



The impact of air quality on international tourism arrivals: a global panel data analysis

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Abstract

Using data from World Development Indicators (WDI), this research constructs panel data of 99 countries from 1996 to 2018 and employs a spatial econometric model to analyze the impact of air quality on international tourism arrivals. Evidence shows that Moran's I values are significantly positive, indicating a strong positive spatial dependence in each country and that poor air quality does have a negative impact on the number of tourist arrivals. The results of grouped data illustrate that middle-income countries, low-income countries, high concentrations of PM_{2.5}, and countries with less numbers of tourists have negative effects on tourist arrivals in neighboring countries. The contrary groups, however, have positive effects on tourist arrivals – that is, the influence of air quality on the number of tourist arrivals exhibits heterogeneity. In addition, tests of the interaction term show that countries with higher R&D intensity have better air quality and thus attract more tourists. Therefore, countries with poor air quality should improve the environment through international cooperation and undertake technology transfer, thus ultimately increasing the number of tourists.

Keywords Air quality · International tourist arrivals · Spatial econometric models · R&D intensity · Heterogeneity

Introduction

As an imperative part of the tertiary industry, tourism is one of the fastest-growing business sectors in the world, known as a “sunrise industry.” International tourist arrivals (overnight visitors) worldwide grew 4% in 2019 to reach 1.5 billion, in which all regions enjoyed an increase in arrivals, and growth in international tourist arrivals continued to outpace the general economy (UNWTO 2020). Total international tourism receipts also hit US\$1.507 trillion, or 7.56% more than in 2018. Many nations rely on tourism as a primary source for generating revenues, employment, private sector

growth, and infrastructure development (World Tourism Organization 1997). Studies have shown that its development could also trigger overall economic growth (Lee and Chen 2022; Lee et al. 2022), thus spurring many studies related to tourism topics in order to see what factors relate to economic growth, environment, culture, or society. In this paper, we focus on the topic of air quality and tourism in a cross-country framework.

Evidence suggests that air quality ranks very high among factors that tourists take into consideration when making decisions about where to travel (Lise and Tol 2002; Moore 2010; Lee and Chen 2021). During their travel, people expect to see beautiful scenery, enjoy satisfactory service, and obtain good memories. However, many factors relating to environmental change influence natural sceneries, such as the impact of climate change on tourist destinations (Ame-lung and Nicholls 2014; Michailidou et al. 2016; Atzori et al. 2018) and air pollution, such as smog, particulates, greenhouse gases, and haze pollution (Becken et al. 2017; Dai et al. 2021). Two common air pollutants, PM_{2.5} and CO₂, tend to reduce visibility and pose significant health risks (Apergis and Payne 2009; Atasoy 2017; Churchill et al. 2019; Zhu and Lee 2021). To be more specific, Sajjad et al. (2014) concluded that climate factors and air pollution

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have a negative impact on tourism indicators in the form of deforestation and natural resource depletion. Becken et al. (2017) showed that feelings toward the risk of air quality have a significantly negative impact on destination image as well as intention to visit China. Wang et al. (2018) concluded that air quality in the place of origin creates a pushing effect as local outbound tourism demand increases when air quality deteriorates. Zhou et al. (2019) demonstrated that air pollution has a negative influence on tourism flows and that this effect is more pronounced for inbound tourism than for domestic tourism. Churchill et al. (2022) found that the growth of both CO₂ and PM_{2.5} emissions adversely affects international tourist arrivals. All these conclusions show the negative impact of air quality deterioration on tourism.

In addition to the above-specific research directions, existing empirical methods mostly entail causal analysis, such as the Vector Error Correction Model (VECM) (Katircioglu 2009; Ridderstaat et al. 2014), time-varying causality (Hall et al. 2010), Granger causality test (Kim and Chen 2006; Aslan 2014), and the panel data approach (Brun et al. 2005; Dumitrescu and Hurlin 2012). In addition to these four common methods, there are also the EGARCH-M model (Chen and Chiou-Wei 2009), Autoregressive Distributed Lag (ARDL) approach (Aslan 2016), autoregressive (VAR) (Hatemi-j 2003), TYDL bootstrap causality approach (Tang and Abosedra 2016), sys-GMM (De Vita 2014; Chen et al. 2021), and threshold effects or say the non-linear effect (Wang 2012; Wang and Chen 2021; Li et al. 2021).

To sum up, recent studies are paying more attention to the impact of environmental quality on tourism industry development. Due to data limitations, most methods use either questionnaire analysis or time series analysis, with few of them employing panel data, let alone spatial econometric analysis. However, there is a strong and obvious spatial relationship in pollution (Maddison 2006; Li et al. 2014; Guo et al. 2022; Wang and Lee 2022). For example, using Chinese data, Dong et al. (2019) find that air pollution demonstrates significant spatial spill-over effects – that is, if the PM_{2.5} in other cities simultaneously increases by 1 µg/m³, then the number of domestic tourists traveling to the local city rises by 4.1%. Xu et al. (2020) also noted that haze pollution and inbound tourism growth in mid-eastern China have apparent spatial autocorrelation and significant spatial spillover effects. These findings support that spatial correlation between air quality and tourism does exist, but studies rarely take all countries in the world as the research object. Most importantly, related studies rarely have considered spatial dependence or spillover effects when using panel data.

When the research sample involves multiple countries, the spatial correlation between research units cannot be ignored. Everything relates to other things, but similar things more closely correlate. Therefore, this paper utilizes the spatial

econometric model to analyze the impact of air quality on tourism development in countries around the world and examines the impact of environmental degradation on the number of tourist arrivals from neighboring countries from the perspective of the spatial marginal effect. Furthermore, the improvement of technological innovation has a great impact on the environment, and technological innovation greatly affects countries with relatively higher emissions (Chen and Lei 2018; Liu and Lee 2021; Wen et al. 2021). Efficient technological innovations, such as energy conservation technologies and renewable energy technologies, can help reduce the emissions of pollutants and gases and reduce the burden on natural resources (Dinda 2004). Costantini et al. (2013) showed that technological spillovers drive environmental efficiency more than internal innovation – that is, the level of R&D development inhibits environmental pollution, and the R&D spillover effect also impacts other countries (Rubio 2017). Based on this mechanism, this paper further analyzes how technological improvement works on the environment as well as on the number of tourist arrivals.

To provide a good supplement to the existing literature, this paper presents the impact of air quality on international tourism arrivals using spatial econometric models. The main contributions are as follows. First, we study the relationship between air quality and international tourist arrivals worldwide. Many studies are limited in scope as they tend to focus on single countries or specific geographic areas and rarely focus on the international perspective (Churchill et al. 2022). However, tourism resources are available all over the world. With such perfect technology information and transportation facilities, people can enjoy a wide range of scenery wherever they want to go. Second, we derive the direct, indirect, and total effects of air quality on international tourist arrivals using the spatial econometric model. Through this method, not only is the influence of domestic air quality on tourist arrivals obtained but we are also able to observe the impact of air quality in neighboring countries on tourist arrivals. Third, considering the heterogeneity problem, we group the data according to the income level, PM_{2.5} concentration, and number of tourist arrivals to find the connections between air quality and tourist arrivals. Fourth, this paper examines whether R&D intensity influences the link between air quality and international tourist arrivals. In most cases, the R&D level of developed countries is higher and environmental protection is stronger. It is hoped that the technology spillover effect in developed countries can radiate to developing countries to help them do their best to protect the environment.

The rest of this paper goes as follows. The “[Data and variables](#)” section introduces the data and variables. The “[Methodology](#)” section presents the methodology of the spatial econometric model. The “[Empirical results](#)” section shows the empirical results, including the basic model, spatial

Durbin model (SDM) results, the heterogeneity results, and the influence of moderators. Finally, the “[Conclusions and policy implications](#)” section summarizes this paper and provides some policy implications.

Data and variables

All the data employed in this study come from World Development Indicators (World Bank). The datasets are selected based on availability and integrity and help construct balanced panel data for a total of 99 countries within the period 1996–2018.¹ The number of international tourism arrivals is used as the proxy for tourism activities. Compared to international tourism receipts at current US dollars, the number of arrivals (larrival) may better measure tourism volume, which is the same as in Gunduz and Hatemi-J (2005). Moreover, a multicollinearity problem does emerge when tourism receipts are used (Katircioglu 2009). According to the U.S. Environmental Protection Agency, PM_{2.5} with an aerodynamic diameter of 2.5 µm (µm) or less poses more danger to health and the environment than ozone, nitrogen dioxide, and sulphur dioxide. Therefore, the mean annual exposure of ground-level PM_{2.5} (lpm) can measure air pollution.

Following previous research (Balli et al. 2020; Wang and Chen 2021; Wen and Lee 2020; Lv et al. 2021), we take GDP per capita, total population, total exports and imports, forest area, and transportation accessibility as control variables in the regression models and use lairline (total passengers carried by plane) to denote transportation accessibility, in order to control the effect of infrastructure and its convenience on tourist arrivals. The variable lpgdp denotes GDP per capita (constant 2010 US\$), is a country's economic output per person, and reflects to what extent a country can exploit its resources to offer tourism activities, which is supposed to positively relate to international tourist arrivals. The variable lforest is forest area (% of land area), and the influence on tourist arrivals may be ambiguous. While a forest covers a large area and a good environment can attract more tourists, a forest is also underdeveloped and does not have enough space for sightseeing. The variable lim_ex is a country's exports and imports of goods and services (constant 2010 US\$), reflecting its openness. The variable lindus denotes industry value added (constant 2010 US\$), and we think that industrial structure determines air quality to a large extent. Lastly, the variable lpop is a country's total population, and therefore, the more people there are, the more people there will be who want to travel abroad.

Table 1 Descriptive statistics of variables

Variable	Obs	Mean	Std. dev	Min	Max
larrival	2277	14.48	1.958	6.551	18.30
lpm	2277	3.104	0.622	1.735	4.613
lairline	2277	14.74	2.305	7.703	20.61
lpgdp	2277	8.837	1.482	5.351	11.63
lforest	2277	2.750	1.684	−5.042	4.517
lindus	2277	22.63	2.688	15.98	29.23
lim_ex	2277	13.27	2.050	3.953	17.84
lpop	2277	15.05	2.328	9.775	21.05

Table 1 reports the descriptive statistics of the variables. As shown, the mean value of PM_{2.5} is about 22 µg/m³ from 1996 to 2018, which is less than two times the level of good air quality for PM_{2.5} concentrations (12 µg/m³), according to the Environmental Protection Agency (2013).² The minimum of PM_{2.5} (5.6689 µg/m³) is obviously lower than the safe levels for PM_{2.5} concentrations, while the maximum of PM_{2.5} (100.7861 µg/m³) is about eight times the safe level and is thus very unhealthy.

The sample includes both developed and developing countries, and there are large differences in economic conditions, air quality, and tourism resources between them. We follow the income group divided by WDI and set up 38 high-income countries in the high-income group, 25 upper-middle-income countries in the middle-income group, and 20 lower-middle-income and 16 low-income countries in the low-income group. The more similar the pollution levels are between two countries, the more likely it is that their citizens will travel to the other country. Countries that have more tourist arrivals are more easily affected by the environment or have better air quality. It should be noted that there are no commonly used grouping standards for PM_{2.5} and tourist arrivals. As per the practice of Bonamente (2017) and Chen and Lee (2020), the whole sample is grouped according to the median of the intermediate year (2007). Therefore, we construct high-PM_{2.5} with low-PM_{2.5} as well as high-arrivals with low-arrivals for these four groups. There are 47 and 52 countries in the high-PM_{2.5} and low-PM_{2.5} groups and 54 and 45 countries in the high-arrivals and low-arrivals groups, respectively.

² According to the U.S. Environmental Protection Agency (2013), air quality is considered good if an annual mean concentration of PM_{2.5} is less than 12 µg/m³; moderate if PM_{2.5} is between 12.1 and 35.4; and unhealthy for sensitive groups if the value is between 35.5 and 55.4. If the mean concentration of PM_{2.5} is between 55.5 and 150.4, then it is considered unhealthy and the risks increase as the value increases.

¹ The WDI provides data for 263 countries. To ensure the integrity of the data as much as possible, after deleting the missing values of major variables, a total of 99 countries' data can be used for research.

Methodology

Because of interaction and spillover effects, adjacent regions often have more in common with each other than with distant regions. An important assumption in the general model regression is that each observation is independent, but the spatial correlation between observed variables will lead to a failure of traditional OLS analysis (Anselin 1988). Under the effect of spatial correlation, the change of an independent variable in any region will not only directly affect its dependent variable but also affect the dependent variable in the region with spatial correlation. The cross-sectional spatial regression model incorporates spatial dependence, so that a more robust and accurate estimation result can be obtained (Lee et al. 2021; Liu et al. 2021).

We establish the general nesting spatial model (GNS) containing all spatial variables of N countries with the application of cross-section data, specified as.

$$Y = \rho WY + \alpha I_N + X\beta + WX\theta + u, u = \lambda W_u + \varepsilon \quad (1)$$

where W is the space weight matrix of order $N \times N$; WY is the lagging variable of the dependent variable Y , which is used to represent the interaction of dependent variables in neighboring countries on Y ; WX is the lagged variable of the independent variable X , which is used to represent the interaction of independent variables in neighboring countries on Y ; ρ , α , β , and θ are the corresponding regression coefficients; I_N is $N \times 1$ and the elements are all 1; u is a column vector for the error terms; and W_u is the interaction effect of the error terms. According to the different settings of ρ , θ , and λ , the general model can be transformed into different forms of the spatial model. In Eq. (1), if $\lambda = 0$, then the model reduces to SDM. In SDM, when $\theta = 0$, it reduces to the spatial autoregressive model (SAR). When $\theta = -\rho\beta$, it changes to the spatial error autocorrelation model (SEM). When $\rho = 0$, it is the spatial lag of the X model (SLM). Therefore, SAR, SEM, and SLM are all regarded as special cases of SDM (Halleck Vega and Elhorst 2015).

The variation of the independent variable in a country affects its dependent variable, which is called the direct effect. The effect on the dependent variable in the neighboring countries is called the indirect effect (LeSage and Pace 2009). When $\lambda = 0$, we take the expectation of Eq. (1) and then take the partial derivative of the k th independent variable to get.

$$\left[\frac{\partial E(Y)}{\partial x_{1k}} \dots \frac{\partial E(Y)}{\partial x_{Nk}} \right] = (I - \rho W)^{-1} [I\beta_k + W\theta_k] \quad (2)$$

In Eq. (2), the elements on the diagonal represent the direct effect, and the elements of the diagonal present the indirect effect. If SDM reduces to SAR, then Eq. (2) simplifies to.

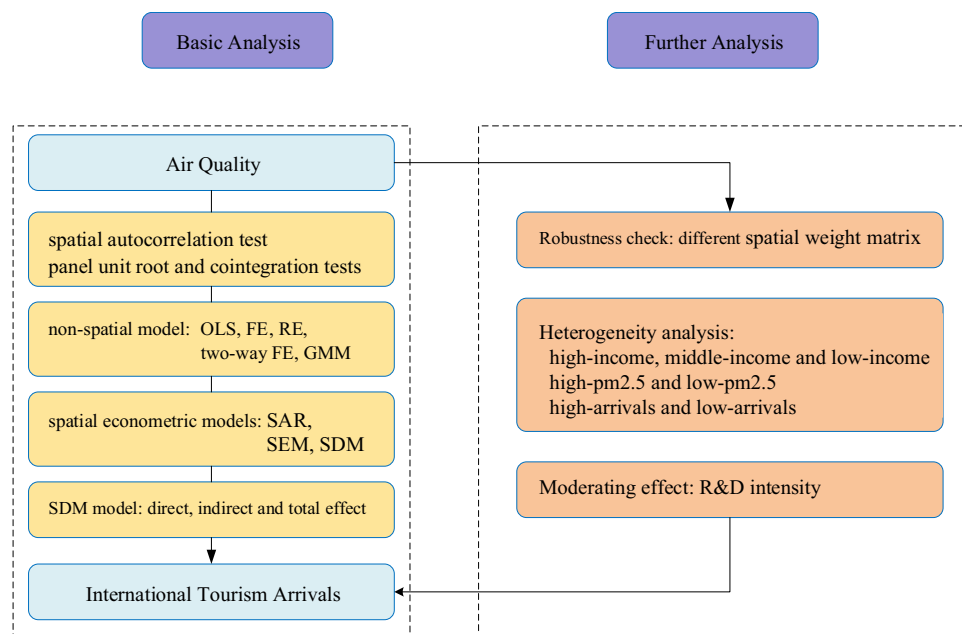
$$\left[\frac{\partial E(Y)}{\partial x_{1k}} \dots \frac{\partial E(Y)}{\partial x_{Nk}} \right] = (I - \rho W)^{-1} \beta_k \quad (3)$$

In Eq. (3), the direct effect is still represented by the diagonal element, while the indirect effect is presented by the off-diagonal element. If the model degenerates into SLM, then β_k is the direct effect and θ_k is the indirect effect. If the model reduces to SEM, then there is only a direct effect and no indirect effect (Halleck Vega and Elhorst 2015).

Compared with other spatial models, SDM includes the spatial lag explanatory variable WX , which is more helpful to prevent the error of omitted variables that often happens in empirical analysis. In addition, if the data generation process is SEM or SLM, then the SDM model can still guarantee the unbiased property of coefficient estimation (Lesage and Pace 2009). Gerkman (2012) used housing price data to compare SEM and SDM, showing empirical results in which both the Hausman test and the direct and indirect effect analyses support that SDM is optimal. In view of this, SDM widely appears in studies on the analysis of endogenous and exogenous interaction effects (LeSage and Pace 2009). Therefore, based on a comparative analysis of other regression models, this paper focuses on the impact of air pollution on the number of international tourist arrivals through SDM regression results. To check the robustness of the SDM model, we employ the LR test to determine which model is more appropriate. The null hypothesis of this test is whether the SDM model can be replaced by the SAR or SEM model; if it can be rejected, then we use the SDM model. The spatial weight matrix is essential for the spatial econometric model. This paper employs the inverse distance matrix to measure non-adjacent countries. To make the spillover effect interpretable, the matrix exhibits row standardization.

In the SDM model, the direct effect of air quality on international tourist arrivals refers to the effect domestically and the indirect effect is the impact of air quality in neighboring countries. The influence on neighboring countries is complex. First, as the environment in neighboring countries deteriorates, domestic residents with a greater tourism tendency will choose to travel abroad. Second, when residents of neighboring countries observe that the environment of neighboring countries or target tourist countries becomes worse, it will reduce their intention to go abroad. Finally, as the environment deteriorates around the world, the concepts of green energy and green development are constantly put forward. The realization of these concepts requires the development of relevant science and technology. Therefore, the increase in a country's R&D cost not only improves its own environment but also radiates to other countries' economic transformation and environmental quality. After analyzing the results of the spatial model, we also analyze the moderating effect of R&D on air quality.

Fig. 1 The research framework of this paper



The framework of the empirical part is shown in Fig. 1. As the figure shows, the basic analysis of the regression part starts with two tests. The first one is the spatial autocorrelation test and uses the value of Global Moran's I to see if there is spatial autocorrelation. The second one is the panel unit root and cointegration tests to test whether or not non-stationarity exists. We then go to the non-spatial models to understand the relationship between air quality and travel arrivals. After that, we move to spatial econometric models, like SAR, SEM, and SDM. The LR test can determine whether SDM is more applicable. The SDM model presents the direct effect, indirect effect, and total effect of air quality on international tourist arrivals. To delve in further, we do a robustness check to verify the steadiness of the baseline model. We divide the three different groups (high-income, middle-income, and low-income; high- $PM_{2.5}$ and low- $PM_{2.5}$; high-arrivals and low-arrivals) to conduct a heterogeneity analysis. Finally, we use R&D intensity as the moderating effect to see if technology innovation can reduce the negative effect of air quality on international tourist arrivals.

Empirical results

Spatial autocorrelation test

Spatial correlation refers to the statistical correlation between the observations of neighboring countries having a similar spatial distribution. If similar observations tend to aggregate, then it denotes a positive spatial correlation;

otherwise, it means a negative correlation. Moran's I is a good method for measuring spatial autocorrelation. Its value is between -1 and 1 . The higher the value is, the higher the spatial correlation is. When the statistical value is greater than 0 , it indicates a positive spatial correlation between different regions – that is, countries with high (low) air pollution aggregate with countries having high (low) air pollution. Less than 0 indicates a negative spatial correlation, as countries with high (low) air pollution cluster with countries having low (high) air pollution. Equal to 0 means that each region has no spatial correlation and there is no spatial correlation.

Table 2 Global Moran's I of lpm and larrival

Year	larrival	lpm	Year	larrival	lpm
1996	0.046***	0.032***	2008	0.061***	0.038***
1997	0.047***	0.034***	2009	0.070***	0.040***
1998	0.047***	0.034***	2010	0.072***	0.045***
1999	0.040***	0.033***	2011	0.075***	0.048***
2000	0.031***	0.034***	2012	0.079***	0.051***
2001	0.049***	0.036***	2013	0.071***	0.055***
2002	0.052***	0.041***	2014	0.075***	0.053***
2003	0.061***	0.046***	2015	0.077***	0.049***
2004	0.067***	0.048***	2016	0.081***	0.047***
2005	0.062***	0.035***	2017	0.084***	0.043***
2006	0.063***	0.037***	2018	0.082***	0.046***
2007	0.069***	0.038***	Average	0.064	0.042

***Significance at the 1% level.

Table 3 CD test of the variables

Variable	larrival	lpm	lpgdp	lforest	lim_ex	lairline
CD test	239.65***	123.65***	218.87***	10.98***	268.96***	132.65***

***Significance at the 1% level.

Table 4 Panel unit root test

Variable	LLC	IPS	Breitung	CIPS
larrival	11.9119*** (0.0000)	6.8826*** (0.0000)	7.0423*** (0.0000)	− 2.6652***
lpm	10.2595*** (0.0000)	5.9268** (0.0327)	2.6215** (0.0394)	− 2.5481*
lpgdp	8.7015*** (0.0000)	4.9966*** (0.0014)	1.8776* (0.0573)	− 2.6232***
lforest	7.2121*** (0.0000)	5.9961*** (0.0014)	2.5224** (0.0436)	− 2.5365*
lindus	7.4932*** (0.0000)	5.2461*** (0.0020)	2.3681** (0.0395)	− 2.6212**
lim_ex	9.3710*** (0.0000)	4.6378*** (0.0021)	2.6729** (0.0412)	− 2.7018**
lairline	9.5813*** (0.0000)	4.5795*** (0.0039)	2.7658** (0.0163)	− 2.5934*

*Significance at the 10% level.

**Significance at the 5% level.

***Significance at the 1% level.

From Table 2, the value of Moran's I is greater than 0 at the 5% significance level, rejecting the null hypothesis that there is no spatial autocorrelation. It indicates that there is a strong positive correlation between the environmental quality of neighboring countries, countries with high environmental quality gather with other high environmental quality countries, and countries with low environmental quality gather with other low environmental quality countries. At the same time, the number of international tourism arrivals in each country also shows a strong spatial positive correlation – that is, a region with a large number of international tourism arrivals aggregates with countries having the same condition, and this also applies to a region with a small number of international tourism arrivals. Considering the spatial autocorrelation, the commonly used linear estimation model may yield biased conclusions for testing the influence of air quality on the number of international tourism arrivals. Therefore, we use the SDM model to derive the link between $PM_{2.5}$ concentrations and international tourism arrivals.

Panel unit root and cointegration tests

Before any regression, this paper tests whether or not non-stationarity exists. First, to further confirm spatial dependence exists, we employ the cross-country dependence (CD) test (Pesaran 2021; Shen et al. 2022). From Table 3, we see that the null hypothesis is obviously rejected, which highlights the importance of considering the spatial dependence among countries in this paper. Next, using the approaches of LLC, IPS, Breitung, and CIPS to do the panel unit root tests, the results in Table 4 show that there is no unit root and it

is a stable sequence with all variables stationary. Therefore, we do not need to test for panel cointegration.

Spatial econometric regression results

Table 5 reports the estimated results of non-spatial models for 99 countries over the period 1996–2018. To understand the relationship between air quality and travel arrivals, we use a basic model like OLS, fixed-effect (FE) model, and random effect (RE) model to estimate the coefficients and use the Hausman test for the chi-square statistic (32.61, $P = 0.0000$) to indicate that the FE model is suitable. Moreover, to control the time effect, we utilize the two-way fixed-effect model. After controlling the year dummy, the parameter becomes larger than other estimation results. In order to solve the endogenous problems caused by omitted variables or measurement error, the generalized method of moments (GMM) regression can help analyze the model. Specifically, the first-order lag of a dependent variable is used as an instrument variable, and the regression results after adding the instrument variable show that air pollution has a greater negative impact on tourism.

Table 6 presents the estimation results for the spatial econometric models: SAR, SEM, and SDM, respectively. The value of “rho” and the value of “lambda” are respectively 0.4251 and 0.6908, which are significant at the 1% level. This can prove the existence of spatial independence, and to get more accurate regression results, these characteristics should be taken into consideration. Furthermore, the LR test value is 80.18 ($P = 0.0000$) and 177.06 ($P = 0.0000$), respectively. In other words, the hypothesis that SDM can be changed by SAR and SEM is rejected.

Table 5 Estimation results of the non-spatial model

	OLS	FE	RE	two-way FE	GMM
lpm	−0.3530 (−0.94)	−0.3397** (−2.48)	−0.3298 (−1.41)	−0.2687*** (2.60)	−0.2557*** (−3.00)
lairline	0.1271*** (5.70)	0.1108*** (5.97)	0.1252*** (6.87)	0.0941*** (5.17)	0.1167*** (6.42)
lpgdp	0.1034*** (3.31)	0.8018*** (11.43)	0.5532*** (9.03)	0.5133*** (6.94)	0.7258*** (10.21)
lforest	0.0275 (1.45)	−0.0464*** (−3.03)	−0.0802 (−1.33)	−0.6508*** (−4.50)	−0.4468*** (−2.98)
lindus	−0.0192** (−1.85)	−0.0248*** (−2.95)	−0.0631 (−1.47)	−0.0408*** (−3.98)	−0.0614*** (−4.31)
lim_ex	0.5940*** (22.69)	0.4926*** (15.22)	0.5689*** (19.23)	0.3263*** (9.39)	0.5239*** (15.88)
lpop	0.0136 (1.39)	0.3699*** (4.23)	0.1319*** (3.22)	−0.2018** (−2.05)	0.3597*** (4.08)
_cons	3.6915*** (9.28)	−4.0618*** (−2.73)	−1.0429 (−1.11)	7.3651*** (4.03)	
<i>N</i>	2277	2277	2277	2277	2178
<i>R</i> ²	0.6717	0.4993		0.5315	0.5069
<i>F</i>	109.73	360.94		87.12	355.16
<i>P</i> -value	0.0000	0.0000	0.0000	0.0000	0.0000

*Significance at the 10% level.

**Significance at the 5% level.

***Significance at the 1% level.

Table 6 Estimation results of spatial econometric models

	SAR	SEM	SDM
lpm	−0.0359*** (−8.36)	−0.0378*** (−8.78)	−0.0362*** (−8.43)
lairline	0.1066*** (6.11)	0.1053*** (6.00)	0.0962*** (5.55)
lpgdp	0.6643*** (9.57)	0.6936*** (9.14)	0.5874*** (8.33)
lforest	−0.5778*** (−4.16)	−0.6005*** (−4.36)	−0.5676*** (−3.82)
lindus	−0.4032*** (−3.67)	−0.5028*** (−3.94)	−0.4728*** (−2.94)
lim_ex	0.3131*** (9.48)	0.3204*** (8.70)	0.2839*** (8.51)
lpop	0.0580 (0.64)	0.0588 (0.45)	0.0604*** (4.43)
rho	0.4251*** (10.59)		
lambda		0.6908*** (10.69)	

*Significance at the 10% level.

**Significance at the 5% level.

***Significance at the 1% level.

Therefore, SDM is more applicable, and we need to pay attention to the corresponding results.

Table 7 presents the direct effect, indirect effect, and total effect of air quality on tourist arrivals. The direct

Table 7 Estimation results of the SDM model

Variable	Direct effect	Indirect effect	Total effect
lpm	−0.0665*** (−3.28)	−0.0364* (−1.91)	−0.1029** (−2.42)
lairline	0.0955*** (5.71)	0.0334 (1.04)	0.1289 (1.08)
lpgdp	0.5969*** (8.80)	1.1204** (2.52)	1.7173** (2.16)
lforest	−0.5713*** (−3.98)	0.8512* (1.72)	0.2799 (1.13)
lindus	−0.3864*** (−4.52)	−0.1961*** (−4.14)	−0.5825*** (−3.56)
lim_ex	0.0282*** (9.04)	0.0684*** (3.33)	0.0966*** (4.66)
lpop	−0.6013*** (−4.44)	0.8900*** (4.96)	0.2887*** (4.10)

*Significance at the 10% level.

**Significance at the 5% level.

***Significance at the 1% level.

effect presents the influence of a country's air quality on its tourist arrivals, while the indirect effect indicates the relationship in neighboring countries. Here, the direct effect is totally different from the coefficient value in the fourth column of Table 6 because a tradeoff exists after considering that spatial dependence matters. The direct effect of the key independent variable, air quality (lpm), is negative at the 1% level of significance, the indirect effect is negative at the 10% level of significance, and the total effect is negative at the 5% significance level. For this phenomenon, we take China for example, because of its large population and developed manufacturing industry, in which most foreigners think it is the world's factory. They believe the developed manufacturing industry is accompanied by a poor environment, especially the serious problems of smog and haze. Neighboring South Korea has become one of the top three countries with the most serious pollution in the world. Considering the spillover effect, fewer people choose to come to China in the Asian region, while more and more foreigners travel to Southeast Asia. This result is consistent with most existing research (Dong et al. 2019; Xu et al. 2020; Churchill et al. 2022), which can highlight the importance of considering the spillover effects when evaluating the relationship between air quality and international tourism arrivals.

For the control variables, we focus on the total effect. A larger number of people carried by plane indicate that the international or domestic flight route is firmly established and that travel is convenient. The coefficient is positive, but not significant, which can be explained by the tourists choosing to travel by railway after arriving in a country. However, data are seriously lacking, and the impact on tourism cannot be observed. Countries with higher per capita GDP have a more diversified expense structure, and residents have a higher possibility to travel, which has a significantly positive influence

on the number of tourists. The larger the area is that a forest occupies in the total territory, the more obvious the improvement effect is on the environment. A possible explanation for the insignificant coefficient is that the large area occupied by a forest hinders the development of tourism and reduces the area available for tourism. The increase in industrial output means that the proportion of the tertiary industry is relatively low, meaning that the country has high energy consumption and high pollution. It is also bound to have an adverse impact on the environment. The larger the import and export volume is, the more a country is open to trade, which is conducive to the dissemination of information related to tourist resorts. If a country has a larger population, then its residents are more likely to want to travel abroad, which is similar to the impact of GDP per capita.

In addition to constructing the spatial weight matrix based on the distance between nations' capitals, there are three other ways to construct it. The first one is if the distance between two countries' capitals is less than 1750 miles; if so, then they can be defined as neighbors, which is written as w1750 in Table 8. The second one is labeled as wpop, whereby the distance between the most populous cities serves as the distance between the two countries. The last one is wcapital², or an inverse distance square space weight matrix (Chen and Lee 2020). In addition, we use CO₂ (CO₂ emissions) to proxy for air quality (Zaman et al. 2016). From the results, we know that even when the spatial weight matrix or the proxy indicators change, the direct effect, the indirect effect, and the total effect of air quality still tend to decrease the number of tourists arrivals. All the results show that poorer air quality does reduce the number of outbound tourists. The indirect effect and the total effect are negative, indicating that the spatial effect is relatively important, and when the environment deteriorates, the overall tourism intention decreases.

Table 8 Robustness check: estimation results of the SDM model

	w1750	wpop	wcapital ²	CO ₂
Direct effect	−0.0304*** (4.17)	−0.0384*** (8.38)	−0.0325*** (8.28)	−0.0381** (1.97)
Indirect effect	−0.0235*** (−6.63)	−0.0147*** (8.78)	−0.0252*** (−3.24)	−0.0297*** (−3.65)
Total effect	−0.0539*** (−5.85)	−0.0531*** (8.43)	−0.0577* (−1.82)	−0.0678*** (−4.61)
Control variables	Y	Y	Y	Y

*Significance at the 10% level.

**Significance at the 5% level.

***Significance at the 1% level.

Heterogeneity analysis

This paper studies the spatial impact of air quality on the number of international tourist arrivals – that is, the number of tourist arrivals in a country may be affected by the air quality of neighboring countries. In addition to the decrease in tourists' expectations of neighboring countries due to the deterioration of their own country's environment, this impact may also be influenced by technological development in periphery regions. Maddison (2006) found evidence to suggest that having high-income neighbors is associated with having much lower per capita nitrogen oxide emissions. Costantini et al. (2013) demonstrated that technological spillovers drive environmental efficiency more than internal innovation. With a rise in neighboring countries' R&D levels, their industrial structure and economic development patterns will correspondingly change, and thus, the level of environmental pollution drops, and the spillover effects of their knowledge and skills become larger. This will eventually make the country upgrade its own industrial structure, which then indirectly protects the environment, so as to help raise the number of international tourist arrivals. According to the agglomeration effect, countries with similar income levels will have similar research levels, environmental protection methods, and tourism preferences. Therefore, all countries can be divided into three groups to investigate the heterogeneity of air quality on the number of tourists.

From Table 9, we use the SDM model to investigate the influence of air quality on the number of international tourism arrivals in different income groups. We focus on the total effect, and the influence of air quality on tourist arrivals is positive at the 10% significance level in high-income countries, but air pollution significantly reduces international tourist arrivals at the 1% significance level in middle-income countries. Similarly, air pollution in low-income countries also discourages tourism, but is slightly less than the negative impact in middle-income countries.

To be more specific, for high-income countries, the result runs contrary to common sense, in that poor air quality stimulates international tourist arrivals. Its possible explanation is that high-income countries' tourism development is relatively sound, and thus, there are more supporting facilities and consumable channels. In addition to natural sceneries, there are more famous cultural sceneries. Compared with middle- and low-income countries, due to the relatively perfect industrial structure and economic growth mode as well as advanced technology-intensive industries, the overall air pollution level is low, which has less impact on tourism. In middle-income countries, their biggest goal is to develop their economy, and so they give little consideration to the environment. Moreover, the industrial structure is dominated by capital-intensive industries represented by heavy and chemical industries that give off serious environmental pollution, which results in less attraction to tourists. Finally, the negative impact on low-income countries is also significant. Compared with middle-income countries, their possible advantages lie in better natural scenery and relatively low environmental pollution during their process of transformation into the secondary industry, which is more attractive to tourists who like wild, undeveloped scenery.

According to the principle of agglomeration, countries with a higher pollution level are more likely to have the same situation as their neighboring countries. Moreover, among the 47 countries, the proportion of high-income countries and low- or middle-income countries is basically the same. Under the combined effect of the two influences, countries with poor air quality have an obvious effect on inhibiting tourists to travel abroad. However, in countries with good air quality, such a negative impact does not exist. Tourists will choose to enter a country that has better air quality. In addition, for countries with more or less international tourist arrivals, they have the same situation – that is to say, a country that can attract more tourists is a tourism country with domestic features. More tourists also reflect that a country's environmental quality is good. Thus, good air quality will not reduce the number of visitors due to health risks or poor scenery. For countries with fewer tourists, the situation is the

Table 9 Estimation results for heterogeneity analysis

	Direct effect	Indirect effect	Total effect
High-income	0.0362*** (4.95)	0.0207* (1.78)	0.0569** (2.10)
Middle-income	−0.0462** (−2.08)	−0.0304*** (−3.80)	−0.0766*** (−2.87)
Low-income	−0.0543*** (−4.21)	−0.0485*** (−3.80)	−0.1028** (−2.50)
High-PM _{2.5}	−0.0518 (−0.37)	−0.0974* (−1.80)	−0.1492* (−1.96)
Low-PM _{2.5}	0.0167*** (10.18)	0.0276** (2.38)	0.0443** (2.52)
High-arrivals	0.0147** (2.13)	0.0136* (1.82)	0.0283** (2.36)
Low-arrivals	−0.0232 (−0.56)	−0.0472* (1.89)	−0.0704* (1.91)
Control variables	Y	Y	Y

*Significance at the 10% level.

**Significance at the 5% level.

***Significance at the 1% level.

Table 10 Estimation results of moderators on Iarrival

	wcapital	w1750	wpop	wcapital ²
Direct effect	−0.0232*** (−2.93)	−0.0258** (−2.42)	−0.0226** (−2.21)	−0.0215** (−2.86)
Indirect effect	−0.0164** (−2.20)	−0.0193*** (−3.33)	−0.0179*** (−4.79)	−0.0183*** (−2.85)
Total effect	−0.0396** (−2.35)	−0.0451*** (−3.02)	−0.0405*** (−4.06)	−0.0398*** (−3.51)
Control variables	Y	Y	Y	Y

*Significance at the 10% level.

**Significance at the 5% level.

***Significance at the 1% level.

opposite, with the hidden danger of poor air quality being the biggest obstacle to tourists.

Moderating effect of R&D

The above results show that air quality has a significant spatial spillover effect on the number of international tourism arrivals, and the number of international tourism arrivals in a country will change under the influence of air quality in neighboring countries. As an economic community, thanks to the rapid development of technology, the public can learn about the environmental conditions of other countries easily. From other aspects, countries with high research and development intensity have low levels of domestic environmental pollution. Moreover, knowledge is a form of spillover, and the surrounding countries will be affected by technological progress, which will change the mutual influence relationship between air quality and the number of tourists to some extent (Goñi and Maloney 2017; Herzer 2022).

The above logic can be expressed through the framework related to R&D. A general form of this production function is.

$$\dot{A}_{it} = \delta_i A_{it}^{\phi} \left(\frac{I_{it}}{E_{it}} \right)^{\gamma} \quad (4)$$

where $\dot{A}_{it}$ is the flow of new knowledge in country i at time t ; δ_i is a country-specific constant of proportionality; A_{it} is the stock of previous knowledge; ϕ is a parameter that describes the returns to the stock of knowledge; I_{it} stands for the input of R&D; γ is a parameter that captures the possibility of duplication the new knowledge, $0 < \gamma \leq 1$; and E_{it} represents the scale of the economy, whereby if the scale of the economy increases, then the effectiveness of R&D will

decrease, causing a given amount of research effort to be spread over a larger number of varieties.

We rewrite Eq. (4):

$$\frac{\dot{A}_{it}}{A_{it}} = \delta_i A_{it}^{\phi-1} \left(\frac{I_{it}}{E_{it}} \right)^{\gamma} \quad (5)$$

Assume $\phi = 1$, and then Eq. (5) reduces to $\frac{\dot{A}_{it}}{A_{it}} = \delta_i \left(\frac{I_{it}}{E_{it}} \right)^{\gamma}$. The terms of I_{it}/E_{it} can be regarded as R&D intensity, and taking logs can be written as

$$\Delta \log A_{it} = a_i + \gamma \log \left(\frac{I_{it}}{E_{it}} \right) + \eta_{it} \quad (6)$$

In this equation, the changes in the growth rate of knowledge positively correlate with changes in R&D intensity.

The R&D spillover runs from developed countries to developing countries through exports, imports, and some other channels. Thus, Eq. (7) can be extended as.

$$\Delta \log A_{it} = a_i + \gamma^d \log \left(\frac{I_{it}^d}{E_{it}^d} \right) + \gamma^f mi_{it} \log \left(\frac{I_{it}^d}{E_{it}^d} \right)^f + \eta_{it} \quad (7)$$

where d and f represent domestic and foreign, respectively; and mi is the share of imports from developed countries in GDP. From this structure, we see that R&D is critical to new knowledge and R&D spillovers do exist.

This paper also explores the interaction effect of R&D intensity, focusing on the coefficient of $\ln pm * \ln rd$. In other words, we add the R&D intensity interaction term to investigate the mitigation effect of scientific research efforts on pollution and then see whether it has a positive impact on the number of tourists. To verify the robustness of the results, the other three spatial weight matrices are incorporated into the previous method to measure the coefficient value, and

Table 11 Estimation results of moderators on larrival

	Direct effect	Indirect effect	Total effect
High-income	0.0498* (1.86)	0.0146*** (3.48)	0.0644*** (3.50)
Middle-income	− 0.0147*** (− 4.17)	− 0.0358*** (− 6.63)	− 0.0505*** (− 5.85)
Low-income	− 0.0369*** (− 8.28)	− 0.0264*** (− 3.24)	− 0.0633* (− 1.82)
High-PM _{2.5}	− 0.0464** (− 2.06)	− 0.0325** (− 2.25)	− 0.0789*** (− 3.62)
Low-PM _{2.5}	0.0473 (1.03)	0.0372*** (6.30)	0.0845*** (5.95)
High-arrivals	0.0158** (2.20)	0.0143*** (3.20)	0.0301** (2.31)
Low-arrivals	− 0.0183** (− 2.20)	− 0.0325*** (− 4.79)	− 0.0508*** (− 4.06)
Control variables	Y	Y	Y

*Significance at the 10% level.

**Significance at the 5% level.

***Significance at the 1% level.

the specific results appear in Table 10. The coefficient of the indirect effect or the total effect of the interaction term ($\ln pm * \ln rd$) is significant at least at the 5% level in any weight matrix. Although the coefficient is still negative, the coefficient value is significantly smaller than that with no interaction term. This means that with the enhancement of national R&D, the negative impact on international tourism arrivals due to the deterioration of air quality tends to disappear, or the better air quality will attract more tourists and eventually increase the number of international tourism arrivals. Therefore, if a country's investment in scientific research increases, then it shows that it is determined to change its industrial structure and optimize its economic growth mode, which will lead to a gradual improvement of its own air quality.

This paper further presents whether the R&D intensity in different countries can alter the impact of air quality on international tourist arrivals (see Table 11). In general, high R&D intensity in high-income countries not only improves the domestic environmental quality but also reduces the pollution of other countries. For middle- and low-income countries, the increase of R&D intensity and improvements in air quality in neighboring countries can help mitigate environmental pollution in their own countries, thus in turn increasing tourism.

Aside from different income levels having different R&D intensity, a large difference exists in environmental protection and governance. For countries grouped by PM_{2.5} concentration and number of tourists, the higher the PM_{2.5}

concentration is, the greater the R&D intensity's impact will be. For low-concentration countries, due to a good foundation in the early stage, R&D intensity may play a limited role. This effect also applies to countries grouped by the number of tourists, and technological innovation can greatly improve environmental pollution. In general, better research and development can improve air quality and thus increase the number of international tourism arrivals.

In the context of economic globalization, the world is becoming an increasingly interconnected one, and no country can stay immune. International organizations like the United Nations have advocated for the transfer of advanced technology from developed countries to developing countries to help mitigate climate change (Li and Wang 2017). Therefore, under the influence of spatial dependence, countries at the forefront of economic, scientific, and technological development should play a leading role in improving environmental quality, and other countries should also jointly protect the earth's fragile ecosystem. Only when the environment improves can other forms of development be guaranteed, and the number of tourists will naturally increase.

Conclusions and policy implications

By constructing panel data of 99 countries from 1996 to 2018 and using a spatial econometric model, this research examines the impact of air quality on the number of international tourist arrivals. We focus on the analysis of the spillover effect of air quality on the number of tourist arrivals and the heterogeneity analysis by income, PM_{2.5} concentration, and number of arrivals and then verify the moderating effect of R&D intensity. Global Moran's I proves the existence of a spatial relationship among tourist arrivals and air quality, indicating that the factor of spatial autocorrelation should be considered. The following regression results indicate that poor air quality has a negative effect on international tourist arrivals for the direct effect, indirect effect, and total effect, lasting even when a different spatial weight matrix and independent variable are used.

Heterogeneity analysis shows that, in groups of middle-income countries, low-income countries, high concentrations of PM_{2.5}, and countries with a little number of tourists, bad air quality would have negative effects on tourist arrivals, while the opposite results exist in the country group. In addition, tests of the moderating effect show that countries with more R&D intensity have better air quality and thus attract more tourists. This shows that R&D can reduce the impact of environmental pollution on foreign visitors. At the same time, with the spillover effect of R&D, if a country's R&D intensity is high, then

it can help drive the corresponding development of surrounding countries – that is, countries with higher levels of R&D should make full use of its advantages in technology and other related aspects, exporting knowledge to other countries. At the same time, countries with low R&D levels should try to avoid allowing the transfer of backward industries from other countries. The two types of countries should cooperate and help each other to protect the world's environment.

The results also show that the influence of air quality deterioration on the number of international tourists is significantly negative. Travelers are concerned about air quality, and they have a deep understanding of the health hazards and other potential risks caused by excessive PM_{2.5} concentration. Thus, the state of air quality can significantly affect the image of a country. During the process of tourism construction, all countries must pay high attention to air quality governance and actively respond to any negative changes. At the same time, air quality has become an important factor that cannot be ignored in the selection of potential tourist destinations. While strengthening environmental governance, relevant departments should emphasize the dissemination of environmental quality improvement – that is, try their best to create a better image of improving climate conditions.

The rampant COVID-19 has made every country seals cities and regions, restricting the scope of action and prohibiting travel. Many companies have allowed employees to work at home, reducing the number of vehicles on the road. Construction projects have been stopped, and the discharge of wastewater, waste gas, or other pollutants has decreased significantly. Most studies have found that environmental quality has greatly improved in a short time during the lockdown period. Although outbound travel or domestic tourism cannot be carried out in a short time, with the resumption of work and production, travel plans interrupted by the epidemic will be re-started. The longer people have had to stay at home, the stronger they want to travel outside their border. Generally speaking, the epidemic has inhibited people's tourism activities for a short time, but the world will eventually return to normal, tourism activities will become orderly, and the influencing factors related to tourism before the epidemic still apply.

For policy implications, the national construction of tourist destinations demands that the whole society participate, and so governments should strengthen education on the hazards and prevention of severe weather, improve the social responsibility of enterprises and individuals, and advocate healthier ways of production and life to reduce the emissions of air pollutants and the occurrence of extreme weather. Policy intervention is needed to provide more energy-efficient and less carbon-intensive

mobility. In addition, the spatial dependence of inbound tourism should be taken seriously. When enacting tourism development measures, countries should not only make their own tourism development and management plans but also pay attention to cooperation and differentiation with neighboring countries, thus seeking common ground while reserving differences, so as to jointly create a tourism agglomeration economy. Authorities should also actively improve the quality of inbound tourism services, increase language service stations and relevant personnel, combine standardized services with personalized services, and strive to ease the discomfort and worry of tourists during international tourism (Law and Cheung 2007), while at the same time paying attention to the convenience of a hotel and high-speed rail service.

Governments and the tourism sector must also take measures to minimize the negative effects of environmental degradation on tourists and the tourism market (Yaw 2005; Hu and Wall 2005). Many important international tourism cities have made some attempts and achieved good results. For example, when a tourist suffers a meteorological event such as continuous storms and extremely high temperatures, the Australian government will compensate the tourist for the losses caused, thereby successfully protecting the local tourism image. It also offers daily travel advice and guides travelers to avoid high-risk times, places, and activities (Pearce 2005). Other countries can similarly publish environmental quality indices daily, in real time, to guide tourists to make appropriate travel arrangements and to support and encourage them to flexibly adjust their travel schedules and activities.

The reasons affecting the number of tourists in a country are diverse and extremely complex, and so this study still has some limitations. In the future, the selection of control variables should be as comprehensive and scientific as possible. Water pollution, solid waste, and forest coverage can also be regarded as other pollution sources to replace air quality. It would be interesting to find the channels through which air pollutants work to influence tourism. Understanding them can contribute toward more targeted policies that will aim at mitigating the negative effects of air pollutants on tourism. For high-income and low-income countries, the two most representative countries can be selected for specific analysis according to the data, so as to have a clearer understanding of the impact of environmental quality on tourism. Furthermore, the current research on air quality and international arrival tourists is mostly based on panel data. If there are more detailed micro-level data, then research can be carried out from the aspects of individual characteristics, income level, subjective feelings about the environment, and requirements for quality of life.

Appendix

Table 12

Table 12 List of countries

Afghanistan	Burkina Faso	El Salvador	Hungary	Mexico
Albania	Burundi	Eritrea	Iceland	Micronesia, Fed. States
Algeria	Cabo Verde	Estonia	Indonesia	Moldova
Andorra	Cambodia	Eswatini	Ireland	Morocco
Angola	Canada	Ethiopia	Israel	Myanmar
Antigua and Barbuda	Central African Republic	Faroe Islands	Japan	Namibia
Armenia	Chad	Fiji	Kiribati	Nepal
Aruba	Chile	Finland	Korea, Dem. People's Rep	New Caledonia
Australia	China	France	Korea, Rep	Niger
Austria	Colombia	Gabon	Kuwait	Nigeria
Bahrain	Comoros	Gambia, The	Latvia	North Macedonia
Belarus	Congo, Dem. Rep	Georgia	Lebanon	Norway
Belize	Congo, Rep	Ghana	Liberia	Oman
Bermuda	Cote d'Ivoire	Gibraltar	Lithuania	Palau
Bolivia	Croatia	Greece	Luxembourg	Panama
Botswana	Cuba	Greenland	Macao SAR, China	Papua New Guinea
Brazil	Cyprus	Grenada	Madagascar	Peru
British Virgin Islands	Czech Republic	Guinea	Malaysia	Philippines
Brunei Darussalam	Djibouti	Guinea-Bissau	Maldives	Qatar
Bulgaria	Dominica	Guyana	Marshall Islands	

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Data availability The data that support the findings of this study are available on request from the corresponding author.

Declarations

Ethics approval This is an original article that did not use other information, which requires ethical approval.

Consent to participate Both authors participated in this article.

Consent for publication Both authors have given consent to the publication of this article.

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