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Dynamic effect of smartness on environmental sustainability: Based on PVAR model for 72 Chinese cities

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Abstract: With the continuous implementation of the smart city concept, smart cities have become an important tool for the country's new urbanization. Therefore, it is of great concern whether smart cities can help promote environmental sustainability. Most of the existing studies mainly discuss whether the proposed smart policies are effective for environmental sustainability, but the specific impact paths are not clear and long-term dynamic implications for policy have not yet been explored in depth

This study takes 72 cities in China as an example, and divides the impact path of smart cities into four aspects: internet technology, science and technology innovation(STI), smart environment and smart people's livelihood. Environmental sustainability is measured by energy consumption and air pollution, and the cities are divided into characteristic cities according to resource endowment and economic development, and the dynamic impact on environmental sustainability is explored based on the Panel Vector Auto-Regression (PVAR) model. The results indicate that STI has a negative effect on air pollution in all cities in the early stage and a positive effect in the later stage, with the overall effect being more significant in developed cities. Internet development has an impact on air pollution control in developed cities, but the effect is positive in the early stage and negative in the later stage. STI and Internet technology have very significant results on energy consumption reduction. But for developed cities, the effect of STI on energy consumption is positive. This paper provides policy suggestions for the sustainable development of environment in cities with different characteristics in China from the perspective of smart city development.

Keywords: Environmental sustainability, Smart city, Driving factors, PVAR, Dynamic impact

1. Introduction

Environmental sustainability is not only one of the 17 international sustainable development goals, but also an important task for China to jointly promote global ecological and environmental governance and the realization of the carbon peaking and carbon neutrality. Cities are the largest application scenario for the realization of the carbon peaking and carbon neutrality, and as the concept of new smart cities rises to become a

national strategy, the need for the development of new green smart cities has also become a top priority. Therefore, it is of great interest to explore whether smart cities can help promote environmental sustainability. Most existing studies use the DID model to analyze whether the proposal of smart policies is effective for environmental sustainability, and the specific path of influence is not yet clear. In addition, there is no in-depth investigation on how the long-term effects of smart city policies. To this end, this study first constructs a smart city indicator system from four dimensions: Internet technology, scientific and technological innovation(STI), smart environment and smart people's livelihood, and then takes carbon emission and air pollution as the indicators of environmental sustainability, and analyzes the effect of the long-term dynamic impact(Rebound effects) of the smart city on environmental sustainability by using the Panel Vector Auto-Regression (PVAR) model, and finally, divides China's cities into different categories according to the resource endowment and the GDP, and explores the effect of the smart city policy in cities with different characteristics, respectively. Finally, based on resource endowment and GDP, Chinese cities are divided into different categories to explore the effect differences of smart city policies in cities with different characteristics. Based on the above analysis, this paper will provide policy recommendations for the sustainable development of urban environment in China.

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2. Data and Methods

2.1 Data

In order to study how smart city policy can improve urban environmental sustainability, this paper adopts four aspects of internet technology, scientific and technological innovation, smart environment and smart people's livelihood as the way to influence smart city policy on environmental sustainability, and urban environmental sustainability is measured by two dimensions of air pollution and carbon emission.

In order to fully study the impact of smart city policies, this paper selected the first batch of smart cities in 2012 and the additional smart cities in 2013 as samples. Due to the serious lack of data in some cities and regions, 72 smart cities were finally selected and analyzed in this paper. Considering the impact of COVID-19 on various cities in 2020, the period 2009-2019 was selected as the time span. Carbon emission data refer to Wu Jianxin's1 Research method, comprehensively considering the direct carbon emissions of urban liquefied petroleum gas, gas and the carbon emissions of electric energy and heat energy consumption calculation. The annual average PM2.5 concentration is derived from Columbia University statistics, and the basic data and other indicators used to calculate carbon emissions are taken from the national and regional statistical yearbooks. For the two indexes of internet technology and STI, the secondary indexes such as the number of Internet users and mobile users, the number of patents granted and the number of science and researchers are measured after the integration of principal component analysis method, as shown in the following table(Table 1).

Table 1. Indicator system for environmental sustainability and smart city

dimension	metric	attribute
Internet Technology (net)	Number of Internet users	benefit
	Number of mobile users	benefit
Science and technology innovation (sci)	Number of patents granted	benefit
	Number of science and researchers	benefit
Smart environment (gre)	Green coverage rate of the built-up area	benefit
Smart people's livelihood (hos)	The number of urban medical institutions	benefit
Air pollution (pm)	Mean annual PM2.5 concentration	benefit
Carbon emission (c)	Carbon dioxide emissions	benefit

2.2 Methods

On this basis, this paper divides the 72 cities into three categories of less developed cities, moderately developed cities and developed cities by 2015 regional GDP respectively, and divides the cities into two groups of resource cities and non-resource cities according to resource endowment with reference to the National Sustainable Development Plan for Resource Cities (2013-2020), as a means of in-depth study of the role of the smart city policy on cities with different conditions.

To study the relationship between each variable, the PVAR model proposed by Holtz-Eakin2 was used. The PVAR model does not need to set the causal relationship between variables in advance, but regards each variable as endogenous variables, analyzes the influence of each variable and its lagging variables on other variables in the model, and has the characteristics of large section and short timing.

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$$Y_{it} = \sum_{j=1}^{p} A_j Y_{it-j} + \mu_i + \varphi_t + \varepsilon_{it} \quad (1)$$

Among them,i represents the city, t represents the province, μ_i represents the fixed effect of the city, φ_t represents the city time effect, ε_{it} represents the error term, A_j and represents the lag order.

Using the PVAR model, the unit root test is required to test the data to verify the data stability. After the data is stable, the optimal lag order is selected according to the Akchi Information Criterion (AIC), Bayesian Information Criterion (BIC) and Hannan-Quinn Information Criterion (HQIC). Then, the causal relationship between each variable was revealed by Granger test, and the final results were obtained by drawing the pulse response map. In this paper, stata16.0 was used to process the data and plot the pulse response map and other results.

3. Results

3.1 Carbon emission and air pollution classic example

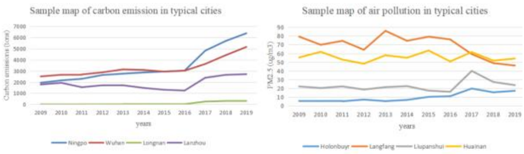

Figure 1 Sample example of carbon emission and air pollution

As can be seen from the sample chart, in the overall trend, urban carbon emissions gradually increased, and air pollutants gradually decreased.However, some of the samples had trends different from the overall, for example, air pollutants in Hulonbur and Liupanshui gradually increased with years.

3.2 Impact of smart city construction on carbon emissions

3.2.1Analysis of all cities

Now take the first order difference after the logarithm of the data to make it stable, and the results of the unit root test are as follows(Table 2).

Table 2 Unit root test results for the data

Variable	Harris-Tzavalis tests		Im-Pesaran-Shin tests		Levin-Lin-Chu tests	
	Staistic	P -value	Staistic	P -value	Staistic	P -value
d_lnnet	-0.1729	0.0000***	-17.5198	0.0000***	-21.0923	0.0000***
d_lnsci	-0.1170	0.0000***	-0.80808	0.0000***	-11.6769	0.0000***
d_lngre	-0.1591	0.0000***	-14.7390	0.0000***	-23.9680	0.0000***
d_lnhos	-0.2161	0.0000***	-909013	0.0000***	-17.8252	0.0000***
d_lnc	-0.1574	0.0000***	-9.2766	0.0000***	-16.3174	0.0000***

Note: d_ means take the first order difference after the logarithm of the data

Note:**P<0.05,***P<0.01

Table 3: Granger causality test results

hypothesis	Chi2	P-value
Cause of why d_C is not d_Net	4.677	0.031
Cause that d_C is not d _ Sci	5.254	0.022
Cause why d_C is not d _ Gre	2.448	0.118
Cause that d_C is not d _ Hos	0.592	0.442

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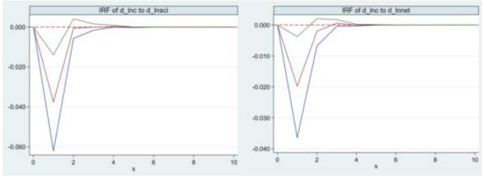

Figure 2. Impulse response plot for all cities

For all cities, the relationship between carbon emissions and Internet technology and STI has passed the Granger causality test at a lag order of 1(Table 3).

As can be seen from the figure above(Figure 2), the ability of STI and Internet technology have a significant effect on the reduction of carbon emissions. Compared with Internet technology, the ability of STI has a more significant effect on the reduction of carbon emissions, and is concentrated in the early stage, and the long-term effect is not very significant.

3.2.2Analysis of the pulse response map to the characteristic cities

For less developed cities, the impact of STI on carbon emissions is significantly higher than that of STI for all cities, indicating that for less developed cities, STI ability is more helpful to reduce carbon emissions. It is worth noting that, for moderately developed cities, the carbon emission reduction effect of STI and Internet technology ability is not particularly significant compared with that of all cities, as shown in the figure below(Figure 3). And focus on the early stage of the role, the long-term effect is not very significant.

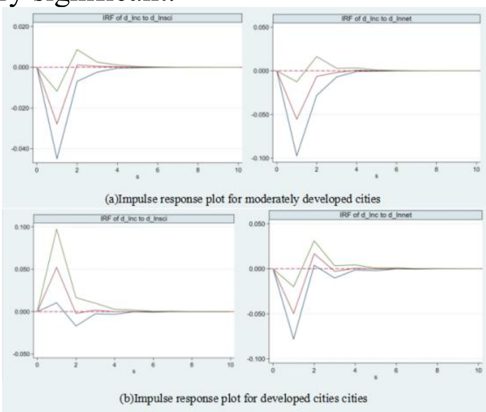

Figure 3 impulse response diagram

For developed cities(Figure3), although the Internet technology capability can inhibit the carbon emissions of cities, its effect is further weakened compared with that of medium developed cities, and it will become a positive effect in the later stage. The STI capacity intensifies the carbon emissions, which is the biggest difference from other cities.This may be that although STI reduces production costs and improves production efficiency, it expands the production scale and market demand, which makes the carbon emissions of regions with strong STI ability increase instead3.

The above data prove that, with the development of GDP, STI and internet technology ability to the city of carbon emissions inhibition effect gradually weakened, even in the developed areas of STI ability may increase the carbon emissions.

For non-resource-based cities(Figure 4), internet technology has a stronger ability to suppress carbon emissions. Thus Internet technology for the positive role of urban carbon emissions, the Internet city of different economic conditions, resource conditions of carbon emissions have inhibitory effect, this may be the development of Internet technology by accelerating the spread of advanced technology and communication, promote the upgrading of industrial structure, prompting urban residents' life online, intensive and formed.

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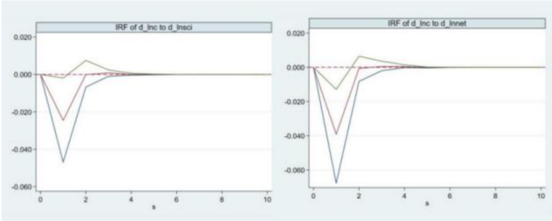

Figure 4 Pulse response map of non-resource cities

3.3 The impact of smart city construction on air pollution

3.3.1Analysis of all cities

Table 4. Results of the unit root test

Variable	Harris-Tzavalis tests		Im-Pesaran-Shin tests		Levin-Lin-Chu tests	
	Staistic	P -value	Staistic	P -value	Staistic	P -value
d_lnnet	-0.1729	0.0000***	-17.5198	0.0000***	-21.0923	0.0000***
d_lns ci	-0.1170	0.0000***	-0.80808	0.0000***	-11.6769	0.0000***
d_lngre	-0.1591	0.0000***	-14.7390	0.0000***	-23.9680	0.0000***
d_lnhos	-0.2161	0.0000***	-909013	0.0000***	-17.8252	0.0000***
d_ln pm	-0.2931	0.0000***	-14.9274	0.0000***	-15.1948	0.0000***

Note:**P<0.05,***P<0.01

Table 5: The Granger causality test form

hypothesis	Chi2	P-value
The d _ Pm is not the cause for the d_Net	0.918	0.338
The d _ Pm is not the cause of the d _ Sci	3.733	0.053
The d _ Pm is not the cause for the d _ Gre	5.675	0.017
The d _ Pm is not the reason for the d _ Hos	8.782	0.003

From the above table(Table 5), it can be concluded that the relationship between the degree of air pollution and the ability of STI, smart environment and smart people's livelihood passes the Granger causality test at lag order 1

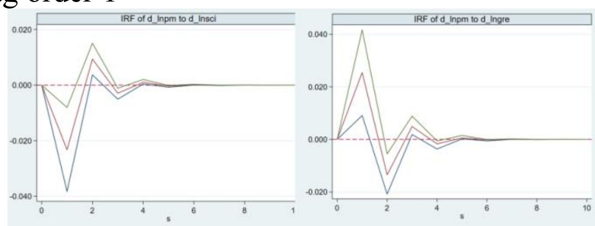

Figure 5. All of the pulse response diagram

From the pulse map(Figure 5), STI ability has a negative impact on air pollution in the early stage and positive stage in all cities. The effect of technological innovation in the early stage is very significant, but in the later stage, pay attention to the scale effect and the air pollution caused by new emission sources.

It is worth noting that the growth of green space plays a role in inhibiting air pollution in the long term, but it will aggravate air pollution in the short term(Figure 5).

The smart environment driven by the growth of green space has a negative effect on air condition and a positive effect in the later stage. Green space plays a role in purifying the air through the adsorption of pollutants, but at the same time, the tree planting in the green space hinders the air circulation, which will increase the concentration of local pollutants and aggravate the air pollution4.

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3.3.2Analysis of characteristic cities

For moderately developed cities(Figure 6), the inhibitory effect of STI ability on air condition is lower than that of all cities.

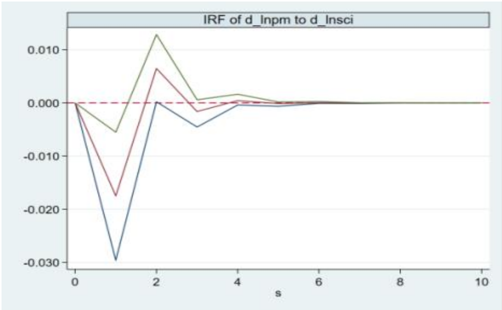

Figure 6 Pulse response plot in moderately developed cities

For developed cities(Figure 7), air pollution is mainly related to the level of smart people's livelihood and Internet technology, among which Internet technology has a significant inhibitory effect on air pollution, while the construction of smart people's livelihood has improved the air pollution level of cities.

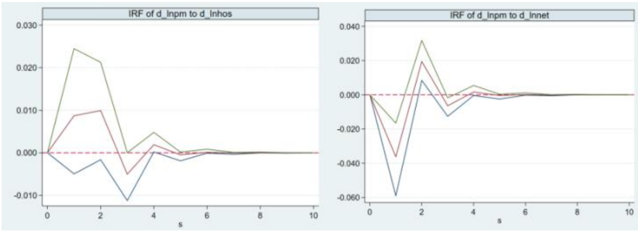

Figure 7 Pulse response diagram in developed cities

4. Conclusion and Policy recommendations

This study takes 72 cities in China as an example, and divides the impact path of smart cities into four aspects: internet technology, STI, smart environment and smart people's livelihood. Environmental sustainability is measured by energy consumption and air pollution, and the featured cities are divided according to resource endowment and economic development, and their dynamic impact on environmental sustainability is explored based on the PVAR model.

STI has a negative effect on air pollution in all cities in the early stage and a positive effect in the later stage, with the overall effect being more significant in developed cities. Therefore, for all cities where smart policies are implemented, especially developed cities, it is important to promote technological development while being wary of the consequences of more serious air pollution at a later stage due to scale effects and increased consumer demand. The impact of Internet development on air pollution management in developed cities has a positive effect in the early stages and a negative effect in the later stages. Targeted measures should be taken to strengthen the coverage of Internet infrastructure in order to cross the inflection point and enter the downward zone of the curve as soon as possible5, and to realize the effectiveness of Internet facilities in reducing air pollution as soon as possible. In the early stage, pay attention to the negative impact on environmental quality caused by the electronic waste that is constantly eliminated under the rapid updating and iteration of Internet-related products, and improve the treatment process and method of electronic waste. In addition, we should also be alert to the fact that the effect of green space on air pollution control may be interfered by the neighboring geographical environment, which may affect the adsorption of pollutants by green space.

STI and Internet technologies have had very significant results in reducing carbon emissions. However, for developed cities, the impact of STI on energy consumption is positive. Therefore, for non-resource cities, moderately developed cities and less developed cities, we should actively

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utilize the advantages of STI to reduce energy consumption, and promote the scale of science and technology development and application. For developed cities, they should be wary of the rebound effect of STI, actively promote the development of intensive industries, and control the scale of industry and consumption.

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