The Short-term Effects of Transport Improvement on Urban Compact development in China—An Empirical Analysis Based-on 217 Prefecture Cities

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***Abstract*—Compact cities are considered sustainable in western developed countries, is it also fine in China? Based on the statistical data for 217 prefecture cities in China, this paper investigates the short-term (10 years) effect of transport improvements on urban compactness. Firstly, using the method of entropy, we get the urban compactness of 217 prefecture cities from 1999 to 2012, and then explore the relationship between transportation and urban compactness. Results show that transport improvements contribute to increasing urban compactness in short-term, but the effects have time lag. Transport agencies should pay more attention on the transport improvement, especially public transport. These results suggest guidelines for the future of China's urbanization.**

***Index Terms*—transport improvement, compact city, urban compactness, public transport**

I. Introduction

With the rapid growth of China's population and the acceleration of urbanization, the sustainable urban development debate has become a hot topic. Numerous studies have explored the best mode of sustainable urban development. The compact city as an "urban form of sustainable development" is getting more and more attention. The compact city is usually defined as a development pattern of high density [1] and mixed land use. They are considered as an alternative to urban sprawl. Throughout the past few decades of urbanization in China, the rapid increasing number of small cities and the sprawling expansion of big cities have proven to be inefficient. Furthermore, China has a large population on little land, so the sprawl has some long-run drawbacks. Compact city development mode may be an efficient and inevitable choice.

Urban transport is an important force for urban expansion and agglomeration. The compact city theory emphasizes the efficient public transport system, owing to its lower-dependence on the cars and lower infrastructure requirements (K. Williams, *et al*., 2000) [2]. The positive relationship between urban compactness and public transport is generally accepted in western studies. This argument is, however, not proven statistically in the context of China (H. Chen, *et al*., 2008) [3]. In recent decades, China's government paid much attention to infrastructure investment. Large amounts of government funds are still invested into transport affairs. Although transport related problems, such as traffic congestion and pollution, exist in many cities in China, it is hard to deny that accessibility has been improved greatly, and it also has expanded the urbanized area. J. Krupp and K. Acharya (2014) [4] argue that public transport has no long-term impact on road congestion. The extension of transport lines had led to the changes in urban compactness. At the beginning, it may bring about a temporary reduction of urban compactness, but with the urban development and expansion, urban compactness will further increase. Therefore, it is important to better understand the exact relationship between transportation and urban compactness.

This paper is structured as follows. The next section presents the approach and model specification. Section III presents all the data and the variables. Section IV reports and analyses the results of urban compactness affected by transport. Last section is conclusion.

II. Model Specification

Previous researches or theories have concluded that transport is an important factor affecting the development of compact city, but has not explicitly investigated the casual chain implicit in the hypothesis that transport improvement can increase urban compactness. Our work builds on this body of research by using urban compactness variable, which is measured by instructing the appraisal index system of the synthesis level of compact city embarking economic compactness, land compactness, transport compactness and population compactness. With the method of entropy, this paper explores the comprehensive urban compactness of 217 prefecture cities in China from 1999 to 2012 (detailed in III.B). And then construct Transport-Urban Compactness Model to explore the explicit effect from transport on urban compactness.

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We put the transport measures as main explanatory variables and urban compactness as dependent variable to build the multiple regression model tracking the link from urban transport to compactness. The transport-urban compactness model is set, as follows:

$$Comp_{it} = F(Trans_{ijt}, X_{it}) \quad (1)$$

$Comp_{it}$ is the urban compactness of city *i* in year *t*; $Trans_{ijt}$ represents different transport measures j, including number of public bus per 10,000 residents, area of paved roads per capita, number of taxi per 10,000 residents and the annual ridership (100 millions); X_{it} is other control variables, such as GDP per capita, gross industrial output per capita, the ratio of urban built-up area to urban area and employment density, which all play an important role in urban compact development.

Transportation is a guiding force of urban compactness and also the important support for urban function. Transport development can promote closer integration in many areas of land use, economy, society and environment so as to the comprehensive development of city. The guiding role of transport on urban compactness is played mainly by extending the transport infrastructure, continuously improving accessibility and guiding the gathering of population, industry and other economic activities. The effect of transport on urban compactness is not really linear relationship (Y. Tian, *et al*., 2013) [5]. At the beginning of urban expansion, the roads expand as liners for destroying the urban integrity, and decreasing the urban compactness. After that, the unused land among roads is filled with residents or other economic activities, resulting in the improvement of urban integrity and urban compactness. So we can see that the relationship between transport and urban compactness is nonlinear. We take the log-log form. Finally, we set the model as follows:

$$\ln Comp_{it} = \alpha + \beta \ln Trans_{ijt} + \sigma \ln X_{it} + u_{it} \quad (2)$$

However, urban compactness also has some effect on transport to some extent. The improvement of transport leads to the changes of urban compactness, while the changes of urban compactness also bring about the improvement of transport. The temporary decrease of urban compactness can contribute to the further development of urban land. With the increase of population and economic activities, a bigger travel demand requires further transport improvement. The rise of urban compactness may stimulate transport agencies to provide more services as travel demand. To control the mutual causality in the mode, we rely on the lagged independent variable $Trans_{ijt-1}$ and the lagged dependent variable $Comp_{it-1}$, observed one year prior to the year in which the dependent variable is measured. So we set the function as follows:

$$\ln Comp_{it} = \alpha + \beta_0 \ln Trans_{ijt} + \beta_1 \ln Trans_{ijt-1} + \theta_0 \ln Comp_{it-1} + \sigma \ln X_{it} + u_{it} \quad (3)$$

III. Data and Variables

This paper uses the data of prefectural cities from 1999 to 2012, which mostly from the Annual Urban Statistical Yearbook of China (Volume 2000-2013) and partly from China Urban Construction Statistical Yearbook (Volume 2000-2012). The data about some cities in some years are missing, which are excluded from the dataset. Finally, the data of 217 prefectural cities in China is comprehensive and available. The prefecture-level cities in China govern large rural cities as well. While data are given for the whole area (the municipality), they are also given separately for the urbanized portion, called the “city proper” (C. Au and J. V. Henderson, 2006) [6]. This paper uses the data of city proper in prefectural cities. The main variables used in the paper are described as following:

A. Urban Transport

The transport variable includes 4 indictors: number of public bus per 10,000 residents (*trans1*), area of paved roads per person (*trans2*), number of taxi per 10,000 residents (*trans3*) and the annual ridership (*trans4*). The Annual Urban Statistical Yearbook of China provides these transport data for 217 prefecture-level cities from 1999 to 2012.

B. Urban Compactness

Compact city is considered as a sustainable urban development mode in western developed countries, is it also fine in China? Throughout the past few decades of urbanization in China, the rapid increasing number of small cities and the sprawling expansion of big cities have proven to be inefficient. With lots of labor rushing into the cities, most of cities tend to be compact. So how to measure the compact level of cities is an important issue.

To build the bridge from transport improvement to urban compactness, the first thing is to measure urban compactness. The methods of measuring urban compactness mainly include two types: single-index method and complex-index method. The single index is just to calculate the relationship among measures, such as urban proper area, perimeter, diameter and so on, but it cannot reflect the degree of a compact city completely, and just some aspects of urban spatial or function. Complex-index method is based on the connotation of compact city and selects a number of inter-connected but independent indictors from urban economy, population, land and transport areas. And then construct an index of urban compactness, which can reflect urban compact degree comprehensively through some certain measuring method, to investigate the “quality” and “efficient” of cities. Thus, complex index method can help to get the urban compact degree relatively complete.

So this paper establishes appraisal index system of the synthesis level of urban compactness embarking on economy compactness, land compactness, population compactness and transportation compactness. With the method of comprehensive evaluation index system, the paper selects 4 first-level indicators and 19 secondary-level indexes, which can cover a compact city as far as possible (Table I).

TABLE I. COMPREHENSIVE EVALUATION INDEX SYSTEM ON URBAN COMPACTNESS OF PREFECTURE-LEVEL CITIES

First-level indictors	Population compactness	Economy compactness	Land compactness	Transport compactness
Secondary-level indictors	Population density (persons/ sq.km)	Gross industrial output per capita (10,000 RMB per person)	The urban built-up area/urban area ratio(%)	Number of Public bus Per 10,000 residents
	No-agricultural population/population in urban area ratio(%)	GDP per capita (10,000 RMB per person)	Urban development land /urban area ratio(%)	Number of taxi Per 10,000 residents
	Employment density (persons/ sq.km)	Secondary and tertiary industry output/ GDP ratio	Residential land/urban built-up area ratio(%)	Area of paved Roads Per capita(sq.m)
	No-agricultural population/ residential land(persons/ sq.km)	Capital input per unit area (10,000 RMB per person)	Production land/ urban built-up area ratio(%)	Road area/ urban area ratio(%)
	Secondary and tertiary employment/ all employment (%)	GDP per unit area(100 million RMB per person)	Urban development area/urban built-up area(%)	

We have 3038 observations and 57722 data on 217 prefectural cities from 1999 to 2012. With the method of entropy, first of all, construct the matrix of original index data: sample cities m, and evaluation index items n, and get the original data matrix:

$$X = \{X_{ij}\}_{m\times n}(0 \le i \le m, 0 \le j \le n)$$

Secondly, all original data are standardized, using the formula: $x_{ij}^{'} = \frac{x_{ij}}{x_{j\max}^{*}}$ and get the standardized matrix $Y = \{y_{ij}\}_{m\times n}(y_{ij} = x_{ij}^{'} / \sum x_{ij}^{'}, 0 \le y_{ij} \le 1)$.

Thirdly, based on standardized data, use the formula of entropy to calculate the entropy of each single index $e_j = -k\sum (y_{ij} * \ln y_{ij})$.

Fourthly, calculate the difference coefficient of 19 indexes $g_j = 1 - e_j$, and then get the weight of each index $w_j = g_j / \sum g_j$.

Lastly, use the formula $f_{ij} = w_j \times x_{ij}^{'}$ to calculate the urban compactness of 217 prefectural cities from 1999 to 2012.

Table II shows the statistical description of urban compactness. We divide all the cities into three hierarchies based on urban compactness: low compactness, median compactness and high compactness. Low compactness is below 0.2; median compactness is between 0.2 and 0.4; and high compactness spans from 0.4 to 0.6. A significant difference can be found in Fig. 1. Most of cities are located in the median level. The number of median compactness cities is also gradually increasing year by year, while the low-compactness and high-compactness cities have a small increase firstly and then get decreasing. That may owe to the rapid urbanization in China. In the past decades, a large amount of labor from countryside rushed into cities, bringing about a rapid increase on urban population. Meanwhile, cities also keep expanding and city sizes become larger and larger. To some extent, this leads to the improvement of urban compactness, and many cities develop from low-compactness level into median-compactness level. In contrast, some extra-large cities show a dispersed trend during the past decade, such Peking, owing to the congestion, pollution, high living-cost and so on. Many people trend to work in the downtown during the day and live in the suburb at night. This may be the reason for a decreasing number of high-compactness level cities.

TABLE II. STATISTICAL DESCRIPTION OF URBAN COMPACTNESS

Urban compactness			
Mean	0.281338	Kurtosis	0.581035
Standard error	0.001343	Minimum	0.131079
Median	0.270292	Maximum	0.569734
Std. Dev.	0.074021	Sum	854.7054
Variance	0.005479	Observations	3038

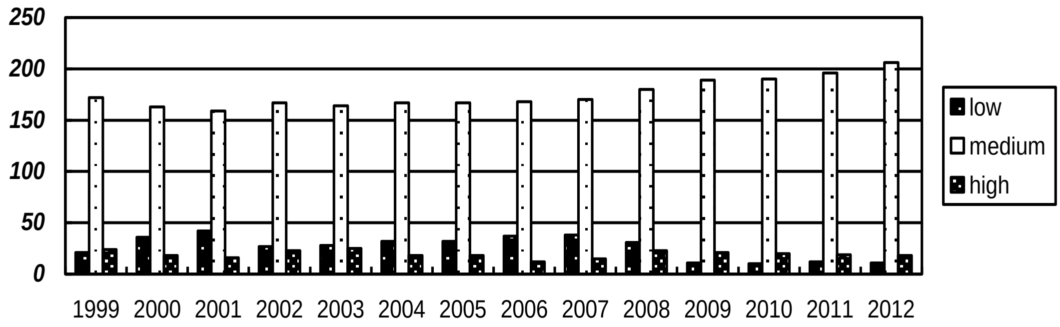

Figure 1. Hierarchy distribution of urban compactness. ("low"≤0.2; 0.2<"median"≤0.4; 0.4<"high"≤0.6.)

C. Controls and Other Variables

There are many factors affecting urban compactness and productivity. According to the research from G. Mao(2009) [7], we choose several important factors, including industrial output per capita (*indusp*), the ratio of urban built-up area to urban area ratio (*area1*), the area of urban built-up (*area2*) and employment density (*dens*). The original data can be obtained from Urban Statistical Yearbook of China (volume 2000-2013). These variables can be calculated easily.

Labor variable (*l*) is the sum number of labor force employed in the enterprise, private sectors and self-employment within city proper each year. Capital input (*k*) is measured by the capital stock per capita within city proper each year. We adopt the data of fixed assets investment per capita as the proxy variable of capital stock per capita. Land input(*s*) is measured by urban built-up area as the proxy variable.

IV. Results Analysis

The panel data model can be estimated under two different methods: Panel Least Squares and Generalized Method of Moments (GMM). The first one is based on the assumptions: fixed effect and random effect. We use Hausman test to decide which assumption is better. Hausman test rejects the random effect model. So in the fixed effect model, we test the effect without and with lagged transport variables, which maybe play distinct roles on urban compactness. The results are as follows:

TABLE III. Results of Transport-Urban Compactness Fixed Effect Model

Model number	1	2	3	4
Dependent variable	Urban compactness(logged)			
Trans1 (logged)	0.052*** (9.24)		0.065*** (13.43)	
Trans2 (logged)	0.056*** (10.92)			
Trans3 (logged)	0.105*** (18.25)		0.111*** (18.90)	
Trans4 (logged)	-0.034*** (-10.37)			
Trans1_lag1 (logged)		0.060*** (10.01)		0.075*** (14.76)
Trans2_lag1 (logged)		0.036*** (6.57)		
Trans3_lag1 (logged)		0.083*** (13.67)		0.085*** (13.98)
Trans4_lag1 (logged)		-0.010* (-2.92)		
constant	3.097 (104.61)	2.982 (94.47)	2.878 (167.42)	2.933 (165.33)
N	3038	2821	3038	2821
R^2	0.89992	0.89695	0.89418	0.89524
Prob (F-statistic)	0.00000	0.00000	0.00000	0.00000

Note: ***, **,* each corresponds to significance at 1% level, 5% level and 10% level, respectively.

As shown in Table III, we find some positive correlations between most transport measures and urban compactness in the fixed effect model. In the column2, the coefficient of bus vehicles per 10,000 residents (*trans1*) to urban compactness is 0.052, which means that a doubling of the bus vehicles per 10,000 residents will improve the urban compactness of city in China by 0.052%. Meanwhile, a 100% increase on area of paved roads per person (*trans2*) and the number of taxi per 10,000 residents (*trans3*) will have a positive increase by 0.056% and 0.105% on urban compactness. Therefore, it is prominent that urban transport improvement can contribute to the higher urban compactness. In contract, the variable *trans4* (the annual ridership) also shows some significant but negative effect on urban compactness, which presents that the increase of urban passenger capacity will lead to some reduction of urban compactness. Actually, if all the residents live in a high density district, the ridership is low, because residents can reach some destinations (workplaces, shopping mall, public infrastructure and so on) by walking or bicycling, so as to reduce the dependence on the transport (such as public transport or private cars, etc). On the reverse, the big ridership means urban function and spatial structure is not compact and there is a long distance between residents and their destinations, which requires more dependency on transport infrastructure. Furthermore, we take the lagged transport variables into account in model 2. It also yields some significant results. We also test the independent effect from public transport variables (*trans1* and *trans3*) on urban compactness in model 3 and 4. This yields some significant and positive elasticity of 0.065 and 0.111 in model 3, which illustrates public transport's improvement can result in the higher urban compactness.

To control the mutual causality, we add the lagged dependent variable $Comp_{ijt-1}$ into the model, which gives rise to autocorrelation. Besides, time-invariant city characteristics, such as geography and demographics, may be correlated with the explanatory variables. The fixed effects are contained in the error term in the equation (3), which consists of the unobserved city-specific effects v_i and the observation specific errors $e_{it:}$

$$u_{it} = v_i + e_{it}$$

The panel dataset has a short time dimension (T=14) and a larger city dimension (N=217). Finally, the Arellano-Bond difference GMM estimator is designed for small-T and large-N dynamic panel data. The city's fixed effect showed in the error term will decline with time, and the correlation of lagged dependent variable with the error term will be insignificant (D. Roodman, 2006) [8]. Table IV gives the Stata output for the Arellano and Bond GMM one-step estimator using (xtabond2, one-step). To distinguish the different effects of transport variables from the lagged terms, we set the model 5 and model 6. This estimator yields two lagged compactness coefficients estimate of 0.692 and 0.703 respectively, both highly significant. Nevertheless, the effects of transport variable are complicated. *trans1* and *trans2* have some obvious effects on urban compactness, but the coefficient of *trans1* is negative (-0.438) and *trans2* is 0.469. That is a dynamic equation and the GMM model takes the year dummies into account. Actually, in the short term, public transport improvement, such as public bus per capita (*trans1*), which presents the extension of bus lines, leads to urban expansion, so as to the temporary reduction of urban compactness to some extent. The annual ridership (*trans4*) also reveals a positive and significant effect (0.219), while taxi number per capita (*trans3*) doesn't present any obvious relationship with urban compactness. In model 5, it yields the coefficient estimate of lagged transport variables, all significant. But the coefficient of area of paved roads per person (*trans2*) is negative (-0.339), owing to time-lag effect. Actually, the increase of area of paved roads per person means more new roads built and expanded in *t-1* year, there is no residents to move outwards in *t-1* year; nevertheless, more and more residents tend to live along new road lines in *t* year, no doubt that it results in the lower compactness, but temporarily. Finally, the Sargan test for overidentification does not reject the null, which means the effective instrument variables.

The results suggest a relatively strong relationship between transport and urban compactness in the city, which implies that transport agencies should pay more attention on improving transport infrastructure. The improvement of urban transport, especially public transport, can contribute to the development of compact city. From the empirical result about China prefecture cities, transport should be regarded as a significant force for urban compact development.

TABLE IV. RESULTS OF TRANSPORT-URBAN COMPACTNESS ONE-STEP DIFFERENCE GMM

Model number	5	6
Dependent variable	Urban compactness (logged)	
Comp_lag1 (logged)	*0.692*** (6.37)*	*0.703*** (7.14)*
Trans1 (logged)	*-0.438*** (-3.37)*	
Trans1_lag1 (logged)		*0.117** (2.14)*
Trans2 (logged)	*0.469*** (3.28)*	
Trans2_lag1 (logged)		*-0.339** (-2.98)*
Trans3 (logged)	*0.045 (1.34)*	
Trans3_lag1 (logged)		*0.122*** (3.93)*
Trans4 (logged)	*0.219* (2.09)*	
Trans4_lag1 (logged)		*0.225** (2.67)*
AR(2)	*0.013*	*0.73*
Sargan test	*0.181*	*0.509*

Note: ***, **,* each corresponds to significance at 1% level, 5% level and 10% level, respectively.

V. CONCLUSION

With the acceleration of urbanization progress in China, due to the large amount of population and little land resource, no doubt that compact city development mode is an efficient and inevitable choice. This paper uses 3038 observations on 217 prefectural cities in China from 1999 to 2012 to verify the effect of this compact development mode on urban productivity. Firstly, with the method of entropy, we get the urban compactness of 217 prefecture cities from 1999 to 2012. The results suggest that most of cities in China are located at the median-compactness level.

This paper also explores the impact of transport on urban compactness. The result confirms that transport improvement can contribute to the increase of urban compactness effectively, but the effects have time lag. Transport is an important driving force for urban development and economic growth. Therefore, transport agencies should pay more attention on improvement of urban transport, especially public transport, which will play a significant role on guiding the urban expansion and agglomeration.

Furthermore, a lack of reliance and consistory of data released in statistical resources in China may affect the accuracy of research findings in this study. Besides, in the process of exploring the relationship between transport and urban compactness, there isn't distinguishing the effects of different urban transport modes (public transport or automobile transport) on urban compactness, due to unavailable and unreliable data. Future studies based on reliable database covering more transport and urban development attributes to more Chinese cities will be definitely helpful.

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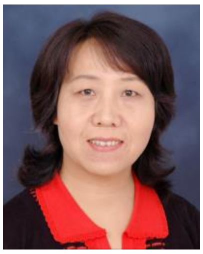

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