A Systematic Decision Criterion for Urban Agglomeration: Methodology for Causality Measurement at Provincial Scale

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***Abstract*—The paper employs the synergism theory and grey relative technique to analyze the inner nonlinear relationships among factors that attribute to process of urban agglomeration, and builds a synergic model to reveal the causality running urban agglomeration system. The grey relative analysis shows that the urban agglomeration system is an open and dissipative system, and it is affected by many factors, which are not just simple linear relative but relevant, non-uniform and irreversible. Meanwhile, the synergic model reveals that the key parameters that dominated the process of urban agglomeration in Jiangxi province are the rate of industrialization, percentage of urban fixed asset investment in the total fixed asset investment and the highway mileage on per unit area. Obviously, the simulated results are available in practice, so the nonlinear systematical methods can be applied to analyze the causality mechanism in process of urban agglomeration.**

***Index Terms*—Urban agglomeration; causality measurement; grey relative technique; synergic model**

I. INTRODUCTION

Urban agglomeration is made up of cities with different sizes to be linked by traffic network in a given area, and it is an inevitable result when urbanization reaches a certain level [1]. Today, while the global economic development is integrated, the urban agglomeration has become a carrier, by which a country or region can participate in international competition. For example, in the United States, three urban agglomerations including the New York area, Los Angeles area and the Great Lakes concentrated about 46% of the national population and 67% of the GDP. So, it is vital for a nation and area to nurture and build a stronger and competitive urban agglomeration for participating in international competition. How to nurture and build the urban agglomerations, rapidly? This is not only an actual problem for city planners and urban managers, but also an important academic issue for the theoretical scholars.

Although many scholars pay more attention to the city cluster in the developed areas of western countries, the modern researches have been extended to the developing areas including Africa and Asia countries. Here, mechanism and pattern of urban agglomeration are still a focus and topic in urban planning field. For example, Naude and Krugell(2003)analyzed the spatial development of urban agglomeration in South Africa, and thought that the size of the primate city in Johannesmore-east Rand might be relatively too large[2]. Kanemoto et al.(2005)took Tokyo metropolitan as an example, and analyzed the rational size of Tokyo as the primate city[3]. Qin et al.(2006) analyzed formation mechanism and spatial pattern of urban agglomeration in central Jilin of China[4].

Most modern scholars of urban development acknowledge that transnational processes are having an increasingly important influence on the evolution of urban agglomeration. An early observation was the recognition of an emerging system of world cities[5], a kind of urban elite which is shaped in part by the new international division of labor. These urban agglomerations are also thought to be controlling and coordinating global finance, producer and business services[6]. The view of world cities as the “key nodes” of the international urban system is a widely held one, underpinned in particular by rapid advances in the development of information technology and telecommunications. However, because the surrounding metropolitan area has experienced profound changes of spatial organization, with suburbanization bringing the most radical reorganization of metropolitan space[7][8][9], the growing role of suburbanization in metropolitan development is not unique as other major cities in post-communist countries follow a similar path [10][11][12][13][14][15][16][17].Suburbanization should thus be considered as one of the crucial topics in the study of urban agglomeration in post communist cities. Consequently, a variety of explanation attribute to urban agglomerations at present.

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When we carefully review the relevant operation mechanism of urban system, we may find that urban agglomeration being a complicatedly non-linear systems, has a lot of "disturbance" and "fluctuation" in orderly appearance. The "disturbance" and "fluctuation" can make the self-organized process changed and promoted, and then the system can change from disordered to ordered (or from junior orderly to senior orderly). The process of urban agglomeration also can appear a "Lorenz Butterfly Effect" phenomenon when the system inclines to recession or collapse[18]. Therefore, we have to depend on non-linear mathematical methods to analyze the interaction mechanism of formation and evolution of urban agglomeration, by which we can find the quantitative relationship among the key factors and reveal the causality in the system. However, there is still a lack of studies on the integrated systems from the holistic region point of view, thus we take Jiangxi province in China as a case, and use the grey relative technique to analyze the main factors of urban agglomeration evolution and develop a synergic method to reveal the causality. The objective of this study is to investigate the key factors of urban agglomeration in Jiangsu province. Improved understanding of its interactive mechanism will certainly help planning efforts for future urbanization management.

II. METHODOLOGY AND DATE

A. Grey relative technique

Grey system theory thinks that the world is the material world, and it is also the information world. In the information world, the white system can be understood and the black system can not be known relatively and temporarily, only the grey system can partly be explained eternally and absolutely. The grey system theory is just an analytical method which generally is used to study relationships with incomplete information. The main characteristic of the grey system theory is to compare the data arrays and to calculate the grey relational degrees between each element of the system with incomplete information. Hereinto, the grey relative technique is an effective way to reveal the grey relation. So-called grey relative technique is to find the links among the elements through the quantitative analysis. Thus, we can reveal the incomplete information world by the grey relative technique. The basic idea of grey relative technique is to judge similar of its close link by grey relational degrees [19]. To calculate the grey relational degree r_{ij}, the first step must calculate the grey relational coefficient between main-array and sub-array. The grey relational coefficient is defined as:

$$r_{ij}(k)=\frac{\min_j \min_k \left|x_i(k)-x_j(k)\right|+\xi \max_j \max_k \left|x_i(k)-x_j(k)\right|}{\left|x_i(k)-x_j(k)\right|+\xi \max_j \max_k \left|x_i(k)-x_j(k)\right|} \quad (1)$$

Where $r_{ij}(k)$ is the grey relational coefficient of the main-array and sub-array at time k; $x_i(k)$ is the main-array; $x_j(k)$ is the sub-array and ξ the differentiation coefficient, which is used to increase the most prominent differences between two arrays. Generally, the value is assumed to be 0.5. The second step is to calculate the grey relational degree between the main-array and sub-array. It is defined as:

$$r_{ij}=\frac{1}{n}\sum_{k=1}^{n} r(x_i(k),x_j(k)) \quad (2)$$

Where r_{ij} is the grey relational degree of sub-array j and main-array i; n is the length of the arrays.

B. Synergic model

The formation of urban agglomeration is the result of nonlinear links among the elements of system, and its evolution results from their synergy, cooperation and competition. Therefore, there exists a relatively stable form in process of urban agglomeration, in which the form changes from the disorder state to orderly another. Besides, the process of urban agglomeration is also an interminable developing period with temporal-spatial structure on the whole. In order to reveal the inner mechanism and evolution causality, we develop a synergic model to analyze the nonlinear function and find out theirs quantitative relationship[20].

If the dynamic system of urban agglomeration have n state variable, the $x_1, x_2, \ldots, x_m$ are the date sequences during 1-m. Because the variables have different units, they can not directly be applied for the synergic model formerly, and the variables have to be normalized. Supposed normalized variables be $x_i^{(0)}(t)(i=1,2,\cdots m)$, and the corresponding sequence after first accumulation is $x_i^{(1)}$, thus the variation rate is $\frac{dx_i^{(1)}(t)}{dt}$. The variation rate is determined by two aspects. The first aspect results from the inner synergic effects among the elements of system, and it is self-development result. If the self-development items is $a_{ii}x_i^{(1)}(t)$, the restrain items is just $-b_{ii}(x_i^{(1)}(t))^2$. The second one lies in the exterior synergic effects among the subsystems, and it is so-called the synergic function. If the synergic items is $a_{ij}x_i^{(1)}(t)$, the restrain items is just $-b_{ij}(x_i^{(1)}(t))^2$. Thus, the total variation rate $x_i^{(1)}(t)$ can be expressed as follows:

$$\frac{dx_i^{(1)}}{dt}+a_{ii}x_i^{(1)}=-(b_{ii}+b_{ij})(x_i^{(1)})^2+\sum_{j}^{m}a_{ij}x_j^{(1)} \quad (3)$$

If $b_{ii}+b_{ij}=b_i$, we can get the following nonlinear equation:

$$\frac{dx_i^{(1)}}{dt} + a_{ii}x_i^{(1)} = -b_i(x_i^{(1)})^2 + \sum_j^m a_{ij}x_j^{(1)}(i \neq j) \quad (4)$$

Because the evolution of system is from one critical point to another, the fluctuation is only a disturbance. Correspondingly, the stability mechanism of system always makes the fluctuation to decay or even disappear. Considering the synergic model of urban agglomeration that we build is to find out the dominant driving parameters, they can lead to formation and evolution of urban agglomeration. In practical, we will give the parameters an important action to strengthen the synergic function between systems. Beside, the purpose of our work help the systems promote a higher orderly development and not forecast its trend when the system happens to change or transition. Therefore, we neglect the role of the fluctuation when we build model.

The parameters a_{ii}, a_{ij} and b_i are indicators, by which we measure the intensity of synergy and competitive among the elements. These parameters can be solved through using the nonlinear differential equations. To analyze the status equations of the model, we can found which is the positive relaxation coefficient among the state variables? And which is the negative relaxation coefficient in the status equation? When the state variables with the negative relaxation coefficient are eliminate with adiabatic approximation approach, the remained state variables are all the slow ones of this system, and they is so-called order parameter. On the other hand, we can also use numerical method, i.e. Runge-Kutta approach with four times differences, to gain the numerical solution of the equation, and then eliminate the rapid state variables of system by adiabatic approximation approach. At last, the remaining slow state variables are just the order parameters of system. Because the $x_i^{(1)}(t)$ is obtained by first accumulation and normalization in the equation. After the numerical solution of the equation is reduced, the simulated values of state variables in line with synergic development of urban agglomeration system can be obtained by Runge-Kutta approach, subsequently.

C. Date collection

Jiangxi province is located in Southeast China, bordering Fujian, Guangdong, Zhejiang, Hunan, Hubei and Anhui provinces. It represents about 1.8% of the surface of the P.R. of China and 3.5% of its population. In Jiangxi province, agricultural production dominates its economy. The share of agriculture in GDP was 17.93% in 2005, i.e. 5.32% higher than the average level of the whole country. Its GDP per capita in 2006 was equal to 9440.62 Yuan (US$8.19), i.e. 67.24% of the national average[21].

The data of non-agricultural population and GDP of provincial cities and the other major cities of central region origin from "China city statistical yearbook (2007)"which is drawn up by urban social-economic survey department of National statistics bureau[22]. The social-economic data of major cities of Jiangxi province origin from "Statistical yearbook of Jiangxi province (2007)", which is edited by statistics bureau of Jiangxi province[23]. The distance between every city of Jiangxi province and the other cities is measured by mileage of railway of National railway ministry, these data origin from http://qq.ip138.com/train/ , specially, when there is direct train between the two cities, we adopted their nearest distance. Taking into account that the considerable number of cities doesn't have any direct train, we use the shortest distance of transit based on the accessibility.

III. RESULT AND ANANLYSIS

A. Factors analysis

For the evolution of urban agglomeration is interaction process among variables, in order to find out their behavior characterize, we have to inspect the relationship between elements of urban agglomeration system. According to qualitative analysis, it can be found that the dominant driving force of formation and evolution of urban agglomeration in Jiangxi province comes from six aspects, i.e. industrialization, migration and transferring of industries, foreign investment, pressure of competition in the central area, construction of traffic network and macro-control of government[24]. Because the relationship among the variable in the internal dynamic systems is relatively complex, and they are affected by some man-made policy, therefore, it is very difficult to directly quantify the action characteristics of urban agglomeration system. Thus, we can use the indirect variables to character the dynamic systems. First of all, we selected six variables as the original series during 2000-2006. The six variables are respectively the rate of industrialization, percentage of the tertiary industry in GDP, percentage of the actual utilized foreign investment in GDP, percentage of urban fixed asset investment in total fixed assets investment, the highway mileage on per unit area, and percentage of financial income in GDP (Table 1). We can use grey relative technique to calculate the grey relational degrees of the six variables, and then obtain cross table of the dynamic elements during 2000-2006 in Jiangxi province (Table 2). Through grey relative analysis, we can have four results from table 2. The first result shows that the grey relative degrees are all above 0.45, which indicates the interactive intensity and the mutual constrains of the various elements in urban agglomeration are significant. The second result shows that the grey relative degrees of the variables are different, and they are not simple linear relative but relevant, non-uniform and irreversible, which indicates the system is complex. The third result shows that there is a higher grey relative degree between percentage of the actual utilized foreign investment in GDP and the other variables, which indicates that the ability of attract foreign investment is more important than that of other elements in process of urban agglomeration in Jiangxi province. At the same time, the rate of industrialization, percentage of the tertiary industry in GDP, percentage of urban fixed asset investment in total fixed assets

investment, the highway mileage on per unit area and percentage of financial income in GDP pay an important role in the ability of attracting foreign investment. The last aspect shows that there exists a higher relationship between percentage of urban fixed asset investment in total fixed assets investment and the other variables, which indicates that the city construction investments have an important impact on the evolution of urban agglomeration. However, the rate of industrialization, percentage of the tertiary industry in GDP, financial income and the highway mileage on per unit area are also play a vital role in urban fixed asset investment.

Table 1. The data of action characteristics of urban agglomeration during 2000-2006 in Jiangxi province,China

items	variables	times						
		2000	2001	2002	2003	2004	2005	2006
The rate of industrialization (%)	x_1	27.2	27.7	28.7	30.8	33.0	35.9	38.7
Percentage of the tertiary industry in GDP (%)	x_2	40.8	40.6	39.6	37.2	35.5	34.8	33.5
Percentage of the actual utilized foreign investment in GDP (%)	x_3	1.021	1.637	3.993	5.169	5.344	5.375	5.408
Percentage of urban fixed asset investment in total fixed assets investment (%)	x_4	84.4	84.6	85.1	85.8	86.4	87.7	88.5
The highway mileage on per unit area(km/km^2)	x_5	0.361	0.364	0.368	0.369	0.371	0.373	0.768
Percentage of financial income in GDP (%)	x_6	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table 2. The cross table of factors of urban agglomeration in Jiangxi province,China

	x_1	x_2	x_3	x_4	x_5	x_6
x_1	1	0.66	0.65	0.76	0.59	0.62
x_2	0.62	1	0.74	0.72	0.55	0.67
x_3	0.65	0.77	1	0.64	0.67	0.90
x_4	0.71	0.75	0.60	1	0.58	0.65
x_5	0.56	0.57	0.64	0.57	1	0.72
x_6	0.46	0.45	0.47	0.46	0.43	1

B. Causality analysis

Supposed that the rate of industrialization, percentage of the tertiary industry in GDP, percentage of the actual utilized foreign investment in GDP, percentage of urban fixed asset investment in total fixed assets investment, the highway mileage on per unit area and percentage of financial income in GDP are the state variables in urban agglomeration, respectively, and they can be denoted as $x_1^{(0)}(t)$, $x_2^{(0)}(t)$,, $x_3^{(0)}(t)$, $x_4^{(0)}(t)$, $x_5^{(0)}(t)$ and $x_6^{(0)}(t)$. With the software of MATLAB applied, we can get the parameters of system by using the synergic model. And then the parameters are put into Equa.(4), we can get the state equations of system:

$$\begin{cases} \dfrac{dx_1^{(1)}}{dt} = -0.5870x_1^{(1)} + 0.2503(x_1^{(1)}(t))^2 + 0.3474x_2^{(1)} + 0.5219x_3^{(1)} + 0.4146x_4^{(1)} + 0.3292x_5^{(1)} + 0.4158x_6^{(1)} \\ \dfrac{dx_2^{(1)}}{dt} = 0.3037x_1^{(1)} - 0.7274x_2^{(1)} - 0.0529(x_2^{(1)})^2 + 0.4679x_3^{(1)} + 0.5047x_4^{(1)} + 0.4053x_5^{(1)} + 0.3922x_6^{(1)} \\ \dfrac{dx_3^{(1)}}{dt} = -0.7287x_1^{(1)} + 0.3509x_2^{(1)} + 0.3726x_3^{(1)} + 0.0724(x_3^{(1)})^2 + 0.4635x_4^{(1)} + 0.5064x_5^{(1)} + 0.4826x_6^{(1)} \\ \dfrac{dx_4^{(1)}}{dt} = 0.3275x_1^{(1)} + 0.3062x_2^{(1)} + 0.2272x_3^{(1)} - 0.7271x_4^{(1)} + 0.0807(x_4^{(1)}(t))^2 + 0.4627x_5^{(1)} + 0.5243x_6^{(1)} \\ \dfrac{dx_5^{(1)}}{dt} = 0.4276x_1^{(1)} + 0.3907x_2^{(1)} + 0.1278x_3^{(1)} + 0.4347x_4^{(1)} - 0.5264x_5^{(1)} - 0.0902(x_5^{(1)}(t))^2 + -0.3526x_6^{(1)} \\ \dfrac{dx_6^{(1)}}{dt} = -0.5264x_1^{(1)} + 0.3281x_2^{(1)} + 0.5071x_3^{(1)} + 0.2229x_4^{(1)} + 0.3281x_5^{(1)} + 0.3209x_6^{(1)} - 0.4563(x_6^{(1)}(t))^2 \end{cases} \quad (5)$$

Using Runge-Kutta approach with four times differences, we can get the numerical solution as the indicate $\tilde{x}_i^{(1)}(t)(i = 2, \cdots, 6)$. After the numerical solution of the equation is reduced, the simulated values of state variables can be got, i.e. $\tilde{x}_i^{(0)}(t)$. Through analyzing the state equations of this model, we can get some results. Firstly, except that the coefficients of the first state variable (the rate of industrialization), the third state variable (percentage of urban fixed asset investment in total fixed assets investment) and the fourth state variable (the highway mileage on per unit area) are

positive, the coefficients of other three variables including percentage of the tertiary industry in GDP, percentage of the actual utilized foreign investment in GDP and percentage of financial income in GDP are negative. Secondly, with the adiabatic approximation approach employed, we can eliminate the three state variables, and the remaining state variables which are the rate of industrialization, percentage of urban fixed asset investment in total fixed assets investment and the highway mileage on per unit area are just the slow state variables, which can be called order parameter. By contrasting the cumulative curve of initial values and that of forecasted values (Fig.1 and Fig.2), it can be seem that the simulated rule of dynamic evolution of urban agglomeration is consistent with the actual situation, so the model is success.

The synergic model reveals that the dominant parameters of urban agglomeration in Jiangxi province are the rate of industrialization, percentage of urban fixed asset investment in total fixed assets investment and the highway mileage on per unit areas, which are key driving factor in formation and evolution of urban agglomeration. Therefore, the degree of industrialization, the competition ability of the central urban agglomeration and the construction of transport network play an important role in all driving factor. Therefore, we should pay more attention to the new industrialization for developing urban economics in the process of urban agglomeration. At the same time, the expenditure and maintenance funds in urban construction and the construction of transport network take a vital impact on developing of urban agglomeration in Jiangxi province. It is showed that urban construction and transport links are an important foundation for economic development. If there is no a guarantee for good urban environment in economic growth, the healthy economic development can not be achieved. Therefore, we should pay more attention to planning on the whole urban construction in practice, and raise funds for construction and accelerate the infrastructure of transports in Jiangxi province.

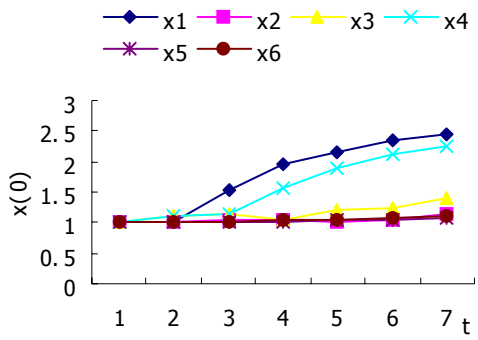

Figure 1. Cumulative curve of initial values

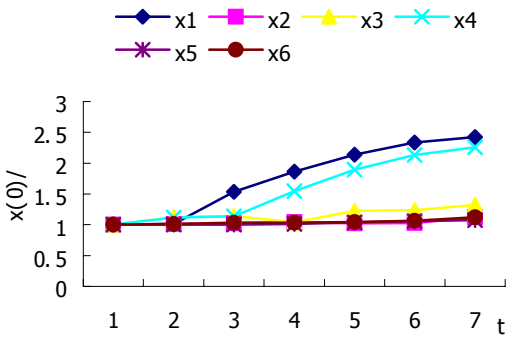

Figure 2. Simulation curve of forecasted values

IV. CONCLUSIONS

There is still a lack of studies on the integrated urban agglomeration systems from the holistic region point of view, thus we take Jiangxi province in China as a case, and use the grey relative technique to analyze the main factors of urban agglomeration evolution and use synergic method to build a nonlinear differential model that can reveal the causality in the process of urban agglomeration and get the parameters of system by simulation. The results by grey relative analysis shows that urban agglomeration system is an open and dissipative system, and it affected by many factors, which are not simple linear relative but relevant, non-uniform and irreversible. And the synergic model further reveals that the dominant parameter of urban agglomeration in Jiangxi province are the rate of industrialization, percentage of urban fixed asset investment in total fixed assets investment and the highway mileage on per unit area, which are key driving factor in formation and evolution of urban agglomeration. Therefore, the promoting of industrialization, the enhancing of competitive ability of the central urban agglomeration and the boosting construction of transport network are vital in process of urban agglomeration.

The studied result shows that the integrated model constituted of the grey relative technique, the synergic model and numerical analysis can to the degree reveal the evolution direction of urban agglomeration, and hold the internal mechanism of its formation and evolution. Therefore, the nonlinear systematical methods can be applied to analyze the mechanism of urban agglomeration development. As an applied research, when we use the other variables to describe the action characteristics in the dynamic systems, the method is simple but it can reflect the uncertainty and subjectivity. At the same time, only a series of assumptions is considered do we build the synergic model by nonlinear differential grey system when. Because the fluctuation is not considered, the universal practicability can not be ensured when it is applied. Therefore, we should amend the model in accordance with the specific issues in practice.

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