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# A Study on the Impact of Reform and Opening-up on Sustainable Development: Evidence from China

## Badanie wpływu reform i otwarcia na zrównoważony rozwój: dowody z Chin

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## Abstract

This paper selected the data of 284 prefectural-level cities in China in the time range of 2011 to 2020 as the research sample, and established an index system of sustainable development consisting of 22 indicators including economic development, social progress, ecological environment and public institutions and so on, to comprehensive evaluate the sustainability of the cities. Total annual investment in pollution control is selected as the proxy variable of reform, and annual actual amount of foreign investment used is selected as the proxy variable of opening-up, to empirically explore the impact of the two on sustainable development. The results of empirical analysis show that reform and opening-up has a significant positive impact on sustainable development. After fixing time and individual effect, it is found that the effect of reform is more prominent. Regional heterogeneity analysis shows that, the impact strength of reform and opening-up in the east is larger than that in the middle and west of China. To study the spatial auto-correlation and spillover effect, Moran's I was calculated and spatial Durbin model was constructed based on the weight matrix of geographical distance, which produced the results that spatial agglomeration is evident for sustainability, and that reform has a significant positive spillover effect. Further, considering the time auto-correlation of sustainability, a dynamic panel model is established, and dynamic threshold regression is carried out. Results show that lag effect of sustainability is significant, and a certain threshold must reform reach can sustainable development be promoted. This paper puts forward several policy suggestions in terms of formulating effective sustainable development strategy, to provide insights for new-pattern urbanization in the future.

**Key words:** sustainable development, reform and opening-up, environment protection, spatial Durbin model, dynamic panel threshold model

## Streszczenie

W niniejszym artykule jako próbę badawczą wybrano dane z 284 miast na poziomie prefekturalnym w Chinach w okresie od 2011 do 2020 r. Ustanowiono system wskaźników zrównoważonego rozwoju składający się z 22 wskaźników, w tym rozwoju gospodarczego, postępu społecznego, środowiska ekologicznego i instytucji publicznych itd. dalej, aby kompleksowo ocenić zrównoważony rozwój miast. Całkowite roczne inwestycje w kontrolę zanieczyszczeń wybrano jako zmienną zastępczą reformy, a rzeczywistą roczną kwotę wykorzystanych inwestycji zagranicznych wybrano jako zmienną zastępczą otwarcia, aby empirycznie zbadać wpływ tych dwóch czynników na zrównoważony rozwój. Wyniki analizy empirycznej wskazują, że reforma i otwarcie mają istotny pozytywny wpływ na zrównoważony rozwój. Po ustaleniu czasu i efektu indywidualnego okazuje się, że efekt reformy jest bardziej widoczny. Analiza regionalnej heterogeniczności pokazuje, że siła oddziaływania reform i otwarcia na wschodzie jest większa niż w środkowych i zachodnich Chinach. Aby zbadać przestrzenną autokorelację i efekt

uboczny, obliczono Morana I i skonstruowano przestrzenny model Durbina w oparciu o macierz wagową odległości geograficznej, co pozwoliło wykazać, że aglomeracja przestrzenna jest oczywista dla zrównoważonego rozwoju, a reforma ma znaczący pozytywny efekt uboczny. Ponadto, biorąc pod uwagę autokorelację trwałości w czasie, ustanawia się dynamiczny model panelowy i przeprowadza się dynamiczną regresję progową. Wyniki pokazują, że efekt opóźnienia w zakresie zrównoważonego rozwoju jest znaczący i istnieje próg, który musi osiągnąć reforma, aby można było promować zrównoważony rozwój. W niniejszym artykule przedstawiono kilka sugestii politycznych dotyczących sformułowania skutecznej strategii zrównoważonego rozwoju, aby nakreślić nowy wzorzec urbanizacji odnoszący się do przyszłości.

**Słowa kluczowe:** zrównoważony rozwój, reforma i otwarcie, ochrona środowiska, przestrzenny model Durbina, dynamiczny panelowy model progowy

## 1. Introduction

Over the past decades, the idea of sustainable development has received great attention from governments and academia at its advent, and gradually evolved into a science. China has made great progress in promoting sustainable development, which can to a large extent be attributed to the reform and opening-up (hereinafter referred to as R&O). In 2015, the UN adopted the 2030 Sustainable Development Goals (SDGs), while China issued its *National Plan for the Implementation of the 2030 Agenda for Sustainable Development* in 2016. So far, the index system as well as its evaluation method and research model have become important content of sustainable development research. The research on this issue is of great theoretical and practical significance. This paper explores the correlation between sustainable development and R&O, in the hope of providing scientific views for the government's decision-making regarding the promotion of sustainable development.

Scholars have conducted in-depth empirical research on the evaluation of sustainable development. Many have studied indicators of sustainable development based on various methods. For example, Huang (2000) applied the Delphi method to assign weight, Ulla et al., (2013) applied the assessment model based on scene analysis, Chen (2014) applied the energy value analysis method, Ma et al., (2015) applied the entropy weight method and quadrant graph method, and Neumann et al., (2018) used SDGs to establish a sustainable development indicator system. Although there are still great disputes and difficulties in the statistics, measurement and stringency of SDGs, it points out a clear direction of sustainable development, which is very fit with the current world situation, making it very pragmatic and thus recognized globally.

In addition, the research results of influencing factors of sustainable development show that, on one hand, regional sustainability is related to basic conditions such as geographical location, resource endowment, climate characteristics and population density (Zhang et al.,2015; Fan et al.,2020). On the other hand, it mainly depends on social and economic factors such as ideology, resource and environmental system, level of economic development, industrial structure, scientific and technological progress, and so on (Lopez and Figueroa, 2016; Chen and Liang, 2021). Relevant empirical studies on the influencing factors of regional sustainability mainly focus on the factors stated above. Anna (2022) used correlation coefficients, ordinary least squares (OLS), vector autoregression (VAR) model and simultaneous equations to evaluate the impact of selected factors involving energy, economy and other aspects on sustainable development, and found that the reform of environmental taxes and EU Emissions Trading System is critical to effectively reduce greenhouse gas emissions. Zhang (2013) took the data of 31 provinces, cities and autonomous regions in China in 2010 as the research sample and adopted Tobit model to empirically analyze the influencing factors of industrial eco-efficiency, and found that regional per capita GDP and geographical location has positive effects on the improvement of eco-efficiency, while the effect of economy openness is negative. Yang (2013) used panel data of 28 provinces of China, and constructed quantile regression model to study the factors influencing the efficiency of regional sustainable development, and found that the economic scale, the level of opening-up, the proportion of local fiscal expenditure and the capacity of independent innovation all have significant positive effect on the efficiency of sustainable development. Huang (2020) used the Super-SBM model considering the non-expected output to analyze the data of the 60 countries along the Belt and Road from 2005 to 2014, and established a Tobit model to identify the factors influencing the sustainability of all the sample countries, and found that the level of opening-up is negative to the sustainability for the countries dominated by resource-based product and labor-intensive industries.

The main contributions of this paper are as follows: (1) A dynamic panel model was established, which incorporates the continuous influence of the lagged explained variable on the current explained variable and better control the endogeneity problem. (2) The agglomeration of the cities in China regarding sustainability was investigated by using Moran's I, and the spatial spillover effect of reform among the cities was investigated by using spatial Durbin model. (3) It enriched the nonlinear research in the field of sustainable development, further explored the relationship between reform and sustainable development, and included pollution control investment as the threshold variable into the model to investigate the nonlinear impact, making the results more complete and robust. (4)

In terms of research objects, most previous studies used provincial panel data or time-series data, this paper used a panel data to better observe the impact of R&O on sustainable development.

## 2. Research design

### *2.1. Model specification*

#### *2.1.1. Linear model*

In order to test the influence of pollution control investment (proxy for reform) and foreign investment (proxy for opening-up) on the degree of sustainability, this paper constructed a linear panel model with two-way fixed-effects in terms of both city and year. A sample of 284 prefecture-level cities of China from 2011 to 2020 is used for multiple regression analysis. The general form of the linear model is as follows:

$$sus_{it} = \alpha + \beta_1 pci_{it} + \beta_2 fi_{it} + C_{it}\gamma + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Where $sus_{it}$ denotes sustainability, $pci_{it}$ denotes investment in pollution control, $fi_{it}$ denotes foreign investment. $C_{it}$ is a set of control variables including economic development level, industrial structure, technological progress, environmental pollution index, population size, and government financial resources. $\alpha$ is constant term, $\mu_i$ is individual fixed effect, $\lambda_t$ is time fixed effect, $\varepsilon_{it}$ is error term.

#### *2.1.2. Spatial Durbin model*

In consideration of the spillover effect of key explanatory variables, spatial Durbin model (SDM) was established. The idea is that explained variable of a region is not only affected by the variables of the local area, but also affected by the variables of the surrounding areas. SDM improved spatial lag model (SLM) and spatial error model (SEM) by adding lag terms of the explanatory variables into the model. The model expression is as follows:

$$sus_{it} = \alpha + WX_{it}\beta + C_{it}\gamma + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

Where $sus_{it}$ denotes sustainability, $X_{it}$ is a set of explanatory variables including pollution control investment and foreign investment, $C_{it}$ is a set of control variables including economic development level, industrial structure, technological progress, environmental pollution index, population size, and government financial resources, $\alpha$ is constant term, $\mu_i$ is individual fixed effect, $\lambda_t$ is time fixed effect, $\varepsilon_{it}$ is error term.

#### *2.1.3. Dynamic panel model*

Considering the auto-correlation of sustainability in time, this paper constructed a dynamic panel model to incorporate the lag effect, i.e., $sus_{i,t}$ will be affected by $sus_{i,t-1}$. To overcome the bias caused by weak instruments, this paper employs system generalized momentum method (GMM) to estimate the model. The model is expressed as follows:

$$sus_{it} = \alpha + \beta_1 sus_{i,t-1} + \beta_2 pci_{it} + \beta_3 fi_{it} + C_{it}\gamma + \mu_i + \varepsilon_{it} \quad (3)$$

Where $sus_{i,t-1}$ is the first-order lag of $sus_{it}$, meaning sustainability in the previous period, the rest is the same as equation(1).

#### *2.1.4. Dynamic panel threshold model*

There may be nonlinear influence of pollution control investment and foreign investment on sustainability, so a threshold model is needed to verify the nonlinearity and determine the turning point. Meanwhile, given sustainable development is a continuous dynamic process, sustainability of the previous period will inevitably affect that of the current period. Therefore, in order to control the continuity and inertia of sustainability per se, its first-order lag is included into the model. The model is expressed as follows:

$$sus_{it} = \alpha + \beta_0 sus_{i,t-1} + \beta_1 pci_{it} * I(pci_{it} \leq \varphi) + \beta_2 pci_{it} * I(pci_{it} > \varphi) + C_{it}\gamma + \mu_i + \varepsilon_{it} \quad (4)$$

Where $sus_{i,t-1}$ is the first-order lag of $sus_{it}$, $pci_{it}$ denotes investment in pollution control, $I(\cdot)$ is an indicative function (the value is 1 if the expression in parentheses is true, and 0 if not), $\varphi$ is undetermined threshold value, $C_{it}$ is a set of covariates, $\alpha$ is constant term, $\mu_i$ is individual fixed effect, $\varepsilon_{it}$ is error term.

### *2.2. Data source*

This paper selects city-level data in China for research. The original data are from National Bureau of Statistics of China and China Statistical Yearbook. Due to the lack of data, all the cities in Tibet Autonomous Region and Taiwan Province, as well as Hong Kong, Macao and Sansha City were excluded from the sample, and a total of 284 prefecture-level cities' data in the time range of 2011-2020 were collected. Since a small part of the data in the sample is missing, linear interpolation method was employed to fill the missing values. All data have been min-max normalized in this paper.

### *2.3. Variable selection*

#### *2.3.1. Explained variable*

This article chooses four dimensions including environmental, societal, and economic and public indicators to build a sustainable development index, to indicate sustainability of a city. Entropy weight method was employed to calculate the index. The index system is shown in table 1:

Table 1. Index system of sustainability, source: own considerations

| Level-1 indicator | Level-2 indicator | Level-3 indicator |
|---|---|---|
| | Economic | Proportion of primary industry in GDP.<br>Proportion of tertiary industry in GDP.<br>Investment in fixed assets.<br>Total retail sales of consumer goods. |
| Sustainability | Societal | Number of urban workers covered by basic endowment insurance.<br>Number of urban workers covered by basic medical insurance.<br>Number of people covered by unemployment insurance.<br>Expenditure for education.<br>Expenditures for social security subsidies.<br>Green coverage of built-up areas.<br>Pension and social welfare. |
| | Environmental | Compliance rate of industrial wastewater discharge.<br>Compliance area of environmental noise.<br>Green land area.<br>Product output value of comprehensive utilization of waste water, waste gas and solid waste. |
| | Public | Number of hospital beds.<br>Number of hospitals.<br>Number of general secondary schools.<br>Number of full-time teachers in general higher education institutions.<br>Public library collections per 100 people.<br>Culture, sports, and entertainment.<br>Health, social security, and social welfare industry. |

#### *2.3.2. Explanatory variables*

The proxy variable of reform is total annual investment in pollution control ($pci$), which is the investment in pollution control facilities with direct environmental benefits.

The proxy variable of opening-up is annual actual amount of foreign investment used ($fi$), which is the amount of investment actually executed in accordance with investment agreements by Chinese government and other economic organizations in the process of raising overseas cash, equipment, technology and other resources through foreign loans, foreign direct investment and other means.

#### *2.3.3. Control variables*

This paper selects 6 control variables covering industrial, environmental, demographic and economic characteristics of cities. Specifically, industrial structure is expressed by the proportion of secondary industry in GDP ($indstr$). Environmental pollution index is expressed by the amount of industrial fume and dust removal ($indpol$), which is the emission reduced by technical means by the production unit. Technological progress is expressed by the scientific and technological expenditure ($techexp$), which is the expenditure invested in human, financial, material, time, information and other resources related to scientific and technological activities at the stage of research and experimental development. Financial resources of local government are expressed by the expenditure of the local general public budget ($govexp$), which is the expenditure arranged by the government for planned distribution from centralized budgetary revenue. Population size is expressed in population density ($popden$), which is the number of people per unit land area. Level of economic development is expressed by real GDP ($rgdp$), taking 2011 as the base period.

## 3. Results and discussion

### *3.1. Descriptive statistics*

As stated above, all data has been normalized to [0,1], so as to eliminate the adverse effects caused by singular sample data and make the coefficient of variables with different dimensions comparable. Therefore, min values are all 0, and max values are all 1. The standard deviation of the sustainability, the proportion of secondary industry in GDP, and the population density is large relative to other variables, which to some extent indicates that, in the observed sample data, there is a large degree of dispersion, namely that there are obvious differences over time

and among different regions regarding these three variables. See table 2.
The statistics show that in terms of total annual investment in pollution control, Shanghai, Guangzhou and Suzhou, which are located in the eastern region, rank the first among all the cities. In comparison, Ankang, Hulunbuir and Huangshan in the middle and western region rank the last, their sustainability in sum is less than one thirtieth of that of the previous three. In terms of total annual foreign investment, Tianjin, Beijing and Shanghai in the eastern region see the largest amount, while Dingxi, Zhaotong and Guyuan in the western region see the least. In terms of sustainability, Beijing, Shanghai and Guangzhou in the east rank the first, while Jiayuguan, Jinchang and Shizuishan in the west rank the last, which is consistent with the statistics of R&O. In summary, significant regional differences are observed. The eastern region has achieved great success in R&O, while the western region still has a long way to go, and the middle region is in between.

Table 2. Descriptive statistics, source: own calculations

| variables | obs | mean | sd | min | max |
|---|---|---|---|---|---|
| *sus* | 2,840 | 0.0840 | 0.110 | 0 | 1 |
| *pci* | 2,840 | 0.0251 | 0.0548 | 0 | 1 |
| *fi* | 2,840 | 0.0292 | 0.0689 | 0 | 1 |
| *indstr* | 2,840 | 0.447 | 0.138 | 0 | 1 |
| *indpol* | 2,840 | 0.0273 | 0.0362 | 0 | 1 |
| *techexp* | 2,840 | 0.0160 | 0.0659 | 0 | 1 |
| *govexp* | 2,840 | 0.0283 | 0.0740 | 0 | 1 |
| *popdens* | 2,840 | 0.158 | 0.118 | 0 | 1 |
| *rgdp* | 2,840 | 0.0735 | 0.0994 | 0 | 1 |

### *3.2. Empirical analysis*

#### *3.2.1. Benchmark regression*

AS shown in Table 3, the estimated coefficients of pollution control investment and foreign investment are significantly positive at the level of 1%. This shows that both reform and opening-up can promote sustainable development. The results in column (2) show that, after controlling for unobservable factors of city and year, the coefficient of pollution control investment is even larger, indicating that the effect of reform on sustainable development is prominent and robust. The coefficient of foreign investment is small relative to that of pollution control investment, only accounted for less than half of the later after controlling for city and year. This suggests that although the use of foreign investment (opening-up) can to an extent promote sustainable development, its effect is much weaker than the direct investment in pollution control (reform).

Table 3. Benchmark regression, source: own calculations

| *sus* | (1) | (2) |
|---|---|---|
| *pci* | 0.159*** | 0.167*** |
| | (0.013) | (0.012) |
| *fi* | 0.094*** | 0.082*** |
| | (0.006) | (0.006) |
| *indstr* | 0.005** | -0.003 |
| | (0.002) | (0.003) |
| *indpol* | 0.044*** | 0.040*** |
| | (0.007) | (0.006) |
| *techexp* | -0.022** | -0.013 |
| | (0.010) | (0.010) |
| *govexp* | 0.085*** | 0.079*** |
| | (0.015) | (0.014) |
| *popdens* | 0.019*** | 0.014*** |
| | (0.004) | (0.004) |
| *rgdp* | 0.313*** | 0.318*** |
| | (0.012) | (0.013) |
| constant | 0.045*** | 0.626*** |
| | (0.002) | (0.008) |
| city FE | YES | YES |
| year FE | NO | YES |
| Adj. $R^2$ | 0.435 | 0.565 |
| obs | 2840 | 2840 |

Note: Standard errors in parentheses, * p<0.1, ** p<0.05, *** p<0.01

All control variables except industrial structure and technological expenditure are significant at the 1% level when controlling for city and for both city and year. Industrial structure and technological expenditure are significant at the 5% level when controlling for city, and insignificant after controlling for both city and year. This means the selection of control variables is mostly appropriate and effective, and the model is well fitted and convincing.

*3.2.2. Regional heterogeneity analysis*

Based on the descriptive statistics, this paper studied the regional heterogeneity of the impact of R&O on sustainable development. Specifically, this paper constructed a regional dummy variable according to the location of the cities, and assigned value [1,2,3], corresponding respectively to the east, the middle, and the west. The cross term between pollution control investment and the dummy variable, and the cross term between foreign investment and the dummy variable were created and introduced into model(1), and the regression results are shown in Table 4.

It can be seen that the coefficient of pollution control investment for the east and west of China is significantly positive, while it is significantly negative for the west of China. The coefficient of foreign investment for the east and west is significantly positive, but insignificant for the middle region. The reason may be that economically developed cities is capable of allocating large amount of investment for environmental improvement, which can mostly satisfy the needs of environmental protection, and is conducive to sustainable development. However, the inhibiting effect of the pollution control investment in the west may be due to that the many cities in the western region are resource-based and less developed, their industrial structure is unbalanced, and the governance capacity of the local governments is low, rendering the investment futile.

In contrast, the coefficient of foreign investment for the west and east is significantly positive. However, the coefficient for the middle is insignificant. It shows that the extent of openness in China presents obvious regional characteristics, the west sees the largest effect of foreign investment. The reasons may be, the eastern part of China was the first to open to the outside world and has received tremendous amount of foreign investment for a long time, the marginal benefit is wearing down compared to the west. While the east is highly open and developed, and the west is promising and supported by many preferential policies from central government, the middle region is relatively mediocre and inefficient in leveraging foreign investment for sustainable development.

Table 4. Regional heterogeneity analysis, source: own calculations

| *sus* | (1) | (2) |
|---|---|---|
| *pci* | | |
| east | 0.101*** | 0.104*** |
| | (0.013) | (0.012) |
| middle | 0.400*** | 0.416*** |
| | (0.025) | (0.023) |
| west | -0.431*** | -0.437*** |
| | (0.072) | (0.067) |
| *fi* | | |
| east | 0.102*** | 0.093*** |
| | (0.006) | (0.006) |
| middle | 0.018 | -0.017 |
| | (0.016) | (0.014) |
| west | 0.240*** | 0.231*** |
| | (0.023) | (0.021) |
| *indstr* | 0.003 | -0.001 |
| | (0.002) | (0.003) |
| *indpol* | 0.041*** | 0.037*** |
| | (0.006) | (0.006) |
| *techexp* | -0.004 | 0.008 |
| | (0.009) | (0.009) |
| *govexp* | 0.060*** | 0.053*** |
| | (0.014) | (0.013) |
| *popdens* | 0.008** | 0.003 |
| | (0.004) | (0.003) |
| *rgdp* | 0.283*** | 0.278*** |
| | (0.012) | (0.013) |
| constant | 0.051*** | 0.051*** |
| | (0.001) | (0.001) |
| obs | 2840 | 2840 |
| Adj. $R^2$ | 0.478 | 0.566 |

Note: Standard errors in parentheses, * p<0.1, ** p<0.05, *** p<0.01

### *3.3. Spatial econometric analysis*

#### *3.3.1. Spatial correlation test*

This paper used the scatter plot of local Moran's I to test the local spatial auto-correlation of the sample cities. According to the final linear trend, the scatter points in the first and third quadrants are significantly more than the points in the second and fourth quadrants, that is, there are more cities clustered by the *low-low* and *high-high* types than those of the *high-low* and *low-high* types, which means the spatial difference is small. As can be seen from Figure 1, the Moran's I of the sustainability of 284 prefecture-level cities in China all present significant positive spatial correlation, indicating that cities with high sustainability tend to border upon cities also with high sustainability, and the same for cities with low sustainability. The above analysis also verifies that spatial econometric model, by incorporating the spatial correlation into the model, is suitable to analyze the impact of R&O on sustainable development in depth, and uncover the spatial externality among cities.

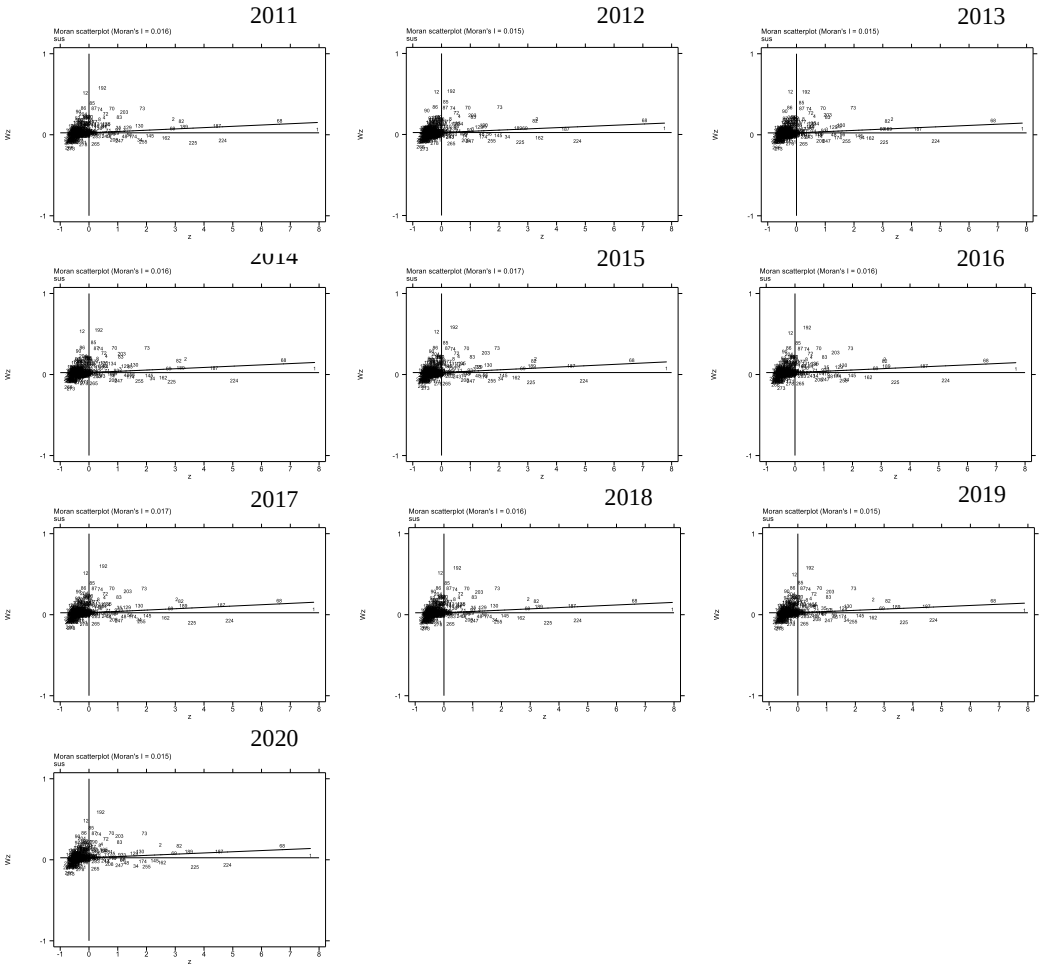


Figure 1. Scatter plot of Moran's I, source: own calculations

#### *3.3.2. Spatial Durbin model*

According to the general practice, LM test and robust LM test are used to determine the appropriate spatial econometric model. Since all of them passed the 1% significance test and rejected the null hypothesis, spatial Durbin model was chosen in this study. The estimated variance of the individual fixed effect is small, and the goodness of fit of the model is relatively large. The estimated variance of the two-way fixed effect is even smaller, but the goodness of fit of the model is small relative to the individual fixed-effect model. Therefore, in consideration of proper effectiveness and explanatory power, this study established the spatial Durbin model with individual fixed effects.

In order to accurately analyze the influence of each variable on sustainable development, this paper further conducts spatial effect decomposition for SDM of individual fixed effect, that is, the total effect of each variable is decomposed into direct effect and indirect effect. Direct effect refers to the influence of variables on the sustaina-

bility of local area, and indirect effect refers to the externalities of variables to surrounding areas, or spatial spillover effect. As presented in table 5, the results of SDM show that the spillover effect of pollution control investment is significantly positive, and both of its direct and indirect effects on sustainability are significantly positive. In contrast, foreign investment does not possess a significant spillover effect and its total effect is much lower than that of pollution control investment. Therefore, regarding sustainable development, as far as the proxy variables are concerned, the promotional impact and spillover effect of reform is greater than that of opening-up.

The spatial spillover effect mainly derives from three aspects. First, the neighboring effect: When the surrounding areas strengthens R&O to promote sustainability, the effect overflows to the local area as they are geographically neighbored. For example, when a city invests in river pollution control, downstream cities will directly benefit from that. Second, the demonstration effect: As the surrounding areas better leverage R&O to achieve high sustainability, the success inspires the local area and forms a demonstration, pushing the local area to learn, imitate and catch up, and finally increase sustainability. Third, the competition effect: For neighboring areas, especially those with similar location and resource conditions, there is fierce competition for enterprises, talents, capital and other resources, and for sustainability due to economic and social demands. When the surrounding areas put forward more effective policies and measures to increase the marginal benefit of R&O, the local area will try the same to follow up, so as to maintain a competitive edge. All effects form a positive externality, mutual promotion among cities enhance sustainable development.

Table 5. Results of spatial Durbin model, source: own calculations

| *sus* | Spatial Durbin | Direct effect | Indirect effect | Total effect |
|---|---|---|---|---|
| *pci* | 0.166*** | 0.178*** | 3.687*** | 3.864*** |
| | (0.047) | (0.045) | (1.424) | (1.427) |
| *fi* | 0.078*** | 0.080*** | 0.286** | 0.366*** |
| | (0.014) | (0.014) | (0.136) | (0.139) |
| *indstr* | 0.005 | 0.005 | 0.013 | 0.018 |
| | (0.004) | (0.004) | (0.012) | (0.016) |
| *indpol* | 0.044*** | 0.045*** | 0.128** | 0.173** |
| | (0.014) | (0.014) | (0.063) | (0.074) |
| *techexp* | -0.010 | -0.010 | -0.026 | -0.035 |
| | (0.018) | (0.018) | (0.049) | (0.066) |
| *govexp* | 0.074* | 0.075* | 0.197* | 0.271* |
| | (0.038) | (0.039) | (0.104) | (0.139) |
| *popdens* | 0.016 | 0.017 | 0.045 | 0.062 |
| | (0.011) | (0.011) | (0.031) | (0.040) |
| *rgdp* | 0.327*** | 0.330*** | 0.926*** | 1.255*** |
| | (0.065) | (0.062) | (0.356) | (0.399) |
| W×*pci* | 0.830*** (0.217) | | | |
| W×*fi* | 0.018 (0.039) | | | |
| obs | 2840 | 2840 | 2840 | 2840 |
| $R^2$ | 0.827 | | | |

Note: standard errors in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

### *3.4. Dynamic panel-data analysis*

#### *3.4.1. Dynamic panel model*

In order to examine the influence of R&O on sustainable development from a dynamic perspective, this paper constructed a dynamic panel model including the first-order lag term of sustainability. Considering that the correlation between dynamic terms and random error terms may be endogenous, and there may be unobserved individual effects related to explanatory variables, this paper used the system generalized moment estimation method (GMM) to estimate the model. The system-GMM method effectively solves the endogeneity problem by using the orthogonal moment between the level variables and the first-order differential error term, and the orthogonal moment between the first-order differential variables and the level error term. Sargan-Hansen test was used to test the overall effectiveness of the instrumental variables. If the value of the statistic is greater than 0.1, the instrumental variables are effective. The results prove that they pass the over-recognition test. The first and second order autocorrelation (AR (1), AR (2)) of the differential conversion equation was assumed to test whether serial correlation of the level error term exists. It is significant for AR (1) and insignificant for AR (2), indicating that GMM estimators are consistent and there is no second-order serial correlation. Thus, the choice of instrumental variables was reasonable, and the model was set correctly. The results are shown in Table 6.

It is found that the coefficients of both pollution control investment and foreign investment are significantly positive. The coefficient of the first-order lag of sustainability ($L\_sus$) is significantly positive at the 1% level, indicating that it is reasonable and necessary for the model to incorporate the lag effect. Sustainable development is a consistent process, the sustainability of the previous period has an impact on the current period. By introducing lag term into the model, endogeneity due to missing variables can be corrected to some extent, making the conclusion more robust.

Table 6. Results of dynamic panel model by system-GMM, source: own calculations

| *sus* | System-GMM |
|---|---|
| *L_sus* | 1.023*** |
| | (0.0268) |
| *pci* | 0.0540** |
| | (0.0240) |
| *fi* | 0.0480** |
| | (0.0200) |
| *indstr* | 0.00162 |
| | (0.00352) |
| *indpol* | 0.0345* |
| | (0.0185) |
| *techexp* | 0.0679 |
| | (0.0629) |
| *govexp* | 0.00315 |
| | (0.107) |
| *popdens* | 0.0141*** |
| | (0.00466) |
| *rgdp* | -0.123** |
| | (0.0533) |
| constant | 0.00111 |
| | (0.00152) |
| AR(1) | 0.000 |
| AR(2) | 0.500 |
| Sargan | 0.508 |
| Hansen | 0.775 |
| obs | 2556 |

Note: standard errors in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

*3.4.2. Dynamic panel threshold model*

From the results of the regional heterogeneity analysis in the previous section, it can be seen that pollution control investment in the west of China has an inhibiting effect on sustainable development, which needs further exploration. This paper introduced threshold model to address this matter. However, the static threshold estimation method cannot reflect the dynamic change or lag effect of the sample data, and also ignores the endogeneity problem. Therefore, this paper employed dynamic threshold model, so as to improve the model by introducing the lag term of sustainability. The LR test for threshold effect indicated a single threshold for pollution control investment on sustainability, and no threshold for foreign investment. Differential-GMM was employed to estimate the model.

As shown in Table 7, when choosing pollution control investment as the threshold variable, the one-period lag of sustainability is significant at the 1% level, suggesting that the sustainability has a significant lag effect. This confirms the rationality of the dynamic threshold model. The threshold value is 7.996 million (in CNY). The coefficient of pollution control is -32.325 below the threshold, while it is 0.07 above the threshold, indicating a non-linear influence manifested as inhibiting first and promoting later. It is evident that, based on the distinct values of the coefficients in the two intervals, once the pollution control investment crosses the threshold, the sustainability will increase rapidly. This to a large extent explains the inhibiting effect of pollution control investment in the west mentioned above: the investment in the west is insufficient and fails to cross the threshold.

*3.5. Robustness test*

In order to ensure the accuracy and reliability of the research results, this paper conducted robustness test by the following three methods, and concluded good robustness of the results.

First, replacing the explained variable. The data envelopment analysis (DEA) method was used to re-calculate sustainability for the regression. Pollution control investment turns insignificant while foreign investment remains significant at the 1% level as shown in column (1) of Table 8.

Second, one-period lag. Key explanatory variables were lagged one period to weaken the effect of reverse causality. Pollution control investment and foreign investment were replaced by their one-period lag. The coefficients of

the both remain significantly positive at the 1% level, consistent with the benchmark regression, as shown in column (2) of Table 8.

Third, shrink-tail treatment. 1% bi-lateral tail reduction treatment was carried out for the key explanatory variables. The value and significance of the coefficients are quite consistent with the benchmark regression, as shown in column (3) of Table 8.

Table 7. Results of dynamic panel threshold model, source: own calculations

| | Low threshold interval | High threshold interval |
|---|---|---|
| *sus* | $pci \leq 7.996$ | $pci > 7.996$ |
| | | |
| *L_sus* | -0.552*** | 0,583*** |
| | (0.148) | (0.149) |
| *pci* | -32.33*** | 0.07*** |
| | (7.731) | (7.732) |
| *fi* | -0.0227 | 0.0344 |
| | (0.0347) | (0.0350) |
| *indstr* | 0.0705*** | -0.0545*** |
| | (0.0191) | (0.0227) |
| *indpol* | -0.0310 | -0.0402 |
| | (0.0297) | (0.0311) |
| *techexp* | 1.276*** | -0.007*** |
| | (0.317) | (0.315) |
| *govexp* | -1.851*** | 0.02*** |
| | (0.425) | (0.425) |
| *popdens* | -0.0365 | 0.0146* |
| | (0.0273) | (0.0297) |
| *rgdp* | -0.543** | 0.027** |
| | (0.238) | (0.239) |
| obs | 2840 | 2840 |

Note: standard errors in parentheses, $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$.

Table 8. Results of robustness test, source: own calculations

| *sus* | (1) | (2) | (3) |
|---|---|---|---|
| *pci* | -0.0227 | | 0.173*** |
| | (0.124) | | (0.0190) |
| *fi* | 0.100** | | 0.122*** |
| | (0.0495) | | (0.00830) |
| *L_pci* | | 0.218*** | |
| | | (0.0208) | |
| *L_fi* | | 0.112*** | |
| | | (0.00858) | |
| *indstr* | 0.0126 | -0.00122 | -0.00184 |
| | (0.0281) | (0.00344) | (0.00338) |
| *indpol* | -0.146*** | 0.0553*** | 0.0311*** |
| | (0.0554) | (0.0106) | (0.00665) |
| *techexp* | -0.191** | 0.00783 | 0.00402 |
| | (0.0817) | (0.00951) | (0.00956) |
| *govexp* | -0.196 | 0.0367*** | 0.0333** |
| | (0.125) | (0.0132) | (0.0131) |
| *popdens* | 0.0711** | 0.0214*** | 0.0274*** |
| | (0.0333) | (0.00379) | (0.00387) |
| *rgdp* | 0.0539 | 0.230*** | 0.305*** |
| | (0.119) | (0.0151) | (0.0141) |
| City FE | YES | YES | YES |
| Year FE | YES | YES | YES |
| obs | 2,832 | 2,556 | 2,840 |
| $R^2$ | 0.749 | 0.447 | 0.548 |

Note: standard errors in parentheses, $^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

*3.6. Discussion*

This paper evaluated the sustainability of 284 prefecture-level cities in China from 2011 to 2020 by entropy weight method, and found that the cities with higher scores of sustainability (Shanghai, Guangzhou and Suzhou) all belong to the east. The main reason is that the eastern region has experienced higher degree of reform and opening-up,

and so developed strong ability in balancing economic development and environmental protection, while the western region being inland is poor in both. As a result, the sustainability of the cities (Ankang and Hulunbuir) in the west ranks the last and faces severe challenge. The overall regional heterogeneity is significant, manifested as the pattern: high in the east, low in the west and flat in the middle. The middle region has achieved positive results from opening-up and regional cooperation. However, compared with the east, the overall level of sustainability in the middle region is still relatively low in terms of its own development needs, and further efforts are needed to push its opening-up to a higher level. The west has been continuously developing industries at the expense of environment under the policy of large-scale development, resulting in a large number of serious pollution problems which eventually hinders economic development. The inherent shortages of the west undermine sustainability, making it rank at the bottom, but it also means there is great potential for improvement.

The empirical study on the correlation between sustainable development and R&O shows that R&O has a significant positive effect on sustainable development, and the same conclusion can be reached after considering lag effect and using dynamic panel model. The pollution control investment as the proxy variable of *reform* has a stronger promoting effect on sustainability than the foreign investment as the proxy variable of *opening*, which, however, varies in different regions. Further results of spatial econometric analysis show that cities with similar levels of sustainability are clustered, and the pollution control investment has a significant spillover effect in space, meaning that urban pollution control has a positive externality, and that an internal mechanism of mutual promotion in terms of sustainability among Chinese cities is in effect. In addition, pollution control investment has a significant threshold effect, indicating a nonlinear effect on sustainability. The sustainability of the cities decreases with the increase of pollution control investment below the threshold, while the sustainability increases with the increase of pollution control investment above the threshold.

## 4. Conclusion

With the deepening implementation of the reform and opening-up policy, China has continuously practiced and enriched the concept of sustainable development and achieved fruitful results. However, by the discussion above, it is still imperative to further promote reform and opening-up, especially in the western and middle regions. Strong policies must be put in place to make sure pollution control is strengthened, resources are preserved and wastes are comprehensively re-used. Meanwhile, the purpose of utilizing foreign investment must transit from accelerating economic growth alone to promoting sustainable development. The following measures can be taken into consideration.

First, different governance tools can be adopted according to the sustainable development level of different cities. In order to promote the transformation of the production mode of cities in the west to a more sustainable type, the resource conservation support system and green infrastructure must be constructed (WANG et al.,2022), pollution prevention and control must be tightened. The growth mode of *high input, high consumption and high emission* should be gradually changed, and an ecological compensation mechanism should be established. Green transformation and upgrading in the west are needed to prevent backward cities from paying excessive resource and environmental costs in their development.

Second, in terms of domestic pollution control, the government should first increase the pollution control investment, at least over the threshold value which is 7.996 million in CNY, in order to achieve positive marginal benefit. In addition, take such measures as establishing and improving environmental policy system, increasing the use of new energy, improving energy efficiency, advocating low-carbon environmental protection technologies, and implementing energy conservation and emission reduction. Regarding the situation that backward industrial structure is locked in less developed cities, the policy-making should focus on optimizing the industrial structure, promoting the intensive use of production factors, increasing the proportion of tertiary industry, and realizing the transformation from traditional industry to green, low-carbon and environmentally friendly industry.

Third, in terms of foreign cooperation, while giving full play to the comparative advantages, local governments also need to proactively introduce, digest and absorb advanced foreign technologies, so as to continuously optimize the mix of export products, raise the added value of export products and reduce the cost of resources and environment. The governments should step up cooperation on green investment, share experience on green development technologies, and leverage the driving force of foreign investment in promoting sustainable development in the light of existing cooperation mechanisms among international and regional organizations.

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