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Preliminary communication

Influence Mechanism of Smart City Innovation on Green Supply Chain Network Efficiency

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Abstract: The traditional logistics industry faces increasingly prominent problems like high energy consumption, high pollution, and high emissions. The improvement of green supply chain network efficiency (GSCNE) has become the development direction of this industry. Focusing on the panel data of 225 prefectures in China during 2012-2021, this paper uses the difference in differences (DID) method to explore the influence mechanism of smart city construction on GSCNE. The results show that smart city construction can enhance GSCNE via three mediators: information and communication technology (ICT), sustainable development, and technological innovation. Finally, some managerial implications were summarized according to the research conclusions.

Keywords: green supply chain network efficiency; mediating effect; smart city innovation

1 INTRODUCTION

Green development is an important direction of the logistics industry. However, the logistics supply chain faces extremely severe problems like pollution and energy consumption, owing to the high energy consumption, high pollution, and high emissions in the traditional logistics industry [1-9]. That is why the green supply chain came into being. This novel supply chain can improve the supply chain efficiency of logistics enterprises, and better the ecology of the industry. Among the evaluation indicators for green supply chain, GSCNE is the most important evaluation indicator, which not only covers the efficiency factors of supply chain, but also reflects the relationship between the supply chain and the environment [10]. The emergence of green supply chain is accompanied by the continuous development of information technology.

In 2010, IBM formally proposed the vision of smart city, which essentially integrates informatization with urbanization. Advanced information technologies, such as the Internet of things, cloud computing, and big data, need to be relied on to kick off a new round of scientific and technological revolution and industrial transformation. In 2012, China officially listed the first batch of smart cities, which digitize various resources and facilities through information technology, aiming to realize intelligent urban planning and management, improve the quality of life of residents, promote urban sustainability, and inject new impetus for economic transformation [11].

The Cyberspace Administration of China defined the important task of building new smart cities: the goals are providing full-time service for the people, govern cities efficiently and orderly, sharing data in an open and integrated manner, developing green and opensource economy, and ensuring cybersecurity and cleanness; the mission is to achieve the new ecology of coordinated development between the country and cities by promoting the deep integration and iterative evolution between new generation information technology and urban modernization through systematic planning, information prioritization, as well as reform and innovation [12]. Among them, the "green and opensource economy" is the primary goal of new smart city construction.

With the continuous development of information technology, the data collected and utilized in the logistics supply chain can be used to effectively optimize the supply chain system in each link, and achieve the continuous improvement of GSCNE [13]. Therefore, the construction of smart city is a key factor for the improvement of GSCNE. It is necessary to deeply explore the influence mechanism of smart city construction on GSCNE.

Most relevant studies merely evaluate the green development level of a region statically, failing to fully reflect the state of green economic transformation. The impact of economic growth should be further considered [14]. Concerning the factors affecting GSCNE, the previous research mainly examines foreign direct investment (FDI), environmental regulation, and other traditional fields. There are few reports on how smart city construction affects green development, not to mention the improving mechanism of smart city construction on GSCNE [15]. In addition, the policy effect on smart cities is mainly evaluated from a single dimension (e.g., environment and economy). Few have considered the environmental and economic benefits comprehensively. Hence, this research is of great theoretical and practical significance to the construction of smart cities.

2 THEORETICAL ANALYSIS AND HYPOTHESES

Currently, scholars mainly explore the action pathways of smart city construction from three perspectives: The first perspective believes that the application of information and communication technology (ICT) can improve the dexterity of urban operation, thereby creating a smart city [16]. The second perspective stresses the concept of sustainable development, and promotes sustainable development through such measures as encouraging non-motorized vehicles and public transportation, and protecting farmland around the city, before creating an eco-city [17]. The third perspective focuses on the development of urban innovation capabilities, and builds a knowledge city by building an environmental system that is conducive to the improvement of innovation capabilities [18]. The above three perspectives correspond to three driving factors, namely, ICT application, sustainable development, and technological innovation. Therefore, this paper mainly analyzes the influence mechanism of smart city construction on GSCNE from these aspects.

The application of emerging technologies can promote urban development towards informatization, accelerate the cultivation of the information industry, and give birth to the

formation and development of emerging industries in smart cities. The development of the information industry not only promotes its own optimization, but also spurs the further development of related high-tech industries. The integration of emerging technologies and traditional industries can also further promote the transformation of traditional industries, which in turn promotes the optimization of supply chains, thereby supporting the improvement of GSCNE. In this regard, this paper puts forward the following hypothesis:

H1: Smart city construction improves GSCNE through ICT application.

One of the main purposes of building smart cities is to realize sustainable development. In the pursuit of sustainable development, it is necessary to apply more new technologies to traditional industries, so as to promote the upgrading of traditional industries and agricultural modernization, and update production methods. The original industrial form of the city will be changed through the harmonious coexistence of people, nature and the environment, thereby enhancing GSCNE. Meanwhile, the sustainable development puts forward new requirements for environmental protection. During smart city construction, new technological means make it easier for the public to obtain information on environmental pollution or protection, establish the awareness of environmental protection, enhance the enthusiasm for environmental protection participation, and improve environmental regulation measures [19]. In this way, the behaviour of upstream and downstream enterprises in the supply chain is regulated, and GSCNE is further improved. In this regard, this paper puts forward the following hypothesis:

H2: Smart city construction increases GSCNE through sustainable development.

A defining feature of smart cities is technological innovation [20]. During smart city construction, the application of tools such as information technology and social networks helps to enhance the city's technological innovation capabilities. In the rapidly developing technological environment, the open innovation platform of smart cities enables enterprises or industries to more easily access cutting-edge technologies related to their own development. The ensuring acceleration of technology dissemination, application and re-innovation will stimulate industrial expansion and development [21]. While improving the efficiency of the entire supply chain, the impact on the environment is reduced, thereby improving GSCNE. In this regard, this paper puts forward the following hypothesis:

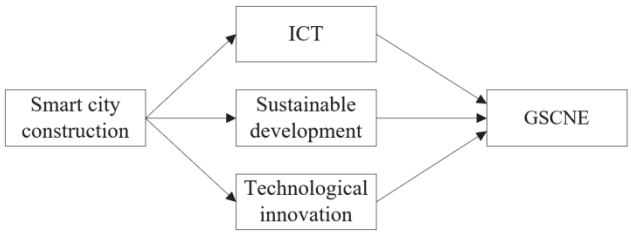

Figure 1 Theoretical model for the influencing mechanism of smart city construction on GSCNE

H3: Smart city construction enhances GSCNE through technological innovation.

To sum up, our theoretical model is shown in Fig. 1.

3 RESEARCH DESIGN

3.1 Sample Selection

China is one of the few countries in the world that has been rapidly developing smart cities in recent years, and has attached great importance to GSCNE. Therefore, the influence mechanism of smart city construction on GSCNE can be studied through the development process of smart cities in China. The first batch of smart cities was announced in China in 2012, and the second and third batches were successively established in 2013 and 2014. Different regions in the country vary in the time of smart city construction. This feature gives smart city construction the nature of quasi-natural experiment. Hence, this paper uses the difference in differences (DID) method to explore the influence mechanism of smart city construction on GSCNE. According to the data released by the China Smart City website, by the end of 2021, China's smart cities involved a total of 290 prefectural and county-level cities. This paper mainly uses the sample data of prefectural cities (hereinafter referred to as prefectures). Some prefectures only designate a few districts or counties in its administration as smart cities. If such prefectures are treated as smart cities as a whole, the influence of smart city construction on GSCNE will be underestimated. Hence, such prefectures were removed from the samples. After matching and screening, the final sample data cover 225 prefectures.

3.2 Model Settings

The following two-way fixed-effects model was constructed for difference in differences (DID) analysis:

$$gscne_{it} = \alpha_0 + \alpha_1 did_{it} + \delta X_{it} + D_i + D_t + \varepsilon_{it} \quad (1)$$

where, subscripts i and t are the serial number of prefectures and years, respectively; the explained variable $gscne$ is the regional level of GCSE; X_{it} is the set of control variables; D_i is the individual fixed effects of each prefecture; D_t is the time fixed effects; ε_{it} is the random disturbance; did_{it} is the core explanatory variable. The regressed value of its coefficient α_1 measures the net effect of smart city construction on GSCNE. If $\alpha_1 > 0$, smart city construction indeed improves GSCNE; otherwise, smart city construction inhibits GSCNE.

3.3 Variable Measurement and Data

(1) Explained variable: GSCNE

Referring to the research of Li [22], the GSCNE of a prefecture was measured by the total inventory of listed companies that have obtained GSCNE in the prefecture.

(2) Core explanatory variable: smart city construction

The values were assigned to the prefectures, according to the list of smart cities announced by the Ministry of Housing and Urban-Rural Development and the Ministry of Science and Technology of China, in the light of the order of enlisting. If a prefecture becomes or is already a smart city in the current year, it will be assigned 1; otherwise, it will be assigned 0.

(3) Control variables

To control the impact of other factors on prefectural GSCNE as much as possible, the following variables were controlled in reference to the previous practices: level of economic development (*pgdp*), measured by per-capita gross domestic product (GDP) [23]; level of human capital (*human*), measured by the number of college students as a proportion of the total year-end population of the prefecture [24]; level of infrastructure (*infra*), measured by the area of paved roads as a proportion of the administrative area of the prefecture [25]; fixed asset investment (*assets*), measured by the total fixed asset investment in the current year divided by the regional GDP [26]; degree of opening-up (*open*), measured by the foreign investment in actual use divided by the total year-end population of the prefecture [27].

This paper investigates the influence of smart city construction on regional GSCNE, using the panel data on 225 prefectures in China from 2012 to 2021. The data were collected from https://www.cnscn.com.cn/, statistical yearbooks of cities and provinces in China, *China Urban Statistical Yearbooks*, and China Economic and Social Development Statistical Database. The descriptive statistics of the variables are listed in Tab. 1.

Table 1 Descriptive statistics of the main variables

	Name	Sign	Mean	Minimum	Maximum
Explained variable	GSCNE	*gscne*	18.2158	13.4785	23.4156
Core explanatory variable	Smart city construction	*did*	0.2135	0	1
Control variables	Level of economic development (log)	*pgdp*	11.1245	7.2145	13.8547
	Level of human capital	*human*	0.1824	0.0932	0.3847
	Level of infrastructure	*infra*	0.2014	0.0015	3.7245
	Fixed asset investment	*assets*	0.8351	0.0957	2.4578
	Degree of opening-up	*open*	0.1324	0.0003	1.2314

4 EMPIRICAL RESULTS AND ANALYSIS

4.1 Analysis on Benchmark Regression Results

This paper employs the two-way fixed-effects econometric model to test the influence of smart city construction over GSCNE. Tabx. 2 reports the preliminary estimations of how smart city construction influences GSCNE. Model 1 controls the time and regional effects. The results of Model 1 suggest that the estimation coefficient of smart city construction on GSCNE was always positive; the estimated value was 0.2365, which is significant at the level of 1%. Model 2 further controls the effects of the other relevant variables. The results of this model indicate that estimation coefficient of smart city construction on GSCNE was always positive; the estimated value was 0.2234, which was slightly smaller than that of Model 1. The above benchmark regression results show that, after the implementation of smart city policies, the test prefectures saw faster growth of GSCNE than the control prefectures. Hence, smart city construction can significantly boost prefectural GSCNE, which agrees with our theoretical expectation.

Table 2 Benchmark regression results

	GSCNE (*gscne*)	
	Model 1	Model 2
did	0.2365*** (0.0438)	0.2234*** (0.0427)
pgdp		0.9367*** (0.1653)
human		2.8542*** (0.6574)
infra		−0.2354*** (0.1529)
assets		−0.9654*** (0.1657)
open		0.3761* (0.215)
Time effects	Yes	Yes
Regional effects	Yes	Yes
Constant term	17.975*** (0.0378)	8.347* (1.0247)
Sample size	2250	2250
R^2	0.5894	0.5264

Note: *, **, and *** are significance levels of $P \leq 0.1$, $P \leq 0.05$, and $P \leq 0.01$, respectively; the standard errors are in parentheses.

4.2 Mediating Effect Testing

The above empirical results prove that smart city construction promotes regional GSCNE. However, the promoting mechanism remains purely theoretical. To provide empirical evidence, this paper decides to empirically verify the mediating effect.

As suggested by H1-3, smart city construction could indirectly boost regional GSCNE via ICT, sustainable development, and technological innovation. To verify these hypotheses, the following recursive equations were constructed, following the Hayes mediating effect testing method:

$$gscne_{it} = \alpha_0 + \alpha_1 did_{it} + \delta X_{it} + D_{1i} + D_{1t} + \varepsilon_{1it} \quad (2)$$

$$M_{it} = \theta_0 + \theta_1 did_{it} + \varphi X_{it} + D_{2i} + D_{2t} + \varepsilon_{2it} \quad (3)$$

$$gscne_{it} = \gamma_0 + \gamma_1 did_{it} + M_{it} + \eta X_{it} + D_{3i} + D_{3t} + \varepsilon_{3it} \quad (4)$$

where, M is a mediating variable, including ICT (MI), sustainable development (MS), and technological innovation (MT); the other variables are of the same meaning as in Eq. (1).

According to the analysis method of mediating effect, the first step is to perform benchmark regression of formula (2), with the aim to verify whether smart city construction promotes GSCNE. If $\alpha_1 > 0$ and is statistically significant, then smart city construction indeed promotes GSCNE. The second step is to perform regression estimation of formula (3), with the aim to disclose the interplay between smart city construction and mediating variables. The third step is to regress formula (4). If the coefficients to be estimated satisfy $\alpha_1 > 0$, $\theta_1 > 0$, and $\alpha_1 > \gamma_1 > 0$, then the above positive mediating effect indeed exists. The regression results of Step 1 are displayed in Tab. 2. The regression results of Steps 2-3 are shown in Tab. 3.

As for the measurement of mediating variables, MI was represented by the users of mobile phones and the users of broadband, MS by the reciprocal of wastewater and waste gas emissions (the reciprocal was taken because

wastewater and waste gas emissions are negative indices), and MT by the per-capita number of patent applications.

The following can be seen from the results of Models 3-4 in Tab. 3: Smart city construction improves GSCNE via the mediating variable of ICT. There are three manifestations: Firstly, the estimation coefficient of smart city construction for GSCNE in Model 3 was significantly positive, which confirms the promoting effect of smart city construction on GSCNE. Secondly, the estimation coefficient of ICT was 0.0374 in Model 4, passing the significance test; this means ICT helps to improve GSCNE. Thirdly, the core explanatory variable (*did*) had a significantly positive coefficient (0.1548) in Model 4, while the coefficient was 0.2234 in the benchmark model of Tab. 2. Therefore, the influence of smart city construction over GSCNE declined after the ICT was controlled. The above regression results imply that ICE is an important channel for smart city construction to enhance GSCNE. H1 is therefore validated.

The following can be seen from the results of Models 5-6 in Tab. 3: Smart city construction improves GSCNE via the mediating variable of sustainable development. There are also three manifestations: Firstly, the estimation coefficient of smart city construction for GSCNE in Model 5 was significantly positive, which confirms the promoting effect of smart city construction on GSCNE. Secondly, the estimation coefficient of sustainable development was 0.0676 in Model 6, passing the significance test; this means sustainable development helps to improve GSCNE. Thirdly, the core explanatory variable (*did*) had a significantly positive coefficient (0.1653) in Model 6, while the coefficient was 0.2234 in the benchmark model of Tab. 2. Therefore, the influence of smart city construction over GSCNE declined after the sustainable development was controlled. The above regression results imply that sustainable development is another important channel for smart city construction to enhance GSCNE. H2 is therefore validated.

The following can be seen from the results of Models 7-8 in Tab. 3: Smart city construction improves GSCNE via the mediating variable of technological innovation. There are also three manifestations: Firstly, the estimation coefficient of smart city construction for GSCNE in Model 7 was significantly positive, which confirms the promoting effect of smart city construction on GSCNE. Secondly, the estimation coefficient of technological innovation was 0.0453 in Model 6, passing the significance test; this means technological innovation helps to improve GSCNE. Thirdly, the core explanatory variable (*did*) had a significantly positive coefficient (0.1875) in Model 8, while the coefficient was 0.2234 in the benchmark model of Tab. 2. Therefore, the influence of smart city construction over GSCNE declined after the technological innovation was controlled. The above regression results imply that technological innovation is an important channel for smart city construction to enhance GSCNE, too. H3 is therefore validated.

Table 3 Mediating effect testing results

Variable	ICT		Sustainable development		Technological innovation	
	MI	*gscne*	MS	*gscne*	MT	*gscne*
	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
did	2.2487*** (0.4125)	0.1548*** (0.0547)	3.1536*** (0.4125)	0.1653*** (0.0654)	2.7654*** (0.4575)	0.1875*** (0.0526)
pgdp	−3.2447*** (1.5254)	1.2545*** (0.1463)	−2.8464*** (1.6534)	1.2756*** (0.1643)	4.7654*** (1.7543)	1.5453*** (0.1756)
human	29.6844*** (1.2357)	3.1478*** (0.6574)	27.1454*** (1.2542)	4.7534*** (0.7456)	31.4564*** (1.6546)	3.7533*** (0.6745)
infra	27.514*** (1.3547)	−0.8454*** (0.2114)	26.7654*** (1.8743)	−0.9563*** (0.3254)	28.4536*** (1.5653)	−0.7956*** (0.2845)
assets	1.3254 (0.9145)	−0.9741*** (0.1368)	1.5642 (0.8914)	0.8745*** (0.1654)	1.5634 (0.8643)	0.8663*** (0.1456)
open	5.2645*** (2.957)	0.3014 (0.2187)	6.1656*** (2.8765)	0.4567 (0.3754)	4.9764*** (3.0845)	0.4673* (0.3215)
MI		0.0374*** (0.0076)				
MS				0.0676*** (0.1246)		
MT						0.0453*** (0.2457)
Time effects	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Regional effects	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Constant term	45.2547** (17.3547)	2.4759* (1.8745)	32.4642*** (15.4642)	3.2312* (2.3454)	20.5656*** (18.5469)	4.456*** (1.8745)
Sample size	2250	2250	2250	2250	2250	2250
R^2	0.5424	0.5546	0.5235	0.5464	0.5509	0.5546

5 CONCLUSIONS AND IMPLICATIONS

This paper treats the batch establishment of smart cities in China as a quasi-natural experiment. Based on the panel data on 225 prefectures in 2012-2021, the authors estimated the influence of smart city construction over GSCNE by the DID method. The results show that smart city construction can significantly enhance GSCNE; this result stands after considering recognition conditions and potential measuring errors. Besides, smart city construction can boost GSCNE via three channels: ICT, sustainable development, and technological innovation. This paper studies the green supply chain from a dynamic and multi-dimensional perspective, and improves the static and single-dimensional shortcomings of previous research.

The conclusions provide insights into improving GSCNE and guiding smart city construction. For governments, they should pay attention to the role of smart

city construction in improving GSCNE, and transform the urban development model into the smart city construction. Firstly, it is necessary to actively apply ICT, build knowledge sharing platforms, and improve GSCNE with the aid of new technologies, such as the Internet, Internet of Things, and big data. Secondly, it is necessary to attach importance to environmental protection and ecological construction, improve pollutant discharge standards, invest more in pollution control, encourage technological innovation of enterprises, develop cleaner production, and use environmental regulations to improve GSCNE. Finally, it is necessary to build an innovative R&D platform, cultivate innovative talents, and use new technologies to incubate new industries, thereby improving GSCNE. For enterprises, they can improve their own GSCNE by strengthening informatization construction, focusing on the sustainable development of enterprises, and carrying out technological innovation activities.

In this paper, the total inventory of listed companies in a city is used to represent GSCNE. However, the diversity of sample industries is ignored. In future research, industries can be classified to explore the impact of smart city construction on GSCNE under different industry backgrounds.

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