it was determined that the cases could not be predicted, especially in the first phase of the pandemic (Table 3) (Australia, Canada, Germany, and the US). In contrast, France, whose case numbers seemed stationary in the first days of the pandemic, lost control of the cases in Phase 2. Phase 3 and Phase 4 were stationary in general of the waves. This situation can be interpreted as France's policy being different from other countries against a possible pandemic shock. In the relief phase and the second wave, it is seen that the countries that were severely affected at the beginning of the epidemic started to control the number of cases by taking adequate measures, thus increasing the efficiency of their health systems. Similar results were obtained by Lupu and Tiganasu (1). The common feature of all the countries we examined is that phase 1, which represents the beginning of the waves, is not stationary. This result may mean that the onset of waves is unpredictable. It was observed that Germany and US could not manage the process consistently. However, until the Omicron variant, Germany and Australia had three pandemic waves, while Canada, France, and the US had four pandemic waves. Hence, this situation may be due to the different case management and, therefore, the health policy implementation of the countries. As can be seen, from the unit root test results in Table 3 of the cases, it can be claimed that predictability of the number of cases for each wave and phase, so they cannot make effective health expenditures. All these results confirmed our Lemma 1, Proposition 1, and Corollary 1. Therefore, if the daily COVID-19 cases are stationary, the countries will reach efficiency at that phase.

4. Conclusion and recommendation

The study analyzed the effectiveness of public health spending in 5 OECD countries during the COVID-19 Pandemic. The results showed that countries experienced the pandemic process of varying lengths and intensities and that dividing the daily number of cases

TABLE 2 The estimation of wave and phases by using cumulative Fourier transform.

		AUS		CAN		DEU		FRA		USA	
		Date range		Date range		Date range		Date range		Date range	
Wave 1	Phase 1	26.1.20	6.3.20	26.1.20	18.3.20	27.1.20	7.3.20	24.1.20	20.3.20	22.1.20	17.3.20
	Phase 2	7.3.20	26.3.20	19.3.20	20.4.20	8.3.20	28.3.20	21.3.20	10.4.20	18.3.20	13.4.20
	Phase 3	27.3.20	10.4.20	21.4.20	27.5.20	29.3.20	12.4.20	11.4.20	29.4.20	14.4.20	30.4.20
	Phase 4	11.4.20	1.5.20	28.5.20	30.6.20	13.4.20	3.5.20	30.4.20	21.5.20	1.5.20	21.5.20
Wave 2	Phase 1	18.6.20	10.7.20	21.8.20	21.11.20	10.9.20	12.10.20	18.7.20	11.10.20	22.5.20	19.6.20
	Phase 2	11.7.20	31.7.20	22.11.20	25.12.20	13.10.20	13.12.20	12.10.20	5.11.20	20.6.20	27.7.20
	Phase 3	1.8.20	19.8.20	26.12.20	1.2.21	14.12.20	16.1.21	6.11.20	22.11.20	28.7.20	25.8.20
	Phase 4	20.8.20	14.9.20	2.2.21	28.2.21	17.1.21	22.2.21	23.11.20	15.12.20	26.8.20	17.9.20
Wave 3	Phase 1	5.7.21	10.9.21	1.3.21	27.3.21	23.2.21	24.3.21	16.12.20	10.3.21	18.9.20	10.11.20
	Phase 2	11.9.21	6.10.21	28.3.21	21.4.21	25.3.21	16.4.21	11.3.21	1.4.21	11.11.20	26.12.20
	Phase 3	7.10.21	2.11.21	22.4.21	16.5.21	17.4.21	12.5.21	2.4.21	24.4.21	27.12.20	30.1.21
	Phase 4			17.5.21	9.7.21	13.5.21	16.6.21	25.4.21	22.6.21	31.1.21	9.3.21
Wave 4	Phase 1			10.7.21	21.8.21	23.7.21	4.11.21	23.6.21	17.7.21	18.6.21	2.8.21
	Phase 2			22.8.21	16.9.21			18.7.21	10.8.21	3.8.21	1.9.21
	Phase 3			17.9.21	5.10.21			11.8.21	31.8.21	2.9.21	25.9.21
	Phase 4			6.10.21	3.11.21			1.9.21	30.9.21	26.9.21	22.10.21

Dates are given as day, month, year.

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TABLE 3 The unit root test results showing the efficiency of health expenditure.

	AUS		CAN		DEU		FRA		USA	
	Intercept	Intercept & trend	Intercept	Intercept & trend	Intercept	Intercept & trend	Intercept	Intercept & trend	Intercept	Intercept & trend
W1P1	−0,514	0,917	4,181	3,983	4,386	6,067	−8,472***	−8,056***	1,649	2,503
W1P2	−0,206	−4,028**	−2,109	−3,481*	−0,324	−3,108	−3,484**	−3,210	−1,858	−0,811
W1P3	−1,875	−5,170***	−1,980	−5,040***	−2,752*	−4,271**	−5,266***	−4,691**	−3,909**	−3,572*
W1P4	−4,725***	−6,074***	−2,177	−3,212*	−2,160	−6,267***	−3,691**	−3,887**	−4,154***	−3,133
W2P1	0,881	−3,459*	0,111	−2,936	6,085	3,635	2,178	−1,211	2,425	1,633
W2P2	−0,281	−3,964**	−5,810***	−6,042***	−2,374	−1,971	−3,060**	−5,187***	−1,933	1,348
W2P3	−0,364	−5,522***	−0,811	−4,392***	−4,969***	−5,183***	−2,531	−5,676***	0,069	−4,414***
W2P4	−1,934	−4,322**	−5,404***	−5,906***	−2,005	1,290	−4,503***	−5,187***	−3,337**	−3,156
W3P1	1,923	−0,653	2,494	0,595	2,318	−4,135**	−1,410	−2,089	4,172	0,876
W3P2	−1,269	−4,137**	−4,206***	−5,183***	−1,315	−4,487**	−3,490**	−5,854***	−4,017***	−4,702***
W3P3	3,071	−2,754	−3,813***	−5,480***	−3,606**	−5,746***	−6,505***	−6,311***	−0,715	−2,070
W3P4			−3,196**	−1,754	−1,679	−5,283***	−1,847	−4,330***	−1,844	−1,596
W4P1			2,873	−1,096	2,033	0,839	0,339	−3,681**	8,384	1,306
W4P2			−5,835***	−4,642***			−3,882***	−4,967***	−1,535	−3,029
W4P3			−4,946***	−4,787***			−1,878	−6,469***	−4,644***	−4,446**
W4P4			−5,796***	−5,245***			−2,017	−0,634	−0,555	−1,831

*, **, *** are representing the %10, %5, and %1 significance level. W and P representing wave and phase.

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into waves and stages according to the contagion coefficient is a more accurate method. The unit root test performed in the second stage showed that health expenditures were effective in waves and phases where the number of cases was stationary. The results naturally showed that the onset of waves was unpredictable, and countries could not make effective health expenditures for each wave and stage. In the study, it was concluded that the periods when countries made effective health expenditures during the pandemic period were when they started to control the number of cases by taking adequate precautions after being seriously affected by the epidemic.

The findings of this study have important implications for public policies in managing pandemics. Firstly, the results highlight the importance of preparedness and effective health systems. In all the first phases of the countries, the daily COVID cases are found unit root process, which indicates that they are not prepared at the first phases and lead to inefficiency in their health expenditure. The unpredictability of the pandemic's first phase in most countries highlights the need for countries to have a robust plan to manage the pandemic effectively. Secondly, the study results show that the countries experience the pandemic process differently and at different times, highlighting the importance of a tailored and flexible approach to public health policy. Each country should design its policies based on its specific situation and needs. Thirdly, examining health expenditures indirectly through daily data allows for examining the capacity and ability of national economies worldwide to prevent, detect, and respond rapidly to the emergence of infectious diseases and other acute forms of public health endangerment. Finally, the results show the importance of data analysis in pandemic management. It is possible to get an idea about the trends and patterns in the spread of the pandemic by applying the Cumulative Fourier function and the unit root test, which we employ in the study. This information can be used to inform public policies and make evidence-based decisions.

Of course, the effectiveness of health expenditures alone does not stop or slow the pandemic. Health expenditures will be effective when people's cultural behaviors and the level of democracy of countries are taken together with stringency measures, which are called non-pharmaceutical measures. In future studies, the effectiveness of the measures taken in the pandemic process can be measured by examining short-term data on the pandemic process and these variables together. Thus, the decisions to be taken by policymakers can be improved.

5. Limitation of the study

Like all studies, this study also has certain limitations that should be considered.

Firstly, the study is limited by the data used. The analysis is based on the number of daily cases; some cases may have been missed or underreported. Therefore, the correctness of the data limitation could lead to inaccuracies in the results and conclusions.

Secondly, the study only focuses on five advanced countries (Australia, Canada, France, Germany, and America), and it is possible that the results may not be generalizable to other countries. The experiences of these countries may not be representative of the experiences of other countries. Further studies would be needed to examine the impact of the pandemic on different countries.

In conclusion, the limitations of this study should be considered when interpreting the results and conclusions. Further studies would be needed to address these limitations and to gain a more comprehensive understanding of the impact of the pandemic on different countries.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://ourworldindata.org/covid-cases.

Author contributions

EB: conceptualization, investigation, review and editing, resources, data curation, writing, formal analysis, visualization, and writing—original draft preparation. KBA: conceptualization, investigation, review and editing, and supervision. TO: conceptualization, methodology, formal analysis, investigation, resources, and writing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Vahit Yigit,
Süleyman Demirel University, Türkiye

REVIEWED BY
Nicola Spagnolo,
Brunel University London, United Kingdom
Yusuf Çelik,
Marmara University, Türkiye

*CORRESPONDENCE
Esref Ugur Celik
✉ esref.celik@atilim.edu.tr

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Convergence of economic growth and health expenditures in OECD countries: Evidence from non-linear unit root tests

Esref Ugur Celik[1]*, Tolga Omay[1] and Dilaver Tengilimoglu[2]

[1]Department of Economics, School of Business, Atilim University, Ankara, Türkiye, [2]Department of Business, School of Business, Atilim University, Ankara, Türkiye

Introduction: The relationship between human capital, health spending, and economic growth is frequently neglected in the literature. However, one of the main determinants of human capital is health expenditures, where human capital is one of the driving forces of growth. Consequently, health expenditures affect growth through this link.

Methods: In the study, these findings have been attempted to be empirically tested. Along this axis, health expenditure per qualified worker was chosen as an indicator of health expenditure, and output per qualified worker was chosen as an indicator of economic growth. The variables were treated with the convergence hypothesis. Due to the non-linear nature of the variables, the convergence hypothesis was carried out with non-linear unit root tests.

Results: The analysis of 22 OECD countries from 1976 to 2020 showed that health expenditure converged for all countries, and there was a significant degree of growth convergence (except for two countries). These findings show that health expenditure convergence has significantly contributed to growth convergence.

Discussion: Policymakers should consider the inclusiveness and effectiveness of health policies while making their economic policies, as health expenditure convergence can significantly impact growth convergence. Further research is needed to understand the mechanisms behind this relationship and identify specific health policies most effective in promoting economic growth.

KEYWORDS

convergence, health expenditure, growth, non-linear unit root tests, OECD

1. Introduction

Health expenditures play an essential role in maintaining economic wellbeing and improving living standards (1). Health expenditure enhances overall wellbeing and prosperity as a form of consumer goods (2). Additionally, increasing the labor productivity resulting from health expenditures further supports the rise of wellbeing.

The impact of human capital on the value added in production through the increase in the quality of the workforce is undeniable. The level of education, both in terms of duration and quality, is generally considered to be the primary factor associated with increased human capital (3). Health expenditures, directly and indirectly, impact access to education and training of the qualified workforce, as they improve living conditions and facilitate healthier participation in the labor market. Health expenditures can also contribute to an increase in productivity by providing a healthier workforce (2).

In addition to its potential positive impact on total factor productivity, increased health spending is anticipated to increase economic output (2, 4). In summary, health expenditures can create healthier and more productive societies. Health expenditures are expected to positively impact economic growth, primarily through the human capital channel. In other words, the fact that health expenditures could be a primary determinant of human capital can significantly impact the output.

Many studies consider human capital as one of the critical determinants of economic growth. The study of Binder and Pesaran (5) also dealt with this relationship. The analysis results in the study show that there are "the same limiting time series properties" between human capital and output. This determination shows that the unit root level of human capital is dominant in determining the unit root level of output. Therefore, it may also mean that human capital convergence leads to output convergence.

On the other hand, considering that health expenditures are one of the main determinants of human capital, an increase in health expenditures means an increase in human capital. Thus, the integration order of the health expenditures series can determine the integration order of human capital. Therefore, based on the impact of human capital on output, it is expected that the integration order of health expenditures will similarly impact the integration order of output. For these reasons, convergence in health expenditures causes convergence in output.

The study's starting point empirically tests the convergence assumption for health expenditures and output mentioned above. The relevant assumption was tested over the variables of health expenditure per qualified worker and output per qualified worker in the 1976–2020 period of 22 OECD countries. The non-linear unit root tests show convergence in health expenditure per qualified worker for all countries included in the analysis. Similarly, almost all the countries in the sample (excluding two countries) show convergence for output per qualified worker. The convergence of health expenditure per qualified worker and output per qualified worker confirms the assumption that the convergence of health expenditure will empirically lead to convergence in output.

Empirical research has important policy implications. The findings suggest that in order to achieve a stable growth structure, countries need to have at least as much spending on healthcare as the average of other countries. This finding is a requirement, but it is not sufficient. It is crucial to transform the nature of human capital to make a significant impact on economic growth. It is also necessary to increase the quality of health expenditures while increasing the value of health expenditures to achieve this efficiency. In other words, the channels for health spending must be properly and effectively prioritized to increase efficiency and contribute to GDP growth.

For this reason, it is of great importance for policymakers to determine appropriate policies consistently when determining the channels through which health expenditures will be transferred. Furthermore, as can be seen from the data used in the study, the data on health spending is facing severe non-linearity (6). This is why considering the non-linearity of health expenditure variables in the analyses performed is vital for the results to be accurate and reliable (6). In addition to all these, another issue that policymakers should pay attention to is the income inequality problem that health expenditures can create. Increasing the quality and quantity of healthcare spending will give individuals access to better education. This qualified education received by healthy individuals will provide high salary expectations.

Consequently, health expenditures should be distributed fairly and equally across all members of society. This situation can manifest itself as both individual and regional differences in income. Therefore, policymakers must inclusively implement health expenditures.

In the first part of the study, a literature review on convergence hypotheses, health expenditure convergence, and growth convergence was conducted. The second part discusses theoretical background. The third part focus on data, methodology, and methods, and an empirical analysis was carried out. In the last part, the study's general findings and the policy proposal are given.

2. Literature review

2.1. Conceptual framework of the convergence hypothesis

The economics literature classifies the convergence hypothesis into four broad categories. β convergence is one example of this. The income per capita growth in a certain period is estimated using the starting level of income per capita, and time lag is typically used to capture β-convergence. Areas with lower beginning levels of income per capita expand more quickly than regions with greater initial levels of income per capita, according to the regression coefficient of β with a negative sign (7). In the literature, there are two distinct forms of β -convergence. These two types of convergence are unconditional (absolute) and conditional. Absolute β -convergence is founded upon the premise that all nations will eventually reach the same steady state. Therefore, the assumption is that economies are similar in terms of their human capital, savings rates, technology levels, population growth, industrial structures, and various structural characteristics. There is a greater chance of detecting unconditional convergence, while the model is being examined for cross-sections of more homogenous regions in this scenario. As a result, for absolute β convergence, the β parameter is determined without taking a set of control variables into account (8).

Contrarily, each unit will converge to a distinct steady state point when economies have diverse structural characteristics. In this situation, convergence is conditional, and β is calculated by including several structural conditioning elements that are thought to affect the rate of increase in income per capita. Less poor economies may grow slower than wealthier ones, mainly if they are nearer to their steady state, as the rate of convergence is determined by an economy's distance from its steady state (9).

The sigma technique is another alternate method for determining convergence (10). Convergence measures the dispersion of actual income per capita across economies in a region using either the standard deviation or coefficient of variation of the cross-sectional series. Convergence is shown by a decline in the coefficient of variation or standard deviation, demonstrating that disparities income in per capita amongst entities in an

area get less over time (11). Divergence occurs when the series' coefficient of variation or standard deviation for income per capita rises with time. When the coefficient of variation or standard deviation alternately rises or falls, a hybrid convergence and divergence occur (11). By regressing time as a variable on the coefficient of variation or the standard deviation of output between nations, one can also examine α-convergence. The presence of α-convergence is established when the parameter of the time variable is both negative and statistically significant, whereas a positive measurement supports divergence. It is demonstrated that nations may not reflect convergence because beta-convergence exists (12). The stochastic convergence technique is another factor to consider when evaluating whether convergence exists (13). The stationarity of income per capita in this scenario leads to the conclusion that convergence exists. Convergence is considered to have occurred when a country's income per capita is stationary compared to that of a reference country. This is because the income's stationarity creates a steady state for the income level (14). Club convergence is a different approach than all other methods (15). Convergence happens in several steady states in this situation. Club convergence is based on the fact that it depends on disparities in a group of nations' income, productivity, or living standards. It seems that nations with comparable income groups tend to converge, making high-income countries more likely to have high expenditures and vice versa.

2.2. Health expenditure and growth convergence

Many studies exploring the convergence problem in health expenditures using the concept of convergence have produced mixed results. Following the analysis by Alcalde (16), the convergence of health spending per capita was investigated across 21 OECD countries between the years 1975 and 2003. The study utilized Theil's measure to demonstrate convergence among these nations. The convergence of GDP shares is primarily explained by the convergence of health expenditures, labor productivity, and employment rates. Schmitt (17) states that by using error correction models, it is possible to examine the conditional convergence and β convergence of various categories of social expenditure in 21 OECD countries from 1980 to 2005. The empirical results, taking into account the conditional variables, show that there is significant evidence of convergence in all social expenditure types, particularly in health expenditure. Leiter (18) focuses on the convergence and divergence of healthcare funding, a crucial aspect of any healthcare system. Applying several concepts of convergence, using data from 22 OECD nations between 1970 and 2005, they discover that healthcare finance (HCF) is converged. Fallahi (19) examines the beta and stochastic convergence in total healthcare spending as a percentage of GDP for 11 OECD nations between 1960 and 2006. The findings confirm that stochastic convergence exists for all nations. However, beta convergence is only supported for specific nations before the breakpoints. Panopoulou's (20) study examined convergence in healthcare expenditure per capita among 19 countries during the years 1972–2006 by using the approach of Phillips and Sul. Their findings confirm there is convergence in healthcare expenditure across 17 nations. In the study of Albulescu (21), health expenditures of 6 OECD countries were examined with bound unit root tests for the period 1972–2019. The analysis results indicate the importance of the variety of health systems and the limited convergence process between nations. Kizilkaya and Dag's (22) study used the Fourier unit root test method to analyze the convergence of health expenditures across 17 OECD nations for 1975–2019. The study's findings show that the convergence theory holds in most nations. The non-linear unit root test method was used in Akarsu et al. (23) study to find out if there was a convergence in health spending in 18 OECD nations between 1979 and 2016. The results of this article demonstrate that even though private health expenditures converge, total and public health expenditures per capita diverge.

In order to ascertain whether there was a convergence in health spending in 20 OECD nations between 1971 and 2015, Lee and Tieslau (24) employed the LM unit root testing approach. Convergence among particular country groupings is supported by evidence. In the study by Albulescu et al. (25), bound unit root tests were used to explore the convergence of health expenditures in 6 OECD nations between 1980 and 2012. The ratio of health expenditures to GDP does not appear to be significantly converging. Nghiem and Connelly investigated the convergence of health spending in 21 OECD nations between 1975 and 2014 using Phillips & Sul's technique. According to the findings, there is no indication of convergence in health spending among OECD nations. The LM and RALS-LM unit root tests were used in the study by Payne et al.'s study (26) to analyze the convergence of health expenditures in 19 OECD nations between 1972 and 2008. Health spending per person has converged in most OECD nations.

In the Pekkurnaz (6) research used the non-linear asymmetric heterogeneous panel unit root test, the convergence of health spending in 22 OECD nations between 1980 and 2012 was investigated. The findings do not indicate considerable convergence for all nations; therefore, it would appear most reasonable to consider asymmetry when analyzing convergence regarding health spending. The Lau, Fung, and Pugalis (27) study examined the convergence of health expenditures in 14 OECD countries between 1970 and 2008 using non-linear and panel tests. It is found that there is no convergence in the majority of nations' per capita health expenditures. Using panel data unit root tests, Aslan's (28) study examined the convergence of health spending in 19 OECD nations between 1970 and 2005. The findings of the analysis demonstrated that health spending does not converge across nations. Narayan's (7) study discusses health expenditure convergence for 6 OECD countries for 1960–2000 using LM and IPS unit root tests. The analysis findings indicated that health expenditures in other nations converge on that in the USA.

Considered necessary research has used the idea of convergence to study the issue of growth convergence and has come up with quite a few different results. Uçar and Omay (29) tested the growing convergence of 25 OECD countries in the 1953–2004 period with non-linear unit root tests. Analysis results indicate the existence of income convergence. Furuoka's (30) study tested the income convergence of 5 ASEAN member countries between 1960 and 2015 with Fourier augmented ADF and Fourier ADF

tests. The analysis results cannot show income convergence (very low-income convergence is found there). Ceylan and Abiyev's (31) study examined whether there was a convergence in GDP per capita of 15 EU member countries between 1950 and 2015 with non-linear unit root and non-linear asymmetric unit root tests. The analysis gave different results depending on the technique used, and convergence was generally found in very few countries. In the Yaya et al.'s (32) study, growth convergence for 9 Asian countries was tested with the Fourier unit root test with the break, covering the period 1967–2017. The analyses were conducted by classifying them according to the regions and concluded that the income convergence differs according to the regions.

In Lopes and Lopes's (33) study, the income convergence status of 25 countries in the 1950–2016 period was evaluated with the Fourier-type Dickey-Fuller test. The test results reveal that only 10 out of 25 countries have convergence. Holobiuc (34) analyzed the income convergence of 28 EU member states from 2000 to 2018. In the study, the analysis was carried out using α and β convergence techniques. The analysis reveals that different convergence results are encountered in different parts of Europe. Chandra Das et al.'s (35) study focused on growth convergence in BRICS countries. Unlike other studies, the study examined the period of 2006–2017 with quarterly data. Although the panel unit root tests showed conditional convergence in the first period, it was revealed that there was no convergence process in the entire period. Alataş (36) conducted the growth convergence test for 72 countries from 1960 to 2010. Multiple approaches (β, σ, stochastic, and club convergence) were performed within the study. The findings also differed depending on the nature of the test applied.

There are studies that consider the relationship between health expenditures and economic growth–development together. Raghupathi and Raghupathi (2) investigate the relationship between economic performance and public health expenditure in the United States, using data from 2003 to 2014. The results show a strong positive correlation between healthcare expenditure and economic performance measures such as income, output, and labor productivity. However, multi-factor productivity is inversely correlated with healthcare expenditure. The findings suggest that investing in healthcare can improve overall economic performance and calls for further research into universal access to healthcare and its potential benefits. The ARDL method is used in Erçelik's (37) study to analyze the effect of health spending on the output level in Turkey from 1980 to 2015. The study examines the connection between GDP per capita and healthcare spending as a share of GDP. The results of the study suggest that there is a significant long-term relationship between the two variables. Wang's (38) study uses the system generalized method of moments estimation method to investigate the connection between preventive and curative healthcare spending and economic growth in OECD nations. The results suggest that there is a relationship between preventive and curative health spending and economic performance. Wang et al. (39) examine the effect of government health spending on economic development in various regions of China through a non-parametric additive model. The results show that the economic impact of health expenditure is favorable in the western regions and unfavorable in the eastern and central regions. Additionally, the study also demonstrates that there is a strong positive correlation between government health spending and GDP, which has an effect on economic growth across the board and across all regions. Ivankova et al.'s (40) study analyzed the relationship between healthcare financing, treatable mortality of working-age men and women, and economic development in OECD countries Results indicated that healthcare financing negatively impacted treatable mortality in insurance and tax-based health systems and was linked to economic prosperity. The study identified countries with a high potential for health and economic outcomes improvement. Effective interventions should consider regional, social, and economic factors.

3. Theoretical background

The convergence hypothesis is a general idea in economics that suggests that, over time, countries tend to converge in terms of their economic performance, such as their growth rate, income per capita, health expenditure, or other variables. The convergence hypothesis is based on the idea that various factors can drive economic growth and development, such as technological advancements, investment in human capital, and access to natural resources. Over time, these factors can help to reduce the economic disparities between countries, leading to convergence in regard to economic performance.

In the case of health expenditure convergence, the hypothesis suggests that, over time, countries will converge in terms of their spending on health as a percentage of their GDP. Various factors, such as advancements in medical technology, increasing demand for health services, and changes in health policy, can drive this convergence.

Overall, the convergence hypothesis suggests that, over time, countries will tend to converge in terms of their performance of the economy, whether in terms of their income per capita, growth rate, health expenditure, or other variables. This hypothesis can be tested using various statistical methods, such as unit root tests or regression analysis, to determine whether convergence is occurring and to identify the factors driving it. The following model is a good base to explain the theoretical connections of the convergence process.

The Neoclassical Growth Model and Convergence

$$Y_{it} = K_{it}^{\alpha}(A_{it}L_{it})^{1-\alpha}, 0 < \alpha < 1 \tag{1}$$

with

$$\begin{aligned} K_{it} &= I_{i,t-1} + (1-\delta)K_{i,t-1}, \\ I_{it} &= s_i Y_{it} \end{aligned} \tag{2}$$

If we augment the $A_{it}L_{it}$ technology and employment in one variable, such as $HC_{it} = A_{it}L_{it}$

$$hc_{it} = Ln\,(HC_{it}) = \bar{h}c_{i0} + hc_i t + u_{it}, \tag{3}$$

where Δu_{it} is strictly stationary ergodic.

As measured by capital per effective labor units, $k_{it} = K_{it}/HC_{it}$ we have;

$$\Delta \ln\left(k_{it}\right) = -k_i - \Delta u_{it} + \ln\left(s_i k_{it}^{-(1-\alpha)} + 1 - \delta\right), \tag{4}$$

Under firm assumption on u_{it} and assuming that $0 < \alpha, \delta < 1$. Binder and Pesaran (5) indicate that k_{it} converges to time-invariant distribution for each i. As a result $y_{it} = \log(Y_{it}/HC_{it})$ also converge to a steady state distribution whose evaluation is provided by,

$$y_{it} = hc_{it} + \alpha \ln\left(k_{it}\right), \tag{5}$$

Moreover y_{it} will have the same limiting time series characteristics as hc_{it} [see detailed proof in Binder and Pesaran (5)]. In this case y_{it} has a unit root process if and only if hc_{it} has a unit root process. In this study, following these findings, we will test whether the health expenditure convergence, which means I(0) process leads to growth convergence I(0). As Binder and Pesaran (5) found that under certain assumptions, effective labor stochastic behavior directly affects the stochastic behavior of the growth variable. Therefore, this relationship may also determine the growth convergence behavior due to the stochastic behavior of health expenditure convergence. Health expenditure convergence means that the country's human capital (HC) converges to a better condition concerning the leading country or the average of the well-defined rich-income countries. Therefore, an increase or convergence in health expenditure directly means the technology improvements and/or an increase in the productivity of the human capital. Thus, we can intuitively claim that health expenditure convergence leads to similar findings with related to Binder and Pesaran (5) result where y_{it} has a unit root process only in the event of hc_{it} has a unit root process. In this empirical investigation, we will also search for the feedback effect of the growth convergence to health convergence. Most probably one convergence trigger the other converges as well.

4. Data and the empirical analysis

The study used the data of 22 OECD member countries for the period 1976–2020. The OECD and the EU have 11 nations as members (Austria, Belgium, Denmark, Finland, Germany, Ireland, Luxembourg, Netherlands, Portugal, Spain, and Sweden). The remaining 11 countries are members of the OECD (Australia, Canada, Iceland, Japan, Korea, New Zealand, Norway, Switzerland, Türkiye, the United Kingdom, and the United States).

The following variables were calculated to test the convergence processes between health expenditure per qualified worker and output per qualified worker[1]:

Health expenditure per qualified worker: $\dfrac{Health\ Expenditure}{h.L}$

Output per qualified worker: $\dfrac{GDP}{h.L}$

The health convergence study was conducted with linear, state-dependent non-linear, time-varying non-linear, and hybrid unit root tests. In line with these results, the Sollis (41) test achieved health convergence in all countries in the sample. The results of all tests can be seen in Table 1.

The income or output convergence study was conducted with linear, state-dependent non-linear, time-varying non-linear, and hybrid unit root tests. In line with these results, the Sollis (41) test achieved income or output in almost all countries in the sample except Spain and Ireland. The results of all tests can be seen in Table 2.

The results from Tables 1, 2 confirm the theoretical relationship presented in section 2.3 "Binder and Pesaran (5) theoretical finding: where y_{it} has a unit root process if and only if hc_{it} has a unit root process" this theoretical finding can also be generalize to: y_{it} is a stationary process if and only if hc_{it} is a stationary process. The methodological details are given in Appendix A.

5. Concluding remarks

Health expenditures of countries do not only include medicine and care expenditures. Effective use of health expenditures can positively impact human capital. Furthermore, health expenditures are considered one of the critical components of human capital. In societies where health spending is ineffective, unhealthy individuals are encountered primarily. These unhealthy individuals are not expected to integrate effectively into the education system or production processes. Health expenditures, directly and indirectly, impact education and production processes in this respect.

Many factors enable the education system to function actively. Societies without healthy individuals cannot receive and provide qualified education. For the education system to function effectively, the actors in the system must be healthy. Otherwise, the process may end up in a deadlock. In this respect, the role of health expenditures is essential for the education system to work actively. Countries will see an increase in the proportion of healthy individuals in their societies if they use their health expenditures in a planned and effective manner. The increase in the rate of healthy individuals will also increase the opportunities for effectively utilizing the education system. A high-quality education received by healthy individuals within the educational system can enable them to enter the job market with high-income expectations. The income expectation of a healthy and qualified workforce in the market differs from that of an unhealthy and unqualified workforce. A healthy and qualified workforce is offered a relatively high income which, on the one hand, will raise their standard of living and, on the other hand, will enable them to consume more. One of the main components of GDP is consumption. Increasing health expenses for a healthy and qualified workforce can contribute to the country's growth by increasing GDP.

Health expenditures also affect GDP through another channel. When health expenditures increase effectively in a country, healthy individuals can receive qualified education. The quality of education healthy individuals receives shapes their expectations for wages, as mentioned above. In addition, a healthy and qualified workforce significantly impacts human capital. Countries need to invest in high human capital in order to be able to produce high-value-added products. Health expenditures can contribute

1 h: average education level and L: number of people employed. Health expenditures and GDP variables were accessed from the OECD database. Average training time (h) data were taken from the Barro-Lee database. Employment numbers were obtained from The Conference Board Total Economy Database.

TABLE 1 Results of time series unit root tests—health expenditure per qualified worker.

	ADF		KSS		Sollis (42)		EG		Enders and Lee		LNV			Sollis (41)		
	Intercept Only	Intercept and Trend	Intercept Only	Intercept and Trend	Intercept Only	Intercept and Trend	Intercept Only	Intercept and Trend	Intercept Only	Intercept and Trend	Model A	Model B	Model C	Model A	Model B	Model C
Australia	−1.345	−2.759	−1.376	−2.055	0.923	3.218	1.034	4.383	−1.454	−3.535	−2.273	−3.110	−3.670	2.64553	5.090***	6.575***
Austria	−2.776*	−2.895	−2.860*	−2.438	3.988	3.550	4.258*	4.637	−3.123	−4.574**	−2.630	−3.810	−3.547	3.37806*	7.073***	6.202***
Belgium	−1.546	−3.195*	−2.034	−4.759***	4.032*	11.100***	1.276	5.497*	−3.152	−2.897	−4.343*	−3.368	−3.137	9.63131***	5.796***	5.079***
Canada	−1.297	−2.061	−1.391	−1.367	1.654	1.484	2.643	2.480	−1.194	−2.943	−1.847	−3.476	−3.956	2.18250	6.180***	7.633***
Denmark	−6.917***	−5.289***	−4.688***	−4.558***	19.815***	15.078***	25.006***	18.379***	−6.351***	−4.226*	−3.190	−4.042	−4.127	4.97079***	9.478***	8.367***
Finland	−0.560	−2.829	−0.795	−1.642	0.322	5.367	1.724	4.280	−1.464	−3.172	−2.564	−2.906	−3.814	3.30951	4.134**	7.458***
Germany	−0.352	−2.294	−1.132	−1.947	0.675	2.511	0.351	3.434	−1.042	−2.672	−2.940	−2.628	−4.138	4.42276***	3.510	8.569****
Iceland	−1.389	−1.093	−2.088	−1.525	3.311	2.426	0.947	1.213	−4.891***	−5.324***	−3.008	−4.853*	−5.559**	8.11764***	11.910***	15.177***
Ireland	−1.352	−2.151	−2.699*	−2.538	5.919**	4.442	4.362*	2.370	−0.749	−2.717	−3.248	−4.599	−4.322	5.19027***	10.907***	9.560***
Japan	−1.067	−3.508**	−1.162	−3.058	3.05049	4.860	5.465**	6.721**	−1.734	−4.273*	−2.972	−4.739*	−4.759	4.63492***	11.179***	11.045***
Korea	−2.132	−2.164	−2.232	−2.320	2.670	2.707	2.934	2.868	−2.536	−4.187*	−2.069	−1.925	−3.749	3.62060*	1.805	7.215***
Luxembourg	−0.967	−1.781	−0.604	−2.656	2.922	3.442	5.256**	1.677	−0.933	−3.297	−2.943	−4.146	−4.440	5.13121***	8.576***	10.045***
Netherlands	−0.737	−2.536	−1.242	−3.070	1.734	9.480***	3.685	4.228	−0.873	−4.399**	−3.427	−4.443	−3.434	5.76400***	9.625***	5.752***
New Zealand	−1.422	−1.096	−1.431	−0.796	1.079	0.482	1.180	0.599	−2.590	−2.569	−1.893	−2.802	−3.082	1.78781	4.061*	4.759**
Norway	−1.759	−2.221	−2.103	−2.377	3.325	2.958	1.527	2.495	−2.337	−4.946***	−5.195***	−5.238**	−5.446**	13.23172***	13.383***	14.485***
Portugal	−0.452	−2.827	−1.455	−2.079	1.387	2.274	0.247	4.551	−1.998	−2.729	−3.6734	−3.181	−4.003	6.63369***	4.934***	7.889***
Spain	−0.324	−1.762	−0.173	−2.094	0.073	2.150	0.800	1.517	−1.622	−4.240*	−2.879	−4.264	−4.385	4.05095**	9.147***	9.467***
Sweden	−1.142	−1.168	−0.811	−0.892	0.326	0.411	0.720	0.671	−1.695	−3.013	−1.083	−3.002	−3.392	1.22633	4.501**	5.614***
Switzerland	−1.632	−1.790	−2.240	−3.256*	5.242**	6.191*	2.314	2.629	−3.492*	−2.900	−2.240	−4.206	−3.786	3.10651	9.465***	7.700***
Türkiye	−0.061	−0.553	−0.159	−0.789	0.091	0.402	2.406	0.806	−0.810	−2.997	−2.255	−3.526	−2.860	2.77670	6.756***	4.118*
United Kingdom	−1.248	−1.362	−1.106	−1.479	1.547	1.100	1.231	0.934	−0.642	−2.558	−2.061	−5.249**	−5.482**	2.38588	13.474***	14.775***
United States	−1.167	−0.764	−1.511	−1.237	1.739	1.473	4.430*	0.428	−0.372	−2.520	−2.456	−2.899	−3.831	2.93785	4.237**	7.181***

*, **, and *** are representing 10%, 5%, and 1% significance level, respectively.

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TABLE 2 Results of time series unit root tests–output per qualified worker.

	ADF		KSS		Sollis (42)		EG		Enders and Lee		LNV			Sollis (41)		
	Intercept Only	Intercept and Trend	Intercept Only	Intercept and Trend	Intercept Only	Intercept and Trend	Intercept Only	Intercept and Trend	Intercept Only	Intercept and Trend	Model A	Model B	Model C	Model A	Model B	Model C
Australia	−1.938	−2.209	−1.290	−1.376	0.841	0.980	2.225	3.037	−2.833	−2.853	−2.791	−3.061	−4.182	4.282***	5.887***	8.571***
Austria	−0.313	−2.881	−0.998	−3.170*	0.670	5.337	0.242	4.594	−1.396	−3.628	−3.722	−4.113	−3.718	6.988***	10.123***	6.915***
Belgium	−1.673	−2.611	−1.132	−1.726	1.287	1.495	1.489	3.363	−2.671	−3.245	−4.417**	−4.323	−3.708	9.507***	9.477***	6.809***
Canada	−0.427	−2.598	−0.837	−1.968	0.851	2.354	1.870	3.291	−1.550	−3.364	−3.029	−3.422	−3.817	4.966***	5.872***	7.303***
Denmark	−1.224	−1.642	−1.596	−1.897	1.722	2.174	0.741	1.460	−3.839**	−3.443	−2.144	−3.474	−3.814	2.298	6.035***	7.365***
Finland	−2.440	−2.018	−2.219	−2.699	3.276	3.594	2.906	2.006	−2.244	−4.997***	−2.137	−4.590	−4.496	2.522	10.287***	9.985***
Germany	−1.123	−1.616	−1.392	−1.325	0.950	0.887	0.895	1.274	−1.958	−2.831	−2.546	−2.629	−3.843	3.224	3.419	7.202***
Iceland	−2.071	−2.011	−1.362	−2.287	1.568	2.645	2.096	1.986	−2.890	−4.172*	−2.800	−4.667*	−4.674	4.024**	10.862***	11.223***
Ireland	−0.812	−1.153	−1.178	−1.349	1.136	2.059	2.939	1.535	0.061	−1.433	−1.642	−1.150	−1.903	1.740	1.832	2.06682
Japan	−0.663	−1.733	−0.786	−2.105	1.454	2.487	0.843	1.497	−1.501	−2.366	−2.950	−2.837	−2.394	4.651***	3.969*	2.81705
Korea	−1.096	−0.922	−1.429	−1.649	1.125	1.506	3.631	0.415	0.302	−3.370	−2.745	−2.722	−3.386	3.678**	3.653	6.570***
Luxembourg	−1.601	−1.349	−2.371	−1.904	4.493*	2.992	1.527	1.118	−3.063	−3.004	−1.116	−4.034	−3.607	3.007	8.140***	6.659***
Netherlands	−2.012	−1.777	−2.525	−2.429	3.617	3.032	2.437	1.890	−3.195	−2.669	−1.743	−3.432	−5.046	1.490	5.738***	12.663***
New Zealand	−0.170	−1.690	−0.370	−1.810	0.146	1.784	2.000	1.461	−0.691	−3.844	−2.489	−3.983	−4.393	3.175	8.439***	9.522***
Norway	−1.409	−1.010	−1.656	−1.805	1.383	1.934	0.991	0.652	−4.061**	−2.976	−1.445	−2.936	−6.421***	1.410	4.306**	21.049***
Portugal	−1.521	−1.961	−1.566	−2.058	1.196	2.290	2.712	2.402	−0.689	−3.502	−2.064	−3.872	−2.854	2.247	9.712***	6.627***
Spain	−0.125	−2.115	−0.696	−2.012	0.257	2.150	0.353	2.306	0.652	−1.354	−2.213	−1.389	−2.303	2.389	1.566	2.714
Sweden	−0.667	−2.295	−1.148	−1.546	0.740	1.735	0.483	2.713	−2.185	−3.188	−3.451	−3.189	−3.495	5.912***	5.227***	6.480***
Switzerland	−1.569	−2.781	−1.967	−2.319	2.606	2.631	1.639	3.865	−2.182	−2.502	−3.364	−2.589	−2.604	6.082***	3.268	3.309
Türkiye	−2.256	−1.885	−1.686	−1.073	2.037	1.063	4.710*	2.148	−2.903	−2.809	−1.782	−2.589	−3.093	2.859	4.717**	6.547***
United Kingdom	−0.006	−1.366	−0.120	−1.633	0.915	1.958	1.210	1.074	−1.569	−2.867	−2.797	−2.743	−3.256	4.431***	4.245**	5.326***
United States	−0.290	−2.280	−1.069	−2.626	0.568	3.367	0.387	2.539	−1.003	−4.058*	−3.856	−3.848	−4.278	7.375***	7.328***	9.247***

*, **, and *** are representing 10%, 5%, and 1% significance level, respectively.

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directly and indirectly to increased human capital. The increase in human capital that comes with health spending can increase the country's overall productivity and open the way for producing high-value-added products. One of the critical determinants of economic growth is human capital. The role of health spending in determining human capital cannot be denied. Therefore, an increase in quality health spending in the country will lead to an increase in human capital and bring along an increase in value-added and efficient production, thereby increasing GDP.

The study of Binder and Peseran (5) starts from a similar point and shows the effect of human capital on economic growth through the degree of integration order. Similar to our study, they obtained the theoretical finding that human capital stationarity will lead to growth stationarity. In other words, a convergence in health spending will lead to a convergence in growth.

Non-linear unit root tests were applied to 22 OECD countries empirically to test the hypothesis of health expenditure and growth convergence. While the variable of health expenditure per qualified worker was used to measure health expenditure, the output variable per qualified worker was used as an indicator of growth. The analyzes covering the period 1976–2020 revealed the convergence of health expenditure per qualified worker in all countries. On the other hand, convergence for output per qualified worker was achieved in 91% of the countries. As a result, the assumption mentioned above was confirmed. Our findings are consistent with following studies (37–40).

The results reflecting the policy recommendations obtained from the analysis suggest that in order to have a stable growth path, countries need to make at least as much health expenditure as other countries. The inclusiveness and quality of health expenditures are as crucial as the quantity for the effective functioning of convergence processes. It has been observed in the study that the health expenditure data has a non-linear structure. Therefore, it should not be forgotten that incorrect results may be encountered if this situation is not considered in the analyses to be carried out regarding health expenditures. This situation can also lead to incorrect determination of health policies.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://www.oecd.org/health/health-data.htm, https://data.oecd.org/gdp/gross-domestic-product-gdp.htm, http://www.barrolee.com/, https://www.conference-board.org/data/economydatabase/total-economy-database-productivity.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1125968/full#supplementary-material

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EDITED BY
Dilaver Tengilimoğlu,
Atilim University, Türkiye

REVIEWED BY
Haydar Sur,
Üsküdar University, Türkiye
Deepak Kumar Behera,
Manipal Academy of Higher Education, India

*CORRESPONDENCE
Selma Söyük
✉ ssoyuk@iuc.edu.tr

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The impact of public health expenditure and gross domestic product per capita on the risk of catastrophic health expenditures for OECD countries

Selma Söyük*

Department of Health Management, Faculty of Health Sciences, Istanbul University-Cerrahpaşa, Istanbul, Türkiye

Introduction: Catastrophic health expenditure refers to situations where households face financial ruin due to high healthcare costs. For household spending on health services, the lack of pre-payment mechanisms to equalize the low payment capacity and risk, and the inability of countries' health financing systems to fulfill their duties adequately all contribute to the creation or increase of the risk of catastrophic health expenditure. This situation has devastating effects on poor households first, but if the prevention mechanisms are insouciant, it can threaten the health system of the entire country. The research aims to assess the impact of the pre-paid financing model implementations and income levels on the ability of countries to reduce the risk of catastrophic health expenditure.

Methods: The paragraph explains the data used in the study, which is taken from OECD countries between 2003 and 2019. It also mentions the statistical models used in the study, which are static and dynamic panel regression models.

Results: The findings indicate that pre-paid financing models, such as those based on taxation, can help reduce the risk of catastrophic health expenditure. The study also reveals that income levels play a role in this regard, with countries with higher incomes being better able to reduce the risk of catastrophic health expenditure.

Discussion: The study suggests that healthcare financing systems should aim to provide effective services and financial protection to improve universal health coverage and reduce the risk of catastrophic health expenditure. Further researches using different health indicators and inputs could add to the existing literature on how to limit catastrophic health expenses and address other related questions.

KEYWORDS

catastrophic health expenditures, health spending per capita, income level, panel data, regression

Introduction

Following the United Nations Millennium Declaration adopted in 2000 with the participation of 189 countries, the determined targets were transformed into an action plan. The goals in the development and poverty eradication section of the declaration are to reduce poverty and hunger, combat ill health, gender inequality, lack of education, lack of access to clean water, and environmental degradation. Goals in the field of health include reducing child mortality, improving maternal and child health, and combating HIV/AIDS, malaria, and other diseases. Improving health is central to the millennium development goals because poverty negatively impacts health and poor health leads to loss of income and catastrophic health expenditures (1). Along with improved health status and responsiveness,

fair financing is one of the primary goals of the healthcare system. The World Health Organization (WHO) has identified three main goals for health systems: (1) Improving the health of populations - better health status- (2) Improving the responsiveness of the health system to the population it serves -responsiveness- (3) Fairness in financial contribution i.e., the extent to which the fair distribution the burden of paying for the health system is across households -fair financing- (2).

WHO has defined universal health coverage (UHC) as a mechanism that guarantees equitable access to basic promoting, preventive, curative, and rehabilitative health interventions for all citizens at an affordable cost, thereby ensuring access equality. Healthcare financing is a health system function that mainly serves universal health coverage by providing effective service and financial protection (3). The healthcare financing system aims to protect households from financial risk due to illnesses. This goal is also well-articulated in the world health organization 2010 report as the UHC goal (4, 5). UHC refers to a situation where all people can obtain needed health services at a good level of quality without suffering undue financial hardship (6). The effect of the lack of protection mechanisms is not just that people can suffer the burden of the illness but also the economic ruin and impoverishment of financing their care, yielding increased poverty in the short and long run (7). So, health systems must ensure that individuals have adequate financing mechanisms for acquiring preventive and curative care without deepening into catastrophic health expenditures (CHEs) and poverty (8).

Three factors must be present for catastrophic expenditures to arise; the presence of health services requiring out-of-pocket payments, low household capacity to pay, and lack of prepayment mechanisms for risk pooling. Out-of-pocket costs include all health-related expenditures that households make while receiving services, such as examination fees, purchase of medicines, materials, or devices, and hospital bills. The definition of household paying capacity is the non-subsistence expenditure of the household. Subsistence expenditures include basic needs such as food, shelter, and clothing. Prepayment refers to the situation where funds for health are collected through taxes and/or insurance contributions (9).

CHEs occur when out-of-pocket health payment as a share of the household income or capacity to pay exceeds a predetermined threshold level (10). Catastrophic expenditure is defined as "a morbid condition that results in health care costs that exceed a person's income, or which compromise financial independence, reducing him/her to subsistence or near-poverty levels" (11).

Catastrophic healthcare expenses are not solely due to expensive medical procedures or treatments. Just as a minor health expenditure can force a low-income household to cut back on essential expenses such as food, housing, or education, significant health expenses can lead to financial ruin and bankruptcy for wealthy individuals and families (12). Therefore, catastrophic healthcare expenditures are seen in low-income countries and high-income groups (10). While there is no consensus on the exact threshold for defining a catastrophic expenditure, most agree that it should be based on a household's ability to pay (11).

There are two different methods for calculating catastrophic health expenditures; the first is based on expenditure, and the second is on the income approach. According to the expenditure approach, catastrophic health expenditure occurs when out-of-pocket health expenditure exceeds a certain point of the total expenditure other than the basic expenses made by individuals to sustain their lives. The generally accepted rate is between 45 and 55%. However, because of deficiencies in calculations, this approach has been criticized (13). On the other hand, WHO has defined catastrophic health spending as the out-of-pocket health care expenditure of the household exceeding 40% of the household payment capacity (9). According to the income-based approach, catastrophic health expenditure occurs when out-of-pocket health expenditure exceeds some portion of the household income. In the literature, the most used threshold is 10% of yearly income when the denominator is total expenditure. That represents an approximate threshold at which the household is forced to sacrifice other basic needs, sell productive assets, incur debt, or become impoverished (14).

In addition to enabling people to access care when needed, national health financing systems must shield households from financial disasters by reducing out-of-pocket expenditures. But catastrophic expenses do not automatically disappear with increased income. In the longer term, the aim should be to develop prepayment mechanisms such as social health insurance, tax-based financing of health services, or some mix of prepayment mechanisms. In this direction, this research aims to examine the effects of countries' prepaid financing model implementation and income levels on their capacity to reduce the risk of catastrophic health expenditures.

Materials and methods

This paper investigates the impact of prepayment financing models, in other words, the extent and existence of public health expenditures and income on the capacity to reduce the risk of catastrophic health expenditures with static and dynamic panel regression analysis for 34 OECD countries from 2003 to 2019.

Panel data are multidimensional data containing measurements over time. It covers observations of multiple phenomena in more than one-time period for the same organizations, individuals, or countries. In panel data consisting of N units, and T number of observations, N and T are higher than one (15). The simultaneous use of time and unit dimensions in panel data makes many data analyses usable by increasing the degrees of freedom. The panel data regression model is generally defined as follows:

$$Y_{it} = \beta_{0it} + \beta_{1it}X_{1it} + \beta_{2it}X_{2it} + \ldots + \beta_{kit}X_{kit} + u_{it}$$
$$i = 1 \ldots \ldots N, t = 1 \ldots \ldots T.$$

In the study, the probability of countries making catastrophic expenditures when a surgical procedure is needed, representing the dependent variable, catastrophic expenditure, was taken as a proxy indicator. The proxy indicator of the income level is the income level in dollars according to the state domestic product (SDP) per capita, and the total out-of-pocket health expenditure per person in the relevant year, representing out-of-pocket expenditure. The

study examined the health systems (public premium financing, tax financing, and private financing) of different countries to assess the impact of their prepayment mechanisms. Grouping takes into account the presence or absence of a prepaid model in the country's health services, which are primarily financed by public premiums and taxes. For this, the existence of a prepaid model is accepted as being 70% above the weighted average of public health expenditures among health expenditures.

The data consists of annual data between 2003 and 2019. For this reason, panel data analysis was used. Israel and New Zealand were excluded from the data set and analyses due to missing data from the 36 OECD countries, resulting in a total of 34 countries being studied. STATA 13.0 was used for all estimations.

Dataset and model

The gross domestic product based on purchasing power parity (PPP) per capita GDP as an income-level proxy and domestic general government health expenditure (% of current health expenditure) were used as an indicator along with the risk of catastrophic health expenditures. The share of the risk of catastrophic health expenditures for surgical procedures, public health expenditures and income level data were accessed from the World Bank database. It was used a panel model controlling fixed and time effects and used also dynamic model (Generalized Moments Method-GMM) due to the endogeneity ().

The fixed effects regression model used in the research is as follows:

$$che_{it} = \beta_0 + \beta_1 pre_{it} + \beta_2 income_{it} + u_{it}$$

The dynamic model regression model used in the research is as follows:

$$che_{it} = \beta_0 + \beta_1 che_{it-1} + \beta_2 pre_{it} + \beta_3 income_{it} + u_{it}$$

In the above equation: β is for the independent coefficients, *i* is for the countries, and *t* shows the time. The source of the data in the model, descriptive statistics, and other necessary explanations are given in Table 1.

In the study, the countries whose data are available for the period between 2003 and 2019 were included and used a balanced panel data method. The reason why the data were cut in 2019 in the study is that the data for the last year announced for all the variables included in the model is 2019. In other words, 2019 is the most recent data.

Results

The study sample consists of annual data from 34 OECD countries between 2003 and 2019. Before the model prediction for static regression modal results, the model's structure was tested to reach more accurate results in the study. The presence of time and/or unit effects in the model was tested with F and LR tests to see whether the model was classical regression. The least squares estimator, a classical regression estimator, gives biased results in the presence of unit or time effects. For this reason, in panel regression models, it should be tested first whether there is a unit or time effect in the model. The null hypothesis of the F and LR tests states that there is no unit or time effect, while the alternative states that there is a unit or time effect (15).

Researchers should investigate the relationship between the unit/time effects in the model and the independent variables. If there is a correlation between the independent variables and the unit/time effect in the model, researchers should use a fixed effects model. In this case, where the use of fixed effects model estimators is appropriate, if there is no relationship between the unit effects in the model and the independent variables, it would be more appropriate to use random effects model estimators instead of the fixed effects model. In the presence of unit/time effect, Hausman Test is used to test the relationship between these effects and independent variables (15).

Table 2 shows the results of the F, LR, and Hausman tests, performed before model estimation to determine the model type. The fact that the F and LR test results were statistically significant at 1% means that there is at least one time or unit effect in the model, and therefore it is understood that the classical model estimation is not suitable for this case. Both F and LR tests gave valid results for the one-way unit effect in the model seen in Table 2. In the effect of the unit effect, it should be decided whether the effect is fixed or random, that is, whether the $E(\alpha_i, x_{it} = 0)$ condition is obtained by the Hausman test.

Hausman test is used to make a valid choice between fixed effects and random effects, examining whether the difference between the parameter estimators of the fixed-effect model and the parameter estimators of the random model is statistically significant (16, 17). Since the null hypothesis of the Hausman test for the model was rejected, the fixed effects estimator is valid in this case.

In the following steps, model estimation was carried out with the fixed effects model in the group estimator method. Then, to ensure the model results, the assumptions of heteroscedasticity, autocorrelation, and inter-unit correlation, which are the basic assumptions of the panel regression models, were tested. If any of these assumptions occur, the t statistics and significance scores (*p*) cannot be trusted. In this direction, the Modified Wald test for heteroscedasticity assumption, LBT and Durbin Watson tests for autocorrelation hypothesis, and Pesaran CD tests for correlation between units were applied. The results of the tests showed that there are deviations in all three assumptions, so the current model cannot be used because it includes inter-unit correlation, autocorrelation, and heteroscedasticity. In heteroscedasticity, autocorrelation, and inter-unit correlation, the Driscoll and Kraay standard error correction estimator is one of the robust estimators (18). Therefore, Driscoll and Kraay's standard error correction estimator was used for the final estimation results of the study.

The final model estimation results are in Table 3 for static regression model.

The *F* statistic found at 61.65 indicates that the model is statistically significant at the 1% significance level. The *R*-square value of the model shows that all explanatory independent variables have an explanatory power of ∼18.8% in the risk of catastrophic health expenditures for surgical health services (Table 3).

TABLE 1 Explanations about variables in the model and descriptive statistics.

Variable	Definition	Source	Mean	Min.	Max
che	The proportion of population at risk of catastrophic expenditure when surgical care is required for i country at t time.	World Bank Data (2022). https://data.worldbank.org/indicator/SH.SGR.CRSK.ZS	10.61	0.0	96.8
pre	Domestic general government health expenditure (% of current health expenditure) for i country at t time	World Bank Data (2021). https://data.worldbank.org/indicator/SH.XPD.GHED.GE.ZS	70.5	29.7	87.63
income	Gross domestic product based on purchasing-power-parity (PPP) per capita GDP for i country at t time.	World Bank Data (2022). https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD	37,416	9,587	11,7341

TABLE 2 F, LR, and Hausman test results.

Model	F test	LR test	Hausman test
$che_{it} = \beta_0 + \beta_1 pre_{it} + \beta_2 income_{it} + u_{it}$	$F_{unit} = 1{,}654$ (0.000) $F_{time} = 0.001$ (0.999) $F_{unit-time} = —$	$LR_{unit} = 2{,}052.65$ (0.000) $LR_{time} = 0.002$ (0.999) $LR_{unit-time} = ———$	$H_{test} = 16.90$ (0.000)
Hypotheses	Unconstrained Model: $Y_{it} = X_{it}\beta + \mu_i + u_{it}$ Restricted Model: $Y_{it} = X_{it}\beta + u_{it}$ $H_0 = \mu_{1=} \mu_{2=.....=} \mu_{N-1} = 0$	LR = $-2[l(\text{Limited}) - l(\text{Unconstrained})]$ $H_0 = \partial_u = 0$	H_0 = "there is no correlation between explanatory variables and error term" The random effects model is consistent H_1 = "there is correlation between explanatory variables and error term" The fixed effects model is consistent
Result	H_0 has been rejected. One-way unit domain	H_0 has been rejected. One-way unit domain	H_0 has been rejected. Fixed effects model is appropriate

TABLE 3 Panel data analysis fixed effect model estimate results.

Variables	Coefficients	*t*-statistic	*p*
The dependent variable: Risk of catastrophic health expenditures			
Constant	40.0814 (3.170164)*	12.63	*<0.001*
Pre	−0.3674226 (0.0412815)	−8.19	*<0.001*
Income	−0.000948 (0.00044)	−6.97	*<0.001*
Number of observations	578		
F statistic	61.65		
F prob.	0.000		
Method	Fixed-effects regression		
Within *R*-squared	0.18		

*Values in parentheses indicate the standard errors.

TABLE 4 Arellano-bond robust standard errors GMM estimator results.

Arellano-bond dynamic model prediction Group variable: Countries Time: Years (2003–2019) Vehicle variable number: 35 Ω	Number of observations	578
	Number of groups	34
	Wald test	1,855.93
	p	*<0.001*

che	Coefficient	Std error	*z*	*p*	%95 confidence interval	
che_{t-1}	0.472	0.032	13.43	*<0.001*	0.479	0.654
pre	−0.307	0.111	−2.44	*<0.001*	−0.417	−0.007
income	−0.081	0.028	−3.23	*<0.001*	−0.129	−0.034
GMM: L(2/3).che						
Standard equation D.che D.pre D.income						
Sargan test statistic: 24.25435						
P for Sargan: 0.224						
AR (1): −2.7686 ve *<0.001*						
AR (2): −0.51724 ve *>0.001*						

The negative and statistically significant 1% level of the coefficient of the pre-variable in the model meets the expectations. This value can be interpreted as, keeping other variables constant, a one-unit increase in the rate of public health expenditures will reduce the risk of catastrophic health expenditure for surgical services by 0.36 units. In addition, the coefficient of the income variable, which is the explanatory variable in the model, was also negative and statistically significant at the 1% level. This finding also suggests a one-unit increase in the country's income level, holding other variables constant, is associated with a 0.0009 unit decrease in the risk of catastrophic health expenses for surgical services (Table 3).

Moreover, the model was tested using dynamic panel data method to estimate the effective factor on catastrophic health expenditure for surgical services between 2003 and 2019. The reason for using dynamic model as estimation method is the endogeneity or dynamism.

In Table 4, dynamic model Arellano-Bond GMM estimator results are presented using robust standard errors. Before the interpretation of the panel regression estimation results obtained in the analysis with the Generalized Moments Method (GMM), it is important to perform some consistency tests for the model. Three different tests were used for consistency. The Wald Chi2 test that tests the significance of the variables in the model as a whole, the Sargan test that tests the validity of the tools used in the model, and the Arellano-Bond (AB) autocorrelation tests that show whether the model has an autocorrelation problem.

The model is statistically significant as a whole, according to the Wald test results. In addition, the relationship between instrument variables and error terms was tested with the Sargan test and it was concluded that the instrument variables were valid. The results of AR (1) shows that there is autocorrelation and AR (2) tests show that there is no autocorrelation problem as expected. When the obtained test results are evaluated collectively, it is concluded that the panel regression estimation results can be interpreted properly. The small sample correction suggested by Windmeijer (19) was made in the GMM estimates. *, **, *** indicate 10, 5, and 1% significance levels, respectively (19). As excessive vehicle uses leads to deviating results, it is accepted as a rule of thumb that the number of vehicles should not exceed the number of units in GMM estimates. The Ω indicates that the number of vehicles is therefore limited. The descriptive statistical results of the models also show that there is no problem in the estimation of the models.

It is seen that all of the variables that are determinants of catastrophic health expenditure for surgical services are also significant at 1% confidence levels and the coefficients are consistent with expectations just like static regression model. As a result of both static and dynamic regression models, it is concluded that the share of public health expenditures in total health expenditures and per capita income calculated according to purchasing power parity have a negative statistically significant effect on the risk of catastrophic health expenditure for surgical services between 2003 and 2019 for 34 OECD countries.

Discussion

Globally, although the share of out-of-pocket payments in health expenditures decreases, its share in income does not decrease because, in public health expenditures, states tend to establish an inclusive health system to prevent threats that may arise, especially for their citizens who are in poverty or at risk of poverty (20). It is an important approach to reduce the risk of catastrophic health expenditures by increasing the budget allocated to public health expenditures. The other approach, increasing the income level, can be interpreted as an issue with weak flexibility. Because it may take more time for countries to increase their income level than to increase the share of health expenditure in current income. However, as seen in the results of my study, it is seen that the effect of 1 unit of increase in health expenditure has a more significant effect (0.39) on the catastrophic health expenditure related to surgical procedures. Of course, the use for the difference in income level increase may not only be for health, which can also be considered a reason for the income level effect being low. In this case, it will be beneficial for every country that cares about health outcomes to increase the share of health expenditures in income (21). As Zhou and colleagues (22) mentioned in their research, it will be inevitable that the share of health expenditures in GDP will increase in the coming years due to the aging population. The fact that health expenditures are both low compared to countries with good health indicators and the share of health expenditures in the country's gross domestic product is low, increases the threat that catastrophic expenditures may pose. In addition, countries with high gross domestic product already have high health expenditures and health outcomes. For example, in OECD data for 2020, the countries with the highest health expenditures in terms of their share in GDP are the USA (18.8), Canada (12.9), Germany (12.8), France (12.2), and the United Kingdom (12.0) and the risks of catastrophic health expenditure in these countries are low (23, 24).

A study has shown that as the size of the pooled financial mechanism in healthcare financing increases, out-of-pocket expenditures decrease and the budget allocated to healthcare expenses effectively increases. From this perspective, out-of-pocket spending exhibits similar characteristics to catastrophic healthcare expenditures (25). On the other hand, Dash (26) examined the socioeconomic factors affecting health financing, covering the period of 2000–2013 in low and middle-income countries, and found that low tax revenues, low GDP per capita, and high debt service negatively impact health financing. Meanwhile, another study conducted between 1990 and 2014 using data from 15 major states in India, examined the dynamic relationship between macroeconomic factors such as health expenditures, economic growth, internal income, internal debt, fiscal balance, and central government transfers, showing that improvements in income, increases in tax base, and efficient use of central grants can create fiscal space in the economy and allow governments to allocate more funds to public health services (27). The results of this and my study are similar and coincide with the effect of the share of public health expenditures in total health expenditures and per capita income calculated based on purchasing power parity, reducing catastrophic health expenditure risk in the case of surgical procedures for the 34 OECD countries. On the other hand, an increase in positive macroeconomic factors such as taxes allocated to health financing, internal income, and economic growth can also increase health financing and reduce catastrophic health expenditures.

However, studies have shown that in terms of health outcomes, countries with less health expenditure will have a higher impact on the increase in health indicators for each unit of health expenditure that increases. In this case, another important question arises that needs to be discussed. Will the catastrophic health expenditure reduction results of 0.0003 in 1 unit of income level increase or 0.39 in 1 unit of health expenditure increase have a higher impact or how much impact will they have in developing countries? Boz et al. (28) found that Costa Rica and Turkey, which have a higher share of health expenditures in GDP than other countries, ranked highest in their studies assessing the risk of catastrophic health expenditures, some health indicators, and health systems in developing countries. It is seen that there is public inclusive health insurance in the health systems of both countries (29, 30). Doshmangir et al. (31) argued that setting an

upper limit on catastrophic health expenses is necessary to avoid severe financial consequences related to the public coverage of treatment costs, as demonstrated in their systematic review and meta-analysis. However, further research using different health indicators and inputs could add to the existing literature on how to limit catastrophic health expenses and address other related questions.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Dilaver Tengilimoğlu,
Atılım University,
Türkiye

REVIEWED BY
Salih Haluk Özsarı,
Istanbul University-Cerrahpasa,
Türkiye
Khalid Zaman,
The University of Haripur,
Pakistan

*CORRESPONDENCE
Ahmet Murat Günal
✉ a.muratgunal@gmail.com

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Food insecurity indicators of 14 OECD countries in a health economics aspect: A comparative analysis

Salim Yılmaz[1] and Ahmet Murat Günal[2]*

[1]Department of Health Management, Faculty of Health Sciences, Istanbul Arel University, Istanbul, Türkiye, [2]Department of Nutrition and Dietetics, Faculty of Health Sciences, Istanbul Okan University, Istanbul, Türkiye

Introduction: Food insecurity is a critical issue that refers to a lack of access to adequate food to support a healthy and active lifestyle. This problem has wide-reaching effects and can negatively impact health, education, and overall well-being. Addressing food insecurity requires a multifaceted approach that involves the efforts of governments, organizations, and individuals to ensure access to a balanced and nutritious diet for all.

Methods: The aim of this study is to shed light on macro-level models and evaluate food insecurity risk in international comparisons. We considered six criteria to evaluate food insecurity risk in terms of health expenditure, gross domestic product (GDP) *per capita*, and GDP growth rate among 14 Organisation for Economic Co-operation and Development (OECD) countries. We developed a modeling approach in three stages to compare food insecurity risk and discussed the reasons for the rankings of the countries based on the model results.

Results: According to our findings, the United States has the lowest food insecurity risk, while Colombia has the highest. The results suggest that economic factors, such as GDP per capita and GDP growth rate, play a significant role in food insecurity risk. The study highlights the importance of addressing economic disparities and promoting economic growth to reduce food insecurity.

Discussion: This study provides insights into the relationship between food insecurity and economic factors, indicating that addressing economic disparities and promoting economic growth can reduce food insecurity. Future research using similar models to link economic outcomes with important health components such as nutrition and physical activity could provide a foundation for policy development.

KEYWORDS

food insecurity, OECD countries, health policy, health spending, health economics

1. Introduction

Climate crisis, the COVID-19 pandemic, increasing inflation, fear of recession, and the ongoing war between Ukraine and Russia, two essential grain importers, the world is threatened once more with a not-so-foreign term, food insecurity.

The definition of food security is agreed upon in World Food Summit 1996 as "When all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life." Thus, food insecurity refers to a lack of access to enough food to support a healthy and active lifestyle (1). It is a complex issue that can have a variety of causes and effects. Some of the foremost causes of

food insecurity include poverty, natural disasters, conflict, and inadequate infrastructure for food distribution. These factors can make it difficult for people to access enough food to support a healthy and active lifestyle. Food insecure people may have difficulty getting enough to eat, may not have access to a diverse and nutritious diet, or may have to resort to eating less healthy food to make ends meet (2).

The effects of food insecurity are wide-reaching and can have negative impacts on health, education, and overall well-being. For example, food insecurity can lead to malnutrition, which can have serious health consequences, particularly for children. Malnutrition can cause a range of health problems, including stunted growth, weakened immune systems, and increased susceptibility to illness. When children are not getting enough to eat, they may be less able to focus and learn in school. This can lead to reduced school attendance and lower educational achievement. Additionally, food insecurity can lead to increased stress and anxiety levels, which can negatively impact mental health (3). Food insecurity can also have broader societal impacts, such as increased crime rates and reduced economic productivity (4).

Overall, food insecurity is a serious problem affecting millions of people worldwide and requires a multifaceted approach to address. Governments, organizations, and individuals need to work together to address the root causes of food insecurity and to ensure that everyone has access to enough food to support a healthy and active lifestyle.

2. Literature review

Wars, pandemics, increasing population, and income inequalities are increasingly exacerbating the threat of food insecurity. Furthermore, even before the pandemic, global efforts to control the rising food insecurity by 2030 had not been successful (5). Hunger, poverty, and food insecurity are closely linked to malnutrition, and research has mapped longitudinal changes in gross domestic product (GDP) *per capita* (6–8). Between 1990 and 2010, indicators such as daily energy consumption and meat consumption increased in East Asian and Pacific countries, with an average growth of 2% (6). Warr (9) stated that the GDP growth rate reduces food insecurity and that GDP *per capita* is even more effective in doing so. Beckman et al. (10) found that in the Organisation for Economic Co-operation and Development (OECD) countries, the 7.2% decrease in GDP *per capita* during the COVID-19 period caused a 27.8% increase in the number of people affected by food insecurity and a 9% decrease in the income of crop producers. Moreover, responses to crises also pose an additional threat to groups experiencing food insecurity. For example, in a study conducted in Korea comparing the food insecurity situation before the pandemic in 2019 and after the pandemic in 2020, the vitamin C intake and fruit consumption of individuals in insecure situations remained significantly lower compared to the changes observed in the group with secure food status (11).

There is a correlation between the increase in food insecurity worldwide and the increase in chronic diseases (12). Moreover, studies show that food insecurity may have a two-way relationship with cardiovascular diseases (13, 14). Food insecurity plays a significant role in chronic diseases that put a strain on the health system financially, increasing health expenditures. As countries strive to increase access to comprehensive health services, they are also forced to increase the share of health expenditures in GDP (15). In such a situation, GDP cannot show strong growth in the short term in the face of increasing diseases and population, and the risk of food insecurity is also increasing worldwide (6). In addition to the inevitable increase in health expenditures with an aging population, it is discussed that the risk of food insecurity may put the health system in a more difficult situation in the coming years (16). On the other hand, governments are inclined to determine their policies on healthcare systems according to the expectations of the public, despite all their drawbacks. However, misinformation and various speculative discourses may still inadequately affect public preferences, despite government support. Thus, various socio-demographic factors may indirectly become determinants of the healthcare system and policies. For instance, during the COVID-19 pandemic, it has been shown that age, gender, educational level, and economic prosperity may have an impact on vaccination behavior in terms of vaccine hesitancy and skepticism (17). In addition, it is reported that gender-based opportunity inequalities, economic income inequalities, and gaping differences in educational levels exacerbate this situation (18). Retrospectively, today's world is paying the price of not being able to solve the food insecurity problems of previous years, and it is foreseeable that it will face rising risks in the coming years.

In recent years, political developments have also left indirect evaluations based only on health spending, GDP, and GDP growth rate insufficient. The grain crisis caused by Russia's blockade has reduced the global food supply (19). This situation may bring to the fore the possibility that countries with high production capacity for crops may be less affected by political developments that increase the risk of food insecurity. As a proactive approach to these developments increases the focus on sustainable and resilient food systems, certainly producer protection and producer support have also increased their weight in the dimensions that make up food insecurity (20). While efforts are being made to develop collaborations and protocols for greater transnational integration regarding agriculture and food production and transportation, on the other hand, the insufficient provision of support and protection for agricultural producers continues to pose a significant risk of food insecurity (21). Latino et al. (22) have associated models that try to solve problems such as food supply chains and waste reduction with countries that prioritize the role of local producers in consumption. Accordingly, the low *per capita* production and consumption of local crops in countries that are dependent on imports increases food insecurity risk. In the OECD data, ton-based information of countries in terms of wheat, maize, rice, and soybean with crop production, and the importance of crop production is related to harvested areas, returns per hectare (yields), and quantities produced are shared (23). Despite the fact that food insecurity resulting from insufficient crop production is of utmost importance, it creates both causal and consequential effects. This is due to factors such as decreasing water resources as a result of increasing urbanization and population density, increasing demand for local food transportation and foreign food imports, increasing waste, acquisition of some nutrition habits specific to large cities that threaten health, as well as the loss of agricultural land and required workforce in agriculture due to poverty caused by unemployment (24). Producer protection is directly related to crop production and is defined as the ratio between the average price received by producers (measured at the farm gate), including net payments per unit of current output, and the border price (measured at the farm gate) (25). Meanwhile, according to OECD data sharing, producer support is defined as a subgroup of the agricultural support indicator. Agricultural support is the annual monetary value of gross transfers to agriculture from consumers and taxpayers arising from government policies that support agriculture, regardless of their objectives and economic impacts (26). Another

important OECD indicator in terms of crop production and consumption is meat consumption. Meat consumption is related to living standards, diet, livestock production, and consumer prices, as well as macroeconomic uncertainty and shocks to GDP, and OECD data includes beef and veal, pig, poultry, and sheep per kilogram *per capita* (27). Approximately 200 million people in India suffer from inadequate nutrition and struggle with consuming meat and obtaining protein (28). Consumption of meat is an ecologically controversial issue in terms of meat production, based on the increase in CO2 emissions. However, the correlation between the high level of GDP and excessive use of vehicles complicates the issue. Nevertheless, it is a known fact that population growth is the biggest threat in this regard and is closely related to the risk of food insecurity. In this context, the ability to consume meat can be considered a critical variable for food insecurity (29). Between 2017 and 2021, household spending accounted for 60.5% of India's GDP and contributed to poverty and food insecurity among the Indian people (30). Although poverty appears to be less on average for OECD countries, food insecurity still exists with differences. In some developed countries, the excessive share of household spending in GDP increases food insecurity and contributes to income inequality (31). According to the OECD, household spending refers to the amount of money that resident households spend on final consumption to meet their daily needs, such as food, clothing, housing (rent), energy, transportation, durable goods (including cars), health care costs, leisure, and miscellaneous services (32). Increasing food inflation in recent years directly threatens food insecurity. Households struggling with poverty face financial constraints that lead to inadequate food intake. Food inflation is typically measured using the consumer price index (CPI), which is the change in the prices of a basket of goods and services commonly purchased by households (33). The ongoing war between two major agricultural powers, Ukraine, and Russia, may lead to significant food disruptions in Middle Eastern and North African countries that follow an import-based model for agricultural products, according to Ben Hassen and El Bilali (20). All of this shows that indicators such as producer protection and support, crop production, and meat consumption are in a two-way relationship with each other in terms of risk assessment for food insecurity and can destructively create economic problems, especially for the poor, and increase the need for health spending.

The inadequate data on the determinants of food insecurity risk, the difficulty of estimating, and the fact that it is a multidimensional concept makes it difficult to determine. However, comparative analyses under certain explanatory variables will serve as a resource for policy determination by discussing the reasons for the countries' positions. Urbanization, limited access to water resources, decreasing workforce in agriculture and animal husbandry, rapid decline in the young population, rapidly increasing population, technological access level in production and logistics, climate change, and many other factors are among the other elements that cause food insecurity. In addition, health outcomes that approach food insecurity and create consequential effects, such as difficulties in accessing health services, trained health workforce, habits, and addictions, certainly represent other causes from a health economics perspective. This study sets the research limitations on six food insecurity variables and three health economics area variables related to health economics and food insecurity areas that can be evaluated within a very broad framework and compares countries based on these variables. Thus, determining the situations of food insecurity risks of countries compared to each other in the framework of health economics is the basic hypothesis. Additionally, determining the importance coefficients of which variables according to health economics outputs, revealing the descriptive data of countries regarding these variables, and evaluating the findings of all these situations are among the objectives of the study.

3. Materials and methods

Our study aims to use data from 14 OECD countries to determine the weights of food insecurity dimensions based on risk, using health spending *per capita*, GDP *per capita*, and GDP growth rate, and to rank the countries according to these weights. We also evaluated the 14 OECD countries according to six criteria of food insecurity that we have defined based on this weighted approach.

3.1. Research data

We have used OECD data in this study to ensure that all the data comes from the same source. We have chosen six widely accepted indicators of food insecurity as our criteria for 14 OECD countries for the year 2020. These are total (beef and veal; pork; poultry; sheep) meat consumption (kg *per capita*), total (wheat, maize, rice, soybean) crop production (tons per 1 m people), producer protection (total ratio), producer support (% of gross farm receipts), food inflation (annual growth rate), household spending (% of GDP). Also, we determined GDP *per capita*, health spending, and GDP growth rate as three indirect variables; that interact with each other and the other criteria in terms of both long-term outcome and cause. We are using this data because it is the most recent data available for the year 2020 in the OECD database for all 14 countries in terms of the relevant variables for the study. These ensure our data is up-to-date and allow us to accurately analyze and compare the food insecurity dimensions across the 14 countries.

3.2. Research model

We completed the research model by planning it in three stages. In the first stage, we performed a factor analysis using the principal component matrix method on health spending *per capita*, GDP *per capita*, and GDP annual growth rate variables. We scored the factor using the regression scores method for the observations, creating a single factor under the influence of the three variables. We coded the factor name as Factor_1.

In the second stage, we determined the criterion weights by identifying the distance of the six variables from Factor_1. We incorporated this distance into the model using the Multidimensional Scaling Method (MDS) and calculated it using the Euclidean distance method. We calculated the distance ratios of the six variables from Factor_1 and subtracted them from 1 for ranking the results of the ratio matrix from the lowest risk of food insecurity. Then, to determine the criterion weights, we compared them to the total score. These ratios formed the criterion weights.

In the last step, we used the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method to determine the country with the lowest risk of food insecurity within a set of 6 variables and to

rank them from lowest to highest risk. Another reason we used this method is that it considers variables that have positive and negative effects. In the model, we determined that total meat consumption, crop production, producer protection, and producer support are positive, while food inflation and household spending are negatively effective. The research model is shown in Figure 1.

3.3. Limitations of study

Food insecurity is affected by many interrelated economic data. In our research, we aimed to use as recent data as possible from the OECD, to compare as many OECD countries as possible, and to include as many criteria as possible that are believed to affect food insecurity and are logically related. Therefore, using data from 2020, including 14 OECD countries, and comparing them based on six criteria were the most significant limitations of the study.

3.4. Statistical analysis

We used IBM SPSS 22.0 and MS Excel 16 programs. We interpreted the factor analysis at a 95% confidence level. In the solution-oriented analysis section, analysis was performed using three different and interconnected stages of statistical methods. The first of these is Factor Analysis, which aims to reduce numerous Nutrition Insecurity variables to a single variable and determine the weights of the converging other variables. The variables GDP *per capita*, GDP annual rate, and health expenditure ($) were combined under a single factor. Then, the values of Factor_1 were determined for each country using regression outputs. The generalized method of moments (GMM) was used to obtain the regression outputs in a similar way as applied to cross-sectional data. However, the GMM method is a technique that allows the use of lagged levels of regressors (explanatory factors) as instruments to address the probable link between the lagged regress and the error term, as well as the endogeneity of explanatory factors (34). In our study, cross-sectional data is evaluated from a single time period. Cross-sectional data represents the analysis of n variables related to different variables at a single time, rather than time-series data (35).

In the second stage, Multi-Dimensional Scaling (MDS), which is a multi-factor evaluation technique in cross-sectional data, was used (36). This method is a multivariate technique that can process metric data on an ordinal or nominal scale and measure distances (Euclidean Distance) to the point where the reduced data converge (37). In the MDS analysis, we created priorities using the PROXCAL method. We determined the distance matrix based on variables using *Z* scoring transformation. We checked the model for minimum stress and S-stress values using congruence indices. We determined the proportional weights of the distances and accepted them as criterion weights.

In the final step, we compared the countries using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method based on the criterion weights we determined. In the TOPSIS method, determining the decision option that is closest to the positive ideal solution and farthest from the negative ideal solution through matrices is targeted by a multicriteria approach (38). To make the comparison, we created a benefit and cost matrix from the weighted normalized matrix we determined. Using the benefit and cost matrix, we determined

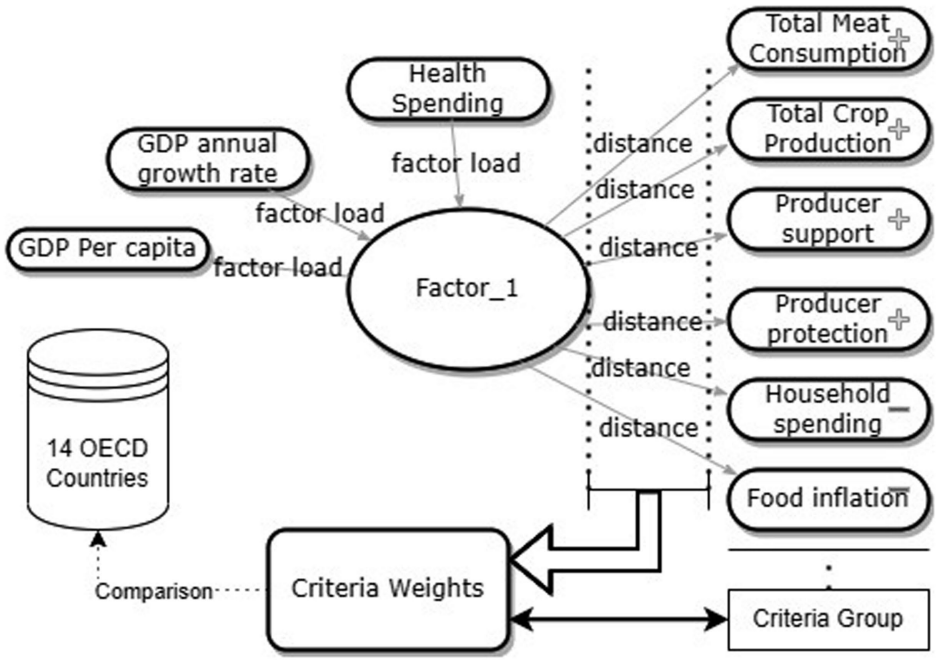

FIGURE 1
Research model.

Table 1 Descriptive statistics of the variables for 14 OECD countries (2020).

	Meat consumption (kg *per capita*)					Crop production (tones)				Population	Total crop production per 1m people (tones)	Producer support (total ratio)	Producer protection (% of gross farm receipts)	Household spending	Food inflation annual growth rate	GDP annual growth rate	Health spending	GDP *per capita*, ($)
	Beef and veal	Pork	Poultry	Sheep	Total	Wheat	Maize	Rice	Soybean	Total								
Australia	19.44	20.21	43.79	5.87	89.32	31164.50	200.79	380.00	44.06	31789.35	25,693,267	1237.25	3.29	1.00	50.66	9.32	−2.21	5627.32	55996.38
Canada	17.58	15.88	35.53	0.97	69.96	35188.18	13563.41	0.00	6358.55	55110.14	38,037,204	1448.85	8.18	1.05	57.16	2.40	−5.23	5828.32	46572.14
Chile	20.26	24.76	37.07	0.48	82.58	1300.00	594.48	117.57	0.00	2012.05	1,945,831	1034.03	2.43	1.00	57.77	6.74	−6.21	2412.75	24647.94
Colombia	8.62	8.99	31.70	0.14	49.46	5.00	1430.00	2005.82	75.00	3515.82	50,911,747	69.06	10.16	1.10	70.51	5.55	−7.05	1335.88	15306.34
Israel	23.21	1.31	64.44	1.53	90.49	85.00	81.00	0.00	0.00	166.00	9,215,113	18.01	15.36	1.16	48.42	0.0	−1.78	3057.41	40090.87
Japan	7.64	16.13	17.73	0.16	41.67	1037.00	0.00	7396.39	241.65	8675.04	126,146,099	68.77	43.50	1.66	53.79	1.20	−4.62	4665.64	42285.33
Korea	11.85	31.57	18.74	0.33	62.49	27.15	73.58	3996.48	98.98	4196.20	51,836,239	80.95	47.91	1.73	46.39	4.43	−0.71	3582.31	45403.24
Mexico	8.97	14.42	30.59	0.54	54.52	2957.48	275599.39	358.23	268.41	279183.51	127,792,286	2184.66	9.52	1.06	63.07	6.62	−8.06	1226.74	19106.97
New Zealand	11.55	19.06	40.08	3.45	74.14	482.06	181.77	0.00	0.00	663.83	50,902	13041.39	0.98	1.01	57.50	3.18	−1.06	4469.38	44698.27
Norway	12.81	21.10	17.84	4.48	56.22	468.97	0.00	0.00	0.00	468.97	5,379,472	87.18	53.40	1.61	43.98	3.26	−0.72	6536.09	62650.38
Switzerland	13.11	22.46	14.77	1.15	51.48	445.99	146.69	0.27	5.93	598.88	863,817	693.28	52.65	1.60	51.61	0.09	−2.51	7178.56	70555.78
Turkey	9.63	0.00	19.18	4.23	33.05	20500.00	6031.00	588.00	140.00	27259.00	83,384,688	326.91	26.03	1.16	56.77	13.85	1.83	1304.71	27554.34
United Kingdom	11.33	15.82	30.45	3.93	61.52	10132.99	0.00	0.00	0.00	10132.99	67,081,234	151.06	18.92	1.05	59.86	0.70	−11.03	5018.70	45644.39
United States	26.20	23.98	50.96	0.43	101.57	49696.42	360251.16	6738.04	112538.16	529223.78	33,150,108	15964.47	11.62	1.02	67.03	3.51	−2.77	11859.18	63480.86

the positive and negative ideal solution values for the observations. We ranked the countries from the one with the lowest risk of food insecurity to the one with the highest by calculating the closeness coefficient of the results we obtained.

4. Results

In Table 1, the data of the total meat consumption (kg *per capita*) and crop production (tons per 1 m people) and their subunits, population, producer protection (total ratio), producer support (% of gross farm receipts), household spending (% of GDP), food inflation (annual growth rate), health spending ($ *per capita*), growth rate (annual total), GDP *per capita* ($) for 14 OECD countries are present.

The Bartlett test has given a significant result. Hence, the number of observations accepted as sufficient. We determined that a significant single factor explained 66.27% of the variance. In the loads explaining the factor, the highest load was carried out by GDP *per capita*, while the least was the GDP growth rate. As a result of the factor analysis with the regressional score method, we created the variable, Factor_1 (Table 2).

When the observation values for the Factor_1 variable are ranked (Figure 2), the highest country is the United States, and the lowest is Colombia (Table 3).

The data priorities were created with a single matrix source using the MDS PROXSCAL. We used the Euclidean distance for the measurement, provided the *z*-score standardization through the transformation, and explained the proportional model. Since the standard deviation for crop production is very high, according to the OECD 2020 data, the countries were divided by their population and multiplied by 1 million to determine the total crop production obtained from 4 different crop production data per 1 million people.

$$\text{Euclidean Distance}\left(x,y\right)=\sqrt{\sum_{i=1}^{n=14}\left(x_i-y_i\right)^2}.$$

We explained the model under the Euclidean distance method (S-Stress: 0.00269). When we examined the variables in the space, it is seen that the total of the elements that make up the crop production is located at the farthest distance from Factor_1. The closest distance is occupied by producer protection (Figure 3). The distances are given in Table 3.

When we examined the distances of the variables according to Factor_1, we determined that the closest to the farthest is producer protection (0.018); food inflation (0.078), producer support (0.373), household spending (0.790), meat consumption (0.897), crop production (1.769; Table 3).

To determine the weights of the criteria, the ratio of each distance value to the sum of the distance values was calculated to create a proportional matrix. Then, the determined values were subtracted from 1 to rank the criteria from most successful to least successful, and the criteria weights were determined by calculating the ratio again (Table 4).

We found the normalized decision matrix by normalizing the values in rows (i) and columns (j) for each observation (d) in the unweighted matrix (Tables 5, 6).

TABLE 2 Factor analysis of GDP annual growth rate, GDP *per capita* ($), and Health Spending *per capita* ($) variables.

	Explanatory of factor_1					
	Initial eigenvalues			Factor loadings		
	Total	% of Variance	Cumulative %	Variables	Component matrix Load	Coefficient
1.	1.988	66.266	66.266	GDP Growth rate	0.478	0.240
2.	0.900	30.002	96.268	Health Spending	0.910	0.458
3.	0.112	3.732	100.00	GDP *Per Capita*	0.965	0.485

Bartlett test χ^2:17.954; *df*:3; p = 0,000450; n = 14.

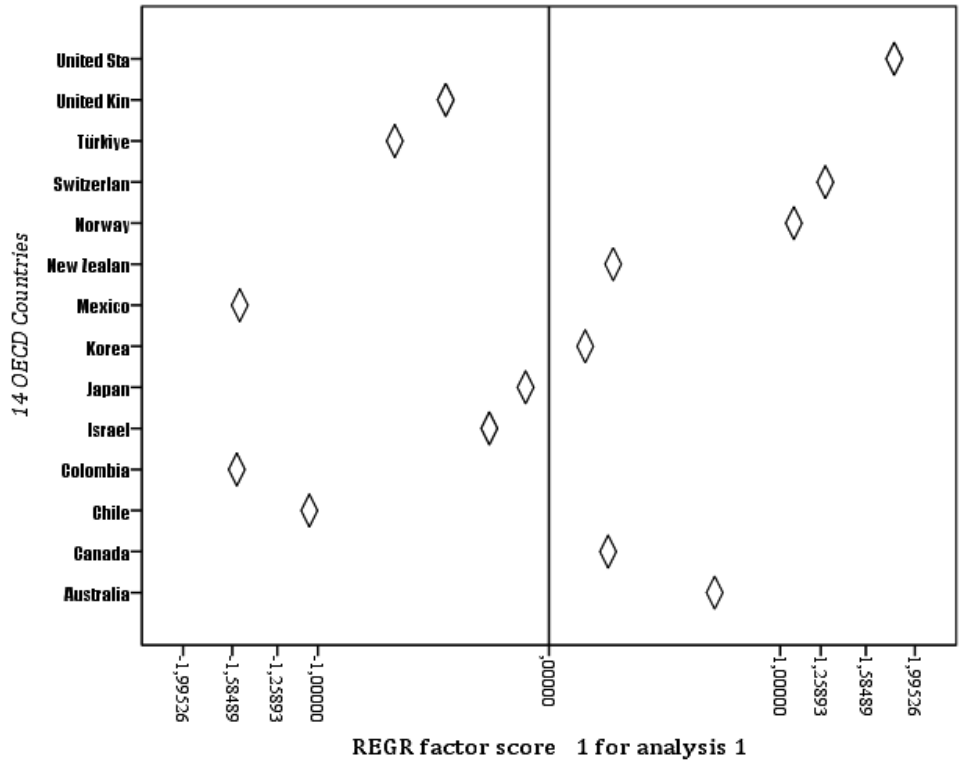

FIGURE 2
Logarithmic distribution of the observation values for the Factor_1 variable.

TABLE 3 Distances of variables according to Factor 1 and priority transformation.

Variables	Dimension 1	Dimension 2	Variables	Distances to Factor_1
Meat	−0.011	0.535		
Crop	1.351	−0.220	Meat	0.897
Support	−0.185	0.027	Crop	1.769
Protection	−0.408	−0.250	Support	0.373
Household	0.056	0.367	Protection	0.018
Food inflation	−0.386	−0.194	Household	0.790
Factor_1	−0.417	−0.266	Food inflation	0.078

$$\frac{d_{ij}}{\sqrt{\sum_{k=1}^{14} d_{11} + \ldots + d_{146}}}.$$

After normalization, we determined the normalized matrix and found the values from before the weighted matrix (Table 7). To find the vector (V), we multiplied the normalized values for each observation by the weights:

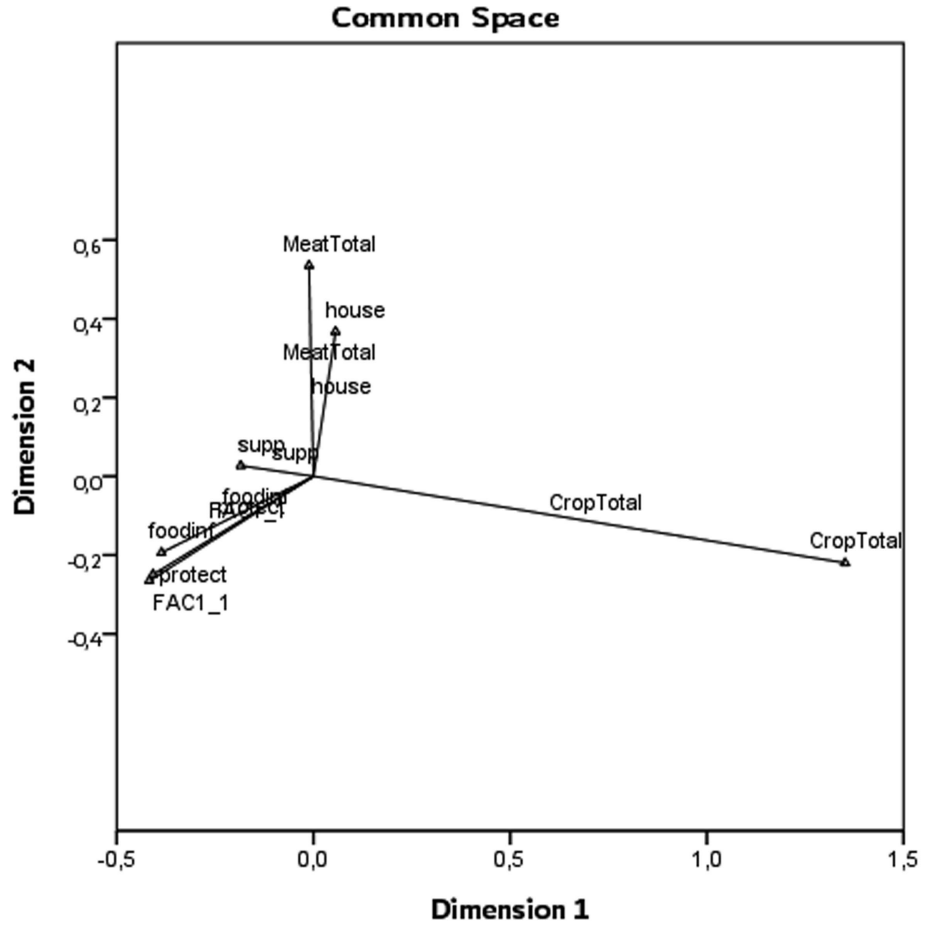

FIGURE 3
Variables in common space and Euclidean distances.

TABLE 4 Criteria weights matrix.

	Distances to Factor_1	Ratio matrix (x_i)	Fixed ($1-x_i$)	Criteria weights (W_i)
Meat	0.897	0.228552737	0.771447263	0.154289453
Crop	1.769	0.450521561	0.549478439	0.109895688
Support	0.373	0.095106865	0.904893135	0.180978627
Protection	0.018	0.004690236	0.995309764	0.199061953
Household	0.790	0.201268933	0.798731067	0.159746213
Food inflation	0.078	0.019859668	0.980140332	0.196028066

$$V=\begin{Bmatrix} w_1r_{11} & w_2r_{12} & w_3r_{13} & w_4r_{14} & w_5r_{15} & w_6r_{16} \\ w_1r_{21} & w_2r_{22} & w_3r_{23} & w_4r_{24} & w_5r_{25} & w_6r_{26} \\ w_1r_{31} & w_2r_{32} & w_3r_{33} & w_4r_{34} & w_5r_{35} & w_6r_{36} \\ w_1r_{41} & w_2r_{42} & w_3r_{43} & w_4r_{44} & w_5r_{45} & w_6r_{46} \\ w_1r_{51} & w_2r_{52} & w_3r_{53} & w_4r_{54} & w_5r_{55} & w_6r_{56} \\ w_1r_{61} & w_2r_{62} & w_3r_{63} & w_4r_{64} & w_5r_{65} & w_6r_{66} \\ w_1r_{71} & w_2r_{72} & w_3r_{73} & w_4r_{74} & w_5r_{75} & w_6r_{76} \\ w_1r_{81} & w_2r_{82} & w_3r_{83} & w_4r_{84} & w_5r_{85} & w_6r_{86} \\ w_1r_{91} & w_2r_{92} & w_3r_{93} & w_4r_{94} & w_5r_{95} & w_6r_{96} \\ w_1r_{101} & w_2r_{102} & w_3r_{103} & w_4r_{104} & w_5r_{105} & w_6r_{106} \\ w_1r_{111} & w_2r_{112} & w_3r_{113} & w_4r_{114} & w_5r_{115} & w_6r_{116} \\ w_1r_{121} & w_2r_{122} & w_3r_{123} & w_4r_{124} & w_5r_{125} & w_6r_{126} \\ w_1r_{131} & w_2r_{132} & w_3r_{133} & w_4r_{134} & w_5r_{135} & w_6r_{136} \\ w_1r_{141} & w_2r_{142} & w_3r_{143} & w_4r_{144} & w_5r_{145} & w_6r_{146} \end{Bmatrix}$$

After the determination of the vector, the positive benefit criterion values (A^*) and negative cost criterion values (A^-) for each column were calculated through the maximum and minimum column values. Then, the positive ideal solution distances (S^*) and negative ideal solution distances (S^-) were found, and the analysis was completed by determining the Closeness Coefficient (C^*) with the formula.

$$J=\left[\ j=(1,2,3,4,5,6)\right];J:\text{benefit},$$

$$J'=\left[\ j=(1,2,3,4,5,6)\right];J':\text{cost},$$

TABLE 5 Unweighted matrix and criteria weights.

Criteria:	Meat	Crop	Support	Protection	Household	Food inflation
Weight:	W_1: 0.154289	W_2: 0.109896	W_3: 0.180979	W_4: 0.199062	W_5: 0.159746	W_6: 0.196028
Alternatives						
Colombia	49.46	1237.25	10.16	1.1	70.51	5.55
Mexico	54.52	1448.85	9.52	1.06	63.07	6.62
Chile	82.58	1034.03	2.43	1	57.77	6.74
Turkey	33.05	69.06	26.03	1.16	56.77	13.85
United Kingdom	61.52	18.01	18.92	1.05	59.86	0.7
Israel	90.49	68.77	15.36	1.16	48.42	0
Japan	41.67	80.95	43.5	1.66	53.79	1.2
Korea	62.49	2184.66	47.91	1.73	46.39	4.43
Canada	69.96	13041.39	8.18	1.05	57.16	2.4
New Zealand	74.14	87.18	0.98	1.01	57.5	3.18
Australia	89.32	693.28	3.29	1	50.66	9.32
Norway	56.22	326.91	53.4	1.61	43.98	3.26
Switzerland	51.48	151.06	52.65	1.6	51.61	0.09
United States	101.57	15964.47	11.62	1.02	67.03	3.51

TABLE 6 Normalized matrix result.

	Meat	Crop	Support	Protection	Household	Food inflation
	(r_{i1})	(r_{i2})	(r_{i3})	(r_{i4})	(r_{i5})	(r_{i6})
Alternatives						
Colombia (r_{1j})	9.562718615	0.228657558	0.962745283	0.256860848	23.51156693	1.43754576
Mexico(r_{2j})	11.61943062	228.8232381	0.84527472	0.23851971	18.81160307	2.045274909
Chile(r_{3j})	26.65771434	51.26237119	0.055072721	0.212281693	15.78283003	2.120095893
Turkey (r_{4j})	4.269884036	5.123760535	6.319348694	0.285646246	15.24115686	8.95231301
United Kingdom (r_{5j})	14.79468784	1.094035397	3.338614289	0.234040566	16.94546807	0.02286819
Israel (r_{6j})	32.00916382	0.015551054	2.200424212	0.285646246	11.08739997	0.000000
Japan (r_{7j})	6.787661151	0.226741211	17.64828456	0.584963432	13.68306005	0.067204477
Korea (r_{8j})	15.26490838	0.314171018	21.4080113	0.635337878	1.1772136	0.915889677
Canada (r_{9j})	19.13254548	10.5281134	0.624066099	0.234040566	15.45128434	0.268817907
New Zealand (r_{10j})	21.48712528	8154.177825	0.00895728	0.216548555	15.63564617	0.471943438
Australia (r_{11j})	31.18678322	73.39176599	0.100952198	0.212281693	12.13697662	4.053848707
Norway (r_{12j})	12.35534382	0.364389742	26.59539823	0.550255375	9.147250962	0.495987706
Switzerland (r_{13j})	1.35977276	23.04356967	25.85358271	0.543441133	12.59644117	0.000378025
USA (r_{14j})	4.32775608	12219.16202	1.259320403	0.220857873	21.24802571	0.574976301

$$A^* = \left\{\left(\max_i v_{ij} \mid j \in J\right), \left(\min_i v_{ij} \mid j \in J'\right)\right\},$$

$$A^- = \left\{\left(\min_i v_{ij} \mid j \in J\right), \left(\max_i v_{ij} \mid j \in J'\right)\right\},$$

$$S_i^* = \sqrt{\sum_{j=1}^{14}\left(v_{ij} - v_j^*\right)^2}; \mathrm{i} = 1,2,3,4,5,6,$$

$$S_i^- = \sqrt{\sum_{j=1}^{14}\left(v_{ij} - v_j^-\right)^2}; \mathrm{i} = 1,2,3,4,5,6,$$

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*}.$$

TABLE 7 Weighted normalized decision matrix with benefit (A*) matrix and cost (A⁻) matrix.

	Weighted normalized decision matrix					
	Meat*	Crop*	Support*	Protection*	Household⁻	Food inflation⁻
Colombia	1.475426624	0.02512848	0.17423632	0.051131222	3.755883779	0.281799315
Mexico	1.792755594	25.14668719	0.152976658	0.047480199	3.005082351	0.400931285
Chile	4.113004163	5.633513551	0.009966985	0.042257208	2.521247328	0.415598298
Turkey	0.658798072	0.563079189	1.14366705	0.0568613	2.43471709	1.754904606
United Kingdom	2.282664294	0.120229773	0.60421783	0.046588572	2.706974351	0.004482807
Israel	4.938676376	0.001708994	0.398229753	0.0568613	1.771170157	0.00000000
Japan	1.047264526	0.024917881	3.193962308	0.116443963	2.185817025	0.013173964
Korea	2.355214364	0.03452604	3.874392492	0.126471599	1.625771331	0.179540082
Canada	2.951949976	11.04760618	0.112942626	0.046588572	2.468284159	0.052695854
New Zealand	3.315236807	896.1089821	0.001621076	0.043106578	2.497735263	0.092514159
Australia	4.811791724	8.065438617	0.01827019	0.042257208	1.938836052	0.794668122
Norway	1.906299239	0.040044861	4.813198657	0.10953491	1.461238701	0.097227511
Switzerland	1.598403672	2.532388943	4.678945901	0.108178453	2.012233773	7.41035E-05
United States	6.222147426	1342.833217	0.227910078	0.0439644	3.394291641	0.112711492
*A**	6.222147	1342.833217	4.813199	0.126472	1.461239	0.000000
A⁻	0.658798	0.001709	0.001621	0.042257	3.755884	1.754905

TABLE 8 Rankings of 14 OECD countries from least to most food insecurity risk (2020).

Rank	Countries	PIS score	NIS score	Closeness coefficient
1	United States	4,978,059,496	1,342,844,104	0.99630659
2	New Zealand	446,7,608,229	896,1,136,357	0.66731006
3	Mexico	1,317,703,183	25,21,855,805	0.018778874
4	Canada	1,331,798,304	11,48,208,296	0.008547793
5	Australia	1,334,77,746	9,300,273,407	0.006919446
6	Chile	1,337,21,048	6,853,240,146	0.005098895
7	Switzerland	134.308923	5,940,425,763	0.004412575
8	Norway	1,342,800,111	5,720,736,254	0.00424223
9	Israel	1,342,839,416	5,049123524	0.00374595
10	Korea	1,342,804,609	4,990,341,484	0.003702597
11	Japan	1,342,819,442	3,980,794,681	0.002955742
12	United Kingdom	1,342,725,943	2,679,238,278	0.001991399
13	Turkey	1,342,288,184	1,834,420,945	0.001364772
14	Colombia	1,342,826,483	1,693,323,546	0.001259426

We used the weighted matrix to calculate the benefit values (A^*) and cost values (A^-). We determined that the country with the highest proximity coefficient in the solution matrix was the most successful in terms of the criteria and weights in the comparative analysis. We also ranked the countries by their success.

As a result of the analysis, the United States was determined to have the lowest risk in terms of food insecurity. New Zealand was in second place, and Mexico was in third. Colombia was found to be the country with the highest risk of food insecurity (Table 8).

5. Discussion

Approximately 13 million children and 23 million adults in the United States lacked food security, a 2005 study indicated (39). In their study, Coleman-Jensen et al. (40) stated approximately 41 million Americans were at risk of food insecurity in 2016. Although there appears to be little difference when considering population growth in recent years, the high healthcare expenditure *per capita* and GDP *per capita* in the United States suggest that the threat of food insecurity may be minimal. However, it is important to note that the increasing healthcare expenditures and global policies prioritizing

protective healthcare services require a reevaluation of food insecurity and its dimensions. In this context, the consumption of domestic agricultural production and meat consumption should also be considered. Unpredictable political developments such as wars, conflicts, and embargoes increase the risk of dependence on external sources for essential needs (41). For example, we have witnessed how the tension between Russia and several other countries in 2022 and Europe's need for energy have led to changes in these countries' strategies. The United States is relatively less at risk due to its production and export capacity. These reasons also apply to Canada based on recent data. Despite its small population, New Zealand is a significant agricultural producer and primarily uses its land for pastoral farming (42). Therefore, New Zealand can reduce the risk of food insecurity through its production capabilities, and they rank second in our study. On the other hand, South Korea, despite its relatively high GDP *per capita*, does not seem to have a successful ranking in terms of food insecurity. A study including 10,655 Koreans suggests 4,988 (46.8%) were mildly insecure and 299 (2.8%) were moderately/severely insecure (43). South Korea also does not rank among the countries with high agricultural and meat production. The same is true for Israel, which has a similar proximity score to South Korea. Efrati Philip et al. (44) noted that the prevalence of non-communicable diseases, obesity, and subjective poor health is significantly high among the general Israeli population, also indicating that users of food pantries are at risk of food insecurity. In the case of Mexico, agriculture-based production plays a significant role. While its GDP *per capita* and healthcare expenditures are not in a favorable position, its meat consumption is relatively high compared to other countries. These situations provide two indicators: the ability to produce and consume agricultural products and meat, or the capacity to purchase them, reduces the risk of food insecurity. The same situation applies to Chile, which is known for its high capacity for milk and meat production (45). A 2007 study in Colombia found that child food insecurity was significantly related to being underweight and mentioned the high prevalence of food insecurity in Bogota (46). Upon closer examination, Colombia does not have high scores regarding healthcare expenditure, GDP, agricultural production, or meat consumption. Therefore, they rank last in our study. In their research, Cuesta and Castro-Rios (47) mentioned the iron, vitamin A, and zinc deficiencies, low availability of food, quality and safety issues of food, and poor eating habits among individuals living in Colombia, and they suggested incorporating mushrooms into the food culture. We can interpret these results obtained with different dimensions as being related to our macro-level comparison analysis. In their study, Borelli et al. (48) mentioned that Turkey's risk of food insecurity, which is also influenced by housing, has been increasing in recent years. In a 2017 study in Turkey, Ipek (49) found that an increase in income level, education level, and healthcare expenditures significantly reduced food insecurity. In developing countries, the increase in healthcare expenditure share of income and the structural breaks in income are expected to have higher marginal benefit outputs (50). For example, in the case of the United States, Popescu's (51) study did not yield significant marginal benefit results. In our study, both Switzerland and Norway were in the middle ranks. This is because both countries have average levels of crop production and meat consumption but are among the top ranks in terms of GDP *per capita* and healthcare expenditures. Therefore, their proximity coefficients have yielded similar results. While in Japan, there is low meat consumption, United Kingdom's producer support is weaker and crop production per million people is low, and both countries' economies are shrinking. In the United Kingdom, there is increasing evidence of the use of food banks, and voices are rising about the potential link to long-term poverty, austerity, precarious employment, the rising cost of living, low wages, and cuts to social assistance and public services. (51). Despite providing food assistance to 1.6 million people living in the United Kingdom each year, the Trussell Trust—the United Kingdom's largest foodbank network—reports that food insecurity is much more widespread in the United Kingdom (52). All of this has contributed to Japan and the United Kingdom being ranked lower on the list despite their high healthcare spending and GDP *per capita*. Studies in the literature have shown that nearly every country has citizens who are at risk of food insecurity, and solutions to reduce this risk are being sought (52, 53). Therefore, our study is important in terms of comparative macro situational assessment, rather than focusing on solutions for a single country. Although it is often repeated that the global healthcare system is moving towards proactive solutions that protect health before illness arises, rather than reactive solutions, perhaps the first step in the solution will be to reduce the risk of food insecurity. If indicators such as food aid, nutrient balance, and food waste are expanded in the literature to cover countries, research on the increasing trend of food insecurity risk will increase.

6. Conclusion

Food insecurity is a global issue affecting millions of individuals and families. While there are varying levels of risk in different countries, our study highlights the importance of considering multiple dimensions such as healthcare expenditure, GDP, agricultural production, and meat consumption. The ability to produce and consume agricultural products and meat, or the capacity to purchase them, reduces the risk of food insecurity. Our study provides a comparative macro situational assessment, highlighting the need for solutions to reduce this risk on a global scale. As the healthcare system moves towards proactive solutions that protect health before illness arises, reducing the risk of food insecurity may be an important first step. Further research on the increasing trend of food insecurity risk and expanded indicators such as food aid, nutrient balance, and food waste can help in finding solutions to this global issue.

Short-term, medium-term, and long-term policy recommendations can be made for countries based on the results of the study. Short-term recommendations may include innovations in food safety legislation, tightening of inspections, encouragement of obtaining documents related to food safety standards, organizing public awareness campaigns, and adding food safety to education curricula. Medium-term recommendations may include developing a national strategic plan and utilizing sustainable agricultural practices and support for producers. Longer-term recommendations may include the promotion of research and development activities for food safety, encouragement of the agricultural sector and food industry to sustainably produce in an ecologically balanced manner, imposition of mandatory continuing education for food producers and businesses, the establishment of international cooperation and certification systems, and deepening of research on international production and distribution of agriculture and animal husbandry.

Additionally, it should not be forgotten that practices that generally reduce income inequality in countries are extremely important for food insecurity.

Although some limitations, the study's novel modeling approach has produced results consistent with previous research, indicating the robustness of these findings. We believe that our study provides a valuable baseline for future research, and that future studies can build upon our work by exploring different variables and larger datasets over time. Comparative studies could be particularly useful in this regard.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Author contributions

SY and AG contributed to the idea, conception, and design of the study. SY organized the database, performed the statistical analysis, and wrote the background and discussion. AG wrote the first draft of the manuscript and the abstract and introduction. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Dilaver Tengilimoğlu,
Atılım University, Türkiye

REVIEWED BY
Milena Lopreite,
University of Calabria, Italy
Anwar Hussain,
University of Swat, Pakistan

*CORRESPONDENCE
Asim Anwar
✉ asimm.anwar@gmail.com

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Government health expenditures and health outcome nexus: a study on OECD countries

Asim Anwar[1]*, Shabir Hyder[1], Norashidah Mohamed Nor[2] and Mustafa Younis[3]

[1]Department of Management Sciences, COMSATS University Islamabad, Attock, Pakistan, [2]School of Business and Economics, Universiti Putra Malaysia, Serdang, Selangor, Malaysia, [3]Department of Health Policy and Management, School of Health Sciences, Jackson State University, Jackson, MS, United States

Introduction: The consistent increase in health expenditures is an integral part of health policy. The aim of this study was to investigate the impact of health expenditures on health outcomes in the OECD countries.

Method: We used the system generalized method of moments (GMM) for thirty eight OECD countries using panel data from 1996 to 2020.

Results and discussion: The findings show that health expenditures have a negative impact on infant mortality while positive on life expectancy. The results further verify that the income measured as GDP, number of doctors, and air pollution has a negative effect on infant mortality, while these variables have a positive effect on life expectancy in the studied countries. The outcome of the study suggests that health expenditures need to be properly utilized and improvements can be made in the health policies to increase the investment in health technology. The government should also focus on measures like economic and environmental to have long-lasting health outcomes.

KEYWORDS

health expenditures, infant mortality, life expectancy, air pollution, income, OECD countries

Introduction

Healthcare is a persistent challenge for nations around the world. The growing economic and environmental challenges pose risks to the healthcare system (1–3). People suffer due to such risks and are prone to various diseases, including a child and maternal mortality, non-communicable diseases, infectious diseases, and lack of healthcare facilities (4, 5). According to research by the PEW research center, 85% of people consider the lack of healthcare facilities as a major problem in their respective healthcare systems (6). A good healthcare system is not only limited to treating diseases but also contributes to the economy (7, 8). Therefore, nations need to finance their healthcare system more effectively, which is a critical component of the health system (9–11).

Investment in healthcare is important for both short- and long-term benefits (12, 13). Good health, an important element of human capital, is considered one of the prerequisites for long-term sustainable economic development (14). The neoclassical growth model suggests healthy and educated human force increases the per capita income for individuals and their families which enhances the value of human life (7, 15, 16). Health expenditures can result in providing better health facilities and opportunities that strengthen human capital, leading to higher productivity and economic performance (8, 17). Increased public spending on curative care, emergency assistance, and vaccination and nutrition activities results in significant health outcomes in the form of reduced mortality (18). The literature has shown mixed results on the impact of healthcare expenditures

on health outcomes. Some studies have shown that health expenditures positively contribute to health outcomes in terms of higher life expectancy and lower child mortality (14, 19, 20). For example, a study (14) found a positive impact of healthcare expenditures on health outcomes measured as life expectancy and maternal and infant mortality in the OECD countries. Similarly, examining 17 OECD countries for the period 1973 to 2000, a study by Kim and Lane (20) found a positive association between health spending and health outcome using infant and life expectancy at birth as health outcome indicators. Another study (1) emphasized that higher health spending improves life expectancy and reduces infant mortality. However, some studies (21, 22) found no relationship between health expenditures and mortality rate in European countries using Spearman's correlation method. A study (23) based on the review of the literature concluded that the relationship between healthcare expenditures and health outcome (life expectancy) is difficult to establish, while some researchers found an insignificant association between health expenditures and health status (24).

Governments around the globe acknowledge the importance of the healthcare system; therefore, health expenditures throughout the world have increased over time (25). Health expenditures are mostly financed through public taxation and are growing more than the global economy accounting for 10% of the world gross domestic product (GDP) (25). The average health expenditures as a share of GDP have increased from 7.8% in 2005 to 9.8% in 2020 in the OECD countries (26). The health expenditures in the United Kingdom, Germany, Portugal, Korea, and Italy have increased from 7.8, 8.4, 10.3, 9.7, 4.6, and 8.3 in 2005 to 9.8, 12.8, 12.5, 10.1, 8.4, and 9.7 in 2020, respectively (26). The swift increase in healthcare expenditures necessitates the need to examine whether such expenditures have really improved health outcomes in OECD countries (27, 28).

Thus, the contribution of this research in the health economics literature is manifold: first, to authenticate the relationship between health expenditures and health outcomes which so far has mixed results (29–31). Second, the OECD countries have the highest healthcare spending, i.e., almost 85% of the world's spending while its population is <20% of the world's total population (32). Therefore, it is necessary to study the impact of higher health expenditures on health outcomes in these countries as a test case for other countries to follow and improve their health infrastructure. Third, the recent studies on health expenditures and health outcomes in OECD countries used either cross-sectional data or the sample size does not cover all the OECD countries. For example, (14) using cross-sectional data for 1 year found that increased health spending improves life expectancy and reduces infant mortality in OECD countries. Christopoulos and Eleftheriou (19) using panel data for 29 OECD countries focused on the fiscal effects of health expenditures on health outcomes and found a significant impact of healthcare expenditures on increasing revenue. Aydan et al. (33), using panel data for OECD countries, focused on healthcare and social spending and found them to be important factors in explaining health outcomes. Therefore, it is important to comprehensively analyze the available data for all the OECD countries over time.

Materials and methods

Various methods are used in the literature to explore the relationship between healthcare expenditures and health outcomes (34). Based on the availability and nature of data, the study used panel data estimation. Panel data estimation has various benefits: first, panel data control for the inter-country differences than cross-sectional or time series data; second, panel data even with unbalanced data provide reliable estimates; third, panel data provide higher degrees of freedom and sample variation (35, 36). Therefore, given these advantages, we use the health model following Rahman et al. (34), Novignon and Lawanson (37):

$$y_{it} = H_{it}\, b + e_t$$

where y_{it} is the dependent variable(s), i.e., infant mortality and life expectancy at birth. H is a vector of independent variables, i.e., government health expenditure, per capita GDP, number of doctors, and population of the country, while b is the vector of coefficient, e is the vector of stochastic terms, and i and t subscripts are used for individual country and time.

Higher government health expenditures would suggest more health facilities, provision of necessary medical equipment, and higher standards of hospitals. Therefore, these facilities are likely to improve the health of the citizens. This is also true for higher per capita GDP, where the higher income of the citizens not only increases the citizens' ability to spend more on treating their diseases but also helps them spend money on those activities which improve their health. One of the most important aspects of any medical infrastructure is the availability of doctors because ultimately it is the doctor that could use the medicine and health equipment to treat its patients. Therefore, doctors are the pillar of any medical system, and hence, we have included the number of doctors to signify the efficacy of the medical structure of the county. Air pollution is one of the main causes of mortality; therefore, we have used carbon dioxide emission as a proxy for air pollution.

Based on the aforementioned arguments, we have used the given econometric model having two equations with the following specifications:

$$IF_{it} = b_0 + b_1 HE_{it} + b_2 GDP_{it} + b_3 Pop_{it} + b_4 CO_{2it} + e_{it}$$
$$LE_{it} = b_0 + b_1 HE_{it} + b_2 GDP_{it} + b_3 Pop_{it} + b_4 CO_{2it} + e_{it}$$

where IF denotes infant mortality and is measured by the number of total deaths per one thousand live births, HE shows the government health expenditures per capita in US dollars, GDP measures the per capita GDP in US dollars, Pop shows the population, and CO_2 measures the carbon dioxide emissions in tones per capita, while LE shows life expectancy at birth in years, i and t measure the usual cross-section and time, and e is the stochastic term.

The econometric model is estimated in double log form, i.e., both the dependent and independent variables are measured in natural logarithmic form; therefore, individual variables could be interpreted as elasticities. The study used the system generalized method of moments (GMM) for estimation. This is because

in assessing the panel model estimation, usually, potential endogeneity issues arise because of unobserved heterogeneity and cross-sectional dependence. To overcome such issues, we used the system GMM. System GMM is also preferable because it requires the number of cross sections to be greater than the time period, which in our case is true; i.e., we have 38 countries, while the time period is 25 (38). In addition, our model has fewer instruments than the number of cross sections. Usually, the basic econometric methods to estimate panel data include panel fixed and random effect models. To select a better model out of the two methods, Durbin–Wu–Hausman test is used. Based on Durbin–Wu–Hausman test, we estimated the fixed effect model to compare our results with those of system GMM estimation.

The annual data for the study were obtained from the OECD dataset for the period from 1996 to 2020. There are 38 OECD member countries from different regions, and European member countries include Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom; from the United States of America, the member countries are Canada, Chile, Colombia, Mexico, Costa Rica, and the United States; from pacific, four member countries are Australia, Japan, Korea, and New Zealand; and from Middle East, there are two members, i.e., Israel and Turkey. Although most of the data were available, however, for some countries data were missing for some years, therefore our data set is unbalanced. The descriptive statistics for various variables are provided as follows:

As Table 1 indicates, the life expectancy is higher, i.e., on average OECD citizens live for around 79 years, and there is little variation within and among those countries, i.e., overall average age ranges from as low as 69 years to a maximum of around 85 years and this is also obvious from smaller values of standard deviation within and between countries. The lowest average is observed in Columbia and the highest in Japan. Similarly, the infant mortality overall average is low, i.e., only 5.5 children die out of 1,000 live births; however, in contrast to life expectancy, there is wide variation observed, i.e., the standard deviation value is much higher, i.e., around 4.5, given the overall average value of 5.5. This can similarly be observed in the overall range with a minimum of 0.7 to a maximum of around 43. This trend is observed within and between OECD countries. The highest infant mortality is observed in Turkey, i.e., 42.7, while the lowest is seen in the case of Iceland, i.e., 0.7.

Most of the independent variables showed higher variation in overall values, and a similar trend is observed between and within the sample countries. For brevity, we will discuss only the overall values. For example, in the case of per capita government health expenditure, the overall average is around 2,100 US dollars. The overall wider variation is evident from the standard deviation value of around 1,300. The minimum overall value is as low as 160 dollars in the case of Turkey to as high as around 10,000 dollars in the case of the USA. Per capita GDP is higher among OECD countries; its overall average is around US $ 32,000. The wide variation is evident from the standard deviation value of around 16,000, which is almost half of the value of the average. The highest per capita GDP is observed in Luxemburg, i.e., around 11,800 while the lowest is observed in Latvia, i.e., around US $ 5,800. Overall, the average population in an OECD country is around 34 million; however, there is too much variation in the sample as the standard deviation value of 54 far exceeds the average. The minimum value is as low as 0.26 in the case of Iceland to a maximum of around 330 million in the case of the USA. The overall average number of doctors in an OECD country is around 3, although it has lower variation as compared to other variables, i.e., its value is 0.9. However, there is wide variation in terms of range, where the minimum number of doctors is as low as 0.86 in the case of Costa Rica and as high as 6.3 in the case of Greece. In the case of carbon dioxide emissions, the overall average is around 8. The wider variation, in this case, is shown by a standard deviation of around 4, i.e., almost half of the average value. This effect is also visible from the range of the values of this variable, where in the case of Costa Rica it has a minimum value of around 1 and the highest value is around 25 in the case of Luxemburg.

Although OECD countries are considered high-income countries with better infrastructure as compared to the rest of the world, however, among OECD countries there is wide variation as can be seen in the case of different variables, with the exception of life expectancy, where most of the countries show similar results.

Results

Based on the results of the Durbin–Wu–Hausman test, we have chosen the panel fixed effect model. The results of the panel fixed effect model are shown in Table 2 and are discussed briefly. The results show that government health expenditures have a negative and significant effect on infant mortality while positive in the case of life expectancy. The results show that a 1% increase in government health expenditures will reduce infant mortality by 0.21% and improves life expectancy by 0.008%. Whereas, income and CO_2 have a negative, the number of doctors and population has a positive impact on infant mortality and life expectancy.

The results of the system GMM are shown in Table 3. We ran the regression on two different dependent variables, i.e., infant mortality and life expectancy while the independent variables remain the same in both models. In Table 3, column 1 represents the results of government health expenditures on infant mortality. The estimation results indicate a positive and significant impact of health expenditures on infant mortality in OECD countries. The result shows that a 1% increase in government health expenditures will reduce infant mortality by 0.28%. Air pollution is also considered to be an important factor affecting infant mortality; our results show the positive and significant effect of air pollution on mortality. It shows that if air pollution is increased by 1%, the mortality will increase by 0.58% in the studied countries.

Infant mortality is not only influenced by health expenditures and air pollution but also by other socio-economic factors like income and the number of doctors. Therefore, we added income and the number of doctors in our model and both of these variables showed a negative impact on mortality. The outcome shows that if we increase the number of doctors and income by 1%, infant mortality will decrease by 0.41 and 0.71%, respectively, whereas the result is positive in the case of the population.

TABLE 1 Descriptive statistics.

Variable		Mean	Std Dev	Min	Max
Life expectancy					
	Overall	78.68	3.23	69.1	84.7
	Between		2.77	72.97	82.58
	Within		1.76	73.63	83.20
Infant mortality					
	Overall	*5.56*	4.56	0.7	42.7
	Between		4.23	2.26	23.12
	Within		2.01	0.75	33.78
Govt health expenditure					
	Overall	2,112.4	1,332.20	159.78	10,052.33
	Between		1,047.75	427.82	4,447.91
	Within		849.41	−536.79	7,716.81
GDP per capita					
	Overall	32,209.5	16,836.24	5,807.335	117,721.2
	Between		13,765.32	10,422.87	82,180.15
	Within		9,938.14	−10,282.96	77,494.44
Population					
	Overall	33.47	54.36	0.26	331.50
	Between		54.92	0.31	302.61
	Within		3.85	0.25	62.35
Doctors					
	Overall	3.07	0.92	0.864	6.32
	Between		0.79	1.57	5.27
	Within		0.48	1.36	5.65
CO_2					
	Overall	8.06	4.29	1.13	24.66
	Between		4.16	1.37	18.87
	Within		1.21	0.99	13.84

TABLE 2 Results of the fixed and random effect model.

Variables	Life expectancy		Infant mortality	
	FE	RE	FE	RE
Constant	3.696*** (0.02)	3.722*** (0.01)	8.558*** (0.38)	8.840*** (0.32)
Govt. health expenditure	0.008*** (0.00)	0.0093*** (0.02)	−0.219*** (0.04)	−0.213*** (0.04)
GDP Per capita	0.0547*** (0.00)	0.0545*** (0.00)	−0.599*** (0.05)	−0.582*** (0.05)
Population	0.0141*** (0.00)	0.00545** (0.00)	0.306*** (0.09)	0.117*** (0.03)
Doctors	0.003 (0.00)	0.00467** (0.00)	0.104** (0.04)	0.106*** (0.04)
CO_2	−0.0005 (0.00)	−0.0026 (0.00)	−0.081** (0.03)	−0.082** (0.03)

*, **, and *** denote results significance at 10, 5, and 1%, respectively, while values in brackets denote standard errors, whereas HE denotes government health expenditures, POP denotes total population in million, CO_2 shows carbon dioxide emission tones per capita, DOC shows the number of doctors per 1,000 inhabitants, GDP shows per capita GDP, and Lag shows the dependent variable's lagged values.

To further validate the impact of health expenditures on health outcomes, we estimate the same model for health outcomes keeping life expectancy as a dependent variable. The independent variables remain the same. The results show a positive impact of health expenditures on life expectancy in the OECD countries. It shows that by increasing health expenditure by 1%, life expectancy

TABLE 3 Results (system GMM).

Variable	Infant mortality	Life expectancy
	1	2
HE	−0.28*** (0.040)	0.0001 (0.001)
GDP	−0.29*** (−0.058)	0.010*** (0.002)
POP	0.71*** (0.071)	0.003 (0.004)
$C0_2$	0.58 (0.127)	−0.006*** (−0.001)
DOC	−0.41 (−0.057)	0.004* (0.002)
Lag	0.22*** (0.040)	0.79*** (0.028)
AR (1)	0.003	0.002
AR (2)	0.243	0.175
Hansen (OIR)	0.913	0.901

*, **, and *** denote results significance at 10, 5, and 1%, respectively, while values in brackets denote standard errors, whereas HE denotes government health expenditures, POP denotes total population in million, CO_2 shows carbon dioxide emission tones per capita, DOC shows the number of doctors per 1,000 inhabitants, GDP shows per capita GDP, and Lag shows the dependent variable's lagged values.

will be increased by 0.001%. Whereas, the results of income and number of doctors show a positive impact highlighting a 1% increase in income and a number of doctors increase life expectancy by 0.05 and 0.003%, respectively, while a 1% increase in air pollution leads to a decrease in life expectancy by 0.004%.

Discussion

The study aimed to analyze the role of government health expenditures on health outcomes in OECD countries using the system generalized method of moments (GMM). The results revealed a positive and significant association between health expenditures and health outcomes proxied by infant mortality and life expectancy at birth. The results are consistent with other studies that have shown similar results in the OECD countries (14, 19, 39). A study (14) found a positive impact of health expenditures on health outcomes in OECD countries while Akinci et al. (40) reported that increased health spending reduces infant mortality in MENA countries. In general, it is observed in countries, providing easy, affordable, and accessible health facilities, especially mother and child healthcare, immunization, and higher government funding for such programs result in lower infant and maternal mortality (41).

Similar to infant mortality, the study indicates that life expectancy also improves with the increase in health expenditures in the OECD countries which is in line with other studies showing a positive impact of health spending on life expectancy (14, 20). The studies (1, 14) found that life expectancy at birth increases with the increase in government health expenditures. The increase in government health expenditures improves the healthcare facilities which reduces the risk of illness through timely and effective utilization of healthcare facilities thus increasing the average life expectancy (14). The important role of government involvement in healthcare acquisition is widely accepted in the healthcare system (42). The government is in a better position to allocate resources to medical research and to develop infrastructure to achieve better health outcomes. The positive result of health spending, as indicated in our study as well as in other studies, translates into better health outcomes. In OECD countries, various government interventions such as the primary public service and the provision of free of cost or subsidized primary healthcare services to children result in better health outcomes (43). The average infant mortality rate in OECD countries stands at 4 per 1,000 live births, making notable progress in reducing the mortality rate by 40% over the last 18 years (44). Life expectancy in OECD countries has increased on average to 81 years, i.e. it has increased by 10 years in 2020 as compared to 1970 (45). Improvement in life expectancy could be attributed to better medical care provision; however, various aspects affecting adult health are also added to support the healthcare system. In this regard, the OECD countries including the United Kingdom, Australia, Turkey, Ireland, and New Zealand adopted comprehensive anti-tobacco policies, including regulation of tobacco use and public education, which were added to improve life expectancy (46). While some countries introduced a tax on the unhealthy diet to fight obesity and promote healthy lifestyles in OECD countries (46), circulatory diseases and cancer were the main reasons for mortality in the OECD countries. During the span from 2000 to 2019, ischemic heart diseases (IHDs) and strokes have decreased on average by 47 and 52% in OECD countries showing the importance of health spending in the studied countries (47). Our study also observed the positive impact of environmental quality on health outcomes. The results showed an increase in CO_2 level increases infant mortality and reduces life expectancy. One might infer that an increase in emissions causes respiratory complications in adults and especially in children as children are more vulnerable to air pollution due to their higher air intake (48), while another research (49) stated that 96% of childhood mortality is instigated by air pollution due to lower respiratory infection. Moreover, exposure to ambient CO_2 in the indoor environment has detrimental effects on the human body causing high blood pressure, heart diseases, and breathing problems. Our results are in line with other studies including (50–52). One interesting study (50) found a two-way causal relationship between CO_2 emission and health expenditures in OECD countries.

The push for attaining higher economic growth causes air pollution to increase in the form of higher greenhouse gas emissions. Air pollution is a major risk factor for health causing respiratory, cardiovascular diseases, and lung cancer (50, 51). Although the CO2 emissions in the OECD countries are reduced by 9% in recent years, it was at their peak in the 2000's era (53). The effects of air pollution are long-lasting, thus, the reduction in air pollution in the OECD countries in recent years will not be fruitful at once.

The results also showed that an increase in the number of doctors improves the health status in the OECD countries. Various studies show similar results (54, 55). For example, one such study (56) noted that a 1% increase in the supply of medical doctors will decrease mortality by 0.08 per 100,000 population. The availability of quality medical staff is the key component of any healthcare system. In OECD countries, the number of doctors has increased over the years, and there were 3.5 doctors per 1,000 population on average in 2019 compared to 2.7 in 2000 (57). The other important

variable, i.e., per capita income, shows a positive effect on life expectancy and a negative on mortality. Other studies also noted that income has a positive effect on life expectancy and a negative on mortality (48, 58, 59). Nations with a higher level of national income tend to spend more on health and support their people by providing better healthcare facilities thus increasing life expectancy and reducing mortality (48, 60). Moreover, individuals with higher income levels tend to be more health conscious and can spend more on their health thus reducing diseases and mortality (61).

This study used life expectancy and infant mortality as indicators for health outcomes; future studies may study other variables for health outcomes. Moreover, other socio-economic variables are also important to analyze that could improve health outcomes like education, income inequality, unemployment, and lifestyle. Therefore, future research needs to study these socio-economic variables for their impact on health outcomes. Moreover, such studies are also needed in the context of developing countries.

Conclusion

Health expenditures act as an important pre-requisite for healthcare performance. The current study investigated the impact of health expenditures on health outcomes using infant mortality and life expectancy as proxies in the OECD countries. The study contributes to the body of literature by studying the impact of health expenditures and other socio-economic and environmental factors on health outcomes in the OECD countries. The results confirmed the negative impact of health expenditures on infant mortality and the positive on life expectancy in the studied countries. The results also revealed the negative effect of income, air pollution, and the number of doctors on infant mortality while positive on life expectancy.

Based on the positive impact of health expenditures on health outcomes, it is necessary that the government should facilitate the healthcare and overall health system by constantly supporting it through productive health spending and appropriate and timely policies. There is a need to strengthen the fundamentals of the health system and increase the number of medical staff like doctors. However, the increase in health expenditures in the OECD countries in recent years raises serious concerns about fiscal sustainability in the long run. Therefore, apart from health spending, the government has to focus on other measures like economic and environmental that ensure positive health outcomes. For this purpose, the government should work on by including patient voice while formulating health policy to obtain productive outcomes at the least cost. The OECD countries need to protect the quality of the environment. The deterioration in the environment increases the occurrence of diseases that enhances health spending. Therefore, the OECD countries should focus on promoting renewable energy consumption.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found here: https://data.oecd.org/.

Author contributions

AA: original idea, paper write-up, methodology, and data collection. SH: methodology, results, and paper write-up. NM: methodology and results. MY: methodology, results, and final validation.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Aysu Zekioglu,
Trakya University, Türkiye

REVIEWED BY
Huangxin Chen,
Fujian Normal University, China
Luisa Marti,
Universitat Politècnica de València, Spain

*CORRESPONDENCE
Longbao Wei
✉ lbwei@zju.edu.cn

†These authors have contributed equally to this work

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Sustainability-oriented innovation system and economic stability of the innovative countries

Faiza Manzoor[1†], Longbao Wei[1*†], Qazi Abdul Subhan[2†] and Mahwish Siraj[3†]

[1]Department of Agricultural Economics and Management, School of Public Affairs, Zhejiang University, Hangzhou, China, [2]Bahria Business School, Bahria University, Islamabad, Pakistan, [3]Allama Iqbal Open University, Islamabad, Pakistan

Novelcoronavirus-19 has created a challenging situation for developed as well as developing countries to sustain economic stability. There are a lot of controversies for policymakers to formulate an effective policy for reviving economic stability and minimizing the economic effects of this pandemic. The present study focuses on the internal mechanism of the Sustainability Oriented Innovation System and its subsequent effects on economic stability in most innovative economies. For empirical analysis of the most innovative countries (12 countries) high-income, middle-income, low-income, and lower-middle-income countries are selected. The Sustainability Oriented Innovation System is represented through the innovation input index and innovation output index. Economic stability is measured through the GDP growth rate of respective countries. A set of panel data was developed for the period of 11years and Fixed Effect Methods were used to ascertain the empirical findings. The outcomes indicate that innovation is the main force of economic stability. The study's results are important to policymakers to promote, stimulate and support economic stability through their strategies. Future studies may focus on the effects of the Sustainability Oriented Innovation System on economic stability in regional blocks like the EU, ASEAN, and G-20 countries.

KEYWORDS

sustainability oriented innovation system, economic stability, innovative countries, innovation input index, innovation output index

1. Introduction

The Novelcoronavirus-19 has distressed the global economy and obligated policymakers to restate their preferences and policy measures for sustainable economic development. It has pushed the world economies into deep and serious recessions (1). COVID-19 has drastic and acute effects on the economies of developing countries, which were already in serious economic, social, and political crunches. According to World Economic Outlook (2), the global economic growth rate is expected to decline by 4.9 percent in the fiscal year 2020–21. The World Economic Outlook has projected a very high degree of uncertainty in the aggregate demand of the global economy. Due to this pandemic, economic activities in developing as well as developed economies have adverse effects on key economic parameters like employment, investment, and growth in the industrial and agriculture sectors (3). Before this pandemic, United Nations has announced the Agenda 2030 in 2015 to transform the global economy for sustainable economic development. Under this Agenda 2030, 17 sustainable development goals (SDGs) and 169

targets have been announced. These goals are integrated and are also based on Millennium Development Goals (MDGs). Each country is having its challenges and opportunities which can be addressed with political commitment, consistent policy formulation for sustainable development, and implementation of these policies in true letters and spirit (4, 5). Furthermore, Ghassim and Bogers (6) have emphasized the importance of the Sustainability Oriented Innovation System (SOIS) for achieving SDGs in developed and developing countries.

There is no perfect prediction about the longevity of this worldwide pandemic, which has been started in 2019. It has deep-rooted and prolonged adverse effects globally. Relatively, developing economies are more affected than developed economies (7, 8). The World Bank has published its flagship report about Global Economic Prospects (2020) and identified the critical situations of developing countries during the Pandemic 2019. The report further explains that global growth is expected to decline by 5.2 percent and this pandemic is considered as deepest global recession since Second World War. All economic and social indicators in the globe are showing declining trends (9, 10). The report has further highlighted multiple sectors to improve the economic situation and make the economies more resilient to cope with the situations in the future. The main areas of improvement are health sector facilities, policy formulations, and more elastic innovative systems. The report emphasized global cooperation to save vulnerable populations in developing countries and improve the country's capacity to cope with this situation in the future (11). Similarly, this study is concerned, it focuses on the current economic situations of developed and developing countries during COVID-19. Secondly, it will discuss UN Agenda 2030 for sustainable development among member countries, and thirdly, the role of the SOIS in achieving economic stability in the most innovative economies. All these three aspects are integrated in such a way that one aspect reflects the prevailing economic and social conditions of the economies around the globe. Second is the objective that should be achieved, and all the economies unanimously agreed to achieve sustainable economic growth. The third aspect is a strategy and technique through which countries can achieve their objectives more efficiently and effectively. This study is important in a way that it covers all aspects of global as well as regional economies regarding prevailing situations. Therefore, the main aim of the present study is an attempt to investigate the impact of SOIS on economic stability in developing countries in the context of the UN Agenda 2030. This study analyzes the status of achievements against Agenda 2030 and the magnitude of devastation due to COVID-19. The global economy is consistently facing multiple challenges on economic, political, and social fronts. To cope with these challenges, there are multiple recommendations by international agencies. More specifically, the current pandemic has compelled policymakers to reframe their policies for long-term development. Implementing a SOIS is one possible solution. The present study further explains the status of developing countries, their bottlenecks, and the deliberation of a possible mechanism for the implementation of SOIS for economic stability in respective countries. This study's findings are the first of their kind in the study region. The study's specific research questions are as follows:

i) *What is the status of the economic stability of the most innovative countries in the current pandemic situation?*
ii) *What are the current achievements of respective countries against the UN Agenda 2030?*
iii) *What are the main components of the Sustainability Oriented Innovation System?*
iv) *How to develop an effective mechanism in the implementation of the Sustainability Oriented Innovation System to attain the objectives of economic stability in developing countries.*

Economic stability is one of the primary goals of all countries. Economic stability can be interpreted as sustainable economic growth, price stability, and employment opportunities (12). An effective management policy can stabilize the economy. The main purpose of this study is to identify the status of economic stability in the most innovative countries. It is admitted fact that innovation is widely recognized as a key driver of economic growth, competitiveness, and social progress. High-income countries, which are generally characterized by strong research and development (R&D) capabilities, highly skilled workforces, and advanced technology infrastructure, have established robust innovation systems that facilitate the creation, diffusion, and commercialization of new knowledge and technologies. These systems typically involve a range of actors, including universities, research institutions, private firms, and government agencies, who collaborate to generate, disseminate, and apply new ideas and technologies (13). High-income countries have invested heavily in innovation over the years, through public funding of research and development, tax incentives for private R&D, and other policies. The respective governments have designed those programs which support the innovation systems. As a result, these countries have been able to generate new products, services, and business models that have helped to drive economic growth and enhance social welfare. However, innovation systems are not static and continue to evolve in response to changing economic, social, and technological conditions, which require ongoing efforts to improve them.

Similarly, innovation systems in low-income countries are often underdeveloped due to a lack of resources, infrastructure, and access to technology (14). To address these issues, governments and international organizations have implemented a variety of initiatives to foster innovation and economic growth. These initiatives include the provision of access to finance, creating incentives for research and development, and encouraging collaboration between the public and private sectors. Additionally, initiatives like Global Innovation Fund are helping to provide resources and support to innovators in low-income countries. These initiatives are helping to create an environment that encourages innovation and economic growth, and ultimately, improves the lives of people in low-income countries. This study will help assess the current challenges of the respective economies and how SOIS may foster innovation-driven economic growth in their respective countries.

The paper is organized in the following manner. The introduction section is followed by a brief review of the literature, methodology and data, results, and discussions. In the last section, the conclusion and recommendations are presented with practical implications and limitations.

2. Literature review

This section covers the current economic situations of developed and developing countries during COVID-19, the UN Agenda 2030 for sustainable development, and the role of the SOIS in achieving economic stability in developing economies.

2.1. An overview of the global economic situation during COVID-19

COVID-19 has embraced astonishing effects on the global economy and pushed the world economies into a deeper economic and social crisis for which the world was neither prepared nor imagined. This crisis has created multidimensional problems in the health sector, employment sector, poverty issues, adverse law and order issues, depravedness of necessities, a vulnerability in the societies, and problems in the nonavailability of medical treatments in the hospitals' (7, 15). This pandemic has created deep-rooted damages to the determinants of economic growth prospects in the world economy and has ruined the standard of living and created a deep recession (16). The World Bank published a Flagship report on Global Economic Prospects in 2020. The report has comprehensively discussed the effects of COVID-19 on global and regional economies. This pandemic has resulted in a huge contraction in financial conditions worldwide. The global economic growth contraction is expected to be 5.2 percent during the financial year 2020–21. The advanced economies are expected to reduce their economic growth by 7.2 percent. Among the advanced economies, the EU has been rigorously affected and their economies are projected to contract by around 9.1 percent (17). The real GDP of High-Income Countries is projected to reduce by 6.8 percent as compared to a contraction of developing economies by 2.4 percent during FY 2020. The world trade volumes have been constricted by up to 13.4 percent which has left a majority of an unemployed and vulnerable population. The low-income countries are expected to grow by 1%. One of the drastic impacts has been observed on oil prices which have reduced by 47.9 percent due to a reduction in international oil demand (18).

All major sectors of advanced economies have been disrupted due to COVID-19. The second wave of this pandemic is on its high surge which may further aggravate the intensity of economic, social, and financial conditions of the economies (19). For instance, the US economy is expected to contract by more than 6.1 percent which has very serious repercussions on its economic and social fronts. The people face high unemployment and rising inflation. There was a massive reduction in retail sales and industrial production during COVID-19. Similarly, the economic growth in emerging economies like Malaysia, China, India, and Thailand has worsened more than expected in the first quarter of 2020 and there is a high probability that it will further decline with massive magnitude in the second quarter (2). The worst effects of this pandemic have been observed in developing economies. For the first time, all the regions projected negative economic growth in FY 2020. All the developing countries have structural differences but particularly, South Asian countries have faced longer lockdowns for more than 6 months which has created a massive decline in aggregate demand and an increase in precautionary savings. In other words, capital formation in developing countries has drastically declined and it has hit the employment sector severely. More than 6.65 million people have become unemployed only in Pakistan during the fiscal year 2020–21 (20). These adverse effects have been observed in all developing nations. For instance, the Indian economy has suffered severely due to Coronavirus-19 and its unemployment went up to 24 percent in Fiscal Year 2020. Due to strict lockdowns in major cities, all economic activities were suspended. There are three main sectors; agriculture, services, and manufacturing sectors, which were directly hit due to COVID-19 in all South Asian Economies (21). When the industrial sector remains closed then there is no question of employment and a high surge in unemployment was observed in the Indian economy during FY 2020–21. The second wave of this pandemic has knocked down the Indian economy to its record level. In April 2021, the number of COVID Cases spiked up to 350,000 per day and the death toll has surged by more than 2,700 per day. This emergency has collided with the whole infrastructure of the Indian economy. The basic reasons behind this situation are the unprecedented intensity of the pandemic, the wrong perception of the people about COVID-19, the lack of public health infrastructure, and the lack of intensive care regarding the SOPs (Standard Operating Procedures) related to COVID-19 (22). Moreover, due to COVID-19 manufacturing, services, and Micro, Small, and Medium Sized Enterprises (MSMEs) sectors have shown a drastic decline in their respective growths (23, 24). Shafi et al. (25) have investigated the effects of COVID-19 on small and medium enterprises in Pakistan. They have observed a sharp decline in sales growth, supply chain, decrease in demand, and reduction in profitability of the MSMEs (24, 26). The almost same situation has prevailed in other developing countries (27).

This pandemic has not given any relaxation to developed economies despite having good health infrastructure, capital availability, and advanced technologies. All European economies, especially Italy, France, and Germany have been seriously affected due to COVID-19. A high death toll has been observed in these countries daily (28). The doctors and other paramedical staff have sacrificed their lives during their official duties and strived their best to recover the patients. Similarly, USA's economy has suffered a serious setback on economic and social fronts. The economic indicators have reflected negative growth in major sectors of the economy. For instance, real GDP growth in the second quarter of FY 2020 in the USA has declined up to 31.40 percent. The unemployment rate has spiked up to 14.7 percent which was not observed since the era of the Great Depression. These adverse numbers have created serious distress in the US economy on economic, social, and political fronts.

2.2. The UN Agenda 2030 for sustainable economic development

In the presence of global recession and slow economic activities, The UN Agenda 2030 is one of the policy guidelines for policymakers. The Agenda 2030 is presumed as a plan of action for the prosperity and nourishment of all countries without any discrimination for the achievement of sustainable development. This Agenda has 17 SDGs and 169 targets. The focus of these Agenda items is the development of human capital, poverty eradication, prosperity, and sustainability with the help of innovative and technological signs of progress, planet safety through optimal utilization of natural resources and minimizing environmental deregulations, fostering peace and harmony among the countries, and establishing global partnerships among the countries for sustainable development (29). These sustainable development goals are interlinked and accomplishing these objectives has significant importance for transforming global miseries. Especially, to minimize the economic sufferings of COVID-19, there is a dire need to focus on these Agenda items and initiate the execution of these objectives in practicality (30).

First and foremost, the area of concentration of Agenda 2030 is to keep the world free of poverty hunger, and diseases. This item mainly

addresses the social infrastructure of the countries like health facilities, education provisions, and economic opportunities. There are certain prerequisites for maintaining minimum benchmarks for creating conducive environments for social facilities. For instance, the vision of government, the status of industrialization within the country, and prevailing health and education facilities. The vision of the government plays a vital role in the accomplishment of these goals (31). If the governments have no vision to develop their respective nations, as has been observed in most of the developing countries, then these objectives become just a dream and the inhabitants of these nations may suffer all sorts of hardships of poverty, hunger, and poor health infrastructure. During the current pandemic, the most affected sectors are health, services, and manufacturing in the world (3).

There is an immense need to revitalize the policies for social development. The UN Agenda 2030 report has discussed the stunning challenges for sustainable development like economic disparities among the countries, income disparities, poverty, problems of gender inequality, health disparities, frequent natural disasters, unemployment issues, terrorism, sectarian violence, natural resource depletion, and humanitarian crisis. It is a matter of fact that these challenges can never be controlled until and unless a comprehensive and cohesive policy framework has not been formulated. The policy formulation may be segmented into short-term, medium-term, and long-term perspectives. For short-term policy objectives, all the countries must concentrate on the remedial measures for this fatal pandemic that has paralyzed the global economy. For instance, the vaccination process should be faster without any further delays and discrimination. This process was accomplished in some countries like England, and Israel, and now the people of these countries are getting a sigh of relaxation but most of the European countries, South Asian, and Southeast Asian economies are still in the clutches of COVID-19. In this regard, the role of the World Health Organization (WHO) is exemplary. WHO has generated COVID-19 Solidarity Response Fund to assist the member economies in caring for the patients, frontline workers supply, and providing relevant information about medical research.

For medium-term objectives, the public sector of developing economies ought to focus on health facilities on a prior basis. These economies have focused on increasing health expenditures up to a minimum of 5 percent of their respective Gross Domestic Product (GDP) to face such kind of severe pandemics in the future. To attain SDGs, more particularly, SDG-16 and SDG-17 which are concerned with peaceful and inclusive societies and to strengthen the means of implementation to promote global partnership for sustainable development among the member countries, The United Nations should play an exemplary role to resolve the deadlocks between respective countries like the matter of Palestine, dispute of Kashmir between India and Pakistan and other prominent issues among the countries under the charter of UN. When these countries will become out of these issues then they may focus on the development of their social and economic infrastructures. Otherwise, they may consume all their energies and resources to mitigate these issues and may indulge in an unending war. Keeping these issues aside, if the countries will make a sincere effort in true letters and spirits, to achieve sustainable economic development in the light of UN Agenda 2030, then a drastic global transformation may be observed. Kılkış (32) has made a comprehensive analysis of the SOIS in Brazil, India, China, Russia, Turkey, and Singapore and has developed the Sustainable Innovation Index (SII) to check the performance of their respective economies. In the research study, he used four layers of SOIS; system analysis, knowledge production, technological innovation, and system efficiency. In the system analysis, support mechanisms and functional dynamics are included. Similarly, knowledge production can be observed through paper analysis, which means how many papers have been produced based on novel ideas. The third layer consists of patent analysis which means how many patents have been granted to local companies which reflect technological innovation. The fourth layer provides a comparative analysis to check the system's efficiency. As well as developing countries are concerned, they have basic institutional flaws, a lack of implementation of rules and regulations, and deficiencies in constitutional implementations. For them, it would be objective and initially, they must promote basic infrastructures to support the innovation activities at individual and collective levels.

Furthermore, Altenburg and Pegels (33) have conducted a comprehensive analysis of SOIS through green transformation. According to the authors, all the developments in advanced countries have been held at the cost of environmental destructions and natural resource depletions which have created environmental problems like global warming, and it has threatened human livelihood. As well as developing countries are concerned, they are exporting agricultural products, primary goods, and other natural raw materials. There is high pressure on the government due to scarcity of food, hyperinflation, increasing poverty, and deficiency of the provision of utilities and other social facilities. To control this issue, there is an immense need to introduce SOIS to control further deterioration in a green environment. The authors have further emphasized improvement in evolutionary innovation systems, which is impossible without better and committed governance. The economies must develop a policy framework that gradually addresses the remedial measures for methodological issues for short-term, medium-term, and long-term objectives. The starting point of this development is to introduce environmentally sustainable technologies which is the need of the day.

The SOIS is considered a new approach to innovation systems. In this system, the prime objective is to generate innovations that reduce environmental pressure. In general, there are certain innovation systems like global Innovation Systems, Regional Innovation Systems, and National Innovation Systems. In these systems, innovation is generated without catering to the sustainability aspects (34). SOIS is used as a new tactic for innovation systems to fill this research gap. The environmentally conducive technologies can be generated with the cooperation's global stakeholders. To develop an effective SOIS, technological knowledge plays a significant role. To develop technological expertise, the commitment of the government is necessary for the shape of policy formulations and regulations with the protection of local industries. Corsi et al. (35) have suggested that developing countries enhance technological information through globalization and technology transfers from developed to developing countries. Technology cooperation among developing and developed economies is another mode to relocate knowledge-intensive activities. Similarly, developing countries may learn from the Organizations for Economic Cooperation and Development (OECD) countries about innovation policies, technological knowledge, and implementation criteria to promote economic development in their respective economies.

2.3. The mechanism for implementing sustainability oriented innovation system

It is a general presumption that innovative firms are more productive and efficient as compared to non-innovative firms. For instance, Camisón-Haba et al. (36) have investigated technology-based economic development and explained that innovative firms are more contributive to economic development than non-innovative firms. Other studies like Ahmad et al. (37) and Silvestre and Ţîrcă (38) have emphasized the promotion of innovative activities because it is considered one of the key drivers of sustainability and amplifies economic development in respective countries. Economic development is the composition of economic growth and social sector development. It reflects the progress in economic as well as social indicators of the country. Innovation can be applied in all sectors of the economy. For instance, innovation in renewable energy, innovation in product diversification, and innovation in processes help in achieving economic development in the country. Moreover, Tabrizian (39) has underlined the importance of innovation in the renewable energy sector to speed up the pace of economic development in developing countries. According to the study, those economies which are reinforcing renewable infrastructures may get competitive advantages in global markets. It is admitted fact that developing countries are facing serious shortfalls in the energy sector to meet the respective demands. Improper planning of energy resources and disproportionate surge in population growth have imbalanced the general equilibrium of developing economies. To fulfill the need for the industrial sector as well as for household consumption of energy, it is indispensable to make innovations in the energy sector. The main rationale behind this is that natural resources are depleting day by day and there is an immense need to move towards alternative energy resources to save a green environment in developing countries.

Zartha Sossa et al. (40) have investigated the effects of an innovation system for attaining sustainability in the Colombian region. Their study indicated that there is a lack of disarticulation between the policies related to sustainability in the innovation system which may amplify economic development. Further suggested that socio-environmental considerations should be included in the innovation system and to amplify the economic growth in the country, there is an immense need to channel natural resources for optimum production.

Uğurluay and Kirikkaleli (41) have investigated that Innovation Systems, in high-income countries, play a significant and positive role in developing cutting-edge technologies which ultimately result in promoting economic activities. Developing countries must focus on technology transfer from developed economies to attain better economic growth. To implement SOIS in developing countries, certain prerequisites are essential to be achieved.

To implement the SOIS to foster economic stability in developing countries, there are certain prerequisites. First and foremost, the thing is respective governments may develop basic economic and social infrastructure and do sincere efforts for the transformation of their respective economies. Keeping all political and sectarian disputes aside, political leaders should join hands for the prosperity and development of their nations. Innovation is an ongoing process and SOIS reflects that innovation which is decoupling economic growth from environmental pressures (40). Silvestre and Ţîrcă (38) have concentrated on the promotion of innovation due to its role in transforming individuals, societies, organizations, and communities. It also requires immediate actions by governments and industries to adopt environmentally friendly innovation systems or eco innovative technologies to foster sustainable development. The authors have suggested three main areas of change before the implementation of SOIS; technology, management, and policy. The respective governments in developing countries must focus on basic infrastructure for technology and innovation development as a foundation for implementing SOIS. Secondly, the management of capital and natural and human resources is one of the key factors which may assist in implementing SOIS. The provision of industrial, labor, and investment policies are a third key factor for implementing the SOIS to increase economic stability. Another key sector for developing countries is the external sector, through which they can progress their economic strength and promote innovative activities. External sector development is one of the key factors for sustainable economic strength. The Exports Led Growth (ELG) hypothesis has proven the progress of transitional economies. If the exportable items are based on semi-manufactured or manufactured goods, then the external sector would develop at a greater pace (42). In this regard, Ahmed and Mahmud (43) have conducted a study related to the determinants of innovation in the manufacturing sector in Pakistan. The authors have highlighted the significance of innovation in achieving competitiveness and comparative advantages which ultimately help in getting high economic growth. Further, that innovation plays a vital role in getting the economic stability of Pakistan. It indicated the significance of innovative and automated systems which may help achieve the economic stability of developing countries effectively. There are multiple factors in introducing innovation in manufacturing sectors like firm size, the scale of production, and type of product; less elastic or more elastic, final goods, or semi-manufacturing goods. Similarly, Aldieri and Vinci (44) have studied the relationship between firm size and sustainable innovation in large international firms. Data were collected from firms in Japan, the United States, and Europe and explained the positive connection between firm size, technological spillovers, research and development activities, and sustainable innovation.

3. Methods and data

To see the impact of SOIS which consists of the innovation input index and innovation output index on economic stability in developing and developed countries, panel data are used. The period of analysis consists of 2011 to 2021. Certain parameters like GDP growth, innovation input index, and innovation output index have been used as a proxy for economic stability and SOIS, respectively. The innovation input index consists of five main subheads: Institutions index, human capital, and research index, infrastructure index, market sophistication index, and business sophistication index. The output innovation index consists of two subheads: the knowledge and technology output index and the index of the creative output. The data was collected from different international sources. Macroeconomic parameters like the GDP Growth Rate of respective countries have been collected from World Development Indicators (WDI) a publication by the World Bank and Key Indicators of Asia and Pacific 2021, a publication by the Asian Development Bank.

The information about the innovation input index and innovation output index for the respective countries are collected from the Global

Innovation Index (GII) which is an annual publication of WIPO (World Intellectual Property Organization). The data was collected for the most innovative countries, segmented based on WIPO (World Intellectual Property Organization). Those countries belong to High-Income Countries (Switzerland, Sweden, and the United States of America), Upper Middle-Income Countries (China, Bulgaria, and Malaysia), Lower Middle Income (Vietnam, India, and Ukraine), and from Low-Income Countries (Rwanda, Tajikistan, and Malawi) are included in the analysis for the period of 2011 to 2021.

3.1. Theoretical foundation of the variables

It is a fundamental truth that innovation has a positive and significant effect on economic growth which is supported by Schumpeter's innovation theory (1934) (45). Schumpeter has claimed that development is deemed a historical process of structural changes. These changes are driven by innovative ideas and their execution in the tangible form either in the shape of products, services, or industries. Schumpeter has advised the nations to adopt novel and innovative methods of production to spur their economic growth. Innovation may assist in the opening of new market avenues at domestic and international levels and develop a competitive business environment along with industrialization which may revolutionize the economic systems of the country.

3.2. Empirical strategy

To check the role of SOIS in the economic stability of respective countries, an econometric model has been developed. SOIS has been translated through the innovation Input Index and innovation output index. To estimate the regression parameters, the software Stata 16 SE has been used by developing a set of panel data. The Fixed Effect Method (FEM) was used to ascertain the empirical results. The detail of the formulation of regression equations as explained below. There are two regression equations, in which the relationship between outcome and explanatory variables has analyzed. Regression Eq. (1) is explaining the effect of the innovation input index on the economic stability of respective countries. Eq. (2) has been formulated to see the impact of the innovation output index on economic stability in the respective countries.

In the light of the regression model, the effects of the innovation input index on economic stability sets out the following form:

$$GDPG_{it} = \alpha + \beta_1 INS_{it} + \beta_2 HCR_{it} + \beta_3 INFR_{it} + \beta_4 MRSOP_{it} + \beta_5 BSOP_{it} + \varepsilon_{it} \quad (1)$$

where:

GDPG is the growth rate of gross domestic product, INS is institutions index, HCR is human capital and research index, INFR is the infrastructure index, MRSOP is the market sophistication index, BSOP is business sophistication index, ε is the error term or residual term, and $i = 1, 2, \ldots, 12$ while $t = 1, 2, \ldots, 11$.

In this model, GDPG is the outcome variable that measures economic stability in respective countries. Institutions Index (INS), Human Capital and Research Index (HCR), infrastructure index (INFR), Market Sophistication index (MRSOP), and Business Sophistication Index (BSOP) are explanatory variables. The institution index consists of the political environment, regulatory environment, and business environment of the respective countries. Similarly, Human Capital and Research Index is consisting of three components: education, tertiary education, and research and development situation in respective countries. The infrastructure consists of three components Information and communication technologies (ICTs), general infrastructure, and ecological sustainability. The market Sophistication index (MRSOP) is calculated based on Credit Investment, Trade diversification, and market scale in the respective countries. The business Sophistication Index (BSOP) is based on Knowledge workers, Innovation linkages, and Knowledge absorption. In other words, how many people are engaged in imparting the latest knowledge to society for the betterment of the business environment? There is a significant impact of innovation linkages among the business entities on the economic stability of the country. If these linkages are strong and persistent then there is the possibility of positive and smooth growth in the country.

Therefore, to study the effect of the innovation output index on the economic stability of the most innovative countries sets out the following shape:

$$GDPG_{it} = \chi_0 + \chi_1 KNTO_{it} + \chi_2 CO_{it} + \mu_{it} \quad (2)$$

where:

GDPG is the GDP growth rate, KNTO is knowledge and technology output, and CO is creative output.

Eq. (2) explains that the GDP Growth rate is a dependent variable while the knowledge and technology outputs index (KNTO) and Creative Outputs index (CO) are independent variables. It is presumed that these two independent variables have a positive effect on the economic stability of the countries. The knowledge and technology output index (KNTO) are consisting of three components: Knowledge creation, Knowledge impact, and Knowledge diffusion. The Creative Outputs index (CO) has been developed based on three components: intangible assets, creative goods and services, and online creativity (Global Innovation Index 2021, WIPO).

4. Empirical results and discussions

To test the stationarity of the data, the panel unit root test (Levin, Lin and Chu Test) has been applied. This test is significant which indicates that mean, variance and covariances are not changing over time. It has been observed that except CO all the variables are stationary at first difference. The detail of the stationarity test results has been mentioned in Table 1.

To estimate Eqs. (1)–(2), Fixed Effect Methods (FEM) have been used due to the nature of the data and the results of the Hausman test, as mentioned in Table 2.

Table 2 represents the results of the Hausman test which indicate that the Chi-Square Stat is significant with a Prob Value less than 0.05. Due to its significance, the use of a fixed effect estimator is appropriate for ascertaining empirical results (46). Table 3 explains the effects of the innovation input index on economic stability, respectively.

Table 3 explains the empirical results of the effects of the Innovation Input Index on the economic stability of the respective countries. According to the results, the infrastructure index has a significant and

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TABLE 1 Results of stationarity test (Levin, Lin and Chu Test).

Variables	LLC at level	LLC at first difference
D(BSOP)	4.60 (1.00)	−10.85 (0.00)*
D(GDPG)	−2.27 (0.15)	−17.45 (0.00)
D(INFRA)	8.31 (1.00)	−35.71 (0.00)
D(INST)	3.54 (0.99)	−44.54 (0.00)
D(HCR)	0.35 (0.63)	−5.45 (0.00)
D(KTO)	6.34 (1.00)	−40.93 (0.00)
D(CO)	−3.65 (0.00)	−25.61 (0.00)

The values in parenthesis are probability values which should be less than 0.05.

TABLE 2 Results of the Hausman test (innovation input index).

Test summary	Chi-Sq. Stat	Chi-Sq. d.f.	*p*-value
Cross-section random	28.36	5	0.000

positive effect on the economic stability of the countries. In other words, Infrastructural improvement plays a pivotal role in the development of a country. The T. Stat value (2.70) indicates the significant and positive effects of INFRA on the economic stability of the countries. The infrastructure of a country, which consists of roads, dams, utilities like electricity, Gas and Water resources, transportation, and communication, provides momentum for the development of a country's economic and social structure. The pace of development amplifies with better infrastructure. The results of the present study also emphasize the importance of the infrastructure of respective countries. These results are consistent with prior studies like (47, 48).

The present study indicates a positive and significant effect of market sophistication, which consists of three main pillars: credit investment, trade diversification, and market scale on the economic stability of the most innovative countries. The T. Stat (3.693) indicates a positive and highly significant effect of market sophistication on economic stability. All three pillars of market sophistication are very important for generating economic activities in the country. For instance, trade diversification creates multiple opportunities for enhancing the trade volume as well as foreign remittances.

Similarly, credit investment is another important tool for promoting economic and business activities in the country. The results of the present study emphasize the significance of market sophistication in increasing the economic strength of respective countries. The result of this study is explaining the importance of business sophistication. The world is lacking behind in this field. The T. Stat (1.481) indicates an insignificant effect on the economic stability of the respective countries. Business sophistication consists of knowledge workers, innovation linkages, and knowledge absorption. There is huge potential in all respective economies if they develop knowledge workers and innovation linkages among developing and developed economies. There is an immense need to develop such a comprehensive and integrated mechanism for innovation linkages among the countries. The results further explain the overall significance of the regression model which is reflected by *F*-Stat. The probability value should be less than 0.05 for overall model significance. The *R*-Square value determines the goodness of fit of the

TABLE 3 Effect of innovation input index on economic stability dependent variable: LOG (GDPG) method: panel EGLS (cross-section weights).

Variable	Coefficient	*t*-statistic	Prob.
D(INST)	0.016	1.392	0.167
D(INFRA)	0.026	2.701	0.008
HCR	−0.002	−0.108	0.914
BSOP	0.007	1.481	0.142
MRTSOP	0.031	3.693	0.001
C	0.876	1.521	0.132
R-squared	0.811	Durbin–Watson stat	1.719
F-statistic	26.502	Prob(*F*-statistic)	0.000

HCR, human capital and research index; INFRA, infrastructure index; INS, institutions index; MRTSOP, market sophistication index; BSOP, business sophistication index.

TABLE 4 Results of the Hausman test (innovation output index)

Test summary	Chi-Sq. Stat	Chi-Sq. d.f.	*p*-value
Cross-section random	7.37	2	0.025

TABLE 5 Effect of innovation output index on economic stability dependent variable: GDPG method: panel EGLS (cross-section weights).

Variable	Coefficient	*t*-statistic	Prob.	
KNTO	0.028	4.836	0.000	
CO	0.006	1.059	0.292	
C	0.169	0.433	0.665	
R-squared	0.816	Durbin–Watson stat		1.772
F-statistic	36.621	Prob(*F*-statistic)		0.000

KNTO, knowledge and technology output; CO, creative output.

model. *R*-Square value ranges from 0 to 1. If the value of *R*-Square is closer to 1, it means that regression model is explaining the observed data in a good manner. In the present study, value of *R*-Square is 0.81 which represents goodness of fit of the model. The D.W value explains the presence of autocorrelation. If the value of D.W is close to 2, it means that there is no autocorrelation. In the present study, the D.W Stat is 1.70 which is closer to 2 and reflects no autocorrelation in the model.

Above Table 4 represents the results of the Hausman test which indicate that Chi Square Stat is significant with Prob Value (0.025).

Table 5 explains the effects of the innovation output index on the economic stability of the respective countries. Table 5 highlights the positive and significant effect of the knowledge and technology output index (KNTO) on economic stability. The T-Stat (4.83) indicates that KNTO has a highly significant effect on the economic stability of the countries. This index is consisting of three components: knowledge creation, knowledge impact, and knowledge diffusion. These results are consistent with the findings of prior studies of Kaneva and Untura (49) and Mao et al. (50). Similarly, CO (Creative Outputs) has a merely significant effect on the economic stability of the countries. These results are consistent with prior studies of Bennett and Nikolaev (51) and Hawkins (52). These studies have concentrated on the significance of innovation for the progress and growth of economic activities in developed as well as developing countries.

5. Conclusion and limitations

The present study is an attempt to review the effects of SOIS on the economic stability of the most innovative countries. To see the impact of SOIS on economic stability, the innovation Input Index and Innovation Output Index have been used as a proxy for SOIS. Economic Stability is measured through the annual growth rate in their respective GDPs. A set of panel data have been developed based on several cross-sections (12 Countries). The Fixed Effect Method (FEM) has been used to ascertain empirical results. The main results are in favor of positive and significant effects of components of the innovation input index (Human Capital & Research and Infrastructure) on the economic stability of respective countries. Similarly, the Innovation Output Index has a positive and significant impact on the economic stability of respective countries.

Due to Novelcoronavirus-19, in the global economy, developed as well as developing countries have shown a drastic decline in their social and economic sector's growth. The manufacturing and services sectors have taken adverse effects in the developing economies due to COVID-19. It is not certain when this pandemic will end but the economies must prioritize their preferences in policy formulation and their abrupt implementation keeping in view the ease of the public and increasing economic strength of their respective countries. It is very painful to see the miseries of the deprived people and the failure of health systems, especially in India during COVID-19. The government must refrain from blame games and sincerely take effective measures to provide basic health provisions to the public. These priorities have already been discussed under the UN Agenda 2030 for sustainable development around the globe. These Agenda items are reflecting the transformational objectives of member countries. Keeping all political, social, and economic conflicts aside, all the economies must join their hands for the prosperity of their respective nations under the Charter of the UN. The UN must play its pivotal role in resolving the deadlocks among the nations like the matter of Palestine, Kashmir, and other disputes through dialogues by using their forum. Those resources should be used for the betterment of their respective inhabitants.

To implement SOIS in developing countries, certain prerequisites are essential to be achieved. These countries must focus on technology transfer from developed economies to developing countries to attain better economic growth. The respective governments in developing countries may focus on the provision of basic infrastructure for technology and innovation development as an underpinning source for implementing SOIS. Managing natural, human, and capital resources is one of the key factors that may assist in implementing SOIS. The provision of conducive industrial and investment policies is key to implementing SOIS.

It is generally impossible to capture the issue from all aspects so there are certain limitations of the study. First, as per the declaration of the Global Innovation Index report, 2019–2020, the 12 most innovative countries are included in the analysis. To take a more comprehensive picture of the study, all 132 countries can be included. Second, this study used secondary data; however future studies can use primary data for analysis. Third, future studies may add other variables for analysis. Additionally, Future studies may focus on the effects of SOIS on economic stability in regional blocks like the EU, ASEAN, G-20, and OECD.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

FM initiated the basic idea, wrote the main part of the manuscript, and built the article structure. LW reviewed and improved the manuscript. QS and MS contributed to the methodology of this study. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Dilaver Tengilimoğlu,
Atılım University, Türkiye

REVIEWED BY
Muhammad Farhan Bashir,
Shenzhen University, China
Çağdaş Erkan Akyürek,
Ankara University, Türkiye

*CORRESPONDENCE
Tao Liu
✉ leo.liutao@163.com

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The spatial linkage mechanism: medical level, public health security, and economic climate from 19 OECD EU countries

Rong Fu[1], Binbin Zheng[1], Tao Liu[2]* and Luze Xie[1]

[1]College of Economics, Hangzhou Dianzi University, Hangzhou, China, [2]Department of Sociology, Hangzhou Dianzi University, Hangzhou, China

Introduction: The global spread of the COVID-19 has brought about global changes, especially in terms of economic growth. Therefore, it has become a global issue to explore the impact of public health security on the economy.

Methods: Employing a dynamic spatial Durbin model, this study analyzes the spatial linkage mechanism of medical level, public health security, and economic climate in 19 countries as well as investigates the relationship between economic climate and COVID-19 by the panel data of 19 OECD European Union countries from March 2020 to September 2022.

Results: Results show that an improvement in the medical level can reduce the negative impact of public health security on the economy. Specifically, there is a significant spatial spillover effect. The degree of economic prosperity hurts the reproduction rate of COVID-19.

Discussion: Policymakers should consider both the severity of the public health security issues and the economic level when developing prevention and control policies. Given this, corresponding suggestions provide theoretical support for formulating policies to reduce the economic impact of public health security issues.

KEYWORDS

COVID-19, public health, economic climate, economic growth, dynamic spatial Durbin model, OECD

1. Introduction

At the beginning of 2020, the COVID-19 pandemic affected national economic growth and individuals' basic life necessities. It has been the largest global public health crisis since the influenza pandemic in 1918 (1) and is still prevalent worldwide. Under the COVID-19 pandemic, global change is inevitable.

Thus, it has become urgent to analyze and interpret the impact of the COVID-19 pandemic as well as what measures should be implemented to handle similar crises. Similar to the COVID-19 pandemic, the SARS outbreak in 2003 had a profound impact on the Asian tourism industry and affected the economic growth of Asia and the world. At the same time, it showed that the ban and measures adopted can effectively prevent the spread of the virus, but they may exacerbate panic (2). From the data available now, the impact of SARS is much smaller than our estimate of its current occurrence (3). The features that differentiate COVID-19 from recent encounters are its wide geographical spread in terms of contagion and its high mortality rate (4). Compared to the impact of the SARS outbreak, the economic impact and spillover effects on the European Union (EU) increased significantly when the COVID-19 pandemic occurred. China's economic growth was affected at the initial stage of COVID-19, but it soon recovered. Thanks to the increase in China's influence, the country was less affected by the negative spillover

effects of other countries during the pandemic (5). Accordingly, we can maintain a wait-and-see attitude for the current prediction of losses caused by the COVID-19 pandemic.

1.1. COVID-19 pandemic and economic growth: a historical overview

The most obvious harm of global change caused by the COVID-19 pandemic is the increased medical burden. In Italy, for example, the number of deaths due to COVID-19 in the first quarter of 2020 reached 18,000, resulting in a loss of economy and productivity (6). The levels of anxiety, depression, and stress of healthcare employees were also significantly affected (7, 8). In the São Paulo intensive care ward, Brazil, the rate of hand hygiene during the COVID-19 pandemic decreased significantly compared to that before the pandemic. This was because the increased medical burden caused by the pandemic and other diseases had not resulted in increased hand hygiene compliance (9). Moreover, the high cost of COVID-19 treatment has exacerbated the existing burden on developing countries. At the same time, economic growth also affects the regional virus transmission rate. Especially in areas with unfavorable economic development, the transmission rate of COVID-19 cannot be well controlled. This situation has formed a vicious circle of the poorer the more serious, the more serious the poorer (10). Developed countries have more medical experience and higher medical standards, which has enabled them to the second and third waves of the handle pandemic better than developing countries (11). On this basis, the national government of developing countries can solve the problems through reasonable measures to reduce the cost of treatment and implement tiered charges for both rich and poor areas (12). The indirect impact of the COVID-19 pandemic is also huge, especially its negative impact on economic growth. Under the conditions of the COVID-19 outbreak, the medical capacities of hospitals were lacking, which inevitably led to economic losses. The cost of adopting different means of prevention and control of COVID-19 varies, and isolation may be the best way to deal with it (13).

In addition to social isolation, the national government should introduce policies to control the spread of COVID-19. Under the COVID-19 transmission model, every country will be affected by economic conditions and government intervention measures. Good economic conditions will exacerbate the spread of COVID-19, while appropriate government intervention measures will greatly reduce its spread (14). Specifically, the COVID-19 pandemic has reduced the activities of the service and manufacturing industries, resulting in an increase in the number of unemployed people. To reduce the negative impact of the pandemic and intervention measures on the economy, the government should take financial, monetary, and other economic measures to expedite economic recovery (15, 16). At a time when rapid antigen diagnostic tests (RTDs) are widely used in COVID-19 detection, the government can turn the COVID-19 pandemic into a controllable infection through rapid testing (17). Standing at the crossroads of this choice, governments should learn a lesson. It is important to revive the economy, but once everyone is dead, then no one contributes to the economy (18). In emergency response, it is usually better for the government to overreact and then scale down when necessary, rather than to react too late (19). Therefore, the government must grasp the intensity of intervention, both development and pandemic prevention and control. Health spending can affect GDP to some extent, and its impact is not entirely linear; increased health spending in a country increases human capital, either directly or indirectly, leading to higher productivity and an increase in GDP (20, 21). Healthcare levels and economic development go hand in hand. For example, Bangladesh's economic growth is hindered by underdeveloped medical care (22). Therefore, the government should increase medical funding to mitigate the impact of the COVID-19 pandemic on residents' lives and economic growth (23). COVID-19 affects not only current economic growth but also the future expectations of investors and consumers. Taking the United States as an example, the study finds that the health crisis and economic downturn will have a negative impact on investors. At the same time, the health crisis in other countries will also have a negative spillover effect on investor expectations (24). The economic recession brought about by the COVID-19 pandemic will inevitably affect the unemployment rate, which will in turn reduce national tax revenue and increase government spending. Therefore, the federal government must avoid major deficits and harmful cuts, and improve the healthcare safety net by increasing Medicaid (25).

1.2. Strategic measures under COVID-19

The relationship between economic growth and the COVID-19 pandemic is complex. In the long run, the harm caused by the pandemic to the country and society is continuous, but the positive environmental impact is only temporary. The outbreak of COVID-19 has slowed or even stalled the global economy, reduced carbon emissions, and improved air quality in many cities around the world. However, when the pandemic subsides, carbon and pollutant emissions will return to the same levels as before, and the positive environmental impact of the pandemic will be lost (26). The mutation and invasion of COVID-19 strains require government departments to develop more powerful strategies to overcome the threat caused by COVID-19 (27). In this regard, Akighir et al. (28) estimated the macroeconomic development level of Nigeria after adopting the economically sustainable development plan, indicating that the sustainable economic development policy of the government has a positive impact on national economic growth, employment, inflation, and so forth. Dorn et al. (29) studied a balanced strategy that can meet the co-benefits of health protection and the economy, and also reduce economic losses without compromising medical goals. Contrary to the economic pain caused by the COVID-19 pandemic to the general public and the non-investment class, the market has brought immeasurable rewards to those at the top (30). For example, the pharmaceutical industry benefitted greatly from the shortage of drugs in the early stage of the pandemic (31). The development of health tourism has also helped the economic growth of countries such as Turkey. The national government can alleviate the economic losses caused by COVID-19 by supporting health tourism (32).

1.3. Aims and contributions of the study

As the most influential public health security issue at present, COVID-19 has had an impact on all aspects of the world. Especially in the economic aspect, the pandemic has brought a huge blow to the economy. With globalization enhancing international exchanges, the

spillover effect of the pandemic cannot be ignored. Many studies have used different models to study the relationship between COVID-19 and the economy (33–35), especially the direct impact of the pandemic on the economy. Different medical levels between countries lead to differences in the way and effectiveness of pandemic prevention in each country, and the medical level becomes an influential factor during a pandemic. The present study combines the economic level matrix and the geographical distance matrix to build a dynamic spatial Durbin model (36). We are more concerned with the indirect impact of the pandemic on neighboring countries. The dynamic spatial Durbin model can well integrate geographical distance into the model, expand the impact of the COVID-19 pandemic from one country to neighboring countries, and more comprehensively describe the spread and harm of the pandemic in the context of globalization. Expanding from COVID-19 to general public health security issues informs future public health security issues. Based on this, the study proposed two main hypotheses.

> *Hypothesis 1*: There is a spatial spillover effect of the medical level on public health safety issues and economic climate.
>
> *Hypothesis 2*: Increased public health safety issues can inhibit current economic growth; however, current economic growth cannot alleviate public health security issues.

This paper only considers the extent to which the medical level and the strictness of policy response affect the public health safety issues and the economy. Other variables do not have a significant impact on the model. Therefore, the study assumes that other variables such as demographic structure, industrial structure, and psychological factors are not significantly different across countries. Moreover, differences in topography and landscape across countries do not affect the construction of the geographical distance matrix.

Compared with the existing literature, this paper possibly makes the following contributions: first, adopting the COVID-19 disability-adjusted life year (DALY) as a public health safety (PHS) indicator and using it to analyze the impact of public health safety issues on the economic climate; and second, adding control variables to the Durbin model (strictness of policy response), which reduces the impact of different national pandemic prevention policies on the results.

2. Materials and methods

2.1. Variable selection and data interpretation

This study selects data from the official statistics of the OECD and the data provided by Martin College of Oxford University and the Global Clinical Development Lead. In particular, it uses the Comprehensive Leading Indicator (CLI) to measure the degree of future economic prosperity; the quadratic interpolation to convert quarterly GDP into monthly GDP, which is then taken as the economic climate level of each country; and the COVID-19 DALY as a public health safety (PHS) indicator. Three control variables are selected: medical level (ML), which is the number of hospital beds per 1,000 people in each country, is selected as a measure of the medical level of each country during the COVID-19 pandemic; policy response strictness (PRS) is the monthly average government response strictness index; and reproduction rate (RR) is the country's monthly virus reproduction rate.

2.2. Public health safety calculation

Most infectious diseases that broke out in recent years have the characteristics of widespread contagion and profound impact. Many human infectious diseases have evolutionary patterns, such as AIDS, malaria, and hepatitis B. Their initial appearance led to a pandemic, with periodic outbreaks experienced in the process of human society, eventually forming endemic diseases and likely to erupt in the future (37). Especially in the process of globalization, geographical restrictions have weakened, and infectious diseases such as tuberculosis have moved from high-prevalence areas to low-prevalence areas with the deepening of international exchanges, thus affecting global public health security (38). COVID-19 has also caused a severe blow to tourism, hotel, education, and other industries (39–41). In addition, the losses caused by the pandemic do not only exist in the present. For instance, many patients have developed long-term physical and even psychological problems due to the disease. Indeed, the impact of the disease is prolonged. For a long time, the incidence of infectious diseases alone could not accurately measure the regional PHS indicators. Compared to disease incidence and mortality, disease burden more comprehensively reflects the regional disease severity and regional public health security level. Disease burden refers to the economic, life, and quality of life loss of patients after the occurrence of the disease (42). Moreover, when the Harvard T.H. Chan School of Public Health, the World Bank, and the World Health Organization (WHO) cooperated to assess the global disease burden in 1993, a new indicator of DALY was introduced in assessing the global disease burden (43). Since then, the DALY measurement has become a common disease burden measurement method. In view of this, the present research uses DALY to measure disease burden and constitute a PHS index. The construction process is as follows (44):

$$DALY = YLD + YLL \tag{1}$$

In Formula (1), YLD represents the number of years of health lost due to disability, and YLL represents the number of years of life lost due to death.

$$YLD = \frac{I \times DW \times L\left(1 - e^{-rL_D}\right)}{r} \tag{2}$$

$$YLL = \frac{N}{r}\left(1 - e^{-rL}\right) \tag{3}$$

In Formula (2), I represent the number of patients infected by COVID-19 (this study adopts the number of cases per 100,000 people), and DW represents the weight of the disease. According to the research on the weight of the disease proposed by Saloman et al. (45), the DW of the COVID-19 pandemic is equal to 0.133; L_D is the disease duration, usually two weeks, or 0.0038 years; and r is the discount rate, usually 0.03. In Formula (3), N represents the number of deaths due to COVID-19 (this study adopts the number of deaths

per 100,000 people), and L represents the life expectancy. The final estimated DALY included panel data of 31 months for 19 countries.

2.3. Spatial correlation test

The basic measure of spatial autocorrelation analysis is Moran's I, which is derived from the Pearson correlation coefficient in statistics and can reveal the laws of geographic space (46). In this research, Moran's I is used to test the spatial correlation of the indicator of the economic climate. The statistical calculation process of the global Moran's I to measure the spatial correlation is as follows:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}W_{i,j}\left(Y_i-\bar{Y}\right)\left(Y_J-\bar{Y}\right)}{S_0\sum_{i=1}^{n}\left(Y_i-\bar{Y}\right)^2} \quad (4)$$

In Formula (4), Y_i is the OECD CLI of each country, $W_{i,j}$ is the economic geospatial weight between countries i and j, n is the total number of countries, and S_0 is the aggregation of spatial weights:

$$S_0 = \sum_{i=1}^{n}\sum_{j=1}^{n}W_{i,j} \quad (5)$$

Since countries within the EU are not only connected by distance but also by mutual economic activities, an economic geospatial nested matrix is constructed (47). The construction process is as follows:

$$w_{i,j}^{1} = \begin{cases} 0 & if\ i = j, \\ \dfrac{1}{d_{i,j}^{2}} & if\ i \neq j, \end{cases} \quad (6)$$

$$w_{i,j} = w_{i,j}^{1} diag\left(y_1, y_2, \cdots, y_n\right) \quad (7)$$

where y_i refers to the GDP *per capita* of each country from 2020 to 2021 (calculated by purchasing power parity), $d_{i,j}$ refers to the distance between national capitals (the unit is kilometers), and $w_{i,j}$ is standardized on the basis of Formula (7):

$$W_{i,j} = \frac{w_{i,j}}{\sum_{j=1}^{n} w_{i,j}} \quad (8)$$

By Formula (8), the $w_{i,j}$ matrix is made dimensionless to make it reflect the spatial correlation structure more clearly, which is convenient for the subsequent drawing of the local Moran exponent map and the establishment of the spatial Durbin model.

From August 2020 to February 2022, Moran's I is positive and significant (Table 1), indicating that the CLI of European countries has a significant positive correlation in the spatial distribution, that is, there is a clustering trend in the economic growth of neighboring countries, and the spatial clustering effect really exists. This paper then draw a LISA scatterplot of the Anselin Local Moran's I (Figure 1). The cross-sectional data in February 2021 and November 2021 are analyzed, and it is found that there were high-high aggregation and low-low aggregation between countries, with a strong spatial clustering effect.

TABLE 1 Global Moran's I from March 2020 to September 2022.

Month	Moran's I	Month	Moran's I
2020/03	−0.024	2021/07	0.658*
2020/04	−1.214**	2021/08	0.675*
2020/05	−0.996**	2021/09	0.735*
2020/06	−0.812*	2021/10	0.746*
2020/07	−0.034	2021/11	0.675*
2020/08	0.111	2021/12	0.525
2020/09	0.283	2022/01	0.306
2020/10	0.555	2022/02	0.043
2020/11	0.767*	2022/03	−0.200
2020/12	0.941**	2022/04	−0.368
2021/01	1.156***	2022/05	−0.459
2021/02	1.211***	2022/06	−0.476
2021/03	0.998**	2022/07	−0.407
2021/04	0.905**	2022/08	−0.328
2021/05	0.788**	2022/09	−0.252
2021/06	0.670*		

*10% significance level, **5% significance level, ***1% significance level.

2.4. Constructing the dynamic spatial Durbin model based on the moderating effect theory

If the relationship between variables X and Y is represented by a function with variab+le M, then M is the moderating variable (48). Compared to the interaction effect, the independent variable and moderating variable in the moderating effect are asymmetric and cannot be interchanged. The current study adopts the most commonly used adjustment model proposed by Wen et al. (49) to analyze the adjustment effect of medical level on public health security issues. The specific test equation is as follows:

$$Y = aX + bM + cXM + e \quad (9)$$

Since there is a time lag in the degree of economic prosperity, the time lag term of the degree of economic prosperity is introduced into the standard static spatial Durbin model. The exogenous variable PRS is introduced as a control variable, and a dynamic spatial Durbin model is established based on the adjustment effect (50):

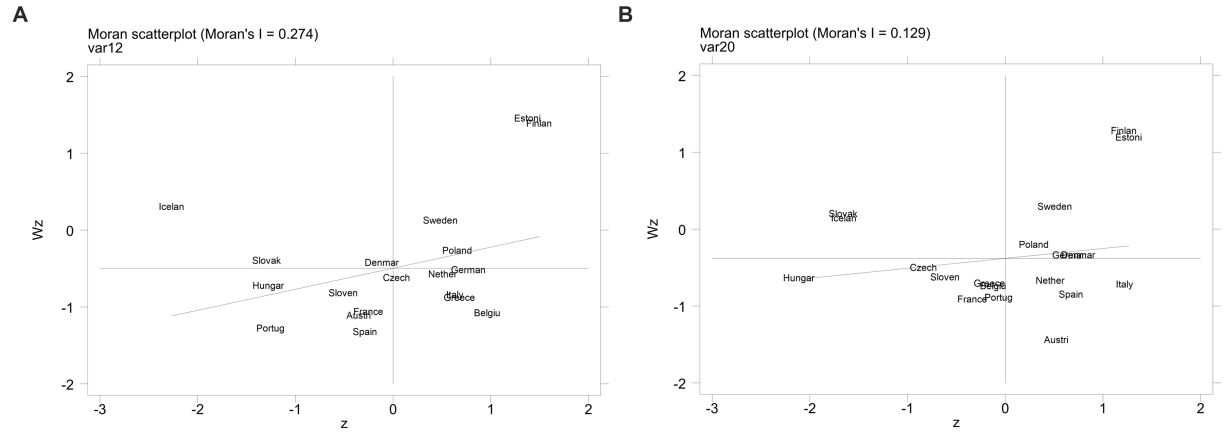

FIGURE 1
Lisa scatterplot of the AnselinLocal Moran's I. **(A)** Lisa scatterplot in February 2021; **(B)** Lisa scatterplot in November 2021.

TABLE 2 Test results of traditional mixed panel model.

Test	*CLI*	*GDP*
LM-lag	50.950***	567.365***
LM-error	59.799***	536.225**
Hausman	37.07***	34.61***

**5% significance level, ***1% significance level.

$$Y_{i,t} = \beta_0 + \beta_1 Y_{i,t-1} + \delta_1 \sum_{j=1}^{n} W_{i,j} Y_{j,t} + \beta_2 PHS_{i,t} + \delta_2 \sum_{j=1}^{n} W_{i,j} PHS_{j,t} + \beta_3 ML_{i,t} + \delta_3 \sum_{j=1}^{n} W_{i,j} ML_{j,t} + \beta_4 PHS_{i,t} \times ML_{i,t} + \delta_4 \sum_{j=1}^{n} W_{i,j} PHS_{j,t} \times ML_{j,t} + \beta_5 PRS_{i,t} + \delta_5 \sum_{j=1}^{n} W_{i,j} PRS_{j,t} + \beta_5 RR_{i,t} + \delta_5 \sum_{j=1}^{n} W_{i,j} RR_{j,t} + \mu_i + \varepsilon_{i,t} \quad (10)$$

In Formula (10), Y is the explained variable future economic climate (CLI) and economic climate (GDP). The degree of PHS is the explanatory variable, ML is the moderating variable, and PRS and virus RR are the control variables.

The following model tests are based on a mixed panel data model with the interaction term removed from the model set up above. On this basis, the LM test is carried out to show the rationality of choosing the spatial Durbin model. As shown in Table 2, both the spatial lag model test and spatial error model test are significant, indicating that both models are supported and the mixed OLS model is rejected. Thus, the rationality of using the spatial Durbin model is confirmed.

Then, the Hausman test is carried out on whether the model adopts the fixed-effect model or the random-effect model. The p value of the Hausman test is less than 0.05, which proved that the fixed-effect model should be selected. The LR test and Wald test are then carried out on the model to analyze whether the spatial Durbin model will degenerate into a spatial auto-regression model and a spatial error model, which shows that the choice of the spatial Durbin model is very reasonable. The results are shown in Table 3.

2.5. Panel model of interaction mechanism

The impact of the COVID-19 pandemic on national economic growth is described above, but the impact between the two is mutual. Health infrastructure, pandemic prevention, and control policies, urban density, urban environment (51), and economic growth will all have an impact on the severity of the COVID-19 pandemic in a region. Structural changes have an important impact on the discovery of causality, for example, Xu et al. (52) found that economic activities mainly caused environmental pollution through the shock of the COVID-19 pandemic. This paper refers to Guven et al. (53) fixed-effect panel model to reset the model and further analyze the impact of economic growth level on the severity of the pandemic. After the Hausman test, it can be seen that the fixed effect model is more suitable, and so the following fixed effect model is set:

$$RR_{i,t} = \beta_0 + \beta_1 Y_{i,t} + \beta_2 Z_{i,t} + \mu_i + \varepsilon_{i,t} \quad (11)$$

The dependent variable is the regional COVID-19 pandemic severity (RR). Z_{it} represents the control variables PHS and PRS, and $Y_{i,t}$ represents the future economic climate (CLI) and economic climate (GDP). After testing, it is known that the inflation factor of each explanatory variable is less than 10, so there is no multicollinearity.

3. Results

3.1. Comparative analysis of Spanish flu and COVID-19

As the most lethal infectious disease in human history, the Spanish flu changed human life. Like COVID-19, which is currently prevalent, hatred makes people regard a country as the culprit. Most infected people have low immunity due to illness and die of other diseases (54). Both pandemics have a severe blow to the global medical and healthcare system. In the early days of pandemics, when confronted with these two pandemics, people underestimated the infection and

TABLE 3 Test results of the fixed effect model.

Test	*CLI*		*GDP*	
LR-test	SDM-SAR	SDM-SEM	SDM-SAR	SDM-SEM
	18.52***	7.97*	49.05***	107.32***
Wald-test	Unconstrained	Constraint	Unconstrained	Constraint
	18.99***	8.12*	49.01***	65.23***

*10% significance level, ***1% significance level.

TABLE 4 Comparison between COVID-19 and Spanish flu.

	COVID-19	Spanish Flu
Influenza duration	December 2019 -	25 months
Scope of influence	Global	Less than half of the countries
Main age group of dead patients	Age more than 65 years	25–40 years old
Proportion of deaths to total population (Italy)	0.2%	5%
Economic loss (Mexico)	180 billion dollars	9 billion dollars

The number of Spanish flu deaths in Italy is based on the study of Burdekin (57).

mortality rates of the viruses associated with them (55). Therefore, this study compares the two pandemics (56).

As shown in Table 4, the death toll of the Spanish flu was higher than that of COVID-19, due to war and low medical levels at that time. The current medical level is far higher than that in 1918, but the proportion of deaths in the total is still not low. We can see the changes in the scope of influence: the world links closely in the context of globalization. The scope of influence of COVID-19 is much larger than that of the Spanish flu. The economic losses from COVID-19 were much higher than those from the Spanish flu due to the globalization of the economy, and the spillover from the COVID-19 pandemic has dealt a severe blow to the global economy. Therefore, the spillover effect between regions needs to be considered in public security research to prepare for the next attack on public health security.

3.2. Comparison of public health security among countries

Clustering analysis was performed on the PHS indicators of each country with the time period as a variable to judge the similarity of the degree of impact of the COVID-19 pandemic among countries as well as analyze whether the similarity is related to geographical distance. These indicators are clustered using the silhouette coefficient method and K-means clustering method. Using the silhouette coefficient method, it is known that the optimal number of classifications is divided into two categories. The classification results are Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Sweden, Iceland, Italy, the Netherlands, Portugal, Spain, and Greece for the first category; and the Czech Republic, Hungary, Poland, Slovakia, and Slovenia for the second category. As shown in Figure 2, the second type of countries are relatively close in geographical location and primarily concentrated in central Europe, while the first type of countries is primarily concentrated in western Europe and coastal areas. This classification shows that the severity of public health security issues between countries with relatively close geographical distances is correlated, and it preliminarily confirms that there is a spatial spillover effect on public health security issues.

According to the clustering results, this study draws a line chart of the PHS of the COVID-19 pandemic in these two types of countries (Figure 3). The changes in PHS during the COVID-19 pandemic vary in different countries, but most of its peaks are concentrated from November 2020 to April 2021. Although the cold weather can inhibit the activity of the virus to a certain extent, the outbreak in winter has brought huge disasters to the residents of all countries due to the unfavorable supervision of the pandemic in European countries. The aggravation of the pandemic situation in European countries in winter also shows that the pandemic is no longer a disaster for one country but a disaster for the whole world. The impact of the spillover effect of the pandemic on neighboring countries is inestimable, and the pandemic should be jointly managed and controlled to prevent its spread. The first category of countries increased significantly in the early stage of the pandemic. It is very likely that this category includes mostly Western European countries with developed tourism, which led to the outbreak of the pandemic due to the flow of tourists in the early stage. After the inflection point in May 2020, it surged after November 2020, but the severity was weaker than that of the second category of countries. It is speculated that the first category of countries had already dealt with the outbreak in the early stage of the pandemic, and so the pandemic control during the second outbreak was more in place than the second category of countries. The second category of countries had relatively mild pandemics before September 2020 and concentrated outbreaks from October 2020 to May 2021, with a sharp increase after October 2021. These countries paid more attention to pandemic supervision in the early stage of the pandemic, such that there was no large-scale outbreak of the pandemic. However, the pandemic was repeated. Owing to the mitigation of pandemic control by the first type of countries, the pandemic broke out in October 2020. At the same time, the countries quickly implemented pandemic supervision and prevention policies such that the COVID-19 pandemic severity gradually decreases after peaking in March 2021. In November 2021, the COVID-19 pandemic severity increased sharply, indicating that the pandemic is threatening and recurrent, and therefore countries should control it scientifically and rationally. After the lockdown was lifted in February 2022, individual countries stopped implementing mandatory closure measures and replaced them with home quarantine measures for sick people. Preventive and control measures are still in place, but they are much more relaxed than they were during the initial period of the pandemic. The economy is also gradually recovering, and the pandemic is steadily declining in both groups of countries. Scientific prevention and control measures can more effectively control the pandemic and promote economic recovery.

Since the EU proposed to completely lift the lockdown in February 2022 and proposed new regulations on February 1, tourists only need to carry proof of vaccination, or proof of recovery or proof of negative test to travel unimpeded among the 27 OECD EU countries without isolation or additional coronavirus testing. Therefore, this study selects PHS and CLI before and after the lifting of the lockdown to conduct a preliminary analysis of the rationality

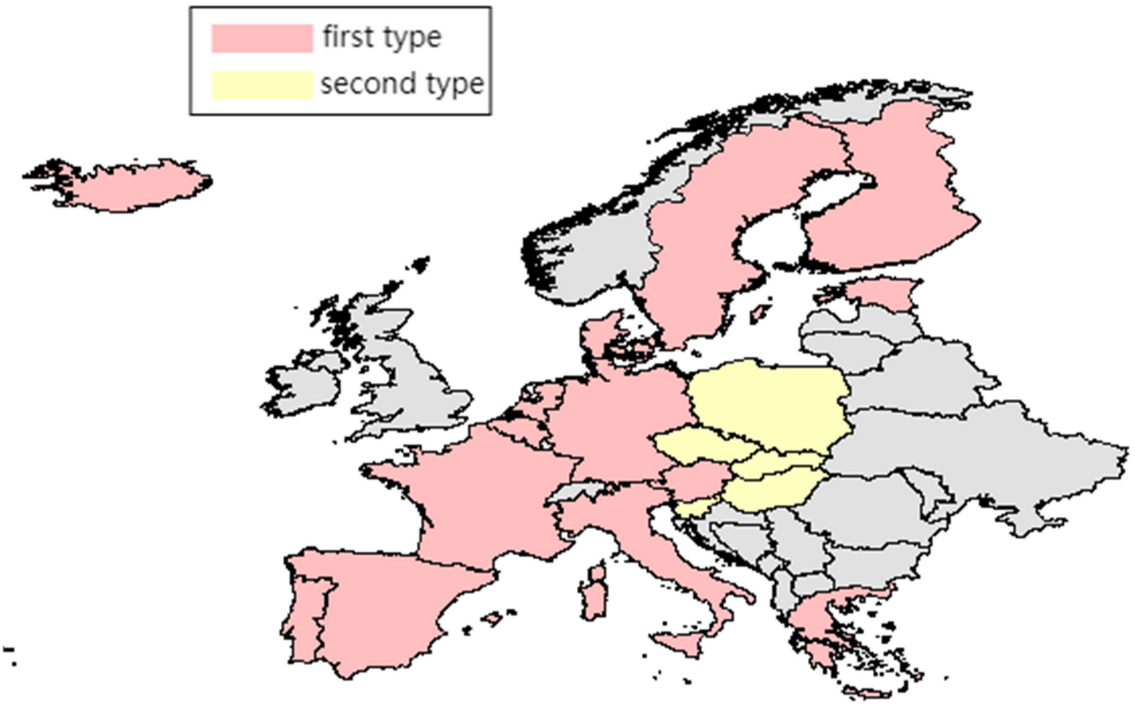

FIGURE 2
Geographical location map of two kinds of countries.

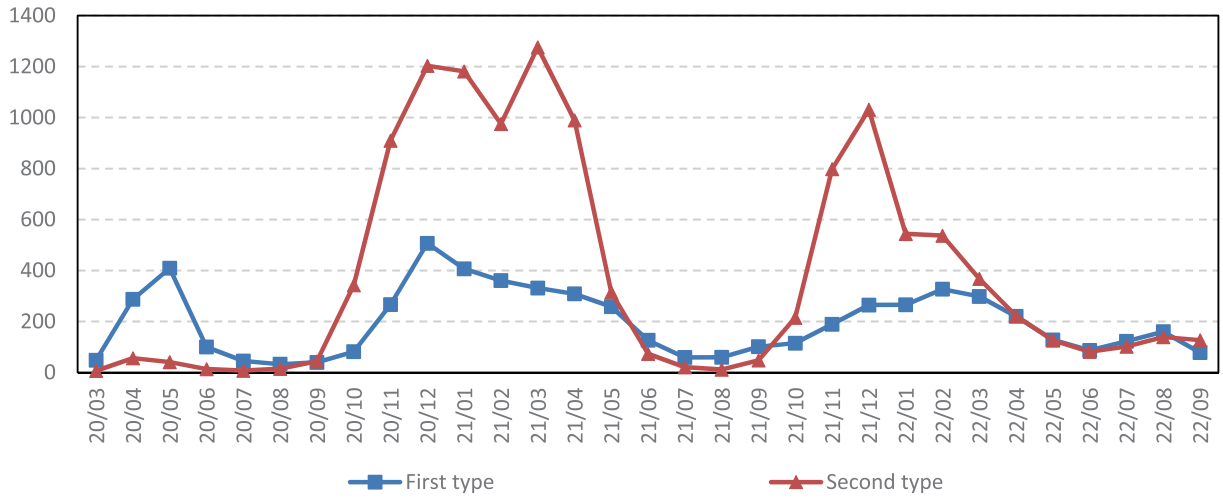

FIGURE 3
Twenty one months PHS line chart for two types of countries.

of its policy. It selects the PHS of 19 countries from December 2021 to March 2022 for K-means clustering, as shown in Figure 4. The countries are clustered into two categories, and the CLI of these two categories of countries are calculated. From this, it can be concluded that the first type of countries (14 countries, including Austria, Berlin, and Denmark) originally had a relatively low burden of disease but were negatively affected by the lift lockdown policy, with public health security issues minor increase. The second type of countries (5 countries, including the Czech Republic and Sweden) has a relatively serious disease burden, and so they have not been negatively affected by the lift lockdown policy. Instead, due to the open-lift lockdown policy, the domestic pandemic has spilled over to neighboring countries. Governments should continue to be concerned about the spillover effects of public health security issues. On the other hand, the lift lockdown policy has not promoted economic recovery, but rather the CLI has declined in these two types of countries. The economic growth of the first type of countries with a lighter disease burden is better than that of the

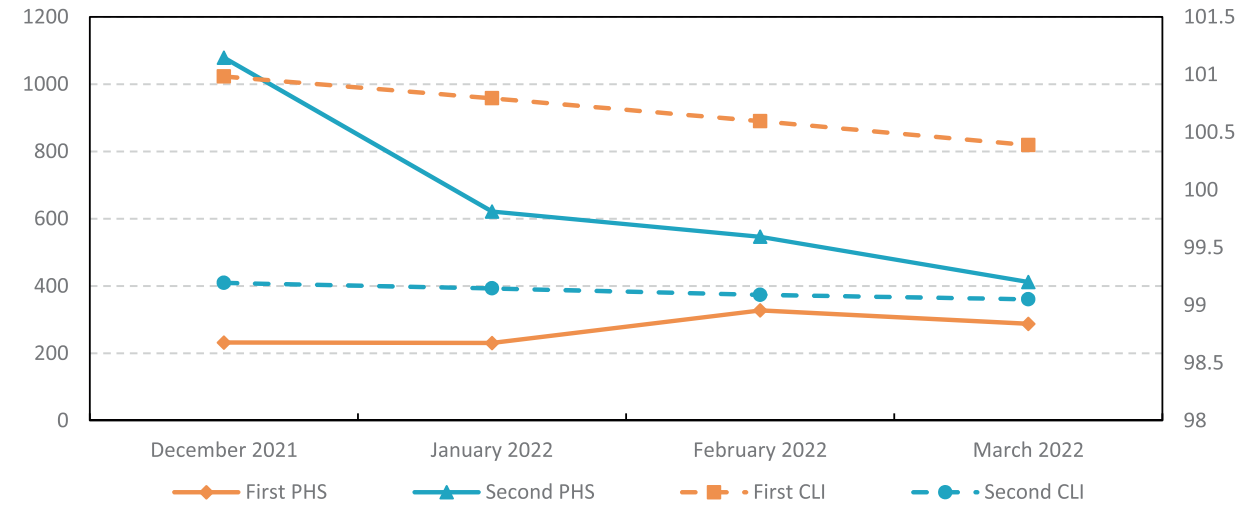

FIGURE 4
The line chart of changes in PHS and CLI before and after the lift lockdown of the two types of countries.

second type of countries with a heavy disease burden. It shows from the side that lifting the lockdown has not immediately led to economic recovery, and the expected ability to lead to economic recovery has some lag. Improving medical care and reducing national disease burdens can, to some extent, promote economic growth.

3.3. Correlation test

In order to measure the correlation between variables, this paper conducted a correlation analysis on explanatory variables and explained variables.

In Figure 5, the variables of public health security and the degree of economic prosperity are negatively correlated, indicating that public health security issues significantly inhibit economic development. The specific relationship between the variables requires further judgment.

3.4. Analysis of spatial linkage mechanism

To obtain more robust results, this study adds the time lag term and spatial effect of the degree of economic prosperity to the panel model and uses the dynamic Durbin model to analyze the problems described in the article. To judge which fixed effects the dynamic Durbin model adopts, the study establishes models, respectively. When testing the variable CLI, the log-likelihood value is the maximum when selecting the individual effect model, so it chooses the dynamic Durbin model of the individual effect. When testing the variable GDP, the log-likelihood value is the maximum when selecting the individual effect model, so it chooses the dynamic Durbin model of the individual effect (Table 5).

The time lag item Y_{t-1} of the economic climate in Table 6 is very significant, proving that the above economic climate has the characteristics of time path dependence. The dynamic spatial Durbin model, which takes into account the endogeneity problem and the time lag effect of the degree of economic prosperity, is more reasonable and reflects economic and social development. Public health security issues have no significant impact on the future economic growth of the country. Although the coefficient of the multiplication term of ML and PHS shown in Table 6 is greater than the coefficient of PHS, it is not significant. In terms of spatial spillover effects, public health security issues will have a significant negative effect on the future economic growth of neighboring countries, indicating that a country's public health security issues will have a negative impact on the future economic growth of neighboring countries. The coefficient of the multiplication term of ML and PHS is significantly positive in terms of spatial spillover, indicating that the improvement of medical level can have a certain mitigation effect on the negative impact of public health security issues in neighboring countries and regions on the degree of future economic prosperity. The coefficient of RR is significantly negative, but there is a significant positive spillover effect. It shows that the increase in RR of the COVID-19 pandemic will aggravate the pandemic and reduce people's confidence in the future economic climate. Therefore, it will inhibit the future economic climate, but will not be negatively affected by the virus RR of neighboring countries. Similarly, the reason why the PRS coefficient is positive but not significant is most likely that the pandemic is serious and the state has responded positively to it. At the same time, the impact of COVID-19 on residents and the strictness of policy response offset each other, so PRS is not significant.

In Table 7, the impact of PHS on GDP is significantly negative and the spatial spillover effect is negative, indicating that increasingly serious public health security issues will inhibit the development of the degree of economic prosperity and have a negative impact on the economic growth of neighboring countries. Similarly, the coefficient of the multiplicative term of ML and PHS has increased and the spillover effect is significantly positive, indicating that the improvement of the medical level can bring a certain mitigation effect to the negative impact of domestic public health security issues on economic climate. Additionally, it can significantly alleviate the negative impact of public health security problems in neighboring countries on economic prosperity. The coefficient of RR is significantly

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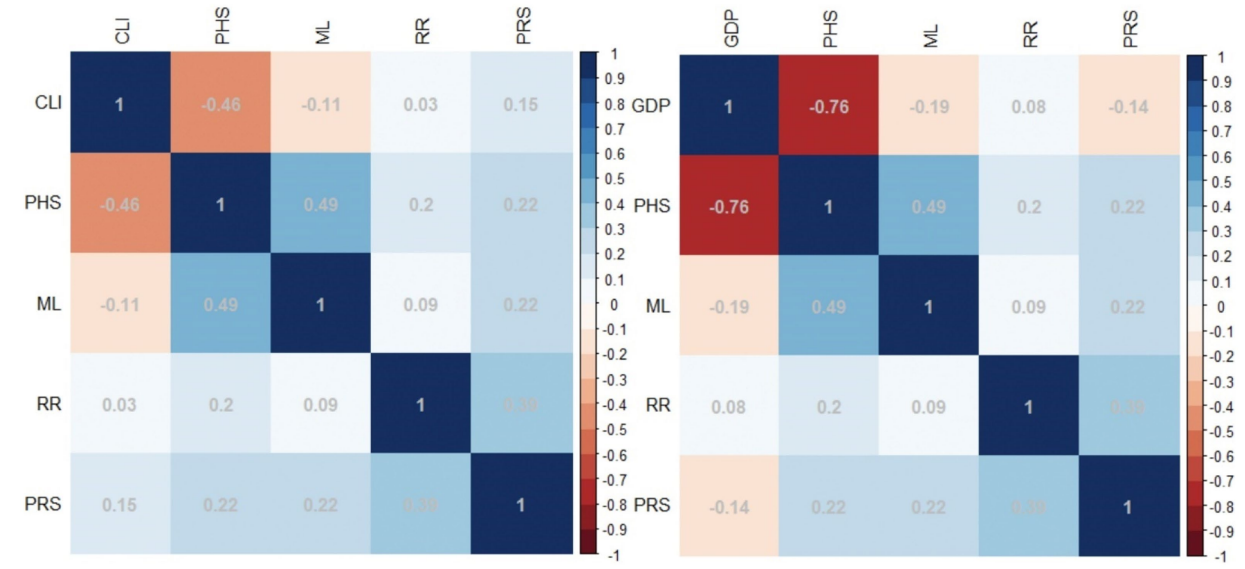

FIGURE 5
Correlation coefficient chart.

TABLE 5 Test results of log-likelihood of the fixed-effect dynamic spatial Durbin model.

Variable name	Individual effect	Time effect	Two-way fixed effects
CLI	−323.5015	−860.8148	−992.2393
GDP	616.7979	−997.6296	−830.0706

negative, but there is a significant positive spillover effect, indicating that the increase in RR of the COVID-19 pandemic will inhibit economic growth at present but will not necessarily have a negative impact on the economic growth of neighboring countries. Similarly, the coefficient of PRS is positive and has a significant negative spillover effect. It may be that the current response of the government to the pandemic will have a positive impact on economic growth but not on the economic development of neighboring countries.

Combining the results in Tables 6, 7, the multiplicative coefficients of ML and PHS are significantly positive in both models in terms of spatial spillover, indicating that the improvement of medical level can bring a certain mitigation effect to the negative impact of domestic public health security issues on economic climate. Hypothesis 1 is confirmed.

3.5. Robustness test

Although the COVID-19 DALY used above can accurately measure the severity of regional public health security problems, the increase in the death rate of COVID-19 is likely to increase people's panic and accelerate the spread of public health security problems. Therefore, a new column of new variables, the COVID-19 death rate (PHS-death), is added below, which is the number of COVID-19 deaths per 100,000 people. Given this, to test the robustness of the dynamic spatial Durbin model, this research replaces the core explanatory variable (PHS) with the COVID-19 mortality rate (PHS-death) for retesting.

From the perspective of coefficient changes, the medical level can also alleviate the negative impact of the death rate of the COVID-19 pandemic on the future and current economic climates. A spillover effect is observed. Within a country, the increase in mortality does not significantly affect people's prospects for future economic development, but it will have a significant negative impact on the current economic climate and negatively affect the degree of future economic prosperity of neighboring countries (Table 8). Similar to the above results and weaker than the above, the findings further show that the selection of the DALY of the COVID-19 pandemic as a PHS indicator is more appropriate than the COVID-19 pandemic mortality rate. It also shows that the results of the dynamic spatial Durbin model constructed above are credible and robust.

3.6. Analysis of the impact mechanism of economic growth on the COVID-19 pandemic

The GDP of coefficient is significantly positive (Table 9), indicating that the faster the economic development, the more serious the public health security issues become. Economic growth cannot alleviate public health security issues. The previous section illustrated that public health security issues can impede economic growth. The two results together confirm Hypothesis 2. The current economy develops faster the virus RR becomes faster. Economic development requires exchange contact, which will become a breeding ground for virus reproduction. But the CLI of the coefficient is significantly negative, indicating that the higher the future economic prosperity degree, the lower the virus RR will be. Due to reasonable and scientific government control measures, people no longer panic about the impending pandemic and are full of confidence in the anticipated economic climate. Therefore, the future economic climate will

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TABLE 6 The impact of PHS on CLI – the moderating effect of ML.

CLI	Main effect	Spillover effect
PHS	−0.041	−0.107**
PHS × ML	0.021	0.244***
Y_{t-1}	0.664***	0.664***
RR	−0.121***	0.075**
PRS	0.054	0.042

**5% significance level, ***1% significance level.

TABLE 7 The impact of PHS on GDP – the moderating effect of ML.

GDP	Main effect	Spillover effect
PHS	−0.007*	−0.012
PHS × ML	0.001	0.048***
Y_{t-1}	0.443***	0.443***
RR	−0.018***	0.019***
PRS	0.021***	−0.038***

*10% significance level, ***1% significance level.

be improved on this basis, which will inhibit the RR of COVID-19, so that the pandemic can be under control.

4. Discussion

We have deeply realized the impact of COVID-19 on human daily life. In the context of economic globalization, public health security is not only a problem for individual countries but also a problem for the whole world. Therefore, besides the negative impact on the economy, is there any spillover effect of the COVID-19 pandemic? To better analyze the spillover effects of medical level and public health security issues on the economic climate, this study selects EU countries with close economic ties and geographical distance as the research object. This paper establishes a dynamic Durbin model under the theoretical framework of a moderating effect and then studies the impact of public health security on the current and future economic climate of the region and the moderating effect of the medical level. Furthermore, the research perspective is expanded to the spatial dimension to study the spatial spillover effect. The medical level can adjust the negative impact of COVID-19 on the economy and alleviate the negative impact of public health security issues on the economy of neighboring countries. The degree of economic prosperity will affect public health security issues to a certain extent.

The global economy has been significantly affected by the COVID-19 pandemic. Some studies show that COVID-19 has spillover effects on the global economy. First, the spread of the virus has limited people's social distance and closed economic activity venues. The national economy is developing slowly. Second, the virus spreads exponentially, which causes consumers and investors to lack confidence in future economic development and makes it difficult for the economy to recover steadily (58). It is consistent with the conclusion of the present study. Public health security issues affect not only the current economic situation but also the future economic development trend.

TABLE 8 Influence of PHS on CLI and GDP–robustness test of the moderating effect of ML.

Dependent variable	Independent variable	Main effect	Spillover effect
CLI	PHS-death	−0.042	−0.108**
	PHS-death × ML	0.021	−0.246***
	Y_{t-1}	0.663***	0.663***
	RR	−0.121***	0.075**
	PRS	0.054	0.042
GDP	PHS-death	−0.007**	−0.012
	PHS-death × ML	−0.001	0.048***
	Y_{t-1}	0.442***	0.442***
	RR	−0.018***	0.018***
	PRS	0.021***	−0.037***

**5% significance level, ***1% significance level.

TABLE 9 Fixed effect regression model of the impact of economic climate on the COVID-19.

Variable name	Coefficient
CLI	−0.206***
GDP	0.600*
PHS	−0.145***
PRS	0.042

*10% significance level, ***1% significance level.

Our study found that the effect of the medical level on the pandemic and the economy is highly significant. In contrast, the impact of pandemic prevention policies on the pandemic and the economy is not fully significant. Pandemic prevention policies can only lead to economic recovery by indirectly influencing people's confidence in the future economic climate. Thus, the negative impact of a strict pandemic prevention policy on the economy during the latter part of a pandemic is greater than its positive impact on pandemic prevention and control. In the event of COVID-19, because the impact of the COVID-19 pandemic on European countries is asymmetric, the challenges brought by this asymmetry greatly reduce the effect of joint measures taken at the EU level. Therefore, many scholars proposed that the EU should formulate flexible plans to combat the pandemic (59). For example, EU member states reached a 540 billion Euro rescue measure in early April 2020 and approved a 1.85 trillion Euro budget stimulus plan on December 10, 2020 (60). On April 15, 2020, the president of the European Council and the president of the European Commission jointly proposed the "EU road map" to gradually eliminate restrictive measures in pandemic prevention and control, flexibly control and gradually restore normality to residents' lives, and restore strict control measures when the infection rate of COVID-19 surges (61). Most scholars agree on the need for a greater policy focus on economic recovery, which is consistent with our findings. Our study confirms that policy response strictness has a positive but insignificant effect on pandemic control. At a time when viruses are weaker, economic recovery is even more

important. At present, all countries have an open attitude toward COVID-19, and this practically confirms that strict prevention and control policies are no longer appropriate for implementation.

Our study observes a relationship between the COVID-19 pandemic and the degree of economic prosperity. The aggravation of the pandemic will slow down economic growth. If we want to improve the economic climate, we must first improve people's confidence in the degree of future economic prosperity, to focus on economic recovery in the post-pandemic era. Taking COVID-19 as an example, we must take a compromise between economic growth and public health security issues control. It will improve the future economic climate, control current public health security issues with a long-term perspective, and achieve long-term economic growth.

5. Conclusion

Our research shows that public health security issues in one country have spillover effects on the economic development of neighboring countries. Severe public health security issues can hurt the economic development of neighboring countries. At the same time, the development of the medical level can not only alleviate the negative effect of the pandemic on the economy in one country but also alleviate the negative effect of the pandemic on the economy in neighboring countries.

5.1. Theoretical contributions

At the moment of the pandemic, countries with high medical levels can better cope with the medical burden brought by the pandemic and effectively alleviate the negative effects of the pandemic. After reading the relevant literature, we found a few articles on the impact of the severity of the COVID-19 pandemic in a country on its neighboring countries, but this was very important in the context of economic globalization. The EU is a political and economic community. It has significant outbreak spillover effects. Therefore, this paper chooses the EU, a region with strong economic cooperation, for research. The 19 countries cited in this article are all from the EU. As a political and economic community, the EU promotes the development of countries in the EU through the implementation of treaties and plans. There are close political and economic exchanges between countries, so it is easier to transmit public health security issues. In order to study the spatial linkage problems encountered in adjacent regions when facing public health and safety problems, this paper introduces the moderating effect theory into the dynamic spatial Durbin model to explain the spillover effect of interregional public health security issues and the moderating role of the medical level. The aggravation of the pandemic in one country is very likely to cause pandemic burdens to neighboring countries. Similarly, the high level of national medical care can provide medical assistance to more patients, reducing the scope of public health security problems in the region. At the same time, it provides medical assistance to neighboring countries to alleviate the negative impact on economic growth trends of neighboring countries due to the spread of the public health security issues pandemic. Previous studies have often discussed the direct effect of the pandemic on the economy and other aspects. However, few studies have studied the spillover effect of the pandemic on the economy and the direct and indirect moderating effects of the medical level. In the process of globalization, countries connect more closely, and the spillover effects will become stronger. This research provides a new perspective and method of interregional linkages for future research on public health security.

5.2. Recommendations

Our research shows that the impact of a public health security problem is extensive, which will affect surrounding countries due to spillover effects. The improvement of medical level can help the country and even neighboring countries resist the attack of public health security problems. It is clear that the medical level is very important in any public health security issue, and therefore the government needs to maintain the medical system in such issues. For example, enhancing the health protection of healthcare workers. Some countries can provide medical assistance, such as medical supplies, personnel, and programs, to neighboring countries when the pandemic is controllable in their own. Our study finds that policy response strictness has a positive but insignificant effect on public health security and the economy throughout the outbreak period. It is because strict pandemic prevention policies are more effective in controlling the spread of the pandemic when the virus is virulent in the early stages of COVID-19. However, as the virus species mutates, the lethality rate of the pandemic decreases significantly, and strict pandemic prevention policies are less effective in controlling the pandemic but harm socioeconomic recovery. For example, the public health security issues do not intensify after the implementation of the lift lockdown policy in the EU. The intensity of pandemic control needs to base on the severity of the public health security issues and the intensity of pandemic transmission. Therefore, in the face of public health security issues, we recommend strict control in the early stages when the virus is strong. In the later period, control measures should be gradually relaxed. Eventually, economic recovery will be achieved.

In this study, 19 countries in the EU were selected as subjects. When selecting other countries, it is necessary to consider the similarity of their political and economic systems. The presence of large political and economic differences among neighboring countries will most likely lead to weaker spillover effects in neighboring countries than in non-neighboring countries. Therefore, it is necessary to take into account the inter-country differences in the geographic distance and economic level matrix when considering the public health security issues' spillover effects among countries with large political and economic differences. When discussing the impact of the COVID-19 pandemic on the economy, this study introduced policy response strictness and virus RR as control variables. However, in real life, there are still many variables that can affect the severity of the COVID-19 pandemic and economic growth, such as psychological factors (i.e., people's fear of the COVID-19 pandemic). These variables are difficult to quantify, so more precise frameworks need to be constructed to measure people's psychological factors. There is still room for improvement in the selection of control variables in this study.

5.3. Future research perspectives

In terms of research methodology, the spatial Durbin model relies on the spatial matrix, and the study of other factors that affect the spatial matrix can make the spatial Durbin model more accurate. At the same time, more control variables should be introduced in future studies to improve the credibility of the model results. In terms of

research content, the COVID-19 of the outbreak impact on all types of economies varies in degree. For the tourism, catering, and retail industries, COVID-19 deals a severe blow. The travel companies, hotels, airports, and train stations have taken a hit large due to a drastic decrease in travel demand. The restaurant companies are facing reduced patronage and operational difficulties due to the ongoing pandemic. The brick-and-mortar stores in the retail industry have seen a decrease in patronage and sales due to the ongoing pandemic. For the healthcare and online economies, the pandemic is both a hardship and an opportunity. During the pandemic, sales in these industries grow as people spent most of their time at home, leading to an increase in demand for home entertainment and digital products. Many gaming industries experience significant economic benefits from the pandemic situation. In addition, the healthcare industry also sees growth due to the ongoing pandemic. Therefore, in future research, we can analyze the economic development of different industries under the background of the COVID-19 pandemic. COVID-19 has significantly impacted the global unemployment rate. Once a country's unemployment rate becomes too high, the society is likely to become unstable. To cope with the effects of COVID-19, the government must take measures, and the purpose of our study is to provide suggestions to address the negative impacts of the COVID-19 crisis. It can even extend the pandemic to global public health and security events, enabling scholars to find the commonalities of economic development under various public health and security events. General conclusions can be drawn in the face of global changes, and future public health and security events must be prepared in advance.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://github.com/owid/covid-19-data/tree/master/public/data.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

RF made substantial contributions and participated in all aspects of the paper, conducted the methodology, analyzed the data, and wrote the manuscript. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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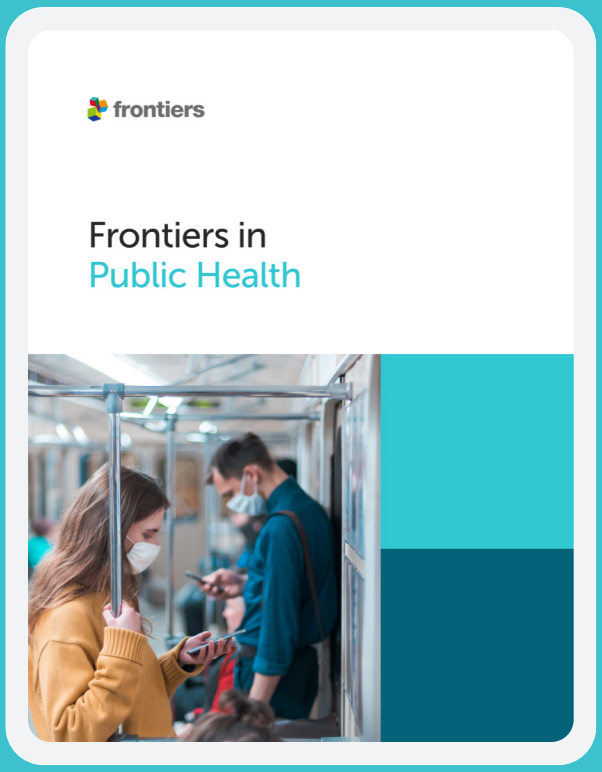

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