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Measuring regional sustainability by a coordinated development model of economy, society, and environment: A case study of Hubei Province

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Abstract

Regional sustainability concerns a complex system that mainly consists of three subsystems, being the economy, society, and the environment. A complex system involves intensive interactions and correlations among its components. Therefore, the way how these components are organized to work together efficiently is of great significance to the development of a complex system. For that reason, measuring regional sustainability should not only focus on changes in each subsystem individually, but also consider the interactions and relationships among the subsystems. In this paper, we apply a modified method to assess coordinated development, which highlights the simultaneous promotions of economic grow, social well-being, and environment al conservation. By introducing the model of coordinated development, we evaluate the sustainable development of Hubei province which is a typical region in Central China. The result shows that Hubei performed poorly in coordinated development. Although the coordinated development index was consistently increasing, the speed was very slow. In a detailed analysis of the economic, societal, and environmental subsystems in Hubei, the shortage of an economic driving force was found the main cause of the poor development of Hubei Province.

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1. Introduction

At the end of 2013, Eastern China was shrouded by intensive smog, caused by a severe bout of air pollution. The social and environmental crises such as poor air quality, heavy metal waste and huge income gaps, led by the consistent rapid economic growth over more than three decades, cannot be overlooked anymore. Consequently, the topic of sustainable development is being addressed with increasingly emphasis in China as well as other developing countries in recent years.

It has been common¹⁻⁴ to represent sustainability in terms of the triangular concept of economy, society, and environment. Together, these three poles define a complex system with multiple interactions among the three subsystems. Within the complex system, we advocate the simultaneous promotion and balanced status of economics, natural capital, and quality of life. This pathway towards sustainability is also argued in a recent report of UNEP⁵, that is, enabling economic growth and improving human well-being while reducing environmental risks and ecological scarcities is envisioned as the hallmark of sustainable development. It's worthwhile to note that how to coordinate these subsystems such that they work together efficiently of great significance to the development of a complex system. Thus, in the context of monitoring progress, measuring regional sustainability should not only focus on the changes in each subsystem individually, but also consider the coordinative interactions and relationships among the subsystems.

Accordingly, we sketch the perspective of sustainability based on a coordinated development of the economy, society, and environment, which articulates the simultaneous development of the three subsystems rather than creating unbalanced development such as : (1) pursuing economic growth with increasing environmental risks and ecological scarcities, (2) employing strong environmental policies that drive inefficiencies in the economy by removing all those firms and industries that generate waste emissions, (3) developing a robust economy without the consideration of improving the livelihoods of the poor and the social well-being of current and future generations. It's difficult to define and quantify the level of coordination among economy, society, and environment, yet it is essential to set targets and track progress for sustainability transition.

Various studies have suggested indicators of sustainable development, e.g. the sustainable development indicators (SDI) developed by different means: by associating sustainable development with components of quality of life^{6,7}, and by focusing on some specific objectives, such as smart transportation⁸, sustainable housing^{9,10}, sustainable urban land use^{11,12}, and reducing air pollution^{13,14}. Many empirical and case studies of sustainable development at the regional scale have been done¹⁵, especially for municipalities and cities. Examples include the study for European cities using European Common Indicators¹⁶, and the evaluation of cities in Canada and America^{6,7,17,18}. When the issue of sustainability evaluation comes to China, plenty of assessing researches have been done¹⁹⁻²³. However, only a few studies considered measuring the coordinative relationships among the three components of sustainability, e.g. the sustainable development index that involved system coordination indicators²² and a coupling model of coordination between urbanization and the environment²⁴⁻²⁶. Currently, the method of coordinated development still stays at a primary stage of development that focuses on the coordinative interactions between two subsystems. There is a gap in the model of coordination measurement among three subsystems.

This paper contributes to this literature by suggesting and applying a modified method for sustainability assessment by measuring the coordinated development of the economy, society, and environment. The remainder of this paper is organized as follows. In the second section, we introduce the evaluation framework of coordinated development. Through a simulation experiment, we try to explain the advantages of the modified model. In order to verify the method in real situations, we collected data for Hubei province from 2004 to 2010. Finally, we come to the conclusion and highlight the most important contributions and limitations of this study.

2. Methodology

A complex system involves intensive interactions and correlations among its subsystems. Therefore, the sustainable, coordinated development of the economy, society, and the environment should consider two different dimensions: one is 'coordination' which involves forming harmonious and synergic relationships among the economic, societal, and environment-related subsystems; the other one is 'development' which requires progress in economics, social well-being, and natural capital.

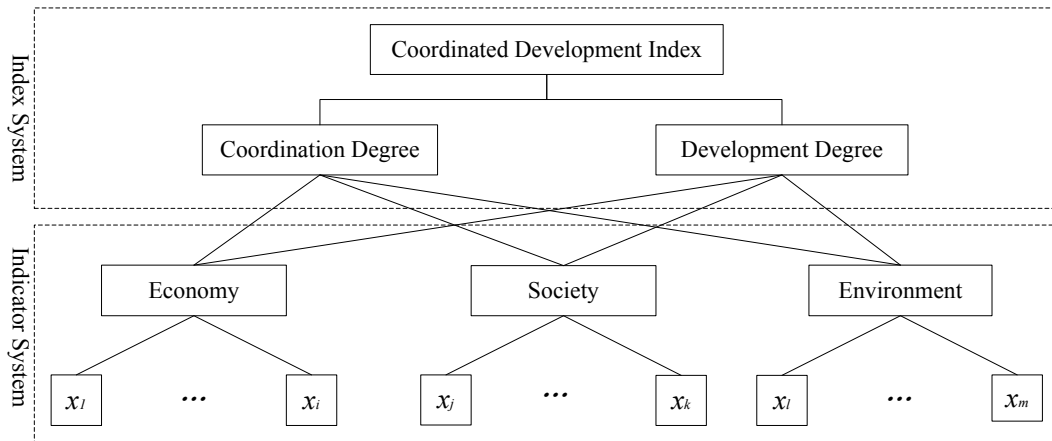


Fig.1. The evaluation framework of coordinated development.

These two aspects constitute the main components of coordinated development. Correspondingly, coordinated development should be constructed by integrating the degree of coordination and degree of development. Both the degree of coordination and degree of development are generated by scores of the economic, societal, and environmental subsystems. These subsystems are measured in terms of a set of indicators as shown in Fig. 1.

2.1. Indicator system of coordinated development

During the last decades, international and regional organizations have composed a list of urban sustainability indicators, which have been used as references by many countries and communities to develop their own sustainable urbanization indicators systems and provide good references for this paper to construct the indicator system.

We use a top-down approach to select representative indicators for economic, societal, and environmental subsystems to demonstrate an in-depth understanding of the degree of coordinative relationship among the three subsystems. Table 1 gives an overview of the selected indicators that were available as time-series analysis for Hubei province, China.

2.2. The modified coordinated development index

An index is a dimensionless, normalised measure of the phenomenon for which the index is intended. Thus, the first step in the formulation of the index is to normalize the indicators. Let x_{kl}^l be the normalized value of observation l in indicator k , x_k^- is the lowest raw score of indicator k and x_k^+ be the highest raw score of indicator k . Monotonically increasing indicators were normalized using equation (1), while monotonically decreasing indicators were normalized using equation (2).

$$x_{kl}^l = \frac{x_{kl} - x_k^-}{x_k^+ - x_k^-} \tag{1}$$

$$x_{kl}^l = \frac{x_k^+ - x_{ik}}{x_k^+ - x_k^-} \tag{2}$$

Table 1. The indicator system of economy-society-environment system

Subsystem	Indicators
Economy	x1. Per Capita GDP x2. Proportion of Tertiary Industry output in GDP x3. Average Urban Income per Capita x4. Proportion of Gross Output Value of High-tech industry in GDP
Society	x5. Number of Collage Student in each 10,000 people x6. Urban Unemployed rate x7. Number of Beds in Health Care Institutions for each 10,000 people x8. Engel's Coefficient of Urban Households
Environment	x9. per Capita local Water Resources x10. Proportion of Wetland in total Area of Territory x11. Days of Air Quality Equal to or Above Grade 2 in the Whole Year x12. Forest Coverage Rate

Next, these normalized indicators should be integrated to arrive at a comprehensive index, which measure the *degree of development* of the three subsystems. Keeping in mind the chosen normalization, in which one observation always becomes zero, a weighted linear compensatory function is chosen to represent the comprehensive indices for the subsystems. Thus, it is assumed that a low score on one indicator can, at least partially, be compensated by high scores on one or more of the remaining indicators. In the present study, weights are assumed to be equal, but any set of normalized weights can be used. Thus,

$$s_i = \sum_k w_k x'_k \quad ; \quad \sum_k w_k = 1 \quad (3)$$

Because we do not allow for any substitution among the different indices of the subsystems, the total degree of development is defined as.

$$D = \prod_{i=1, I} x'_k{}^{w_k} \quad ; \quad \sum_k w_k = 1 \quad (4)$$

The third step measures the *degree of coordination* r . The index is then defined as

$$r = 1 - \frac{\sum_{i,j \neq i} |s_i - s_j|}{I(I-1)/2} \quad (5)$$

Finally, the coordinated development index Z is defined as the geometric mean of the degree of coordination and degree of development. In equation:

$$Z = \sqrt{r \cdot D} \quad (6)$$

3. Empirical Study

In order to illustrate the proposed index, we collected data from the China Statistical Yearbook, the China Environment Yearbook and the China Energy Yearbook from 2004 to 2010 of Hubei province, China.

3.1. The evaluation result

The assessment results of Hubei from 2004 to 2010 are shown in Fig. 2. We can see that the coordinated development index started from a very low level but increased consistently during the seven years. However, the speed of its growth was so slow that the coordinated development index did not exceed 0.5 even in 2010.

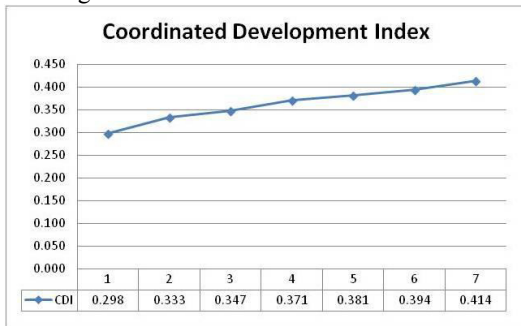


Fig. 2. The coordinated development index of Hubei.

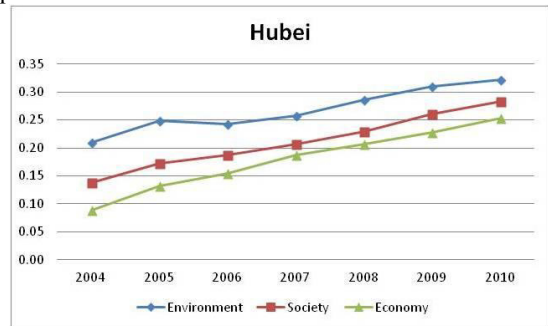


Fig. 3. The three subsystems of Hubei.

When we look into the three subsystems, it shows that they were increasing simultaneously during the period from 2004 to 2010 (Fig. 3). However, the economic system is the most underdeveloped one among them, which means the economics of Hubei can hardly drive its social development and it still need to experience a long-term process of industrialization.

3.2. The analysis of Hubei's development in detail

Hubei, located in the easternmost part of Central China, essentially has a couple of advantages for its economic and social development: (1) Situated at the crossroads of Central China, the capital city Wuhan is a transportation hub for air, railway, and ferry traffic, and the giant Yangtze River (the world's third longest river) pass through the city (2) Hubei is one of the important education regions of China (3) the province has always been one of the main industrial development regions in the national plan. Important industrial projects such as, Wuhan Iron And Steel (Group) Corp., Wuhan Heavy Duty Machine Tool Group Corporation, Wuchang Shipbuilding Industry Company Ltd., have been constructed, creating a solid foundation of industrial development for Hubei province. However, the economics of Hubei always lagged behind other peer regions. In 2004, the State Council of PRC issued a policy, the Rise of Central China Plan, to accelerate the development of its central regions, including Hubei. However, any obvious progress of Hubei's economics can hardly be found in these years after the Plan (Table 2). The lag of Hubei's economics are mainly caused by: (1) the industrial structure of Hubei is unbalanced, among the three main industries, the entire third industry including financial industry has an insufficient development, which only accounted for 38% in 2010, meanwhile the development of high-tech industry in Hubei still stays at the beginning stage, (2) the pattern of industrial production is of high emission, high energy consumption, which will cause more and more cost in the future, as the reform of resource pricing are continuously deepening and more policies of environment conservation will be issued, then such industries will lose their advantages in cost of production.

As it is the trend to transform to sustainable development, Hubei has begun to make efforts for a sustainable development. In 2006, the State Council of PRC approved 8 cities of Hubei together with Wuhan to combine as a city group, which is a reform region for 'Resource-conserving and Environment-friendly Society'. This project has invested many constructions of urban infrastructure and research projects of green technologies, e.g. garbage reuse, clean production. In order to improve the industrial structure, a national high-tech industry development zone was established in Wuhan, by the name of Optic Valley, which is the biggest photoelectron information industry base in China. It will help Wuhan absorb a huge amount of foreign funds and venture investment in the following years, as well as international companies that possess high technologies. The development of 'resource-conserving and environment-friendly society' and high-tech industry zones will offer more vacancies for graduate students that can lead them to a great career.

Table 2. Economic and societal indicators of Hubei and the national average of 30 provincial regions, 2004-2010.

	x ₁ - GDP per capita (RMB/capita)		x ₂ - Proportion of tertiary industry in GDP		x ₄ - Proportion of gross output value of high-tech industry in GDP (%)		x ₈ - Engel's coefficient of urban households	
	Hubei	National Average	Hubei	National Average	Hubei	National Average	Hubei	National Average
2004	10500	14079	36	37,5	4,34	11,5	39,32	38,2
2005	11431	16203	40	40,4	6,86	11,2	38,97	37,3
2006	13296	18662	41	40,0	7,71	11,6	38,78	36,5
2007	16206	21973	42	39,8	7,54	11,7	39,72	37,2
2008	19860	25780	41	39,0	7,48	10,9	42,17	38,9
2009	22677	28737	40	41,6	8,02	10,3	40,42	37,5
2010	27906	33427	38	40,4	8,22	10,7	38,68	36,7

Source: Collected and calculated by the authors based on the China Statistical Year Book (2005-2011)

4. Conclusion

In this paper, we suggested a modified method, coordinated development index, for the assessment of sustainable development, which highlights the simultaneous promotion of economic growth, social well-being, and environment conservation. By applying the method to the data set of Hubei province, we evaluated the sustainable development of this typical region in Central China. The result shows that the coordinated development index of Hubei province stayed at a poor level for the seven years of investigation. Although the coordinated development index was consistently increasing, the average speed of sustainable development was very slow. In a detailed analysis of Hubei's development, we found that a weak economic driving force caused the slow development in Hubei. Based on this, we highlight the policies that stimulate public and private investment in development of low-carbon, resource efficient, socially inclusive innovation and technologies to drive sustainability.

As the comprehensive level that integrates the coordinative relationships and development progress has been measured by the coordinated development index, we need to figure out the problems embraced in the development process of economy, society, and environment. So we need more detailed analysis model that enables the decomposition of the coordinative relationships among the subsystems. We take on this challenge in future research.

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