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Regional difference decomposition and policy implications of China's urban land use efficiency under the environmental restriction

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ABSTRACT

Exploring the general distribution characteristics and evolution rule of urban land use efficiency (ULUE) is of great significance for the efficient integration between urban land use system and the external environment. Most of the existing literature focuses on the existence of differences in ULUE between regions of mainland China, and rarely pays attention to the measurement of the regional differences of ULUE. This study puts the indicators on environmental pollution into the evaluation index system of ULUE and employs a non-radial, non-angular model of slack-based measure (SBM) to measure the ULUE of 31 provinces across mainland China from 2001 to 2014. The results showed that the ULUE in mainland China displayed a general trend of increase in the period, with the national average level increasing from 0.7585 to 0.7989. Besides, the spatial distribution pattern drawn by ArcGIS visualization method presented significant regional differences, with generally higher ULUE in the eastern and western regions compared to the central region. On this basis, the study examines the regional differences of ULUE and its evolution in mainland China by Dagum's Gini Coefficient Decomposition and Kernel Density Estimation. The result showed that the Gini coefficient of China's ULUE presented a trend of fluctuating rise followed by a fluctuating fall, with the greatest difference in the eastern region, much greater than that in central and western regions in most years. Meanwhile, the inter-regional difference is the main source of the overall differences. The study concludes that effective measures should be taken to improve the ULUE and narrow the regional gap of ULUE.

1. Introduction

Urban land, as a factor of production, tends to undergo highly frequent exchanges and drastic transformations during a country's urbanization process (Gao, Wei, Chen, & Chen, 2014; Hegazy & Kaloop, 2015; Marshall, 2007). The efficiency of urban land use has a direct impact on a region's socioeconomic development and human habitat environment (Choi & Wang, 2017; Hu, Legara, Lee, Hung, & Monterola, 2016; Krekel, Kolbe, & Wüstemann, 2016; Taleai, Sharifi, Sliuzas, & Mesgari, 2007). From 1990 to 2014, the area of China's Built Districts had grown from 13148 km^2 to 49882.7 km^2 (National Bureau of Statistics of China, 2015), which had been the physical basis of the rapid urbanization (Deng, Huang, Rozelle, & Uchida, 2010; He, Huang, & Wang, 2014). However, the continuous increase of urban area induced various negative effects (Liu, Liu, & Qi, 2015). In China's eastern coastal regions, the scarcity of available land resources puts a severe constraint on its growth (Ding & Lichtenberg, 2011). Especially the overvaluing of real estate property leads to the irrational expansion of urban areas (Lichtenberg & Ding, 2009; Chen, Gao, & Chen, 2016). Furthermore, large swathes of land was underutilized or used non-optimally in nearly all Chinese cities (Liu, Fang, & Li, 2014; Shen & Zhou, 2014). Therefore, a crucial problem in China's urbanization is how to improve the use efficiency of urban land and maximize their foundational role in urban development (Xie & Wang, 2015).

Urban land use has been investigated from a variety of perspectives, including regional economic (Ding & Lichtenberg, 2011; Veen & Otter, 2001), ecology (Foster, 2006), public management (Keivani, Mattingly, & Majedi, 2008) and urban geography (Heitzman & Rajagopal, 2004). These researches can greatly expand the breadth and depth of this topic. In recent years, scholars from various countries have conducted extensive research into urban land use efficiency (ULUE), especially the evaluation system and methodology of the ULUE. Overall, most of the scholars examined ULUE in terms of economic output, such as "the urban economic output of each land unit" (Cui & Wang, 2015) and "the ratio of total output value of secondary and tertiary industries to the area of urban land" (Wu, Wei, Huang, & Chen, 2017). Du, Thill, and Peiser (2016) employed "average economic output per square kilometer of urban built land" as the measure of ULUE. Zitti, Ferrara, Perini,

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Carlucci, and Salvati (2015) also created an index of per-capita consumption of land (the ratio of built-up areas to resident population) to reflect the ULUE. However, some scholars argued that the key procedure for effective evaluation of ULUE was to establish a comprehensive land use evaluation-indexing system (Hui, Wu, Deng, & Zheng, 2015; Yang, Yang, & Tang, 2012; Zhang, Wu, & Shen, 2011). Yang et al. (2012) developed evaluation indices of ULUE from intensive degree of buildings, intensive degree of lands and intensive degree of traffic. Wey and Hsu (2014) noted that urban land use should not only focuses on the economic benefits, but also attempts to achieve the maximization of economy, society and ecology. Hui et al. (2015) constructed an evaluation index system for urban land use intensity by means of Principal Component Analysis (PCA), and then proffered an empirical investigation of 120 China major cities' urban land use status in 2009. With the deepening study of the research, some scholars regarded the process of urban land use as an input-output system and proposed a few frameworks to evaluate the ULUE via Stochastic Frontier Approach (SFA) (Wang, Li, & Shi, 2015) or Data Envelopment Analysis (DEA) (Chen et al., 2016; Yang, Wu, & Dang, 2017). Those two methods were proven to be more effective in measuring the ULUE. Especially the DEA model, proposed by Charnes, Cooper and Rhodes in 1978, has become one of the mainstream technical tools to determine the ULUE. Due to its advantages like "no need to set the production frontier function form in advance", "non-subjective empowerment", "can analyze the ineffective factors of the decision unit" and so on (Burki & Terrell, 1998; Charnes, Cooper, & Rhodes, 1978; Moutinho, Madaleno, & Robaina, 2017). Chen et al. (2016) used a DEA model to analyze the changes in urban built-up land use efficiency in 336 Chinese cities, and found that more than half of the cities had excessive inputs of built-up land. However, traditional DEA models are mostly radial or angular that do not fully considered the slackness of inputs or outputs, nor can they accurately measure efficiency in the presence of undesirable outputs (Aparicio, Ortiz, & Pastor, 2017; Morita, Hirokawa, & Zhu, 2005). Hailu and Veeman (2001) treated undesirable outputs as input indicators, while Scheel (2001) took the reciprocal of undesirable outputs as desirable outputs. Both approaches can lessen the impact of undesirable outputs, yet are still inconsistent with the actual reality. To address these issues, Tone (2001) proposed a non-radial, non-angular model of slack-based measure (SBM), which directly incorporates slack variables into its objective function and accounts for undesirable outputs (Tone, 2003). This model also provides a new idea for the measurement of ULUE (Choi & Wang, 2017).

The development and use of urban land will reduce the availability of natural resources and increase the waste emissions (Ojima, Galvin, & Turner, 1994; Stephan & Friedrich, 2000; Nuissl, Haase, Lanzendorf, & Wittmer, 2009), which is an important source of deterioration of the ecological environment (Choi & Wang, 2017). Yang, Duan, Ye, and Zhang (2014) constructed a SBM-Undesirable model to evaluate the ULUE of 16 cities in the Yangtze River Delta, China, and they found that the environmental pollution and the presence of undesirable outputs induced the overall level of ULUE in the study area. Xie and Wang (2015) analyzed the dynamic changes of urban land use economic efficiency (ULUEE) in 270 cities across China by the SBM model, and they observed that the spatial difference of China's ULUEE was obvious in the research period, in which the eastern region of China enjoys the highest ULUEE, followed by the western and central regions. In fact, the existence of differences in ULUE between regions of China has been widely recognized by researchers due to the differences of regional economic development, land resource endowment, and so on (Li, Shu, & Wu, 2014; Lu, Kuang, & Zhou, 2016), but few studies have pay attention to the measurement of the regional differences of ULUE. Li et al. (2014) analyzed the disparity of ULUE in Chinese cities from 2000 to 2011 by Theil Index Decomposition, and observed that China's ULUE displayed a trend of convergence and gradually lowering spatial disparity over time. However, as Dagum (1997) argued, Theil Index, when used to measure the differences between different subpopulations, only requires the samples to be independent, homoscedastic, and normally distributed across subpopulations. Besides, the process of Theil index decomposition only takes the differences between subsamples into account, without considering how subsamples within a subpopulation are distributed. To bridge this gap, this study will use the new approach of Gini Coefficient Decomposition proposed by Dagum to explore the regional differences of ULUE quantitatively, and provide an accurate representation of urban land use in mainland China. Considering the existing literature that is mainly concentrated in a single city (Qiu, Sheng, & He, 2016; Wang, Zhang, Chen, Gao, & Huang, 2016; Wu, 2014) or cities at the prefecture level (Chen et al., 2016; Wu et al., 2017; Xie & Wang, 2015; Yang et al., 2017). This study will focuses on the 31provinces (autonomous regions and municipalities) across mainland China. The remainder of the paper is organized as follows: the "Method and Data" section provides general information on the methods and describes the indicator selection and data; the "Results and Analysis" section offers a presentation and an analysis of the acquired results; and the "Conclusion and Policy Implications" section contains the main findings of the study and policy implications for sustainable urban land use.

2. Method and data

2.1. Empirical model

2.1.1. Measurement model for ULUE

Supposing an urban land use system has n decision-making units (DMU), with each DMU contains m inputs, s_1 desirable outputs, and s_2 undesirable outputs. Its elements are defined by the following expressions: $x \in R^m$, $y^g \in R^{s_1}$ and $y^b \in R^{s_2}$. Define the matrices X, Y^g and Y^b as follows: $X = [x_1, x_2, \cdots, x_n] \in R^{m\times n}$, $Y^g = [y_1^g, y_2^g, \cdots, y_n^g] \in R^{s_1\times n}$, Y^b= $[y_1^b, y_2^b, \cdots, y_n^b] \in R^{s_2\times n}$, where: $x_i > 0$, $y_i^g > 0$, $y_i^b > 0$. Therefore, the production possibility set P under constant returns to scale (CRS) can be defined as:

$$P = \{(x, y^g, y^b)|x \geq X\lambda, y^g \leq Y^g\lambda, y^b \geq Y^b\lambda, \lambda \geq 0\} \tag{1}$$

$$\rho^* = \min \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{r0}^g} + \sum_{r=1}^{s_2}\frac{s_r^b}{y_{r0}^b}\right)} \tag{2}$$

$$s.\ t. \begin{cases} x_0 = X\lambda + s^-, y_0^g = Y^g\lambda - s^g, y_0^b = Y^b\lambda - s^b \\ s^- \geq 0, s^g \geq 0, s^b \geq 0, \lambda \geq 0 \end{cases} \tag{3}$$

Where: ρ^* is the ULUE; the variabless_i^-, s_r^g and s_r^b are the slack variables for the i_0-th DMU's inputs, desirable outputs, and undesirable outputs respectively, ands^-, s^g and s^b are their respective vectors; λ is the weight vector; "0" is the unit being evaluated. The objective function ρ^* shows strict monotonic decrease tos^-, s^g ands^b, with $0 \leq \rho^* \leq 1$. For a given unit, it is optimally efficient if and only if $\rho^* = 1$, that is to say, if $s^- = 0$, $s^g = 0$ and $s^b = 0$; if $\rho^* < 1$, that is to say, if some or all ofs^-, s^g and s^b are non-zero, the unit has inefficiency that can be improved. The SBM model for undesirable outputs (Equation (2)) is a nonlinear programming model, and it is often solved by converting into a linear programming model in practice (Charnes & Cooper, 1962).

2.1.2. Dagum's decomposition and Gini coefficient for subpopulations

The Gini decomposition method proposed by Dagum in 1997 can be used to describe the sources of inter-regional disparity and the distribution of subsamples free from the influence of sample overlap. Equation (4) below can express it:

$$G = \frac{\sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{n_k}|y_{ji} - y_{hr}|}{2\mu n^2} \tag{4}$$

Where: y_{ji} (y_{hr}) is the ULUE of a province (or autonomous region or direct-controlled municipality, same below) in the region j (h); μ is the