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A Study of the Effect of Trade Openness on Population Health: Empirical Evidence from China

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Abstract: Currently, the international economy is experiencing profound and intricate transformations, while economic globalization is encountering unprecedented challenges and witnessing a surge in counter-globalization sentiments. Critics express concerns over the potential detrimental effects of trade liberalization on the welfare of low-income groups, particularly in developing countries. China, as the largest developing country, also holds the status of a major trading nation. Using panel data from 285 prefecture-level cities across China during 2000–2019, this study examines how trade openness affects population health to assess the welfare effects of trade openness, providing new theoretical perspectives and empirical evidence to further promote economic globalization and improve human health and well-being. The results show that trade openness can significantly promote population health. And, a series of robustness tests show that the above conclusion is still valid. Trade openness has a greater positive impact on the health of the population of the eastern and central regions, the coastal cities, and high-trade-openness cities. An analysis of the mechanism reveal that trade openness mainly promotes population health through channels such as labor employment, wage income, public health investment, and personal health investment. However, trade openness can also lead to environmental pollution, which has a significant negative impact on population health. Additionally, through threshold effects analysis, it becomes evident that the relationship between trade openness and population health is nonlinear. This implies that there are critical thresholds related to the economic development stage, investment in environmental governance, and environmental infrastructure construction. Falling below or exceeding these thresholds may lead to different interval effects on the impact of trade openness on population health.

Keywords: trade openness; population health; influence mechanism; threshold effect

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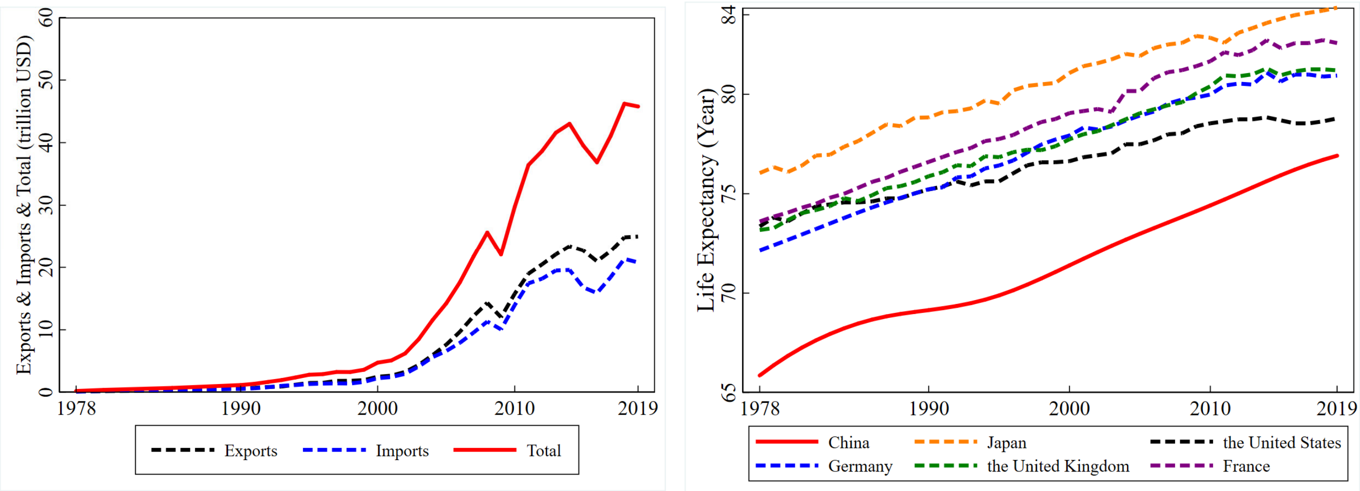
1. Introduction

Currently, there is a prevailing wave of anti-globalization sentiment in the international community. Critics of trade liberalization argue that low-income groups in both developed and developing countries, especially those with lower levels of education and limited international mobility, are often considered as the "losers" of globalization due to their challenges in adapting to the impacts brought about by the process. Healthy human capital serves as a guarantee for achieving long-term, sustainable economic development, with economic factors playing a crucial role as determinants of population health [1]. This study aims to assess the welfare effects of trade openness by investigating its influence on population health, considering that China, being the largest developing country, also holds the status of a major trading nation. Since joining in the World Trade Organization (WTO), China has experienced massive trade expansion by accelerating trade openness, through which manufacturing tariffs fell sharply from 17.4% in 1998 to 9.1% in 2007 [2]. The growth in Chinese imports and exports during the period from 1978 to 2000 can be observed from Figure 1, which shows that the growth was stable during the period. However, after 2000, China entered a period of rapid development, and, by 2019, the total value of goods imports and exports reached a remarkable 45.779 trillion USD, maintaining its position as the world's largest trading nation for 11 consecutive years. At the same time, as a comprehensive indicator of population health that reflects regional medical and health conditions, and compared with the period of late 1970s–1990s, the average life expectancy of China has also showed an accelerated development trend. According to the statistics of the National Bureau of Statistics of China and World Bank Open Data, as shown in Figure 1, the average life expectancy of China has risen from 71.397 years old in 2000 to 76.912 years old in 2019, significantly increasing by 5.515 years, which is much higher than the increases in the United States (2.151 years), Japan (3.280 years), Germany (3.015 years), the United Kingdom (3.463 years), and France (3.522 years) in the same period. By 2019, the average life expectancy of China was close to the United States (78.788 years old). These concurrent trends raise the question: has trade openness had an impact on population health in China, and what are the transmission mechanisms involved? To address the above-mentioned questions, this study aims to provide new theoretical perspectives and empirical evidence for a deeper understanding of the welfare effects of trade openness. Furthermore, it offers policy implications for countries worldwide to promote trade liberalization and improve human well-being, including health.



(**a**) (**b**)

Figure 1. (**a**) represents the evolutionary characteristics of China's trade. (**b**) represents the evolutionary characteristics of life expectancy in China and other developed countries (the United States, Japan, Germany, the United Kingdom, France). Data are obtained from the China Statistical Yearbook and World Bank Open Database for the period 1978–2019.

This study is primarily grounded in two categories of scholarly literature. On the one hand, some scholars have explored the impact of trade openness on population health from the perspective of import trade. For instance, exploring the hidden costs of globalization in the United Kingdom, Colantone et al. (2019) addressed that import competition significantly increased the mental pressure of employees mainly through the channels of increasing unemployment risk, reducing wage growth, increasing work pressure, and deteriorating future expectations [3]. According to Lang et al. (2019), employed workers in local U.S. labor markets exposed to greater import competition from China show worse mental, physical, and general health as a result of increasing import competition from China [4]. Giuntella et al. (2020) indicates that unhealthy food imports can contribute to regional obesity prevalence and that U.S. food imports can explain 20% of the increase in obesity prevalence among Mexican women from 1998 to 2012 [5]. Fan et al. (2020) investigated the effect of reduced intermediate input tariffs on the health of Chinese manufacturing workers, and found that lower tariffs on intermediate inputs led to longer labor hours, resulting in adverse effects on their health [6]. On the other hand, some research focuses on the impact of trade openness on population health from the perspective of export trade. For example, McManus and Schaur (2016) investigated the effects of export growth on the labor force and found that export growth led to increased working hours for workers, as well as an increased likelihood of hypertension, poor health conditions, occupational injuries, and diseases [7]. Using data from emerging and developing countries, Olper et al. (2018) found that trade liberalization can significantly reduce child mortality rates [8]. By exploring the population health of 30 Sub-Saharan African countries, Panda (2020) found that implementing legislation allowing duty-free and quota-free access to the US market can effectively reduce infant mortality rates [9]. Bombardini and Li (2020) examined the impact of export shocks and export-induced air pollution shocks in China on pollution and health, and found that for each additional standard deviation of export-induced air pollution shock, the infant mortality rate significantly increases by 4.1‰ [10]. Using data from China's Health and Nutrition Survey, Feng et al. (2021) found that the reduction in export tariffs in China resulted in increased income, leading to improved health among working-age adults [11]. Based on the export expansion resulting from China's accession to the WTO, Chen et al. (2022) found that export expansion has a significant positive impact on adult diseases/injuries in China [12].

In summary, these present studies have explored the effect of trade openness on population health and its mechanism from the perspective of import trade or export trade, providing valuable insights for this study. However, it is worth noting that there are no clear conclusions about whether trade openness has a positive or negative effect on the health of the population. Some scholars argue that trade openness worsens population health, while some studies show that trade openness can improve population health. In view of this study, the reasons why the existing literature could not reach a consistent conclusion about the effect of trade openness on population health are as follows. Firstly, exploring the effect of trade openness on population health only from the perspective of import or export is one-sided, akin to looking at the front and back of a coin. This approach may not effectively reveal the overall relationship between trade openness and population health, especially in developing countries like China. Compared with the real tariff rate, black market transaction costs, Douglas index, and other trade openness measurement indicators, trade dependence (the ratio of total import and export to GDP, which includes import trade and export trade information) can be a better indicator to reflect the degree of China's economic openness (Singh, 2010) [13]. Secondly, the reasons why trade openness plays a positive or negative role in population health are due to the nonlinear relationship between the two. For example, owing to the different regional economic development stages or environmental governance investments, the effect of trade openness on population health would show significant interval differences.

The marginal contributions of this study can be summed up as follows. Firstly, most studies have examined the impact of trade openness on population health from the perspectives of import trade or export trade. While a few studies such as Levine and Rothman (2006) and Owen and Wu (2007) have explored similar issues from the perspective of trade dependence, there is a lack of research focusing on specific institutional contexts or country-level analysis [14,15]. By re-examining the effect of trade openness on population health from the perspective of trade dependence using Chinese prefecture-level spatial units as an example, this study enriches the perspective of trade openness in population health research and provides empirical evidence at the prefecture level in developing countries within this research field. Secondly, considering the subjective factors in micro-level data from individual population health surveys, this study utilizes commonly used macro-level data such as average life expectancy and mortality rates to measure population health. And, through the dimensionality reduction technique of principal component analysis, new proxy variables for population health are derived, enabling a macro-level characterization of population health. These variables are then used to empirically examine the effects of trade openness, providing valuable insights for macro-level decision-making. Thirdly, both theoretically and empirically, this study discusses some potential pathways through which trade openness affects population health, such as labor employment, wage income, health investment, and environmental pollution. These pathways reveal the 'black box' of how trade openness influences population health and enhances our understanding of the channel mechanism. Finally, using Hansen's (1999) Threshold Panel Model and taking the economic development stage and environmental governance investment as the threshold variables, we identify the non-linear effect of trade openness on population health for the first time, and expand the understanding of the change relationship between these two factors [16]. Furthermore, the findings provide evidence that the lack of consensus in the existing literature regarding the effect of trade openness on population health can be attributed to the neglect of the non-linear dynamics between these variables.

2. Theoretical Analysis and Research Hypothesis

Trade openness affects population health not only through nutritional level, food safety, and disease dissemination, but also including other social and economic factors (Lautier, 2014) [17]. The health demand theory by Grossman (1972) showed that income level, education and medical treatment, environmental pollution, and living habits are all important factors affecting the demand of population health [18]. Therefore, we expect that trade openness might affect population health through labor employment, wage income, health investment, and environmental pollution. Each potential pathway will be theoretically analyzed below.

Trade openness affects population health through labor employment. Previous studies on international trade and health economics have shown that trade openness can enhance residents' employment rate, increase local employment, and improve population health. On one hand, since the early Stolper–Samuelson theorem was put forward, there has been a great deal of theoretical work and empirical research in the field of international trade, and the conclusions basically support the hypothesis that "trade openness has a far-reaching impact on labor employment". This is because trade openness could release the effects of "improving employment creation" and "reducing employment destruction", which significantly promotes the net growth of employment (Dutt et al., 2009) [19]. Both the liberalization of final goods and intermediate goods can increase the probability of individuals engaging in informal employment and the share of informal employment (Dix-Carneiro et al., 2017) [20]. If the degree of trade openness in a region is higher, there is a greater probability of individuals engaging in informal employment, resulting in an increase in the number of informal workers, thereby contributing to the overall increase in employment in the region (Goldberg and Pavcnik, 2003) [21]. On the other hand, the health demand theory represented by Grossman has put forward that health, as an investment, would lead to an increase in residents' consumption expenditure, especially in health consumption expenditure, which would be helpful to improve residents' health status. Combining relevant studies, McNamara (2017) also found that the expansion of trade scale could significantly increase the demand for social labor and employment, which raises residents' food expenditure and medical expenditure, and improves residents' living standards and health status [22]. Using a study of CHNS survey data, Dai et al. (2021) found that rising trade openness after WTO accession raises the probability of disease by crowding out parents' time and reducing child care [23].

Trade openness affects population health through wage income. Wage income plays a crucial role in the relationship between trade openness and population health, as it fosters income and food expenditure growth among residents (Arnould et al., 2009) [24]. Meanwhile, increased income can lead to higher household spending on hygiene and healthcare, thereby contributing to improved population health (Blouin et al., 2009) [25]. On the demand side, trade openness could reduce the production costs of enterprises, improve the overall total factor productivity, increase the variety of products, lower the price of industrial manufactured products, and improve consumer welfare (Fajgelbaum and Khandelwal, 2016) [26]. On the supply side, trade openness improves the critical skill level of individuals choosing to be entrepreneurs, which leads to an increase in labor allocation efficiency and total output and a rise in individual welfare by rising enterprise productivity, the average skill level, and skill types in the labor market (Dinopoulos and Unel, 2017) [27]. The higher the level of trade openness in an area, the more evident the increase in individuals' sense of happiness (Yi and Sun, 2021) [28]. The most recent studies have also shown that trade openness could increase the labor income share (Meschi and Vivarelli, 2009) [29], and that the relationship between wage income increasing and residents' health is linear (Chokshi, 2018) [30]. By improving the material conditions related to residents' food, medical care, and health, and by increasing personal leisure and exercise time, income growth not only reduces the occurrence of obesity and related diseases, as well as physical and mental health issues, but also helps residents to improve their health awareness, safety awareness, and their ability to avoid health risks.

Trade openness also affects population health through health investment. The health demand theory represented by Grossman also showed that health investment is an important factor affecting population health. If a region has a stronger population health awareness and a more comprehensive healthcare service guarantee, with higher proportions of residents' expenditure on healthy food and healthcare, typically, the region tends to have lower mortality rates and a relatively longer life expectancy. On the one hand, trade openness tends to improve demand and enhancement efficiency, accelerate capital accumulation and capital deepening for expanding the scale of output (Sampson, 2016) [31], and promote economic growth through human capital accumulation, innovation, industrial structure adjustment, and total factor productivity improvement (Berggren et al., 2015) [32]. At the same time, regional economic growth increases financial revenue and the government's tax revenue, and improves the public health investment capability of local governments in medical and health fields, so as to promote the improvements in medical security expenditure and medical and health services, which could have a significant positive impact on population health level improvements (Rivera and Currais, 1999) [33]. On the other hand, as analyzed in the potential pathways above, trade openness could significantly improve residents' employment rate, drive the net growth of local employment, and increase wage income, which benefits the increase in residents' health investment, such as expenditure on healthy food and medical care, as well as leisure and exercise. Therefore, we expect that trade openness could effectively improve population health through health investment channels which are mainly in the form of public health investment and personal health investment.

Trade openness also affects population health through environmental pollution. Previous studies have assumed that individuals could enhance their resistance to acute diseases by increasing the stock of health capital, and introduced air pollution as an important parameter influencing the rate of health capital depreciation into Grossman's health demand theory, for re-building a theoretical analysis framework of population health including environmental pollution factors (Cropper, 1981) [34]. Environmental pollution would accelerate the depreciation rate of individual residents' health, which has a direct negative impact on it. At the same time, environmental pollution also reduces the marginal investment effect of residents' health through other health factors, resulting in indirect negative effects. For example, a ten percent rise in the daily NOX index means an increase of 7.7 person-time in the number of outpatients suffering from respiratory troubles, and Shanghai incurs a total of 420 million yuan (RMB) of such losses by the above conservative estimate (Brunekreef and Holgate, 2002) [35]. Undoubtedly, environmental pollution is a major source of health risks around the world, accounting for 8–9% of the global burden of disease, and this proportion is even higher in developing countries (Briggs, 2003) [36]. Related studies have stated that trade openness, especially in developing countries, often adopts lenient environmental pollution restrictions to enhance foreign investment attractiveness. As a result, trade openness deepens and inadvertently promotes environmental pollution (Levinson, 2009) [37]. It has been found to have a significant positive effect on regional carbon dioxide and sulfur dioxide emissions (Managi et al., 2009) [38]. Moreover, the increase in industrial sulfur dioxide emissions further exacerbates the rise in population mortality rates (Jerrett, 2015) [39]. As noted above, we infer that trade openness is likely to increase the emissions of pollutants such as carbon dioxide and sulfur dioxide, leading to an increase in the probability of related diseases, and resulting in a negative effect on population health.

Based on the above analysis, we propose Hypothesis 1 and Hypothesis 2.

Hypothesis 1. *Trade openness might promote population health.*

Hypothesis 2. *Trade openness might have a positive impact on population health through mechanisms such as labor employment, wage income, and health investment, while having a negative impact on population health through environmental pollution.*

3. Research Design

3.1. Basic Regression Model

Referring to Levine and Rothman (2006) and Owen and Wu (2007), we have constructed a panel fixed-effects model to investigate the effect of trade openness on population health [14,15]. The specific baseline econometric model is set as follows:

$$lnhealth_{it} = \alpha_0 + \alpha_1 lnopen_{it} + \alpha_2 ctrx_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (1)$$

where i denotes region, and t denotes year. The dependent variable is $lnhealth_{it}$, which represents the population health level of region i in year t. The explanatory variable is $lnopen_{it}$, which represents the trade openness of region i in year t. $ctrx_{it}$ is a vector of control variables, and μ_i and ν_t are the city and year fixed effects, which control for regional differences and time-varying changes in variables; ε_{it} is an error term that captures other unobserved factories. As noted above, the coefficient α_1 from Equation (1) is the estimated parameter of primary interest in this study, and it is expected to be greater than 0, indicating that trade openness significantly promotes population health.

3.2. Variables

3.2.1. Dependent Variable

The dependent variable is population health ($lnhealth_{it}$). Currently, no single variable can comprehensively encompass all aspects of population health. It is common to use one or more indicators to highlight the primary characteristics of population health. In social and government institutions, such as the World Health Organization and the United Nations, life expectancy and mortality are often used as indicators to assess the health level of countries (regions) (Kan et al., 2012) [40]. In academia, some studies utilize micro-level individual survey data to assess population health, including factors such as disease incidence, blood pressure, and self-rated health, but there are individual subjective factors in these micro-data indicators; some studies utilize macro-level data to reflect population health conditions, such as mortality rate and life expectancy. Based on previous studies and available data, we have selected indicators of average life expectancy and population mortality rate. Firstly, the population mortality rate is transformed in a positive direction, ensuring that both average life expectancy and population mortality rate indicators are aligned. Then, these indicators are standardized and subjected to dimensionality reduction through principal component analysis, resulting in the synthesis of a regional population health index denoted $lnhealth_{it}$.

3.2.2. Explanatory Variable

The explanatory variable is trade openness ($lnopen_{it}$). Most of the literature on population health from the perspective of import trade or export trade uses import tariff rates or export tariff rates as proxy variables for trade openness. However, as noted above, this can only reflect one aspect of trade openness. In addition, import and export tariff rates cannot capture non-tariff barriers. For developing countries, such as China, trade dependence, which incorporates information on both import and export trade, serves as a better indicator to depict the degree of China's economic openness (Singh, 2010) [13]. Therefore, following Levine and Rothman (2006) and Owen and Wu (2007), we adopt the natural logarithm of the ratio of total import and export trade to GDP (trade dependence) as a proxy variable to measure China's regional trade openness [14,15].

3.2.3. Control Variables

Referring to the relevant literature, we set a series of control variables: (1) Economic factor variables, for which *lngdp* represents the scale of economic development, which is measured by the natural logarithm of regional gross domestic product (GDP); *lnistruc* is regional advanced industrial structure, which is measured using the natural logarithm of the ratio of tertiary industry output value to the secondary industry output value; *lnfdi* is foreign direct investment, which is measured using the natural logarithm of the ratio of actual utilization of FDI to GDP; *lnh* is regional human capital, based on the highly skilled labor, which is calculated using the natural logarithm of the location quotient index; *lneng* is the Engel index, which is calculated using the natural logarithm of the ratio of the regional residents' total per capita food expenditure to the per capita consumption expenditure. (2) Public service factor variables, for which, referring to Fleisher et al. (2010), the basic education resources (*lnedu*) and the medical resources (*lntreatm*) are calculated using the entropy method and the natural logarithm, which are based on the number of primary school teachers per student, the number of middle school teachers per student, the number of hospital beds per capita, the number of doctors per capita, and the number of hospitals per capita, respectively [41]. (3) Nature's geographical factor variables, which are expressed as a logarithm of forest coverage (*lnforest*). (4) Other factor variables, for example, transportation infrastructure (*lninfrastr*) is reflected by the natural logarithm of regional per capita highway mileage, and the scale of the regional population (*lnpop*) is measured by the natural logarithm of the population density in the built-up area.

3.3. Data

Combining data availability and sample representativeness, we selected 285 prefecture-level cities in 30 provinces of China (Hong Kong, Macao, Taiwan, and Tibet were deleted due to data missing) as the research objects, which could cover more than 90% of the prefecture-level city samples in China and better reflect the actual situation in China. The sample survey period was from 2000 to 2019. The data of major variables came from the "*China Urban Statistical Yearbook*", "*China Regional Economic Statistical Yearbook*", the statistical yearbooks of various provinces (autonomous regions, municipalities directly under the Central Government), as well as the CSMAR database and the China Economic Net Statistical Database. For the case of missing values in individual variables, we used the linear interpolation method to fill these up. Moreover, taking 2000 as the base period, we converted the value variable into the actual value through the price index. In addition, for reducing the effect of possible heteroskedasticity, referring to the previous studies, we processed all variables via natural logarithm. Table 1 briefly reports the variable names, variable symbols, variable definitions, and descriptive statistics used in this study.

Table 1. Summary statistics.

Variables	Symbol	Definition	Mean	S.D.	Obs.
Population health	lnhealth	Calculated using principal component analysis based on average life expectancy and population mortality	3.386	0.036	5700
Trade openness	lnopen	Total import and export/GDP	0.155	0.230	5700
The scale of economic development	lngdp	Gross Regional Product (GDP)	15.693	1.125	5700

Table 1. *Cont.*

Variables	Symbol	Definition	Mean	S.D.	Obs.
Advanced industrial structure	lnistruc	Production of the tertiary industry/production of the secondary industry	0.623	0.212	5700
Foreign direct investment	lnfdi	Actual utilization of foreign direct investment/GDP	0.020	0.025	5700
Human capital	lnh	Calculated by location quotient based on highly skilled labor	0.430	0.278	5700
The index of Engel	lneng	Per total food expenditure of residents/per capita consumption expenditure	3.570	0.141	5700
The basic education resources	lnedu	Calculated by location quotient based on the number of primary school teachers per student and the number of secondary school teachers per student	0.221	0.112	5700
The medical resources	lntreatm	Calculated by location quotient based on the number of hospital beds per capita, the number of doctors per capita, and the number of hospitals per capita	0.108	0.081	5700
The forest cover	lnforest	Indicators from statistical yearbook	3.391	0.583	5700
Transportation infrastructure	lninfrastr	Road mileage per capita	3.122	0.649	5700
The scale of population	lnpop	Population density of built-up areas	10.797	0.834	5700

4. Empirical Results

4.1. Benchmarking Effect of Trade Openness on Population Health

To improve the validity of the regression results, this study undertakes two comprehensive examinations. On the one hand, there is the stationarity test of variables. Panel unit root tests, including the Levin–Lin–Chu test, Breitung test, Im–Pesaran–Shin test, and Fisher-type tests were employed to examine the stationarity of the variables. The results indicate that both the dependent variable, explanatory variable, and control variables exhibit a favorable level of stationarity. On the other hand, the selection of estimation methods was also used. Comparing the fixed-effects (FE) model to the mixed ordinary least squares (OLS) model, the F-test yielded a significant p-value of 0.00, indicating that the FE model should be employed to estimate Equation (1); similarly, when comparing the random-effects (RE) model to the mixed OLS model, both the B-P test and LR test resulted in p-values of 0.00, suggesting the adoption of the RE model to estimate Equation (1); furthermore, the Hausman test, with a test statistic of 273.38 and a p-value of 0.00, indicates that employing the FE model for estimating Equation (1) is superior to using the RE model. Therefore, it can be concluded that the variables in this study are stationary, and employing the fixed-effects model to estimate Equation (1) is more appropriate.

Table 2 reports the baseline regression results on the impact of trade openness on population health. In Column (1), we present the regression results without additional control variables and fixed effects. It is evident from the results that the estimated coefficient of the core explanatory variable (*lnopen*) is significantly positive, indicating that trade openness significantly promotes population health. To avoid the endogenous problem caused by omitted variables, this study introduces a series of controls in various columns of the regression table. In Column (2), year fixed effects and city fixed effects are included; in Column (3), economic factors are controlled for; in Column (4), the public service factors are incorporated; in Column (5), related natural geographical conditions are introduced; in Column (6), other factors are taken into consideration. As seen from Columns (2)–(6), the results show that the estimated coefficient of the core explanatory variable (*lnopen*) remains significantly positive, and the direction and significance level are highly consistent with those observed in Column (1), indicating that the results of the benchmark regression present good robustness. Therefore, we take the regression results from Column 6 as an example to analyze the economic implications, and the results show that in the ongoing and deepening process of trade openness, a one-percentage-point increase in trade openness per city improves the population health by 0.197 percentage points, confirming that trade openness has a significant promoting effect on population health.

Table 2. Baseline regression results of the impact of trade openness on population health.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
lnopen	0.016 *** (0.005)	0.343 *** (0.072)	0.203 *** (0.069)	0.198 *** (0.069)	0.198 *** (0.069)	0.197 *** (0.070)
Control variables:						
(1) Economic factors	NO	NO	YES	YES	YES	YES
(2) Public service factors	NO	NO		YES	YES	YES
(3) Nature's geographical factors	NO	NO			YES	YES
(4) Other factors	NO	NO				YES
Year effects	NO	YES	YES	YES	YES	YES
City effects	NO	YES	YES	YES	YES	YES
Number of city	285	285	285	285	285	285
Obs.	5700	5700	5700	5700	5700	5700

Note: All regressions include a constant. Robust standard errors clustered by city level are in parentheses. *** indicate statistical significance levels of 1%.

4.2. Robust Checks

To support the causal relationship of our baseline results, this study conducts robustness tests from various perspectives, including variable indicator measurements, sample selection biases, extreme values, adjustments to time window width, exogenous shocks, and endogeneity (the results are reported in Table 3). Firstly, a reevaluation of key variables was conducted. In column (1), we altered the measures of explanatory variable trade openness by using the import tariff of Chinese HS6 code products from the websites of WTO and the world bank data; in column (2), we used the population death rate, which has been transformed through positive scaling and standardization, as a proxy indicator for population health. Secondly, a test for sample selection bias was conducted. In column (3), we excluded the sample cities of provincial capitals and municipalities directly under the central government that have advantages in politics, economy, and medical treatment. Thirdly, a test to exclude sample outliers was conducted. In column (4), to avoid the estimated result bias caused by the extreme values, the dependent and explanatory variables were reduced by 5%. Fourthly, a test to shorten the time window width was conducted. In Column (5), to mitigate the impact of variable stationarity on the estimation results, the time window width was reduced by 5 years, retaining only the most recent 15 years of samples (from 2005 to 2019). Fifthly, a test to exclude exogenous shocks was conducted. In Column (6), to avoid the potential impact of the global financial crisis (2007–2008) on the population health of Chinese cities in a different manner, samples from the years 2007 to 2008 were removed. Sixthly, a test for endogeneity issues was conducted. In column (7), referring to the study of Eichenauer et al. (2021) [42], we employed the reciprocal of the geographic distance (multiplied by 100) between each city and the three major ports (Shanghai, Tianjin, or Hong Kong), multiplied by the nominal exchange rate in US dollars, as an instrumental variable of trade openness for two-stage least squares (2SLS) regression; in column (8), we constructed a dummy variable *post02* in the experimental period, which is taken as 1 if the year is 2002 or later, otherwise as 0, then the intersection term of *lnopen*×*post02* is added into Equation (1) for estimation in the same way.

Table 3. Regression results of robustness checks.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lntariff	−0.004 ** (0.002)							
lnopen		0.200 *** (0.061)	0.228 *** (0.068)	0.331 *** (0.121)	0.217 ** (0.086)	0.172 ** (0.071)	0.100 *** (0.013)	
lnopen×post02								0.070 * (0.040)
Identification Test							3.816 <0.051>	
Weak Instrument Test							79.072 [16.38]	
Control variables	YES	YES	YES	YES	YES	YES	YES	YES
Year effects	YES	YES	YES	YES	YES	YES	YES	YES
City effects	YES	YES	YES	YES	YES	YES	YES	YES
Number of city	285	285	254	285	285	285	285	285
Obs.	5700	5700	5080	5700	4275	5130	5700	5700

Note: All regressions include a constant. Robust standard errors clustered by city level are in parentheses. Identification Test uses Kleibergen–Paap rk LM statistic, *p* value of the corresponding statistics are in angle brackets; Weak Instrument Test uses Cragg–Donald Wald F statistic, Stock–Yogo weak ID test critical values at 10% significance level. Critical values are in square brackets. ***, **, and * indicate statistical significance levels of 1%, 5%, and 10%, respectively.

Table 3 reports the regression results of the robustness test. In column (1), the estimated coefficient *lntariff* of the trade openness proxy variable constructed by the tariff is −0.004 and significant at the level of 5%, which indicates that promoting trade liberalization and increasing trade openness could significantly promote population health. In columns (2)–(7), the estimated coefficient *lnopen* is significantly positive, which indicates that trade openness is an important factor in promoting population health. Among them, in column (7), the *p* value of the Kleibergen–Paap rk LM statistic is 0.051, which significantly rejects the original hypothesis of "insufficient identification of instrumental variables"; the Wald F statistic is greater than the critical value at the 10% significance level of the Stock–Yogo weak ID test, which shows that the instrumental variables selected in this study are reasonable. In column (8), the estimated coefficient *lnopen*×*post02* is significantly positive, indicating that the "quasi natural experiment" test, constructed based on China's accession to the WTO, once again proves that trade openness has a significant positive effect on population health. In the combined columns (1)–(8) of Table 3, the regression results support the causal relationship of trade openness on population health. Therefore, the theoretical hypothesis 1 was verified.

4.3. Heterogeneous Analysis

Indeed, as a vast regional space, there are obvious differences in geographical advantages, resource endowments, economic development, and policy preferences among regions in China. Whether in regard to trade openness or population health, their regional distributions are significantly heterogeneous, which contributes to a significant heterogeneous effect. Therefore, as can be seen from Table 4, we further investigated the differences in the effect of trade openness on population health from two aspects: regional heterogeneity and trade openness heterogeneity.

Table 4. Regression results of heterogeneous analysis.

	Regional Heterogeneity		**Trade Openness Heterogeneity**			
	The Eastern and Central vs. the Western		The Coastal vs. the Inland		High Trade Openness vs. Low Trade Openness	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
reg×lnopen	0.109 *** (0.004)	0.045 *** (0.004)				
cosl×lnopen			0.061 *** (0.003)	0.025 *** (0.003)		
dum×lnopen					0.031 * (0.018)	0.030 ** (0.014)
Control variables	NO	YES	NO	YES	NO	YES
Year effects	YES	YES	YES	YES	YES	YES
City effects	YES	YES	YES	YES	YES	YES
Number of city	285	285	285	285	285	285
Obs.	5700	5700	5700	5700	5700	5700

Note: All regressions include a constant. Robust standard errors clustered by city level are in parentheses. ***, **, and * indicate statistical significance levels of 1%, 5%, and 10%, respectively.

First, this study examines the regional heterogeneity between the eastern and central and western regions. Based on the classification of the China Statistics Bureau and previous studies, all provinces are divided into three major regions: the eastern, central, and western regions. Referring to previous studies, the dummy variable *reg* is taken as 1 when the sample city is located in the eastern or central region, otherwise *reg* is taken as 0. It is worth paying attention to the coefficient of the multiplication term of *reg* and *lnopen*, and the regression results are shown in columns (1)–(2) of Table 4, including column (1) without control variables and column (2) with control variables. The estimated coefficient of *reg*×*lnopen* is significantly positive at the 1% level, which indicates that, compared with the western region, trade openness shows a greater positive effect on population health in the eastern and central regions. One possible reason is that after China's Reform and Opening-up Policy in 1978, with the geographical advantages and policy support, the eastern and central regions have experienced significant development. Trade openness has facilitated the significant concentration of the labor force and an increase in wage income in the eastern and central regions, where residents enjoy noticeably higher living standards and exhibit greater health awareness compared to the western regions. This indicates a regional heterogeneity where the impact of trade openness on population health is more pronounced in the eastern and central regions.

Second, this study examines the trade openness heterogeneity. Considering that maritime shipping is the primary mode of transportation for China's foreign trade, provinces and regions that are closer to the coastal areas have a geographical advantage in terms of proximity to foreign markets, which naturally leads to relatively higher levels of trade openness. Therefore, we take cities where in the provinces with coastlines they are coastal cities (the dummy variable *cosl* is taken as 1), or otherwise they are inland cities (the dummy variable *cosl* is taken as 0). Furthermore, we incorporate the intersection terms of *cosl* and *lnopen* into the econometric model for re-estimation, for which the regression results are shown in columns (3)–(4) of Table 4. The estimated coefficient of *cosl*×*lnopen* is significantly positive, at a level of significance of 1% regardless of the inclusion of control variables, which implies that compared with the inland cities, the effect of trade openness on population health is more obvious in the coastal cities. Additionally, we conducted the intersection terms of *dum* and *lnopen* into the econometric model for re-estimation (the dummy variable *dum* is taken as 1 when regional trade openness crosses the median, otherwise it is 0). The regression results in columns (5)–(6) of Table 4 show that the estimated coefficients of $dum \times lnopen$ are significantly positive, at a level of significance of 1%, which indicates that the effect of trade openness on population health is more significant in high-trade-openness cities.

5. Discussion

5.1. Mechanism Analysis

As noted in the theoretical analysis above, trade openness can affect population health through potential pathways such as labor employment, wage income, health investment, and environmental pollution. Following Kim et al. (2021), we conducted a two-stage mediation model to identify the potential influence mechanism [43].

The first-stage model is specified as follows:

$$med_{it} = \beta_0 + \beta_1 lnopen_{it} + \beta_2 ctrx_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (2)$$

where the *med* is an intermediary variable of the potential pathway. We were interested in a set of intermediary variables, *med*: *lnemplyment*, which is measured by using the natural logarithm of the ratio of the regional employed persons to the total population; *lnwage*, which is presented by using the natural logarithm of the employees' average wage; health investment includes public health investment (*lnpubic*) and personal health investment (*lnprivate*), which are expressed via the natural logarithm of public health care expenditure and resident health care expenditure, respectively; *lnenvironment* is a comprehensive indicator, using data from per capita industrial wastewater, per capita industrial SO_2, per capita industrial soot, and per PM2.5, which are calculated via the quotient method and take the natural logarithm value. Additionally, the data sources of all intermediary variables are the same as the previous data descriptions, and will not be repeated here. It worth noting that the coefficient β_1 identifies the effect of trade openness on the intermediary variable *med*, where other variables are the same as in Equation (1).

The second-stage model is specified as follows:

$$lnhealth_{it} = \alpha_0 + \theta \overset{\wedge}{med}_{it} + \alpha_2 ctrx_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (3)$$

where the $\overset{\wedge}{med}$ is estimator of *med* from Equation (2), and the key coefficient θ identifies how the changes in the intermediary variable *med* caused by trade openness affect population health.

Table 5 reports the regression results of Equation (2), and the dependent variables are the intermediary variable *med*: *lnemplyment*, *lnwage*, *lnpubic*, *lnprivate*, and *lnenvironment*. As seen from columns (1)–(5), the estimated coefficient of *lnopen* is significantly positive at a 1% level, which implies that the average trade openness rises by one percentage per city to improve labor employment by 0.118 percentage points, raise employees' average wages by 0.281 percentage points, increase public health care expenditure and resident health care expenditure by 0.170 and 0.161 percentage points, and reduce environmental pollution by 0.020 percentage points. It means that trade openness can significantly promote labor employment, raise residents' incomes, improve the government's public health investment capacity in medical and health, strengthen residents' health awareness, and increase expenditure on health food and resident health care, so as to make public health investment and individual health investment show an increasing trend. Notably, trade openness not only accelerates the process of regional urbanization and industrialization, but also leads to an increase in pollutant emissions such as carbon dioxide, sulfur dioxide, and nitrogen oxides, which intensify the increase in environmental pollution.

Table 5. Mechanism regression results for the first stage.

	lnemplyment	**lnwage**	**lnpublic**	**lnprivate**	**lnenvironment**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
lnopen	0.118 *** (0.036)	0.281 *** (0.022)	0.170 *** (0.016)	0.161 *** (0.042)	0.020 *** (0.004)
Control variables	YES	YES	YES	YES	YES
Year effects	YES	YES	YES	YES	YES
City effects	YES	YES	YES	YES	YES
Number of city	285	285	285	285	285
Obs.	5700	5700	5700	5700	5700

Note: All regressions include a constant. Robust standard errors clustered by city level are in parentheses. *** indicate statistical significance levels of 1%.

The results in Table 6 report on the regression results of Equation (3). In columns (1)–(4), the estimated coefficient of the intermediary variable *med* is significantly positive at the 1% level; meanwhile, the estimated coefficient of the intermediary variable *med* is significantly negative at the 1% level in column (5). It indicates that the labor employment increase by one percent per city could improve population health by 0.017 percentage points; an average wage increase by one percent per city for employees could improve population health by 0.070 percentage points; public health investment and personal health investment increases by one percent per city could improve population health by 0.342 and 0.569 percentage points, respectively; but, environmental pollution increase by one percent per city could reduce population health by 0.122 percentage points. Combining this with the regression results for the first stage (see Table 5), it can be concluded that trade openness plays a significant role in promoting labor employment, wage income, public health investment, and individual health investment, thereby improving population health conditions. Additionally, trade openness also adversely affects population health through worsening environmental pollution. So, theoretical hypothesis 2 was verified.

Table 6. Mechanism regression results for the second stage.

	The Dependent Variable: lnhealth				
	(1)	(2)	(3)	(4)	(5)
$\widehat{\text{lnemplyment}}$	0.017 *** (0.005)				
$\widehat{\text{lnwage}}$		0.070 *** (0.022)			
$\widehat{\text{lnpublic}}$			0.342 *** (0.033)		
$\widehat{\text{lnprivate}}$				0.569 *** (0.074)	
$\widehat{\text{lnenvironment}}$					−0.122 *** (0.006)
Control variables	YES	YES	YES	YES	YES
Year effects	YES	YES	YES	YES	YES
City effects	YES	YES	YES	YES	YES
Number of city	285	285	285	285	285
Obs.	5700	5700	5700	5700	5700

Note: All regressions include a constant. Robust standard errors clustered by city level are in parentheses. *** indicate statistical significance levels of 1%.

5.2. Threshold Effect Analysis

As mentioned above, there are great differences in the direction of the effect of trade openness on population health, one reason of which is ignoring the nonlinear relationship and interval effects between trade openness and population health. As Owen and Wu (2007) pointed out, the effect of trade openness on population health is affected by the stage of regional economic development [15]. Given this, we employ the threshold panel model proposed by Hansen (1999) to empirically examine the effect of trade openness on population health at different stages of economic development, and use per capita GDP to represent the stage of economic development [16]. Furthermore, the empirical analysis conducted earlier revealed that environmental pollution is an important channel through which trade openness adversely affects population health. Next, we will delve into exploring how to effectively mitigate or even eliminate the negative impact of trade openness on population health. Combining this with the availability of data, this study employs two indicators, namely investment in environmental governance and investment in environmental infrastructure construction, as proxies for environmental governance, in order to identify the impact of trade openness on population health under different levels of environmental governance intensity.

Based on Equation (1), a single threshold panel model is specified as follows:

$$\begin{aligned} lnhealth_{it} &= \phi_0 + \phi_1 lnopen_{it} I(g_{it} \leq \gamma) + \phi_2 lnopen_{it} I(g_{it} > \gamma) \\ &+ \phi_3 ctrx_{it} + \mu_i + \nu_t + \varepsilon_{it} \end{aligned} \tag{4}$$

where $I(\cdot)$ is an indicative function, g_{it} is the threshold variable, and γ is the specific threshold value. The threshold variables of Equation (4) include per capita GDP (*lnpgdp*), investment in environmental governance (*lnegi*), and investment in environmental infrastructure construction (*lneini*).

Furthermore, considering the possibility of double thresholds from a metrological view, a double threshold panel model is specified as follows:

$$\begin{aligned} lnhealth_{it} = \phi_0 + \phi_1 lnopen_{it} I(g_{it} \leq \gamma_1) + \phi_2 lnopen_{it} I(\gamma_1 < g_{it} \leq \gamma_2) \\ + \phi_3 lnopen_{it} I(g_{it} > \gamma_2) + \phi_4 ctrx_{it} + \mu_i + \nu_t + \varepsilon_{it} \end{aligned} \tag{5}$$

The estimation method for Equation (5) assumes a known value for parameter $\hat{\gamma}_1$ in a single threshold regression model, and then searches for parameter $\hat{\gamma}_2$ to minimize the sum of squared errors. Similarly, a multiple threshold model could be constructed on a single threshold panel model and double threshold panel model. The threshold estimation and confidence interval presented in the likelihood ratio function graph are tested via a "self-sampling method" (Figures 2 and 3), and the results show that *lnpgdp*, *lnegi*, and *lneini* all had a significant single threshold effect, with threshold values of 9.900, 11.842, and 12.487, respectively. By substituting the threshold value of the threshold variables (*lnpgdp*, *lnegi*, *lneini*) into Equations (4) and (5), the estimated coefficient of trade openness on population health in different threshold value ranges can be estimated. For robustness, this study also reports the regression results of the threshold variable under both single threshold and double threshold scenarios (see Table 7).

As can be seen from the regression results of the threshold variable of the economic development stage (*lnpgdp*) in Table 7, the estimated coefficient of trade openness on population health is significantly negative when *lnpgdp* is below the first threshold of 9.900. As *lnpgdp* crosses the threshold of 9.900, the estimated coefficient of trade openness on population health is significantly positive. This observation suggests that in the context of lower levels of economic development, economies tend to adopt relaxed environmental pollution restriction policies to enhance the attractiveness of foreign investment. Additionally, it is plausible that economies exhibit weaker capabilities in capturing the knowledge spillover and welfare improvements associated with trade openness. Consequently, trade openness predominantly exerts a negative influence on population health. In contrast, as the stage of economic development progresses to higher levels, their economic policies are more reasonable and the effect of knowledge spillover is more obvious (Owen and Wu, 2007), which makes trade openness significantly promote population health [15]. The double threshold regression results also show that when *lnpgdp* is below 9.900, the estimated coefficient of trade openness on population health is significantly negative. When *lnpgdp* is in the range of 9.900 to 11.574, the estimated coefficient of trade openness on population health turns to become significantly positive. As *lnpgdp* crosses the second threshold 11.574, the estimated coefficient of trade openness on population health becomes larger. This indicates that as the stage of economic development progresses towards higher levels, the effect of trade openness on population health will change from negative to positive, and the positive effect will increase.

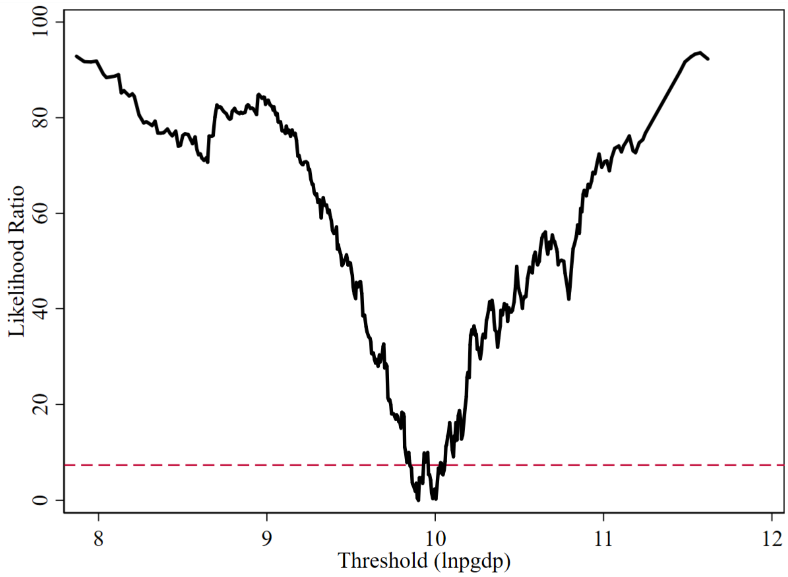
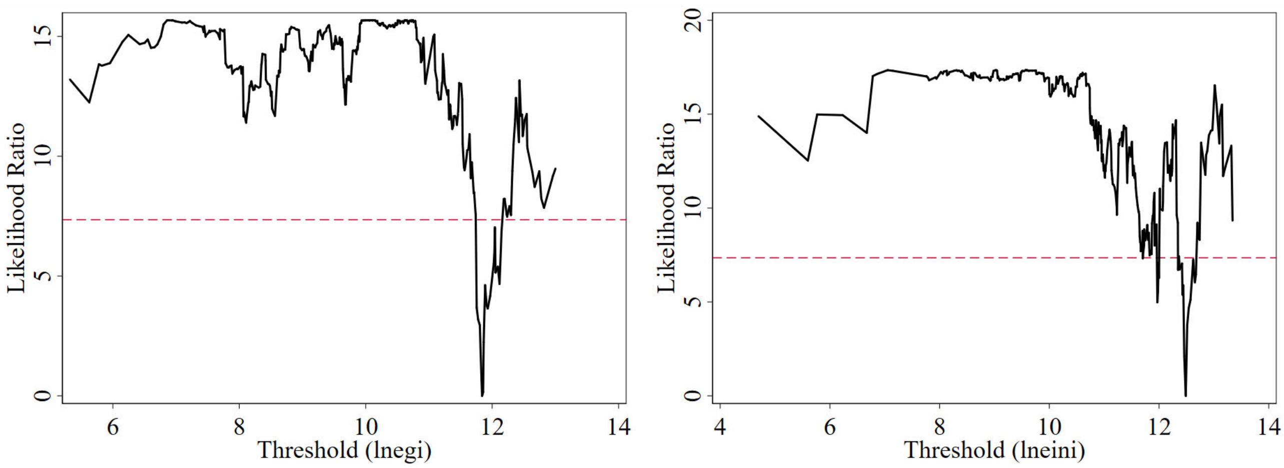


Figure 2. Estimation of threshold of *lnpgdp* based on a likelihood ratio function. The red line indicates the Likelihood Ratio of the 95% confidence interval of the threshold.



(**a**) (**b**)

Figure 3. (**a**) represents the estimation of threshold of *lnegi* based on a likelihood ratio function. (**b**) represents the estimation of threshold of *lneini* based on a likelihood ratio function. The red line indicates the Likelihood Ratio of the 95% confidence interval of the threshold.

Table 7. Mechanism regression results for the second stage.

Threshold Variable	No. of Threshold	Threshold Interval	Coefficients	No. of Threshold	Threshold Interval	Coefficients
lnpgdp	Single	lnpgdp ≤ 9.900	−0.015 *** (0.002)	Double	lnpgdp ≤ 9.900	−0.015 *** (0.002)
					9.900 < lnpgdp ≤ 11.574	0.006 *** (0.002)
		lnpgdp > 9.900	0.005 ** (0.002)		lnpgdp > 11.574	0.028 *** (0.004)
lnegi	Single	lnegi ≤ 11.842	−0.030 (0.091)	Double	lnegi ≤ 10.990	−0.061 (0.092)
					10.990 < lnegi ≤ 11.842	0.088 (0.019)
		lnegi > 11.842	0.349 ** (0.110)		lnegi > 11.842	0.386 *** (0.111)
lneini	Single	lneini ≤ 12.487	−0.020 (0.092)	Double	lneini ≤ 7.480	−0.660 * (0.270)
					7.480 < lneini ≤ 12.487	−0.022 (0.092)
		lneini > 12.487	0.385 ** (0.135)		lneini > 12.487	0.383 ** (0.134)

Note: All regressions include a constant. Robust standard errors clustered by city level are in parentheses. ***, **, and * indicate statistical significance levels of 1%, 5%, and 10%, respectively.

As can be seen from the regression results of the threshold variables *lnegi* and *lneini* in Table 7, the estimated coefficient of trade openness on population health is negative when *lnegi* and *lneini* are below the first threshold of 11.842 and 12.487, but it is insignificant, respectively. When *lnegi* and *lneini* cross the threshold 11.842 and 12.487, the estimated coefficient of trade openness on population health is significantly positive at the 5% level. This implies that overlooking the influence of trade openness on environmental pollution, trade openness may not be favorable for enhancing population health. However, if governments, in the pursuit of trade openness, adopt relatively rigorous market access rules and environmental pollution restriction policies, while concurrently intensifying investments in environmental governance and environmental infrastructure construction, it would be conducive to ameliorating the detrimental impact of trade openness on population health. The double threshold regression results also show that when *lnegi* and *lneini* are below 10.990 and 7.480, the estimated coefficients of trade openness on population health are insignificantly negative at the level of 5%. When *lnegi* is in the range from 10.900 to 11.842, the estimated coefficient of trade openness turns to become insignificantly positive, and when *lneini* is in the range from 7.480 to 12.487, the estimated coefficient of trade openness turns to become insignificantly negative. As *lnegi* and *lneini* cross the second threshold, 11.842 and 12.487, the estimated coefficient of trade openness turns to become significantly positive. These findings reiterate the presence of a non-linear effect of trade openness on population health. Implementing environmental quality improvement measures, such as augmenting investment in environmental governance and environmental infrastructure construction, would contribute to enhancing the facilitating role of trade openness in promoting population health.

6. Conclusions

Based on panel data from 285 prefecture-level cities in China during the period of 2000–2019, this study empirically examines the effects and mechanisms of trade openness on population health from the perspective of trade dependency. The primary research conclusions are as follows. Firstly, trade openness significantly improves population health, and after a series of robustness tests such as variable indicator measurements, sample selection biases, extreme values, adjustments to time window width, exogenous shocks, and endogeneity, the conclusion is equally robust. Secondly, the promoting effect of trade openness on population health demonstrates notable heterogeneity, that is, compared to the western regions, inland cities, and cities with low levels of trade openness, trade openness exhibits a more substantial promoting effect on population health in the eastern and central regions, coastal cities, and cities with higher levels of trade openness. Thirdly, the results of the mechanism analysis show that trade openness significantly promotes population health mainly through channels such as labor employment, wage income, public health investment, and individual health investment, but deteriorates population health through environmental pollution. Fourthly, a discussion of threshold effects reveals that the relationship between trade openness and population health is nonlinear. As the stage of economic development crosses a certain threshold, the effect of trade openness on population health changes from negative to significantly positive, and shows an increasing trend with the economic development stage jumping upwards. This indicates that the reasons why previous studies have not reached an agreement on the effect of trade openness on population health (which may be positive or negative) might be ignoring the nonlinear relationship between trade openness and population health. Additionally, we also found that when investments in environmental governance and environmental infrastructure construction exceed a certain threshold, the impact of trade openness on population health changes from insignificantly negative to significantly positive. This implies that increasing investments in environmental governance and environmental infrastructure construction is an effective policy to mitigate the negative impact of trade openness on population health.

The conclusions of the current study have the following important implications for promoting the effect of trade openness on population health. First, the government should persist in promoting trade liberalization; they should open up channels for labor employment, wage increase, and provide healthy investments that affect population health; and they should take multiple measures to improve residents' trade welfare. Second, the government should transform the economic development model, improve relevant policies, institutions, and legal systems in order to achieve high-quality and sustainable economic growth; they should continue to promote the evolution of the economic development stage, and better serve the domestic residents to capture the healthy spillovers from trade openness. Third, in this process, the government should also guide domestic enterprises in the research and application of green innovative technologies, accelerate the strategic layout of emerging green industries, actively introduce advanced foreign technologies, strengthen the formulation and implementation of environmental pollution control policies, increase environmental protection investments such as environmental governance and infrastructure construction to the extent possible, and eliminate the negative impact of trade openness on population health by aggravating environmental pollution. Moreover, they could even facilitate the realization that trade openness is more conducive to promoting green innovation and industrial transformation, and could upgrade domestic enterprises, effectively reducing domestic environmental pollution rather than exacerbating it. Consequently, this would transform the previously negative impact of environmental pollution on population health into a positive impact channel that can be utilized effectively.

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