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Spatiotemporal Evolution Characteristics and Influencing Factors of China's Automobile Market since Joining the WTO

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Abstract

Since joining the WTO, China's automobile market has shown a rapid development trend, and the automobile market is becoming more and more important to China's economic recovery and high-quality development. The automobile manufacturing industry is one of the pillar industries of China, but facing downward pressure since 2018. The paper studies spatiotemporal evolution characteristics and influencing factors of automobile market since WTO Accession using methods including ESDA, DTW cluster analysis and Spatial panel Dubin model. The result shows that: 1) China's automobile sales have grown rapidly and three development stages have occurred since WTO Accession; 2) Four types of China's automobile markets have significant spatial differentiation, while the same pattern present spatial agglomeration characteristics; 3) The crucial reasons for spatial separation of production and sales in China's automobile market include implementation of purchase restrictions in more and more cities, gradual consolidation of spatial pattern of automobile production, and the fact that some automobile production areas are far away from consumer market; 4) The provincial spatial weighted average centers of automobile sales are mainly distributed in southeast Henan, and show a trend of moving to the southwest; 5) The estimated coefficients of factors such as GDP, financial added value, the proportion of highway, the volume of highway freight, and implementation of automobile consumption incentive policies are all significantly positive, and some factors have positive spatial spillover effects. Existing research on the automobile market lacks analysis based on long-time series data. This study uses long-time series data to provide a certain reference for future research in related directions.

Keywords

Automobile Market, Spatiotemporal Evolution, Spatial Separation of Production and Sales, DTW Cluster Analysis, Space Spillover Effect

1. Introduction

Since joining the WTO in 2001, Transnational automobile corporations such as Hyundai, Nissan, BMW, Mazda, Mercedes-Benz, Toyota, etc., have entered the Chinese market one after another and have continuously increased investment [1], leading to an increasing trend in automobile market. China has become the world's largest automobile market for 11 consecutive years since 2009. In 2017, the automobile manufacturing industry became the pillar industry with the second largest revenue scale and the largest profit scale in China's main business. However, the continuous decline of the automobile market in 2018 and 2019, coupled with the lasting impact of COVID-19 pandemic [2], China's automobile market is facing further downward pressure. The long-term impact of macroeconomic policy makes "separation of production and marketing space" an important feature of China's automobile market [3]. On the one hand, automobile supply in major automobile production and marketing cities such as Shanghai, Beijing and Tianjin are increasing, but due to the limited license restriction, the sales have shrunk significantly. Although the agglomeration of automobile production is conducive to improving the spatial organization efficiency of the automobile industry, the scale of automobile production in central and western provinces and cities with greater market growth potential is very small, and the increase of space difference in automobile production and sales increases the cost of automobile transportation.

On the other hand, the rapid growth of the automobile market for many years has also been accompanied by significant regional differences in automobile consumption between provinces. Car consumption in the eastern region has shifted to a focus on replacement upgrades and new energy vehicles, while most parts of the western region are still for the first-time consumption, and more traditional car products with high quality and low price are needed. In addition, the long-term rapid development has led to the rapid growth of China's car ownership and a series of automobile social problems [4], at the same time, the long-term licensing and purchase restrictions implemented by some provinces and cities have a restraining effect on automobile consumption, the prosperous development of e-commerce, online car-hailing, etc. has caused new demand for automobile consumption [5]. Therefore, studying the spatiotemporal characteristics and influencing factors of automobile market since China's entry into WTO, and putting forward the "14th Five-Year Plan" and future period of time to optimize the spatial layout of automobile production and marketing and promote the healthy and stable development of automobile market, plays an important role in China's economic recovery and high-quality development under the regular epidemic prevention and control.

Western scholars' research on the automobile market mainly focuses on influencing factors, sales forecast and other fields. In the research of influencing factors, only a few factors from the early stage, for instance, income level and automobile prices were used as explanatory variables [6], more and more factors have been introduced into the analysis of automobile sales by scholars, such as automobile ownership [7] and automobile consumption cost [8], interest rate and bank installment payment policy [9], the number of family driver's license holders [10], the quality of automobile products and buyer expectations [11], automobile sharing [12], etc. There are various research that focus on the automobile sales forecast and the application of new measurement methods and the improvement of measurement accuracy, such as time series methods [13], structural relationship recognition methods [14], analysis and prediction based on web crawler data [15] and big data [16], prediction based on artificial intelligence algorithms [17] [18].

Chinese scholars mostly use foreign scholars for reference in the research methods of China's automobile market. The research objects are mainly the influencing factors, sales forecast, and spatiotemporal evolution of the automobile market at the national and inter-provincial levels. Specifically: firstly, analysis of the influencing factors of automobile sales, choose economic development level [19], income level [20], automobile price [21], international oil prices [22], import and export conditions [23] and other factors to conduct research on automobile sales. Secondly, the research literature on automobile demand forecasting is very rich. The methods used mainly include time series methods [24], gray forecasting models [25], analytic hierarchy process [26], etc., and scholars use network search data [27] Baidu Index [28] and other unconventional statistical data to predict automobile sales. Thirdly, it is particularly noteworthy that there is not much research on the spatial distribution of automobile sales by Chinese and other countries' scholars. Existing studies have focused on the spatial pattern of the automobile market and its socio-economic attributes [29], brand preference and its spatial pattern [30], production and sales space separation [30], etc. With the implementation of the Belt and Road initiative, some scholars have used panel data models to empirically analyze the spatiotemporal changes of the Belt and Road automobile market [31]. Generally speaking, the perspectives and objects of automobile market and sales are relatively single. The analysis of automobile market impact and spatial distribution is mainly based on short-term data, especially lack of long-time series data to study the overall situation and spatial distribution trend of automobile market since China's entry into the WTO.

China became the world's largest automobile market only seven years after its accession to the WTO and continues to maintain the first place. In view of the current situation that there is still little research on the long time series data of China's provincial automobile market, this paper systematically analyzes the spatiotemporal evolution characteristics of China's provincial automobile market based on China's long-time series data from 2002 to 2019, using DTW clustering, ESDA and other methods, explores the spatial trends of provincial automobile production and sales. Finally the spatial Durbin model is used to empirically analyze the influencing factors and spatial spillover effects of China's provincial automobile market,which provides references for the formulation of a more scientific automobile industrial policy in China.

2. Data Sources and Research Methods

2.1. Definition of Research Objects and Data Sources

The research object of this paper is the spatiotemporal trend of the automobile market in 31 China's provinces and autonomous regions (excluding Hong Kong, Macao and Taiwan), which uses the number of newly registered civil automobiles at the provincial level to represent the automobile sales, includes private cars, medium-sized and large passenger cars and all kinds of civil trucks, therefore, it can more comprehensively reflect the overall situation and development trend of the automobile market since China joined the WTO. Automobile sales, production and other related statistical data are mainly derived from the *China Statistical Yearbook*. The time range of automobile sales data and the statistical data used in the spatial panel data model is from 2002 to 2019.

2.2. Research Methods

Based on China's long-time series data from 2002 to 2019, this paper systematically analyzes the spatiotemporal evolution characteristics of China's provincial automobile market using exploratory spatial data analysis (ESDA) and DTW time series clustering method to explore the spatial trends of provincial automobile production and sales. Also we use spatial panel Dubin model to empirically analyze the influencing factors and spatial spillover effects of China's provincial automobile market. The technology flowchart of the research is shown in **Figure 1**.

2.2.1. Exploratory Spatial Data Analysis

Exploratory Spatial Data Analysis (ESDA) is mainly used to study the spatial analysis of distribution pattern, spatial association and distribution characteristics [32]. This paper uses the global spatial autocorrelation index to analyze the global spatial autocorrelation of China's provincial automobile sales and related statistical data. In addition, by analyzing the spatial weighted mean centers of inter-provincial automobile production and sales, the change characteristics of inter-provincial automobile production and marketing space center are analyzed. The coordinate calculation formula of the spatial weighted mean center of factors is as follows:

$$X_\omega = \frac{\sum_{i=1}^{n} \omega_i x_i}{\sum_{i=1}^{n} \omega_i}, Y_\omega = \frac{\sum_{i=1}^{n} \omega_i y_i}{\sum_{i=1}^{n} \omega_i} \tag{1}$$

In formula (1), x_i and y_i represent the abscissa and ordinate of the factors (using capital cities coordinates of provinces and cities), ω_i represents the weighted value of the factors, and X_ω and Y_ω represent the abscissa and

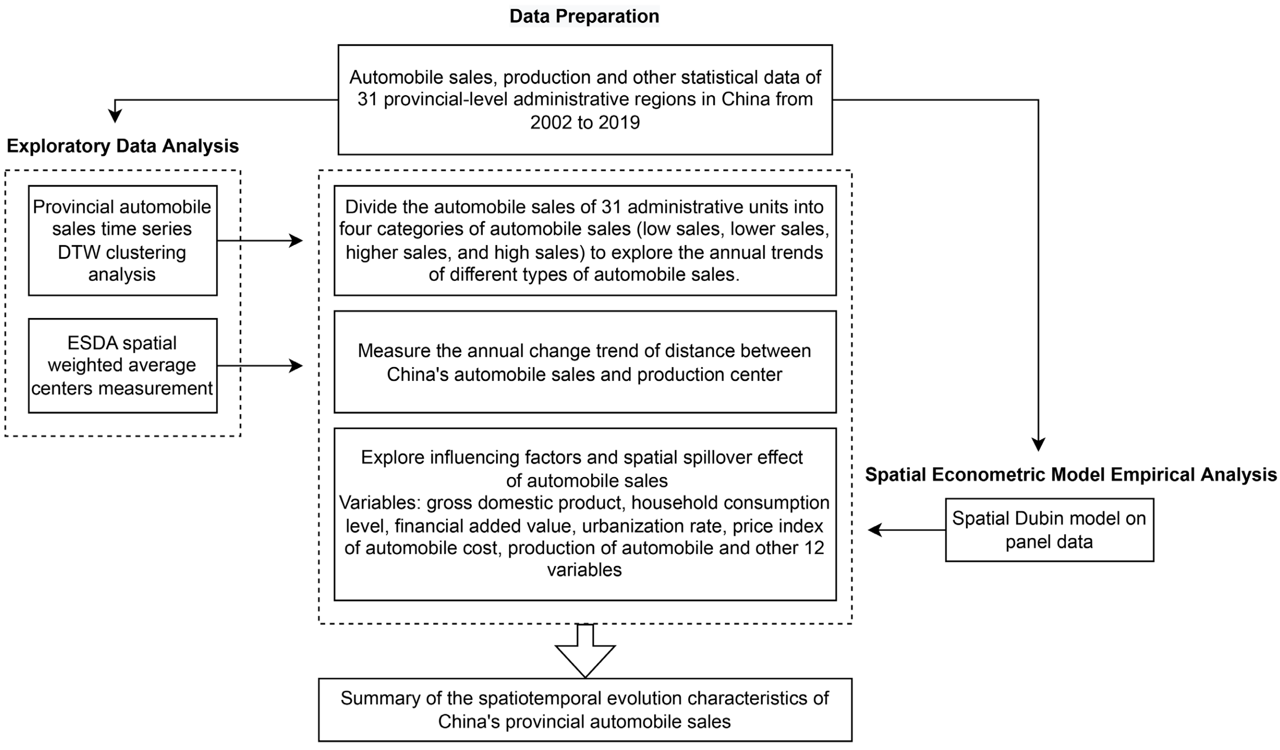


Figure 1. Technology flowchart.

ordinate of the mean center of the spatial distribution of inter-provincial automobiles or sales.

2.2.2. DTW Time Series Clustering Method

DTW (Dynamic Time Warping) is a classic algorithm for sequence matching and sequence distance calculation [33]. DTW method organizes two time series and aligns the feature points to get the shortest distance of two time series. Suppose two time series data are $P = \{p_1, \ldots, p_n\}$ and $Q = \{q_1, \ldots, q_m\}$, and n and m are the sequence lengths respectively. Construct an $n \times m$ matrix, whose $(i, j)^{th}$ factor is the distance between Pi and Qj. The purpose of the DTW algorithm is to obtain a path $W = \{w_1, \ldots, w_k\}$, and $\max(n, m) \le K \le m + n - 1$, such that:

$$d_{DTW(i,j)} = \min \frac{\sum_{k=1}^{K} w_k}{K} \tag{2}$$

In this paper, we use the machine learning open source software "tslearn"[1], which specially process and analyze time series data in Python language to calculate time series data. Formula (2) can be divided into K-means and K-shape [34] according to the difference of distance measurement methods. Among them, K-means calculates the similarity of time series data based on linearly aligned Euclidean distance, while K-shape calculates the distance of similarity based on the shape of the time series data and allows for non-linear alignment. If cluster analysis focuses on distinguishing the size or scale of time series data, K-means is gener-

[1]The machine learning toolkit for time series analysis in Python, https://github.com/tslearn-team/tslearn, version 0.4.1.

ally used; if cluster analysis focuses on distinguishing the evolution mode of time series data (that is, the shape of time series data), K-shape is more appropriate.

2.2.3. Spatial Panel Data Model

Spatial panel data contains three aspects of information: cross-sectional individual, time and spatial lag. Compared with cross-sectional data, it can improve the poor estimation effect caused by multicollinearity in time series analysis. Compared with general panel data, it can also analyze the spatial spillover effects of explanatory variables or explanatory variables. The spatial panel data model has been widely used in the fields of humanities and economic geography [35]. The research object of this paper, inter-provincial automobile sales may have spatial autocorrelation and temporal autocorrelation. We try to use static and dynamic spatial panel Dubin model [36], from which to choose a suitable model for empirical analysis. Use Stata16's "XSMLE" module [37] to calculate.

3. The Characteristics of Temporal and Spatial Evolution of China's Automobile Market

3.1. National Level

After participating in the WTO, more and more multinational automobile enterprises entering the China market, the automobile production has increased dramatically, which promotes the rapid growth of China's automobile market. China's automobile sales increased from 3.379 million in 2002 to 25.446 million in 2019, with an average annual growth rate of 12.62% (see **Figure 2**.).

According to the difference in growth rate, it can be clearly divided into three stages: In the first stage (from 2002 to 2008), the automobile market was dominated by joint venture brands, with an average annual growth rate of 14.02%; in

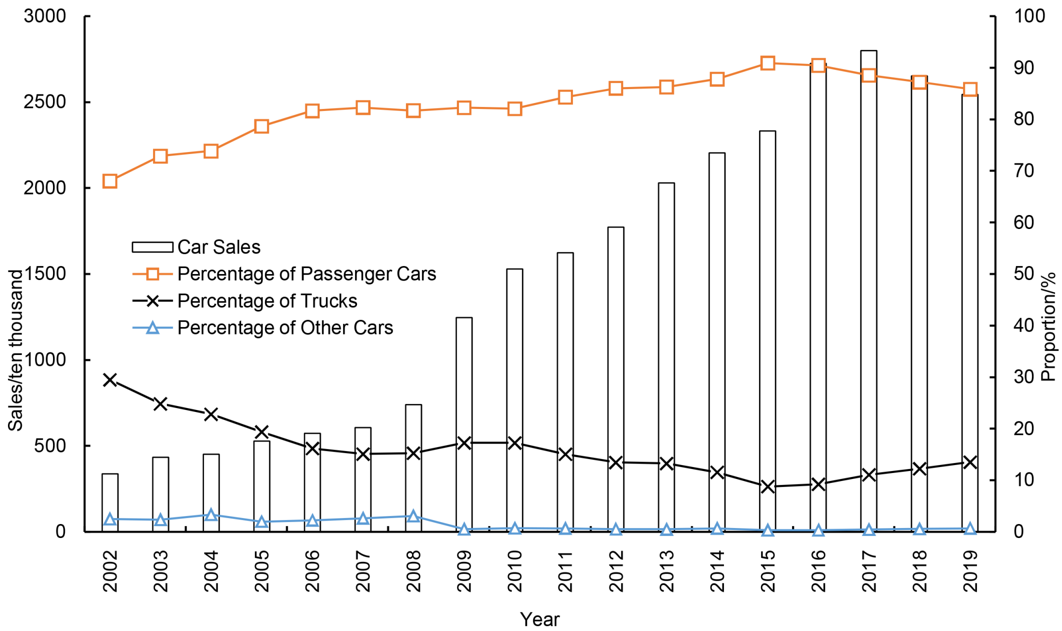


Figure 2. Changes in China's automobile sales from 2002 to 2019.

the second stage (from 2009 to 2017), after the financial crisis, Geely Automobile, Great Wall Motor, BYD, GAC Trumpchi, SAIC Roewe and other Chinese brand cars had risen rapidly, promoting China to become the largest automobile market in the world for 10 consecutive years, with an average annual growth rate of 10.65%, and the growth rate had slowed down significantly; in the third stage (from 2018 to 2019), there was the first negative growth since 1990 and showed a downward trend. With the outbreak of the COVID-19 pandemic in 2020, China's automobile market has entered a new stage of development characterized by negative or micro-growth.

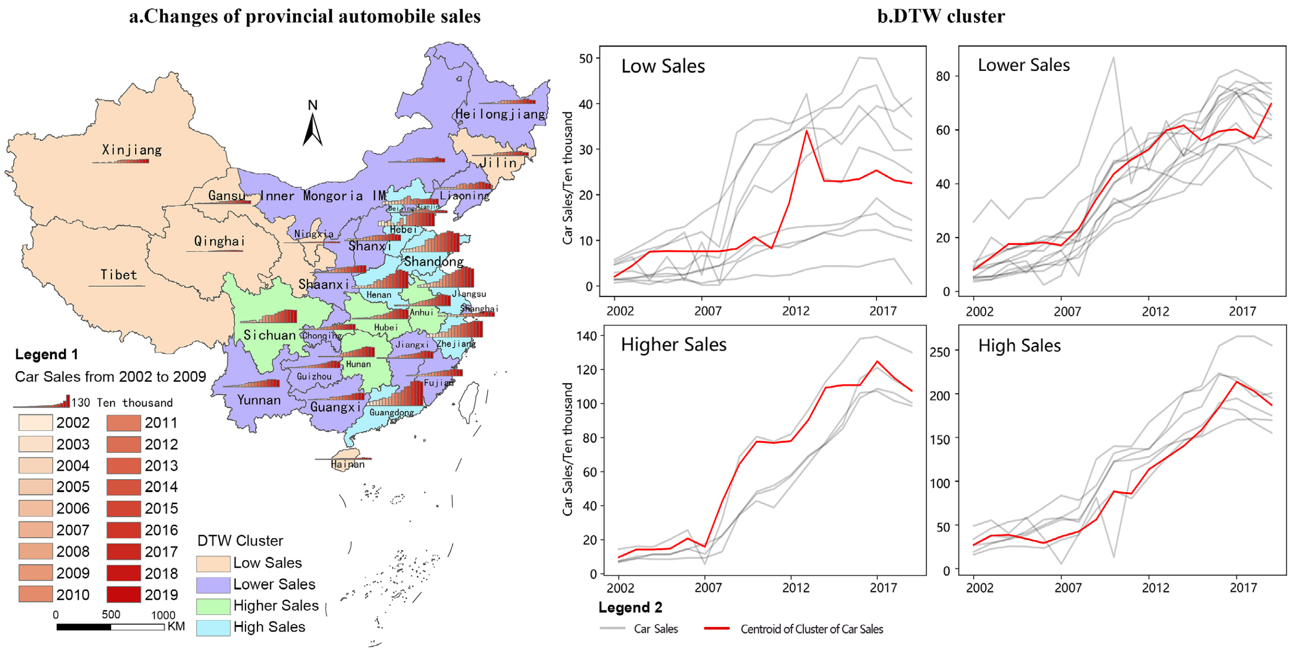
In terms of the types of automobile sales, passenger cars accounted for the consumption ratio continued to rise, from 68.1% of 2020 up to 85.8% of 2019, mainly due to the rapid growth of small passenger automobiles (*i.e.* private automobiles), which was increased from 1.4913 million in 2002 to 21.6481 million in 2019, with an average annual growth rate of up to 17.04%; The proportion of truck consumption continued to decline, from 29.47% of 2002 down to 13.5% of 2019, but still reached average annual growth of 7.57%. Among them, heavy trucks and light trucks grew rapidly, with an average annual growth rate of 10.65% and 9.47% respectively, reflecting that China's rapidly developing e-commerce logistics had a large and continuous growing demand for trucks.

3.2. Provincial Level

From the inter-provincial level, China's automobile market is mainly distributed in the central and eastern regions, while the automobile market in the western and northeastern regions is small; the growth rate of inter-provincial automobile sales has obvious spatial differentiation, showing the characteristics of "small base, high speed growth, large base and medium and high speed growth"; "separation of production and sales space" has become an important feature of China's inter-provincial automobile market.

In this part, we use "tslearn" to perform cluster analysis on inter-provincial automobile sales from 2002 to 2019. Considering the difference in the size of the inter-provincial automobile market and the number of provincial units is only 31, so it is more appropriate to use the K-means method, and it is more appropriate to set 4 to the parameter K of cluster number. The calculation results are drawn into a graph (see **Figure 3(b)**, the gray curve in the figure is the serial data of automobile sales of provinces, and the red is the centroid curve).

The scale and spatial distribution of the automobile market of the four clustering results are obviously different. The low sales provinces and cities are mainly distributed in the northwest, northeast and Hainan, with annual sales of less than 0.5 million; the lower sales are mainly distributed in the southwest, north and Fujian, Jiangxi in the east, with the annual automobile sales no more than 0.8 million; the higher sales are mainly in Sichuan, Hunan, Hubei and Anhui, and the annual automobile sales are less than 1.4 million, which has obvious spatial agglomeration characteristics; the high sales are distributed in Guangdong, Zhejiang, Jiangsu, Shandong, Hebei and Henan, among which Guangdong



Note: This map is based on the map numbered GS (2019) 1815 downloaded from the Chinese national standard map service website (http://bzdt.ch.mnr.gov.cn/), the same below.

Figure 3. Changes of provincial automobile sale in China from 2002 to 2019 and DTW cluster analysis.

and Shandong exceeded 2 million in 2019. The four types of clustering center curves also reflect the temporal change characteristics of different types of markets: firstly, the low sales type has been relatively flat after China's accession to the WTO, and has shown a rapid upward trend after 2009. After a brief decline in 2015, it maintained a steady development trend; secondly, the lower sales type change significantly differently from the low sales types. 2002-2019 maintained an upward trend overall, showing a "ladder" feature of multiple rounds of "rapid rise before gentle development"; third is the slow growth of higher sales type after China's accession to the WTO. After the financial crisis in 2008, the automobile market in these provinces and cities expanded rapidly, and automobile sales began to decline in 2018; fourthly, the high sales type pattern is similar to that of higher sales type, but the speed and range of changes in automobile sales in these provinces and cities are less than those of higher sales type. In addition, from the perspective of the average annual growth rate, the growth rate of Beijing, Shanghai, Tianjin and other regions that implement the license restriction policy is relatively low, which is 4.90%, 8.85%, and 9.00% respectively; in Guizhou, Guangxi, Anhui, Jiangxi, Hunan and other regions, the growth rate is very high, which is 18.64%, 18.19%, 17.65%, 16.87%, 16.58% respectively.

Whether it is the automobile market incentives such as automobile to the countryside, halving the purchase tax on small-displacement automobiles, trading-in old motor vehicles for new ones, or the license restriction and purchase restriction policy implemented by more and more cities, plus the strict control of the state in the early development of the automobile industry, the automobile production pattern is relatively solidified [3]. "Separation of production and sales space" has become a notable feature of China's automobile market since joining the WTO. According to formula (1) the spatial weighted mean centers of inter-provincial automobile sales and production for each year are calculated respectively and the moving trajectory is plotted, which is shown in **Figure 4**.

On the whole, since China's entry into the WTO, the weighted mean centers of China's inter-provincial automobile production and sales have not overlapped or approached within the space of 100 km. All have shown a trend of moving toward southwest, reflecting that under the influence of macroscopic automobile market incentive policies, the growth of automobile market in Sichuan, Guizhou, Yunnan and other provinces promotes the trend of the weighted mean center of automobile production and sales moving toward the southwest. Among them, the spatial weighted mean center of automobile sales moved 169 km to the southwest and the spatial weighted mean center of production moved 222 km to the southwest; the difference between the two is also obvious. The spatial weighted mean center of automobile sales is mainly distributed in southeast

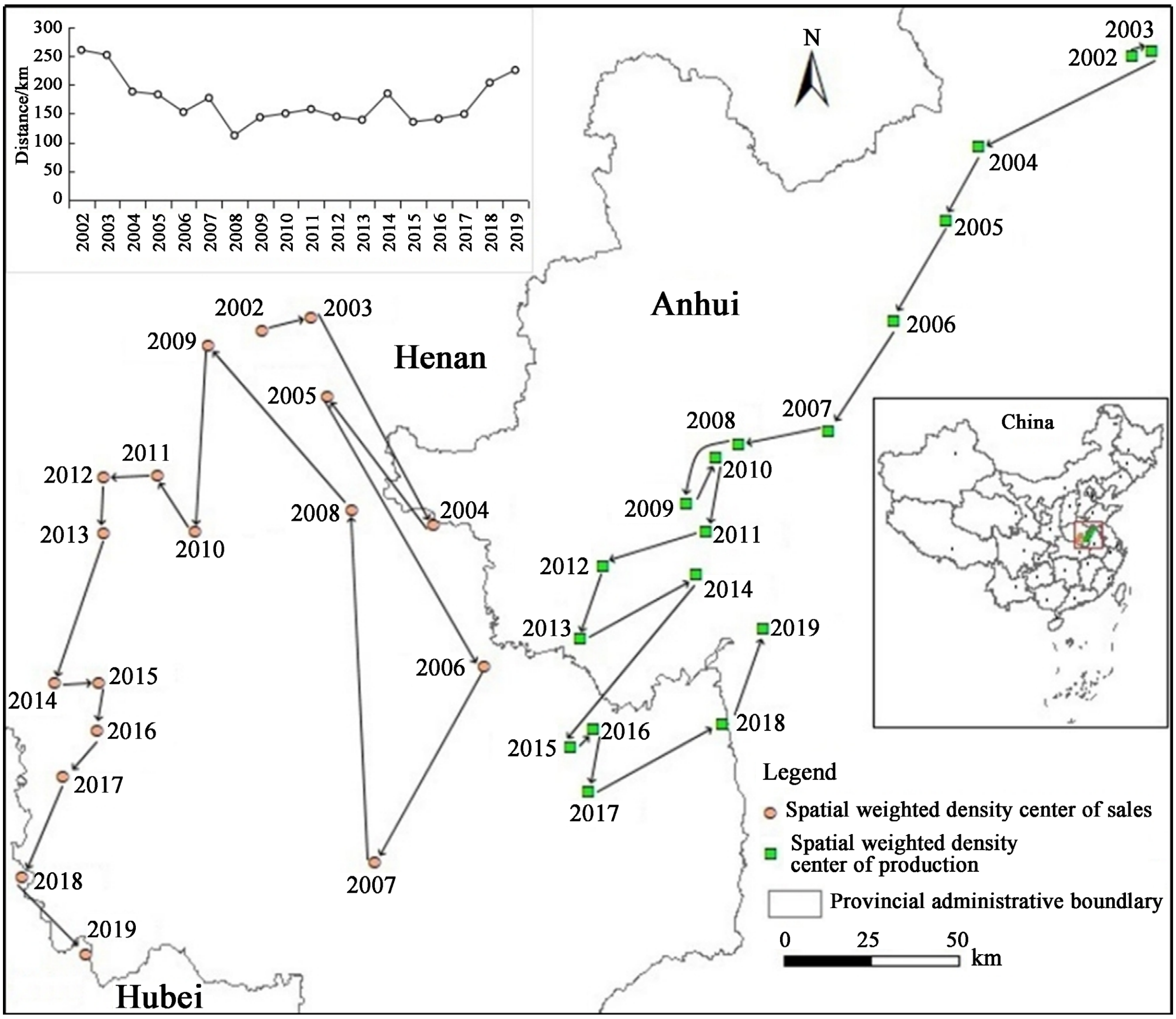


Figure 4. Changes of spatial weighted density center trajectory of provincial automobile production and sales China from 2002 to 2019.

Henan and the migration route is more complicated. Jilin province with long-term high automobile production is significantly affected by geographical location. The distribution of the spatial weighted mean center of production is northward and mainly distributes in the northwest of Anhui Province, with a significant spatial variation. The distance between the centers of the weighted mean of production and sales space has a downward trend. In 2008, the two were the closest, with a distance of 112 km (see the distance curve at the top left of **Figure 4**).

To sum up, due to the gradual solidification of domestic inter-provincial automobile production, Shanghai, Chongqing, Hubei, Tianjin, Guangdong and other automobile production areas are relatively close in space to major automobile markets such as Jiangsu, Zhejiang, Henan, Hebei, and Sichuan. The arrangement is reasonable; while Jilin and Guangxi, which have always been in the forefront of domestic automobile production, are far away from the main automobile markets, which is an important reason for the separation of domestic automobile production and sales space.

4. Empirical Analysis

4.1. Model Design

Since joining the WTO, China's provincial automobile sales have shown regional unbalanced growth, leading to excessive growth of automobile ownership in some areas and a series of automobile social problems [38], in recent years, the automobile market has begun to show a negative growth trend. On the whole, the factors affecting domestic automobile sales are extremely complex. As China's inter-provincial automobile sales may have spatial and temporal correlations, explanatory variables may also have spatial spillover effects. Not only should we focus on the impact of local explanatory variables on local automobile sales, but also on the impact of other local explanatory variables on local automobile sales. Therefore, the following spatial panel Dubin model is constructed:

$$Y_{it} = \rho W_n Y_{it} + \beta X_{it} + \theta W_n X_{it} + \varepsilon_{it} + c_i \quad (3)$$

In Equation (3), Y_{it} is automobile sales in region *i*, period *t*, Y_{it-1} is automobile sales in region *i*, period ($t-1$), is spatial weight, considering that the domestic automobile products are for national sales, so the spatial distance weight is adopted; $W_n Y_{it}$ is the spatial lag of automobile sales in region *i*, period *t*; X_{it} is the explanatory variable in region *i*, period *t*, and $W_n X_{it}$ is the spatial lag in the explanatory variable in region *i*, period *t*; c_i is an individual fixed-effect term of $n \times 1$ dimension; ε_{it} is the residual term. In order to analyze the time relevance of China's inter-provincial automobile sales, a dynamic panel data model is introduced:

$$Y_{it} = \sigma Y_{it-1} + \rho W_n Y_{it} + \beta X_{it} + \theta W_n X_{it} + \varepsilon_{it} + c_i \quad (4)$$

In formula (4), when $\sigma = 0$, it is a static spatial panel data model; when $\rho = \theta = 0$, it is a dynamic panel data model; when $\sigma = \rho = \theta = 0$, it is an ordinary panel data model. Compared with the ordinary panel data model, due to the introduction of the explanatory variable and the explained variable's space or time lag, the interpretation of the estimated parameter becomes more complicated, and the total effect of an explanatory variable on the explained variable is not equal to its coefficient. The lag term in the spatial measurement model can not only achieve the influence of local explanatory variables on the explained variables in the region, but also the influence of the explanatory variables of neighboring regions on the explained variables in the region. The former is called direct effects and the latter is indirect effects. Direct effects and indirect effects can be calculated by the partial derivative method, generally using the average index method proposed by Arnold M. LeSage and Pace [39] based on the partial derivative matrix.

4.2. Variable Selection

Referring to Wang Qifan [19], Yin Zhiyang [20] and other existing studies, highway length, income of urban residents, GDP, fuel consumption, level of financial development and other factors are also important factors affecting automobile sales in China. The prosperous development of e-commerce has promoted the demand for trucks, and the rapid development of online car-hailing has also become a new demand for automobile consumption. Highway freight volume and road passenger volume are selected to reflect the influence of these two factors. In addition, China's government has a strong influence on the market economy, and macro policies have also had a significant impact on China's automobile market. Halving automobile purchase tax, cars to the countryside [40], automobile license restriction policy, new energy vehicle subsidies, exemption from purchase tax [24] and others also have an impact on automobile sales. Empirical analysis is carried out by setting up virtual variables. In this case, based on the above analysis and the availability of long-term series data, select gross domestic product, household consumption level, financial added value, urbanization rate, price index of automobile cost, production of automobile, civilian automobile ownership, the volume of highway freight, the number of highway passenger, the proportion of highway, Implementation of automobile consuming incentive policy (dummy variable) and Implementation of automobile license and purchase restriction policy (dummy variable). The statistical description of each variable is shown in **Table 1**.

The explanatory variables such as gross domestic product, household consumption level, financial added value, and urbanization rate are relatively intuitive and will not be elaborated; a brief description of several virtual variables will be given.

Price index of automobile cost (Cost). Because long time series data that directly reflect the cost of automobile use, such as the inter-provincial automobile price, fuel price, spare parts price and maintenance cost, are difficult to obtain, the inter-provincial automobile use cost is reflected by the consumer price index of automobile fuel and spare parts, and the consumer price index of automobile

Table 1. Statistical description of variables.

	Variables	Abbreviation	Unit	Mean	Std	Min	Max
Y_{it}	New registration of civil automobile	Cars	10 thousand	48.62	51.11	0.19	265.64
	Gross domestic product	GDP	100 million yuan	16,025.89	16,940.02	162.04	107,671.10
	Household consumption level	Consumption	Thousand yuan	13.65	10.65	2.30	69.44
	Financial added value	Financial	100 million yuan	994.82	1343.29	2.81	8881.41
	Urbanization rate	Urban	%	51.35	15.10	19.89	89.61
	Price index of Automobile cost	Cost	-	279.92	49.97	185.80	444.75
	Production of automobile	Production	thousand	528.25	700.68	0.00	3215.80
	Civilian automobile ownership	Ownership	10 thousand	339.53	392.52	5.87	2333.73
X_{it}	The volume of highway freight	Freight	Million tons	796.60	667.82	2.01	3152.23
	The number of highway passenger	Passenger	Million people	655.53	656.81	1.25	5565.10
	The proportion of highway	Highway	%	2.54	1.50	0.00	8.07
	Implementation of automobile consuming incentive policy (dummy variable)	IP	-	0.33	0.47	0	1
	Implementation of automobile license and purchase restriction policy (dummy variable)	RP	-	0.06	0.24	0	1

Note: The unit of cross section is 31. There are 558 observations in 18 periods.

use and maintenance fee. Both price indices are based on 2002 as the base year, and are calculated and summed based on the historical indices. Since China's accession to the WTO, the average annual growth rate of the automobile cost price index in all provinces and cities has been higher than 2%. Among them, Ningxia has the highest average annual growth rate, reaching 4.46%; Heilongjiang has the lowest average annual growth rate, which is 2.05%.

Implementation of automobile consuming incentive policy (IP). Assign values according to the year and region in which the policy was implemented (Value 1 for policy implementation year, otherwise 0). Since China's accession to WTO, China has mainly implemented the following automobile consumption stimulation policies: halve the purchase tax on small-displacement automobiles policy, the implementation period is from October 1, 2015 to the end of 2016; automobiles to the countryside policy, the implementation period is from March 1, 2009 to the end of 2010; trade in old automobiles for new ones policy, the implementation period is from August 10, 2009 to the end of 2010; subsidies and exemptions from purchase tax of new energy automobiles, the implementation period is from 2013 to 2019.

Implementation of the automobile license and purchase restriction policy (RP). Assign values according to the year and region in which the policy was implemented. Since China's accession to WTO, Beijing, Shanghai, Tianjin, Guangzhou, Shenzhen, Guiyang and other cities implemented license restriction policy, while in some cities the implementation of license restriction policy is not enough to significantly affect the automobile changes in sales in their provinces. Therefore, only for the year in which Beijing, Shanghai and Tianjin implement the license and purchase restriction policy, the corresponding year's virtual variable value is 1. Among them, Shanghai has implemented automobile license control policy since 1994, Beijing has implemented license restriction policy since 2011, and Tianjin has implemented it in 2014.

4.3. Estimation of Empirical Model Coefficients

4.3.1. Variable Unit Root and Spatial Autocorrelation Test

In order to avoid the pseudo-regression phenomenon in the parameter estimation of the panel data model and ensure the validity of the results, the data (logarithm of the variables) need to be tested for unit root. The Levin-Lin-Chu test and Im-Pesaran-Shin test in Stata are used to perform unit root test on the original sequence and first-order differential sequence of variables (excluding virtual variables). The results show that the original sequence and first-order differential sequence of all variables are not contained unit roots and are stationary sequences. In addition, use "spatgsa" command in Stata to perform Moran test on inter-provincial automobile sales in each year, the results show that inter-provincial automobile sales have a significant spatial dependence, so the spatial panel Dubin model can be used.

4.3.2. Spatial Dubin Model Estimation Results and Effect Decomposition

Use "XSMLE" module in Stata to conduct empirical analysis of the spatial Dubin model, six estimation results are obtained (see Table 2).

These models include static fixed effect model ① and dynamic fixed effect model ②, four random effect models ③-⑥, among which model ① and ② are used for comparative analysis, and model ④-⑥ are used to test the robustness of the random effect model. The results of the Hausmann test for static fixed and random effects are $chi^2(7) = -24.01$, indicating that the random effect model should be used. While the Wald and Lration tests show that the spatial autocorrelation and spatial error models are not suitable for this case. The symbols of the estimated coefficients of each explanatory variables from model ④-⑥ are consistent, indicating that the model ③ has passed the robustness test, so the results of the model ③ are used for analysis. Tab.2 shows that the spatial autocorrelation coefficient (Spatial rho) of the random effect spatial Dubin model is greater than 0 and passed the 5% significance test, indicating that there is a significant spatial autocorrelation in inter-provincial automobile sales in China. Second, the estimation results of the automobile cost price index $\ln Cost$, household consumption level $\ln Consumption$ and highway passenger volume $\ln Passenger$ fail the significance test. The estimation coefficients of the explanatory variables such as the urbanization level Urban, the implementation of the automobile license restriction policy RP, and the automobile ownership $\ln Ownership$ are negative, and the estimation coefficients of the remaining explanatory variables

Table 2. The regression of Spatial Dubin Model

Variables and indicators	Fixed effect model		Random effect model			
	Static model	Dynamic model	Total samples	Except 2004	Except 2011	Except 2016
	①	②	③	④	⑤	⑥
ln*GDP*	0.559***	0.473***	0.644***	0.629***	0.608***	0.641***
	(4.09)	(3.26)	(9.17)	(8.78)	(8.69)	(8.89)
ln*Consumption*	−0.002	−0.104	0.089	0.061	0.036	0.091
	(−0.01)	(−0.57)	(0.86)	(0.58)	(0.35)	(0.85)
Urban	0.017*	0.012	−0.009**	−0.010**	−0.009**	−0.010**
	(1.86)	(1.31)	(−2.23)	(−2.39)	(−2.16)	(−2.30)
ln*Financial*	0.239***	0.168**	0.270***	0.289***	0.310***	0.274***
	(3.06)	(1.98)	(3.70)	(3.78)	(4.17)	(3.61)
IP	0.216***	0.211***	0.207***	0.202***	0.240***	0.212***
	(5.80)	(5.68)	(5.68)	(5.50)	(6.26)	(5.42)
Highway	0.082***	0.058**	0.076***	0.079***	0.079***	0.075***
	(3.18)	(2.13)	(3.25)	(3.28)	(3.38)	(3.09)
RP	−0.538***	−0.435***	−0.791***	−0.802***	−0.804***	−0.778***
	(−3.74)	(−2.98)	(−6.78)	(−6.82)	(−6.70)	(−6.34)
L.ln*Cars*		0.275***				
		(6.51)				
_cons			−4.264***	−4.141***	−4.123***	−4.251***
			(−11.46)	(−11.11)	(−11.33)	(−11.27)
Wx:						
ln*Production*	0.225***	0.269***	0.068*	0.066*	0.054	0.065
	(4.59)	(5.30)	(1.70)	(1.66)	(1.45)	(1.63)
ln*Ownership*	−0.527***	−0.410***	−0.402***	−0.379***	−0.328**	−0.402***
	(−3.38)	(−2.58)	(−3.31)	(−3.04)	(−2.57)	(−3.20)
ln*Cost*	−0.813*	−0.641	−0.111	−0.076	−0.115	−0.100
	(−1.76)	(−1.32)	(−0.65)	(−0.44)	(−0.70)	(−0.57)
ln*Freight*	0.656***	0.429**	0.347**	0.299**	0.364**	0.344**
	(3.27)	(2.01)	(2.37)	(2.03)	(2.58)	(2.31)
ln*Passenger*	0.021	0.014	−0.079	−0.095	−0.112*	−0.085
	(0.29)	(0.18)	(−1.27)	(−1.51)	(−1.73)	(−1.34)
Spatial rho	0.165	0.098	0.254**	0.275***	0.193*	0.255**
	(1.57)	(0.89)	(2.51)	(2.68)	(1.78)	(2.44)

Continued

Variance:						
sigma2_e	0.112***	0.115***	0.124***	0.125***	0.127***	0.131***
	(16.68)	(17.18)	(15.78)	(15.24)	(15.37)	(15.31)
lgt_theta			−0.293	−0.175	−0.099	−0.171
			(−0.90)	(−0.50)	(−0.29)	(−0.50)
N	558	527	558	527	527	527
R^2	0.781	0.801	0.901	0.899	0.906	0.898

Note: ***, ** and * indicate that the results are significant at 1%, 5% and 10%, respectively; inside the brackets is the corresponding coefficient Z value.

are greater than 0 and pass significant test. Compared with the general panel data model, because the spatial lag terms of both explanatory and explained variables are introduced in the spatial Dubin model, the explanatory parameters are interpreted differently from the ordinary panel data model. So the estimation coefficients of the total effect, direct effect and indirect effect of model ③ are used to analyze them (see Table 3).

4.4. Analysis of Empirical Results

The total effects of variables such as ln*GDP*, ln*Financial*, Highway, ln*Production*, ln*Freight*, etc. are all significantly positive. Among them, the estimated coefficients of the total effect, direct effect and indirect effect of ln*GDP*, ln*Financial*, Highway, ln*Freight* are all significantly positive, indicating that good economic level, the developed financial industry, the proportion of high-speed kilometers, and the highway freight volume in the region itself and its neighborhood can significantly promote the growth of automobile sales in this region; the direct effect of automobile production ln*Production* has not passed the significance test, indicating that the local automobile production has no significant impact on local automobile sales, while the indirect effect is significantly positive, indicating that there is a clear spatial separation between provincial automobile production and sales in China.

The estimated coefficients of the total effect, direct effect and indirect effect of the virtual variable IP are all positive and pass the significance test, indicating that China's implementation of the automobile industry incentive policy has significantly increased automobile sales. On the other hand, the estimated coefficients of the overall effect, direct effect, and indirect effect of the virtual variable RP are all negative and pass the significance test, which shows that even the local areas implementation of license restriction and purchase policy will have a significant inhibitory effect on automobile sales.

The estimation coefficients of total effect of two explanatory variables Urban and ln*Ownership* are both significantly negative, which has an inhibitory effect on automobile sales. Among them, the estimated coefficients of the total effect

Table 3. Total effect decomposition: direct effect and indirect effect.

Variables	Total effect	Direct effect	Indirect effect
ln*GDP*	0.768***	0.651***	0.117**
	(7.53)	(8.97)	(2.08)
ln*Consumption*	0.119	0.102	0.017
	(1.01)	(1.01)	(0.83)
Urban	−0.011**	−0.010**	−0.002
	(−2.30)	(−2.36)	(−1.51)
ln*Cost*	−0.062	−0.002	−0.061
	(−0.52)	(−0.36)	(−0.53)
ln*Financial*	0.315***	0.266***	0.049*
	(3.41)	(3.62)	(1.76)
IP	0.248***	0.211***	0.037**
	(5.98)	(5.78)	(2.19)
Highway	0.090***	0.076***	0.014*
	(3.07)	(3.15)	(1.71)
RP	−0.937***	−0.795***	−0.142**
	(−6.36)	(−6.97)	(−2.09)
ln*Production*	0.049*	0.002	0.047*
	(1.73)	(1.37)	(1.73)
ln*Ownership*	−0.296***	−0.012	−0.284***
	(−2.89)	(−1.64)	(−2.97)
ln*Freight*	0.242**	0.009*	0.233**
	(2.44)	(1.75)	(2.45)
ln*Passenger*	−0.062	−0.002	−0.060
	(−1.32)	(−1.07)	(−1.33)

Note: ***, ** and * indicate that the results are significant at 1%, 5% and 10%, respectively; Inside the brackets is the corresponding coefficient Z value.

and the direct effect of urbanization level Urban are significantly negative, while the estimated coefficients of the total effect and the indirect effect of automobile ownership ln*Ownership* are significantly negative. This indicates that since China's accession to the WTO, the number of automobile ownership has grown rapidly, and automobile consumption has become regionally saturated. The excessively high urbanization rate means that the population is too concentrated. At the same time, Beijing, Shanghai, Tianjin and other areas with high urbanization levels have implemented license restriction policy. This policy, coupled with the excessive growth of automobile ownership, has caused a series of automobile social problems, and has an overall inhibitory effect on automobile consumption.

However, there are obvious differences in the spatial spillover effects between the two. Urban did not form a significant spatial spillover effect, while ln*Ownership* formed a significantly negative spatial spillover effect, indicating that the surrounding areas with higher automobile ownership would have an inhibitory effect on automobile consumption in this region.

The estimated coefficients of the total effect, direct effect and indirect effect of ln*Cost* and ln*Passenger* are all negative and do not pass the significance test, indicating that automobile cost is gradually becoming saturated and that road passenger transport is gradually being replaced by intercity railroads, high-speed rail and airlines, which leads to a less significant contribution of these two explanatory variables to overall car consumption in China.

5. Summary

Based on the inter-provincial automobile production and sales from 2002 to 2019 and related statistical data, the spatiotemporal evolution characteristics and influencing factors of China's inter-provincial automobile market after China's entry into the WTO are analyzed using ESDA method, DTW time series clustering and spatial panel Dubin model. The findings are as follows:

1) After starting the membership of WTO, automobile sales have increased by 12.62% annually over the 18 years, but the growth rate shows a slowing trend and begins to show negative growth in 2018 and 2019. The COVID-19 pandemic not only has a severe impact on the automobile industry in a short period of time, but also will lead to a continuous downward trend in the global automobile market because of its normalized prevention and control trend, and a new round of merger and reorganization of China's domestic automobile industry is coming.

2) The results of inter-provincial automobile sales based on DTW cluster analysis method show that the four types of China's automobile market (low sales, lower sales, higher sales and high sales) have distinct spatial differentiation, while the same type shows spatial clustering characteristics, and the centroid curve reflects distinct differences among different types of evolution modes. "Separation of production and sales space" has gradually become an important feature of China's automobile market. More and more cities implement purchase restriction policies, the spatial pattern of automobile production is gradually solidified, and Jilin, Guangxi and other automobile high production provinces and cities are far away from the consumer market. The weighted mean center of inter-provincial automobile sales mainly distributes in southeastern Henan. The weighted mean center of inter-provincial automobile production and sales does not appear overlapping or less than 100 km of spatial proximity, showing a trend toward southwest.

3) Spatial panel Dubin model empirical analysis shows that the explanatory variables are mainly significantly forming a positive promotion effect on automobile sales. Among them, the estimated coefficients of the total effect, direct

effect and indirect effect of GDP, financial added value, the proportion of highway, the volume of highway freight are all significantly positive, indicating that good economic level, the developed financial industry, the proportion of high-speed kilometers, and the highway freight volume in the region itself and its neighborhood can significantly promote the growth of automobile sales in this region. The direct effect of automobile production has not passed the significance test while the indirect effect is significantly positive, indicating that the local automobile production has no significant impact on local automobile sales and there is a clear spatial separation between provincial automobile production and sales in China. The estimated coefficients of the total effect, direct effect and indirect effect of IP (implementation of automobile consuming incentive policy) are all significantly positive, while RP (implementation of automobile license and purchase restriction policy) are all significantly negative, indicating that both purchase restrictions and incentives are working as intended. The estimated coefficients of the total effect, direct effect and indirect effect of price index of automobile cost and the number of highway passenger are all negative and do not pass the significance test, indicating that the two variables have less contribution to overall car sales.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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