sustainability

MDPI

Article

Land Use Efficiency and Total Factor Productivity—Distribution Dynamic Evolution of Rural Living Space in Chongqing, China

Huikun Hong [1], Deti Xie [2], Heping Liao [1,*], Bo Tu [3] and Jun Yang [1]

1 Chongqing Key Laboratory of Karst Environment, School of Geographical Sciences, Southwest University, Chongqing 400715, China; hhk@swu.edu.cn (H.H.); yangjun20146682@swu.edu.cn (J.Y.)
2 College of Resources and Environments, Southwest University, Chongqing 400715, China; xdt@swu.edu.cn
3 Graduate School of International Studies, Dong-A University, Busan 49236, Korea; tubo110@hotmail.com
* Correspondence: Liaohp@swu.edu.cn; Tel.: +86-23-6825-2370

Academic Editor: Marc A. Rosen
Received: 25 December 2016; Accepted: 13 March 2017; Published: 23 March 2017

Abstract: Research on the land use efficiency of rural living spaces is at the core of conflicts about current rural land use and ecological environment construction in China. It can be effectively dealt with through the rational and healthy use of rural land, by promoting sustainable development and urban and rural coordination. Building on the foundation of ecosystem metabolism and sustainable development theories, this paper utilizes the Data Envelopment Analysis (DEA) Malmquist productivity index to divide the land use efficiency total factor productivity (LUTFP) into Malmquist–Luenberger technical change (MLTECH) and Malmquist–Luenberger efficiency change (MLEFFCH) from the perspective of scale change, and uses Kernel Function to measure and study the distribution characteristics of the dynamic evolution and land use efficiency (LUE) in different functional and productive areas and living space subsystem. The results show that, in the process of land use, desirable output growth in the Chongqing city rural living space is lower than the undesirable output reduction rate. Rural human settlement and construction management appears to damage the environment. The LUE in the obtained results showcases an obvious agglomeration effect in Chongqing. Also, there is a very significant "match-up" effect between the LUE and economic development level. In addition, the paper also finds that the technical change index and efficiency change index work together in rural living space LUTFP. The results presented in this paper can provide a basis for the optimization of regional development strategies and rural land utilization.

Keywords: land use efficiency total factor productivity; rural living space; Malmquist–Luenberger index; undesirable outputs; Kernel Function

1. Introduction

In the last few decades, China's economy has made rapid progress. However, environmental pollution and a shortage of resources continue to haunt the Chinese people [1]. Land resources, being the predominant carrier of socioeconomic activities, direct the spatial and temporal evolution of the social economy. Thus, complicated land use patterns and consequently land change science have emerged as a fundamental component of global environmental change and sustainability research [2]. Land utilization in rural transformation development also brings a variety of economic, social, and environmental problems, such as low economic efficiency, excessive pollutant emissions, and intensifying environmental crisis [3,4]. In recent years, China has adopted a series of environmental Protection of Rural Habitat policies; in 2014, the General Office of China's State Council released guidance and held a conference on improving the national rural human settlement. To realize sustainable development in rural production, it is necessary to improve land resource utilization efficiency and effectively control the non-point source pollution caused during rural development by focusing on the transformation of rural industry's development mode. However, it is imperative to understand the status of rural space land utilization efficiency [5,6]. Scientific measurement of China's rural LUE is important for regional governments to solve the challenges associated with rural development and coordinated development of land resources, the environment, and optimizing regional rural space.

To measure land use efficiency and environmental efficiency, Data Envelopment Analysis (DEA) has been widely used by many researchers. In terms of land use efficiency, foreign scholars place more emphasis on this analysis, which is different from the breadth and depth of urban system research [7–9]. In comparison with the documentation on urban system research, theoretical and practical research on rural land use efficiency is relatively weak because rural systems and the problems related with the subsystems have not yet been addressed in depth by scholars. Scholars such as Wang et al. a national survey to analyze the institutional setups for rural residential land use, to assess the effectiveness of the existing regulations, and to evaluate the efficiencies in rural residential land use [10]; Shen et al. built a rural land utilization efficiency evaluation model through data envelopment analysis [11]; and a biophysical analysis was used by Quaye et al. to determine the efficiency and potentials of the extensive system and its future sustainability in Ghana [12]. Luo et al. discussed the differences in peasants' land awareness from three aspects, land value consciousness, property right awareness, and dependent awareness, to further evaluate different types of peasant land utilization efficiency through DEA [13]. Most of the research works performed to date only consider economic output but ignore hazardous impacts on the environment in the process of rural development, which makes the research results incompatible with reality [14]. Land use efficiency must explicitly model a joint environmental technology and gauge performance in terms of increased desirable output and decreased undesirable output [15]. Due to the restraint of land resource scarcity and the difference in stages of social and economic development of different regions, the land utilization efficiency of rural living space system manifests spatial–temporal heterogeneity. The traditional DEA model analyzes the relative efficiency of the research sample, and therefore the change trends of the efficiency in time series cannot be manifested. However, this problem can be overcome through the ML total factor productivity exponential model. The proposed work suggests an alternative approach to explicitly model the non-point source pollution caused by rural development, enlisted into the analysis framework of total factor productivity. The evaluation index system, evaluation model, and evaluation criterion of land utilization efficiency of the rural life space subsystem are determined with the help of the rural space system theory and metabolism theory. In order to minimize undesirable outputs, the Malmquist Index is employed, which is a radial DEA efficiency measurement method that takes undesirable outputs as output indicators to measure LUTFP. Simultaneously, the DEA–Malmquist model is used to divide the total factor productivity (TFP) index into Malmquist–Luenberger technical change (MLTECH) and Malmquist–Luenberger efficiency change (MLEFFCH) [16–18], so as to discover factors influencing processes in rural land use efficiency of and provide a scientific rationale for local government department policies. Moreover, the land utilization efficiency of rural life space subsystem in different functional zones of Chongqing City was measured and studied on the basis of Kernel function. Contributions of the efficiency of labor, the efficiency of capital, and undesirable output changes to land utilization efficiency of rural life space in Chongqing are distinguished. Also, the research results provide references for rural space optimal development.

The central issues that will be addressed in the proposed work can be listed as: (1) the dynamic and evolutionary characteristics of rural land use efficiency in Chongqing, Southwest China; (2) the spatial imbalance of land use efficiency in rural areas of Chongqing, Southwest China and the factors influencing LUTFP. The paper is organized as follows: Section 2 presents the study area and data sources, among which models such as DEA–Malmquist–Luenberger productivity index were included. The empirical results are presented in Section 3. The conclusions and discussion are given in Section 4.

2. Methods and Data

2.1. Study Area

Chongqing is located in southwest China, at the upper reaches of Yangtze River, on the eastern border of Sichuan Basin, an ecologically sensitive region in the Three Gorges Reservoir Region (see Figure 1). It is the only municipality directly under the central government in Western China. The total population of the city was 33.5842 million in 2013, of which the agricultural population stood at 20.1437 million, accounting for 59.98% of the total population. It is a direct-controlled municipality integrating metropolises, countryside, and a large reservoir area with a huge mountain range. Along with the expedited new industrialization and urbanization construction process, the demand for construction lands has increased day by day. Eventually, the contradiction between supply and demand of national land resource became prominent. In addition, due to excessive human development and utilization of land resources, we are witnessing huge pressures in terms of the environment and society [19]. Chongqing mainly features low mountains and hills. Conflicts among the population over resources and environmental problems are prominent. Due to the high degree of land reclamation, forest vegetation has been destroyed. The application of a large quantity of fertilizers and pesticides on farms results in the production of industrial waste, and the high quantity of city pollutant discharge, the low treatment rate, and the agricultural non-point source pollution are especially prominent [20,21]. The increasingly serious rural non-point source pollution has already evolved into a problem to be solved.

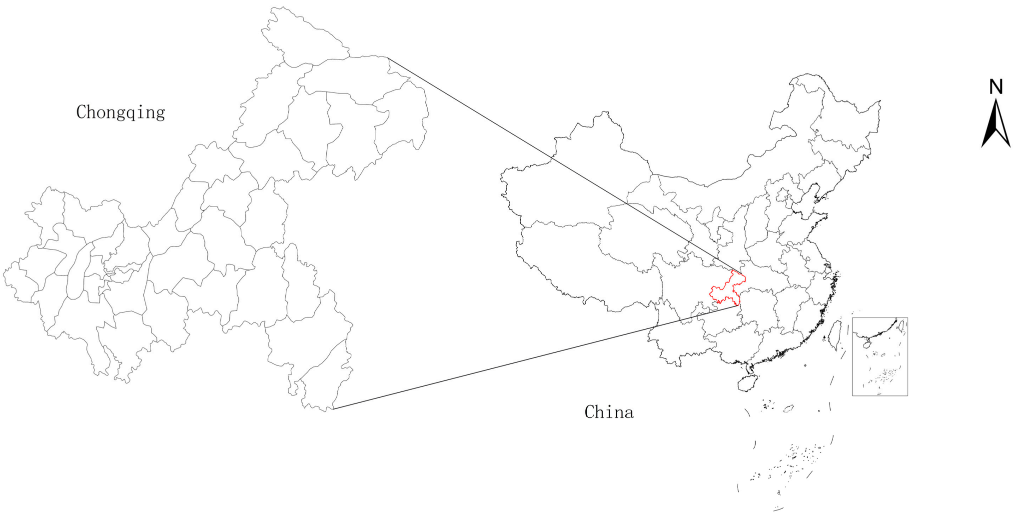

Figure 1. Location of Chongqing in China.

2.2. Data Source

Rural space is a complex system, including all development factors such as ecology, society, and economy in rural areas. The rural space system is analogous to the biological life system. To satisfy the survival and development demands of human beings, human society largely depends on land resources to gain materials and energy from the natural environment. The rural life space subsystem refers to the regional structures that the countryside provides the spaces for: population capacity, cultural inheritance, and social security. To discuss the total-factor land utilization efficiency in rural life space subsystems in the study area, attentions was paid to the input and output elements involved in the construction of human settlements. The utilization efficiency of rural residential areas is defined as the output efficiency, which was manifested by the maximum output from certain inputs of the rural residential area, capital, and labor. The output is directly proportional to the utilization efficiency of the land. High output demands high utilization efficiency of the land, and vice versa. Meanwhile, the utilization efficiency of land also reflects a reasonable allocation of production input elements. Higher land utilization efficiency indicates higher utilization of construction input elements in the rural space subsystem. In this paper, the rural population is selected to represent the carrying capacity of land resources, and rural residential land represents the input of land for construction. The electricity consumption in rural areas, which has a direct link to the agricultural production on behalf of capital investment targets, is selected.

The output factors of land use mainly include economic output, social output, and ecological environment output. Land utilization functions are changed continuously according to social and economic goals in order to maintain rural production and living activities, which bring both desired outputs (e.g., economic productivity, culture, life, and social productivity) and undesirable outputs (e.g., pollutants) [15,22]. The main function of the rural living space subsystem is not only to meet people's needs, but also to raise the quality of people's life. In this paper, we can choose the indicators that best represent the productive efficiency of rural construction land, including output welfare, such as reflecting the landlord's way of life, quality of life, family welfare, and public welfare. Due to the unavailability of data, rural employment posts are chosen to reflect rural life security, the per capita living area of farmers is selected to reflect the level of infrastructure construction, and rural households' Engel coefficient inverse ratio is used to reflect the income of peasant families and the people's living conditions. These indicators represent the productive efficiency of rural construction land, including various beneficial outputs. In the past, rural development paid too much attention to economic development, neglecting the construction of human settlements, which made the relationship between people and land more and more uncoordinated; the rural life process, though it produces "desirable" outputs, will also bring about pollution emissions, an "undesirable" output.

According to the available data of indices, this paper utilizes the environmental regulation input and output data of 37 districts and counties, from 2003 to 2013 in Chongqing, China as the sample set. Because the urban rate of Yuzhong district is 100%, Yuzhong will not be considered here. Rural employment is chosen to reflect rural life security. The evaluation index system of LUE is shown in Table 1. A1, A2, A3, B1, B2, and B3 indicators can be directly obtained from the Chongqing City Statistical Yearbook (2003–2014), Chongqing Municipal Environmental Statistics Bulletin (2003–2014), the main agricultural products production, trade and ranking in Chongqing City, EPA and Agricultural census data, and field survey data, respectively.

C1, C2, C3, and C4 indicators are classified as undesirable outputs. Due to the limited collection of relevant indicators, this study focuses on the pollution of crop plants and the major pollutants produced by livestock and poultry farming. Therefore, COD, NH_3-N, TN, and TP emissions are chosen as the undesirable outputs. The non-point source pollution discharge can be estimated through the following formula:

(a) Domestic sewage emissions ($t \cdot a^{-1}$) = total rural population × rural domestic sewage emission factor × mean sewage content × export coefficient.
(b) Domestic garbage emissions ($t \cdot a^{-1}$) = total rural population × rural domestic garbage emission factor × mean landfill leachate content × export coefficient.

According to a survey of related scholars, rural domestic sewage emissions per capita and rural domestic garbage per capita in Chongqing City are 0.67 $L \cdot d^{-1}$ and 0.67 $kg \cdot d^{-1}$, respectively. The test results of Chongqing Environmental Monitoring Center provide values for COD, BOD_5, TN, and TP of 292.69 $mg \cdot L^{-1}$, 138.33 $mg \cdot L^{-1}$, 44.14 $mg \cdot L^{-1}$, and 4.49 $mg \cdot L^{-1}$, respectively, and the export coefficient was 0.30 for the domestic sewage emissions. In the case of the domestic garbage emissions, COD, BOD_5, TN, and TP were determined as 50.00 $mg \cdot kg^{-1}$, 5.00 $mg \cdot kg^{-1}$, 1.00 $mg \cdot kg^{-1}$, and 0.2 $mg \cdot kg^{-1}$, respectively, in reference to landfill leachate, and the export coefficient was 0.20 [23,24].

Non-point source pollution and other indicators of emissions with reference to Chen et al. are calculated using the list analysis; the specific formula is as follows [25]:

$$E = \sum_i EU_{i\rho_i}(1-\eta_i)C_i(EU_i, S) = \sum_i PE_{i\rho_i}(1-\eta_i)C_i(EU_i, S) \quad (1)$$

$$EI = E/AL, \quad (2)$$

where E refers to the discharge of non-point pollution; EU_i is the statistical quantity of unit $_i$; ρ_i refers to the strength coefficient of production pollution; C_i refers to discharge coefficient of unit $_i$; the output of PE_i refers to the agricultural non-point source pollution; η_i is the use ratio of unit $_i$; EI refers to the unit discharge strength of non-point source pollution; and S refers to the discharge evaluation standard of pollutants.

Table 1. Input and output indicators.

Variable Category	Variable Name	Description	Units
Inputs	LABOR (A1)	Rural population	10^4 Persons
	AREA (A2)	Rural residential land	km^2
	ENERGY (A3)	Electricity consumption in rural areas	10^4 kwh
Desirable outputs	EM1 (B1)	Rural employment	10^4 Persons
	B2	Farmers' living space per capita	m^2
	B3	Rural households' Engel coefficient inverse ratio	Percent
Undesirable outputs	COD (C1)	Chemical oxygen demand	Ton
	NH_3-N (C2)	Ammonia nitrogen	Ton
	TN (C3)	Total nitrogen	Ton
	TP (C4)	Total phosphorus	Ton

2.3. Methodology

2.3.1. Malmquist–Luenberger (ML) Productivity Index

Data envelopment analysis (DEA) has the significant advantage of not needing to set any prior functions or parameter weights [26–28]. DEA is a non-parametric method used to evaluate the relative efficiency of a unit in a production system. It was developed according to the research of Charnes and Cooper which is based on relative efficiency [29]. The traditional DEA model is invalid before time series data. When the cross-section data necessary for the research cannot be acquired, the dynamic analysis model of total factor land utilization efficiency can be built through the application of time series data to analyze and study the volatility of decision-making about unit land utilization efficiency [30]. This model can be used to solve the problem of measuring the radial and oriented deviation.

Under the total factor efficiency evaluation framework, a decision-making unit (DMU) could employ land and other resources (x) such as capital and labor as inputs to generate the normal output as the "desirable" output (y), and the environmental pollution product not expected to be obtained is termed as the "undesirable" output (e) during the rural production process. To include the "undesirable" output into the analysis framework of productivity, a production possibility set (environmental technology) can be built. Assume N kinds of input factors $x = (x_1, x_2, \cdots, x_m) \in R_+^N$ are used during rural production. The superscript in R_+^N indicates evaluation space, while the subscript "+" indicates the evaluation is positive, similarly hereinafter. We have "desirable" output in production M $y = (y_1, \cdots, y_M) \in R_+^M$ and I kinds of "undesirable" output $e = (e_1, \cdots, e_M) \in R_+^I$. In the meantime, assuming the period $t = 1, \cdots, T, K$, there are K decision-making units. Non-parameter data envelopment analysis available for environmental technology can be represented by:

$$P^t(x^t) = \begin{cases} (y^t, e^t) : \sum_{k=1}^{K} z_k^t y_{km}^t \geq y_m^t, m = 1, \cdots, M; \\ \sum_{k=1}^{K} z_k^t e_{ki}^t = e_i^t, i = 1, \cdots, I; \\ \sum_{k=1}^{K} z_k^t x_{kn}^t \leq x_n^t, n = 1, \cdots, N; \\ z_k^t \geq 0, k = 1, \cdots, K \end{cases}, \tag{3}$$

where, $P^t(x^t)$ refers to the production possibility set of input factor x of tth period; y^t refers to the "desirable" output of tth period; e^t refers to the "undesirable" output of tth period; z^{kt} refers to the decision-making unit $k = 1, 2, \cdots, K$, refers to the weight when the environmental technological structure is built; and the sum of z_k^t refers to 1 non-negation can be represented by environmental technology of variable scale remuneration. If the removed sum is 1, it indicates the scale remuneration is unchanged; y_{km}^t refers to the "desirable" output of kth decision-making unit of tth period; e_{ki}^t refers to tth "undesirable" output generated by kth decision-making unit of tth period. x_{kn}^t refers to nth input factor of kth decision-making unit of tth period; x_n^t refers to total n input factors of tth period. Therefore, environmental technology actually maximizes the set of the "desirable" output Y and the "undesirable" output E under an established input X condition. On this basis, the relative efficiency of each decision-making unit can be calculated by building a directional distance function, which gives consideration to the increase in the "desirable" output and the possibility that the "undesirable" output is reduced at the same proportion. Therefore, the total factor land use rate of rural space subsystem of the undesirable output can be measured [31–34]. An aggregated specific land use efficiency total factor productivity with the consideration of undesirable outputs, for each decision-making unit at period t can then be obtained. The concrete form of directional distance function based on output angle is given as:

$$\vec{D}_0^t(x^t, y^t, e^t; g_y, g_e) = \sup\{\beta : (y^t + \beta g_y, e^t - \beta g_e)\}, \tag{4}$$

where (x^t, y^t, e^t) refers to the input and output vectors; (g_y, g_e) refers to the directional vector of output expansion, used for manifesting people's different preferences for the desirable and the undesirable output. It is assumed that the desirable and the undesirable outputs are expanded or contracted at the same rate; β measures the maximum quantity of y increase in the desirable output and e reduction in the undesirable output. The directional distance function of t phase can be converted into the linear planning problem through the data envelopment analysis. That is, β can be obtained by solving Equation (5):

$$\vec{D}_0^t(x^t, y^t, e^t; y^t, -e^t) = \max\{\beta\} \tag{5}$$

$$s.t. \begin{cases} \sum_{k=1}^{K} z_k^t y_{km}^t \geq (1+\beta) y_m^t, m = 1, \cdots, M; \\ \sum_{k=1}^{K} z_k^t e_{ki}^t = (1-\beta) e_i^t, i = 1, \cdots, I; \\ \sum_{k=1}^{K} z_k^t x_{kn}^t \leq x_n^t, n = 1, \cdots, N; \\ z_k^t \geq 0, k = 1, \cdots, K \end{cases}.$$

Measurement of the total factor productivity (TFP) of a certain DMU involves measures for both technological and specific developments [18]. The Malmquist–Luenberger (ML) productivity can be constructed on the basis of the directional distance function. The Malmquist productivity index was employed to measure the productivity change of MFIs between two data points by calculating the ratio of the distances of each data point relative to a common technology; it requires the inputs and outputs from one time period to be mixed with the technology of another time period. In 1953, the Swedish economist Sten Malmquist proposed the Malmquist index, which is used to analyze consumption changes in different periods. The so-called Malmquist index is based on the output distance function, as defined by Caves et al., and Nishimizu and Page. Fare et al. were the first to calculate the Malmquist index by introducing DEA [35–37]. They applied Malmquist's ideas to production analysis and constructed the Malmquist production change index. The intertemporal

ML productivity, according to Chung et al., can be obtained by computing four directional distance functions [38,39]; the Malmquist productivity change index can be expressed as follows:

$$ML_t^{t+1} = \left[\frac{1 + \vec{D}_0^t(x^t, y^t, e^t; y^t, -e^t)}{1 + \vec{D}_0^t(x^{t+1}, y^{t+1}, e^{t+1}; y^t, -e^t)} \times \frac{1 + \vec{D}_0^{t+1}(x^t, y^t, e^t; y^t, -e^t)}{1 + \vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, e^{t+1}; y^t, -e^t)} \right]^{\frac{1}{2}}. \quad (6)$$

Furthermore, the Malmquist productivity index can be decomposed into two parts: Malmquist–Luenberger technical change, $MLTECH_t^{t+1}$ and Malmquist–Luenberger efficiency change, $MLEFFCH_t^{t+1}$, in order to analyze the drivers of productivity change. The difference in technical efficiency between time t and t + 1 represents the change in the relative distance of the observed production from the maximum potential production. The geometric mean of the two ratios measures the shift in technology between the two periods t and t + 1; this could be called technological progress. The product of the two components (efficiency change and technical change) is the Malmquist productivity change (total factor productivity change) [18].

$$ML_t^{t+1} = MLTECH_t^{t+1} \times MLEFFCH_t^{t+1} \quad (7)$$

$$MLTECH_t^{t+1} = \left[\frac{1 + \vec{D}_0^{t+1}(x^t, y^t, e^t; y^t, -e^t)}{1 + \vec{D}_0^t(x^t, y^t, e^t; y^t, -e^t)} \times \frac{1 + \vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, e^{t+1}; y^t, -e^t)}{1 + \vec{D}_0^t(x^{t+1}, y^{t+1}, e^{t+1}; y^t, -e^t)} \right]^{\frac{1}{2}} \quad (8)$$

$$MLEFFCH_t^{t+1} = \left[\frac{1 + \vec{D}_0^t(x^t, y^t, e^t; y^t, -e^t)}{1 + \vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, e^{t+1}; y^t, -e^t)} \right] \quad (9)$$

The Malmquist productivity index can be interpreted as a measure of total factor productivity (TFP) growth. MLTECH, which measures the speed of progress of the technology frontier, is determined by the system differences and management levels. MLEFFCH measures the speed of technology laggards catching up with advanced technology, reflecting the catch-up effect of the production decision-making unit towards the production frontier, determined by the allocation resource structure and size. In each of the formulas above, ML, MLEFFCH (EC), and MLTECH (TC) greater than (less than) 1 represent total factor productivity growth (decrease), technical efficiency improvement (deterioration), and technological progress (regression), respectively.

2.3.2. Kernel Function

The kernel function is an important non-parametric estimation method to study regional uneven distribution. It is been widely applied in financial development, carbon emissions [40,41], population [42], land use [43,44], and other fields. The kernel function mainly views the distribution pattern of investigation objects as a probability distribution and then investigates the variation of its characteristics over time. Distribution positions, forms, and ductility of land utilization efficiency can be known by graphic comparison of kernel function results. The kernel function can be expressed as follows:

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{N} K\left(\frac{X_i - x}{h}\right), \quad (10)$$

where N is the number of observed values, $K(\cdot)$ is a kernel function, h is the bandwidth ($0.9\mathrm{SeN}^{-1/5}$), and Se is the standard deviation of observed values of random variables. In this paper, the Gaussian normal distribution kernel function is used:

$$K(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) \quad (11)$$

3. Results

3.1. The Results and Analysis of LUTFP of Chongqing Based on Malmquist Productivity Index Decomposition

From Table 2, it can be seen that the LUTFP of Chongqing and the total factor land utilization efficiencies of rural life space subsystem of undesirable outputs in 37 districts and counties of Chongqing from 2003 to 2013 were estimated and decomposed by the above study model and related statistical data. Results are given in Table 2. A comparison of the trends of land use efficiency computed without considering undesirable outputs and the land use efficiency based on the ML model considering undesirable outputs is shown in Figure 2. During the research, the calculated value of the model with consideration of the undesirable output is obviously smaller than that without consideration of the undesirable output. Rural human settlement construction achieved extensive growth at a high cost to the environment.

Table 2. Considering undesirable output of rural living space subsystem of land use efficiency ML index and its decomposition in Chongqing during 2003–2013.

Year	Chongqing			Metropolitan Functional Area			Newly Developed Urban Area			Northeastern Ecological Conservation Area			Southeastern Environment Protection Area		
	ML	EC	TC	ML	EC	TC	ML	EC	TC	ML	EC	TC	ML	EC	TC
2003-2004	0.987	1.065	0.983	0.961	0.996	0.986	1.014	1.185	0.987	0.976	1.016	0.975	0.990	1.009	0.988
2004-2005	1.002	0.983	1.011	1.010	0.986	1.014	0.998	0.987	1.004	1.000	0.975	1.013	1.005	0.988	1.017
2005-2006	1.011	1.011	1.015	1.020	1.014	1.019	0.986	1.004	1.009	1.017	1.013	1.006	1.035	1.017	1.035
2006-2007	1.014	1.015	1.046	1.060	1.019	1.044	1.008	1.009	1.041	0.965	1.006	1.014	1.055	1.035	1.116
2007-2008	1.005	1.046	0.947	1.035	1.044	1.009	0.988	1.041	0.937	0.995	1.014	0.943	1.017	1.116	0.890
2008-2009	0.998	0.947	1.079	0.977	1.009	1.026	1.000	0.937	1.122	1.018	0.943	1.079	0.984	0.890	1.064
2009-2010	1.012	1.079	0.943	1.040	1.026	0.978	1.006	1.122	0.913	1.011	1.079	0.959	0.987	1.064	0.931
2010-2011	0.997	0.943	1.000	1.111	0.978	1.100	0.950	0.913	0.935	0.975	0.959	0.993	0.979	0.931	1.008
2011-2012	1.010	1.000	0.985	1.014	1.100	1.024	1.026	0.935	0.940	1.007	0.993	1.005	0.977	1.008	0.984
2012-2013	1.004	0.985	0.963	1.000	1.024	1.010	0.999	0.940	0.895	1.007	1.005	0.985	1.012	0.984	0.999
average	1.004	1.007	0.997	1.023	1.020	1.021	0.998	1.007	0.978	0.997	1.000	0.997	1.004	1.004	1.003

Note: According to the main function division of Chongqing Municipality and considering the integrity of administrative divisions, 37 districts and counties are divided into four categories: (1) Metropolitan Function Area, including the urban function core area and the urban function development area of eight districts and counties: Dadukou, Jiangbei, Shapingba, Jiulongpo, South Bank, Yubei, Beibei, and Banan District; (2) Newly Developed Urban Area: 12 districts and counties including Fuling, Changshou, Jiangjin, Hechuan, Yongchuan, Nanchuan, Dazu, Qijiang, Tongliang, Tongnan, Rongchang, and Bishan; (3) Northeastern Ecological Conservation Area, including Wanzhou District, Fengdu County, Chengkou County, Liangping County, Kaixian, Dianjiang County, Zhong County, Fengjie County, Wushan County, Yunyang County, Wuxi County (11 districts and counties in total); (4) Southeastern Environment Protection Area, including Qianjiang, Shizhu, Xiushan, Youyang, Wulong, Pengshui, and six other autonomous counties. ML\EC\TC, Respectively, The Malmquist-Luenberger (ML) productivity, Malmquist-Luenberger efficiency change, Malmquist-Luenberger technical change.

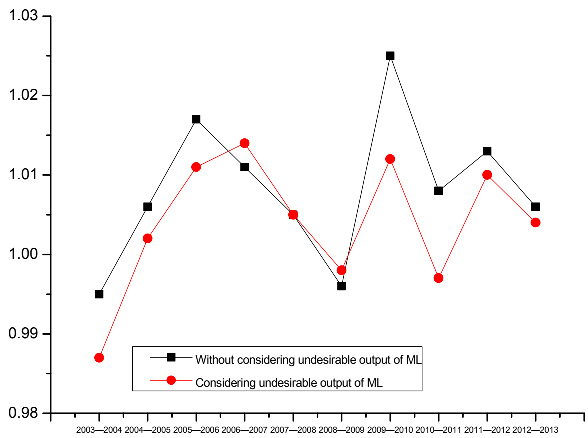

Figure 2. Trend of the land use efficiency ML index of rural living space subsystem in Chongqing during 2003–2013.

Based on a stage-wise comparison of time span, the numerical value of the total factor land utilization efficiency (ML) of the rural life space subsystem in Chongqing from 2003 to 2013 fluctuated around 1. On the other hand, the productivity growth indexes of ET and TC fluctuated violently (see Figure 3). There is a negative correlation between the technical efficiency variability index and efficiency growth index, thus resulting in a slight fluctuation in the total factor land utilization efficiency. This indicates the determination of the land utilization efficiency in the rural life space in Chongqing by the technical efficiency variability index and efficiency growth index together. In general, the land utilization efficiency of rural life space subsystem in most districts and counties of Chongqing still shows room for improvement, although it has improved to an extent.

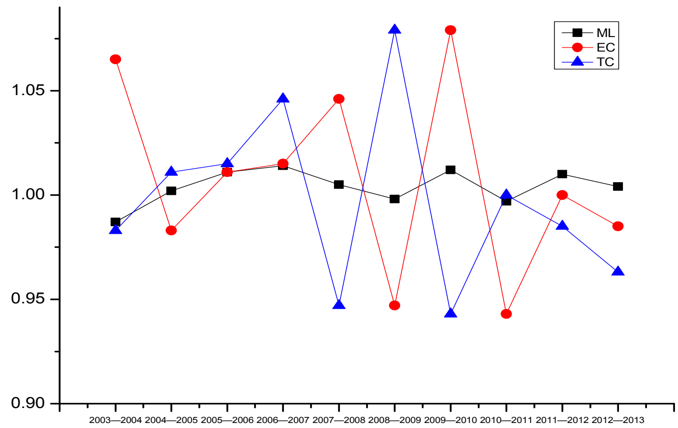

Figure 3. Trends of ML, EC, and TC of rural living space subsystem in Chongqing during 2003–2013.

From 2003 to 2007, ML, EC, and TC mostly increased gradually, indicating that the total factor land utilization efficiency of the rural life space in Chongqing was progressing continuously during this period. This is mainly attributed to a series of China's policies supporting, benefiting, and strengthening agricultural development. For example, from 2004 to 2007, Central Document No. 1 demonstrated the importance of "agriculture, countryside, and farmer issues". Chongqing established a transfer payment special fund to offer financial support to grain production counties and poor counties and suggested a transfer of national infrastructure construction to rural areas. These demonstrate that China's support for agricultural production had been shifting from policies benefiting and supporting agricultural development to policies strengthening agricultural development and land utilization efficiency of the corresponding rural life space subsystem. From 2008 to 2011, a significant negative correlation between ML and TC was observed. Hence, ML fluctuated slightly and kept increasing, except in 2009 (0.998) and 2011 (0.997). This has two reasons: Firstly, the international financial crisis in 2008 caused inadequate market demands and a fall in product values; secondly, due to the long-term development strategy of focusing on cities but neglecting rural areas, rural development lags behind urban development and most rural areas are facing poor infrastructure construction, imperfect public service facilities, and intensifying non-point source pollution and hollow villages. From 2012 to 2013, ML, EC, and TC tended to be uniform. ML kept increasing, while EC and TC began to decrease. When promoting economic growth by expanding internal demand, the Chinese government accelerated infrastructure planning and construction as well as ecological environmental construction in rural areas. In 2013, Central Document No. 1 emphasized promoting ecological civilization construction in rural areas. Soil environmental management in rural areas and a clean rural construction program facilitated ML growth to some extent. However, rural land utilization planners should pay attention to the decreasing trend of EC and TC.

3.2. Spatial Evolution of the Land Use Efficiency in Chongqing Rural Living Space Subsystem

According to the land utilization efficiency of rural living space subsystem of all districts and counties, the research units are divided into three groups: highest efficiency, efficiency higher than a certain limit (higher than 1), and efficiency lower than a certain limit (lower than 1). The highest group contains two districts: The average of the land use efficiency ML index of Jiangbei and Dadukou are the highest at 1.0824 and 1.0553, respectively. This indicates that the land total factor productivity of Jiangbei increased by 8.24% annually and that of Dadukou by 5.53%. It indicates that land use in these districts is optimal. The rest of the districts are divided into two groups on average, called higher and lower groups, respectively. The higher group contains 28 districts whose LUE is between 1 and 1.0500, and the low group contains the remaining seven districts whose LUE is below 1. It can be noted that some districts show relatively poor performance in land use, which suggests that some countermeasures should be taken to improve the input–output allocations. In addition, the spatial distribution map of land utilization efficiency of Chongqing rural living space subsystem from 2003 to 2013 is drawn with ArcGIS software (Environmental System Research Institute (ESRI), Redlands, CA, USA). The spatial distribution of the land utilization efficiency of Chongqing rural production space subsystem shows an obvious imbalance, as shown in Figure 4.

To further explore the regional differences and the dynamic distribution of ML in Chongqing, six years (2004, 2005, 2009, 2012, and 2013) were chosen as characteristic years and a Kernel density estimation two-dimensional graph of ML in 37 districts and counties of Chongqing is made by using the Gaussian Kernel Function. In the investigation period, the peak narrowed significantly and the position of the density function curve remained basically the same as time passed, but the width increased gradually and the curve became flatter, indicating that ML in Chongqing was basically the same and had a small regional difference from 2004 to 2013, as shown in Figure 5a.

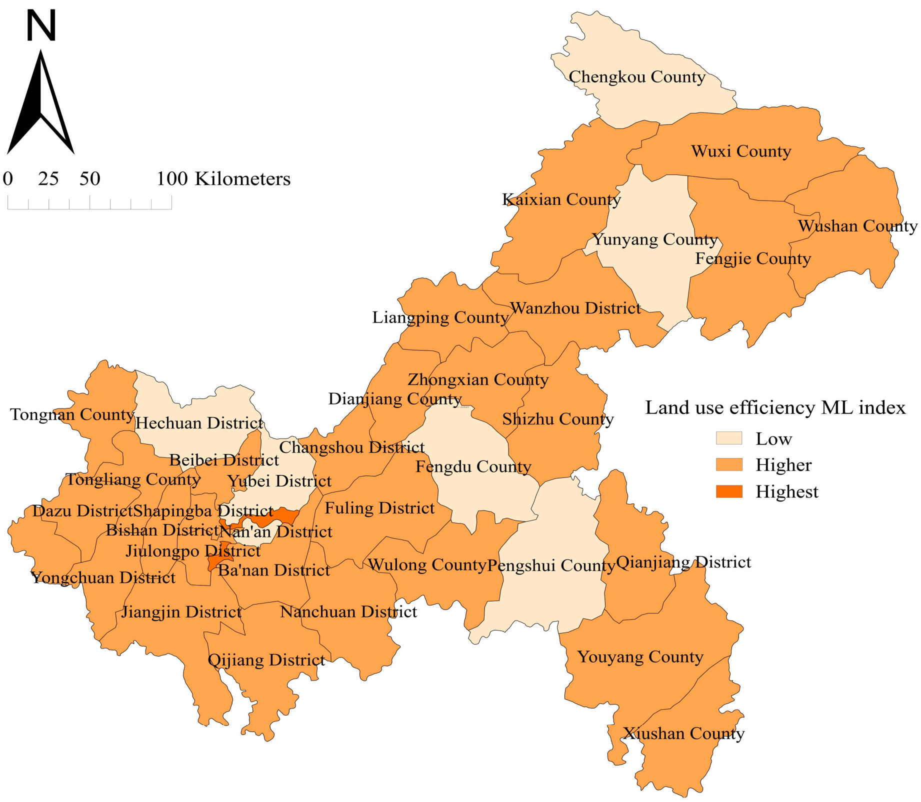

Figure 4. Distribution spatial of land use efficiency ML index of rural living space subsystem in Chongqing during 2003–2013.

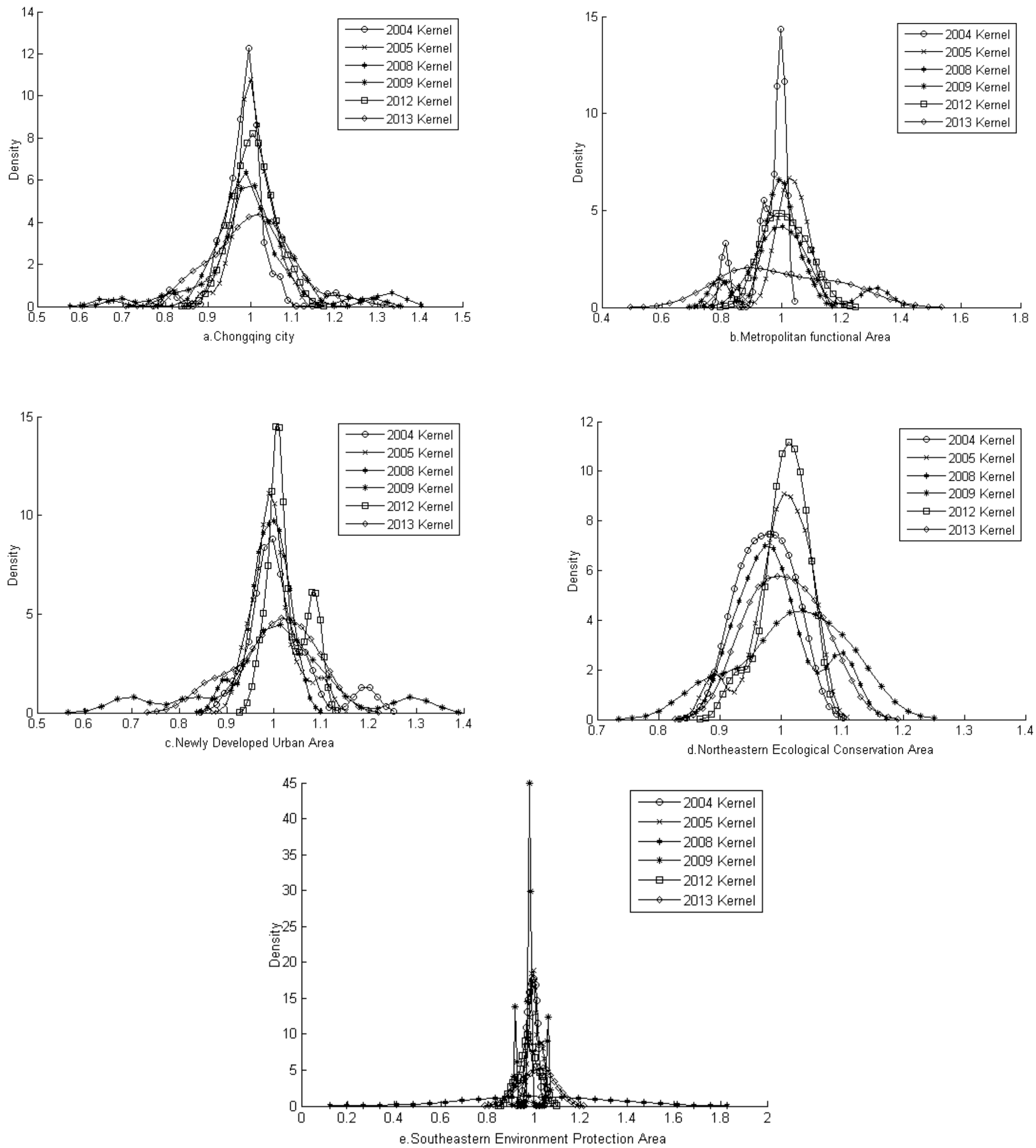

Figure 5. Kernel of land use efficiency ML index of rural living space subsystem in Chongqing and various functional areas' rural living space.

On the whole, the ML curve of Metropolitan functional Area presents a small movement, implying small land utilization efficiency changes in the districts and counties in Chongqing (see Figure 5b). The ML peak declines gradually and the density curve became flatter, while the width increases continuously, showing that the regional difference of land utilization efficiency was increasing. The number of peaks decreases from three to two and then to one, indicating that the characteristic phenomenon of "club convergence" disappeared gradually. Specifically, there were three peaks in 2004, which decreased to two peaks from 2005 to 2012 and further decreased to one peak in 2013, indicating that the regional difference of land utilization efficiency had been increasing but the multi-polar differentiation disappeared gradually.

The ML peak of Newly Developed Urban Area increased in 2005, 2008, 2009, and 2012 compared to that in 2004, but dropped sharply in 2013, as shown in Figure 5c. The density curve moved rightward during the study period. The peak intensity of the density curve decreases and the width increases gradually, indicating the increasing regional difference of land utilization efficiency in the Newly

Developed Urban Area. In the investigation scope, the number of peaks changes between two peaks and one peak and finally decreases to one peak, which reflects that the "club convergence" occurs repeatedly until the final disappearance. This is mainly because the Newly Developed Urban Area covers numerous districts and counties with big differences in resources endowment, economic basis, and locational conditions. There was also a polarization of land utilization efficiency in the early investigation period. With the implementation of the strategy "withdrawing from the secondary industry and marching into the tertiary industry" in the Metropolitan functional Area of Chongqing as well as the promotion of urban–rural integrated planning in Chongqing, the rural living standard in different districts and counties continuously improved and peasants' income increased due to integrated development of primary, secondary, and tertiary industries, which was conducive to the overall rural land utilization efficiency. The spatial polarization of land utilization efficiency disappeared accordingly.

The ML peak of Northeastern Ecological Conservation Area decreased continuously compared to that in 2004, as shown in Figure 5d. The density function curve moved leftward before 2009, and moved rightward after 2009. Its peak intensity decreased and the width increased gradually, indicating that the land utilization efficiency of rural life space substance in districts and counties within the Northeastern Ecological Conservation Area first decreased and then increased year by year. The regional difference was increasing.

On the whole, the ML of the Southeastern Environment Protection Area presented a sharp slope and three peaks in 2009, which represented the obvious multi-polarization in the region (see Figure 5e). However, this did not last long. The location of the density curve remained basically the same in other years. The density curve changed slightly and became smooth in 2013. Therefore, the ML of the Southeastern Environment Protection Area fluctuated slightly on the whole, showing relatively uniform development and small regional differences in this area.

The land utilization efficiency of the four main regions had a reasonably consistent trend. Relatively speaking, the metropolitan functional area had higher land utilization efficiency (1.023 in average), followed by the Southeastern Environment Protection Area (1.004), the Newly Developed Urban Area (0.998), and the Northeastern Ecological Conservation Area (0.997). This has two causes. Firstly, the international financial crisis in 2008 brought inadequate market demand and a fall in product values, and the government did not invest enough in rural construction. Secondly, due to the long-term development strategy of focusing on cities but neglecting rural areas, rural development lags behind urban development and most rural areas are facing poor infrastructure, imperfect public service support facilities, and intensifying non-point source pollutions and hollow villages. Chongqing is in a key period of urban–rural integration development. To highlight the achievements, the governments at the grassroots level often focused on economic benefits, but neglected the existence and value of individual, subjective wishes to improve rural settlement and production conditions, which had many negative impacts on rural environmental construction. According to survey data, basically no sewage treatment facilities were available in most of the rural areas of Chongqing in 2012. Production and domestic sewage were drained directly in rural areas. Only 15.54% of rural areas in Chongqing had fixed garbage sites or cans, but 62.85% of rural areas had few or no garbage facilities [45]. Garbage in the rural areas of Chongqing was mainly disposed of freely, which influenced rural environmental conditions and hindered the improvement of rural civilization. According to regional differences, the Metropolitan functional Area was mostly influenced by TC. It is in the economically developed area in Chongqing and possesses a solid economic foundation and economic outputs. It receives relatively more technical and capital inputs for rural environmental protection. Local peasant households have high income, a commitment to environmental protection, and economic power to improve the rural environment. The undesirable output slightly influences the land utilization efficiency of the Metropolitan functional Area. With social progress and the increasing consciousness of residents about environmental protection, a land utilization system state could be improved by formulating related policies for environmental protection, which can help maintain good structures and functions.

As a result, land utilization efficiency is increased. In other words, new technologies will be launched continuously while satisfying economic demands after the economy has developed to a certain degree. Therefore, TC mostly influences the land utilization efficiency of these areas. The land utilization efficiency of the Southeastern Environment Protection Area is determined by technical progress and pure technical efficiency. It is in the Wuling Mountainous area and belongs to an economically underdeveloped area. Due to small inputs and outputs, it suffers from light environmental pollution, and thus manifests relatively high land utilization efficiency. Scale efficiency plays an important role in the land utilization efficiencies of the Newly Developed Urban Area and the Northeastern Ecological Conservation Area. Land utilization efficiency was negative in recent years. The Newly Developed Urban Area is the urban expanded region of Chongqing. With the transfer of heavy industries and the continuous increase of industrial enterprises in Chongqing, most districts and counties in the Newly Developed Urban Area have accepted the transfer of secondary industrial enterprises from the Metropolitan functional Area, which brought more job opportunities to farmers and increased peasants' household income. Most people staying in rural areas are elderly. Due to the uncertain economic situation, rural areas in the Newly Developed Urban Area have a severe lack of necessary skills, capital input, and technologies, which work against the growth of local land utilization efficiency. Grassroots cadres and the public in the Northeastern Ecological Conservation Area, which is relatively backward in terms of economic development, have a strong desire to shake off poverty and achieve prosperity. However, without correct guidance, it is easy for them to be apathetic or neglect environmental protection when focusing on economic development, resulting in lowland utilization efficiency. Hence, the Newly Developed Urban Area and the Northeastern Ecological Conservation Area have to improve their management structure.

4. Conclusions and Discussion

4.1. Discussion

This study incorporates environmentally undesirable outputs into the ML total factor productivity index framework to evaluate LUTFP, yielding results that are more consistent with actual conditions for the estimation of land utilization efficiency. We avoid ignoring undesirable output conditions, as was done in previous related works. However, the proposed method still has some limitations: Firstly, the undesirable output during the rural development process is not just relevant to the emission problem of non-point source pollution. Secondly, the imbalanced land utilization efficiency of rural living space subsystems is not further studied in this research. In future research, the undesirable output index during rural development will be studied specifically so that the evaluation result can reflect reality. Additionally, quantitative research on factors in land utilization efficiency loss of rural space will be carried out.

4.2. Conclusions

In this paper, a new total factor evaluation index system of land utilization efficiency is constructed that is more comprehensive than previous ones. Based on this new evaluation index system, the DEA–Malmquist evaluation model is used to take into account the environmental constraints. The main conclusions are as follows.

(1) Undesirable outputs such as the surface source pollution factors have obvious negative effects on the LUE, and it is necessary to take undesirable outputs into account in order to make a precise evaluation of LUE. When we avoided the land use efficiency overestimation because of ignoring environmental constraints, it affected the practical significance of conclusions, leading to a discrepancy between research conclusions and practice, so it was hard to propose correct policy suggestions.

During the study period, the growth rate of the desired output was lower than the reduction rate of the undesirable output during rural development in Chongqing. Chongqing is in a period of accelerated development of urbanization, and the rural space is facing the development of restructuring and reconstruction, but rural development achieved extensive growth at a high cost to the environment. According to the DEA–Malmquist model, total factor land utilization efficiency of rural life space subsystem in Chongqing from 2003 to 2013 was 1.004, indicating a growth rate of 4%. Additionally, the Metropolitan functional Area had the highest land utilization efficiency (1.023 in average), followed by the Northeastern Ecological Conservation Area (1.004), the Newly Developed Urban Area (0.998), and the Southeastern Environment Protection Area (0.997). One characteristic of LUTFP is the "agglomeration effect", that is, the basin effect is low in surrounding areas and high in the center.

(2) The Kernel density could better reflect the overall patterns of the distribution of land use efficiency in rural areas of Chongqing, which might be conducive to master stratification and polarization of land use efficiency in regional rural space, and make up for the existing limitations of the short span of the sample period. It was better able to reveal the dynamic evolution of land use efficiency in rural living spaces of Chongqing, and also to provide a scientific and reasonable basis for decisions about the development of rural space in Chongqing. The land utilization efficiency of rural living space in Chongqing showed "club convergence". Although the regional gap was narrowing gradually, an overall difference still existed.

The kernel function test results demonstrated multi-polarization or polarization of the land utilization efficiencies of rural living space in Chongqing City and four main regions in the study period, showing "club convergence." Nevertheless, polarization disappeared as time went on, and the regional gap was small. Even though the regional gap of land utilization efficiency in other regions was continuously increasing, the Southeastern Environment Protection Area achieved uniform development and a small regional gap. All four main regions of Chongqing once had evident multi-peak trends, but the "club convergence" finally disappeared.

(3) The DEA–Malmquist Model measures the contribution degree of the technical changes and the efficiency change indices to the TFP of land utilization efficiency of Chongqing's rural living space from 2003 to 2013. As shown by the measurement results, they work together in rural living space. This result implies that updating technologies, issuing environment-related rules, improving laws and regulations, and strengthening management skills all play important roles in enhancing land use efficiency.

(4) Due to the great differences in geographical environments and economic development levels in different regions of Chongqing, the land utilization efficiency in different regions has different influencing factors. In future, adopting specific policies and measures is a scientific decision-making method to increase the rural land utilization efficiency in Chongqing. We suggest adopting different supporting policies to plan rural construction reasonably with the proper agricultural layout and structural optimization in rural areas of the whole of Chongqing City. The process needs to place appropriate priorities on the southeast and northeast regions of Chongqing, with enhanced infrastructure and public service facility construction. This will in turn result in a narrow regional gap with an increased rural living standard and quality and will help create a "human-oriented", livable rural space.

Acknowledgments: We thank the editor and reviewers for their careful review and insightful comments. This study was supported by the National Fund for Special Funds for Water Pollution Control and Control (Grant No. 2012ZX07104-003) and the "Fundamental Research Funds for the Central Universities" (Grant No. SWU116063; Grant No. XDJK2016C120).

Author Contributions: Huikun Hong and Deti Xie had the initial idea for the study. Huikun Hong is responsible for the data collection. Heping Liao and Huikun Hong conducted the analysis. Bo Tu and Jun Yang set the analysis method. Heping Liao and Bo Tu proofread the paper. All the authors have read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Tang, D.; Tang, J.; Xiao, Z.; Ma, T.; Bethel, B.J. Environmental regulation efficiency and total factor productivity—Effect analysis based on Chinese data from 2003 to 2013. *Ecol. Indic.* **2017**, *73*, 312–318. [CrossRef]
2. Turner, B.L.; Lambin, E.F.; Reenberg, A. The emergence of land change science for global environmental change and sustainability. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 20666–20671. [CrossRef] [PubMed]
3. Long, H.L. Land Use Transition and Rural Transformation Development. *Prog. Geogr.* **2012**, *31*, 131–138.
4. Li, Y.H.; Li, Y.R.; Hans, W.L.; Liu, Y.S. Urban–rural transformation in relation to cultivated land conversion in China: Implications for optimizing land use and balanced regional development. *Land Use Policy* **2015**, *47*, 218–224. [CrossRef]
5. Beames, A.; Broekx, S.; Heijungs, R.; Lookman, R.; Boonen, K.; Geert, Y.V.; Kris, D.C.; Piet, S.J. Accounting for land-use efficiency and temporal variations between Brownfield remediation alternatives in life-cycle assessment. *J. Clean. Prod.* **2015**, *101*, 109–117. [CrossRef]
6. Morgan, C.; Mutoko, A.B.; Lars, H.; Chris, A. Shisanya Farm diversity, resource use efficiency and sustainable land management in the western highlands of Kenya. *J. Rural Stud.* **2014**, *36*, 108–120.
7. Xie, H.L.; Wang, W. Exploring the spatial-temporal disparities of urban land use economic efficiency in china and its influencing factors under environmental constraints based on a sequential, slacks-based model. *Sustainability* **2015**, *7*, 10171–10190. [CrossRef]
8. Halleux, J.M.; Marcinczak, S.; Krabben, E.V.D. The adaptive efficiency of land use planning measured by the control of urban sprawl. The cases of the Netherlands, Belgium and Poland. *Land Use Policy* **2012**, *29*, 887–898. [CrossRef]
9. Färe, R.; Grosskopf, S. *New Directions: Efficiency and Productivity*; Springer: New York, NY, USA, 2005; Volume 17, pp. 979–995.
10. Wang, H.; Wang, L.; Su, F.; Tao, R. Rural residential properties in china: Land use patterns, efficiency and prospects for reform. *Habitat Int.* **2012**, *36*, 201–209. [CrossRef]
11. Shen, C.L.; Li, M.C.; Li, F.X.; Chen, J.L.; Shao, Y.X. Assessment of Rural Land Use Efficiency in Fenshui Town based on DEA. *China Land Sci.* **2011**, *25*, 16–21.
12. Quaye, A.K.; Hall, C.A.S.; Luzadis, V.A. Agricultural land use efficiency and food crop production in Ghana. *Environ. Dev. Sustain.* **2010**, *12*, 967–983. [CrossRef]
13. Luo, H.L.; Wang, C.W.; Li, P. Different types of farmers' land consciousness of land using efficiency evaluation, to wait and see the town, Beibei District, Chongqing as an example. *Teach. Educ. J.* **2012**, *10*, 1–6.
14. Seiford, L.M.; Zhu, J. Modeling undesirable factors in efficiency evaluation. *Eur. J. Oper. Res.* **2002**, *142*, 16–20. [CrossRef]
15. Färe, R.; Grosskopf, S. Modeling undesirable factors in efficiency evaluation: Comment. *Eur. J. Oper. Res.* **2004**, *157*, 242–245. [CrossRef]
16. Molinos-Senante, M.; Maziotis, A.; Sala-Garrido, R. Assessment of the Total Factor Productivity Change in the English and Welsh Water Industry: A Färe-Primont Productivity Index Approach. *Water Resour. Manag.* **2016**. [CrossRef]
17. Baležentis, T. The Sources of the Total Factor Productivity Growth in Lithuanian Family Farms: A Färe-Primont Index Approach. *Prague Econ. Pap.* **2015**, *24*, 225–241. [CrossRef]
18. Baležentis, T.; Baležentis, A. Dynamics of the total factor productivity in Lithuanian family farms with a statistical inference: The bootstrapped Malmquist indices and Multiple Correspondence Analysis. *Econ. Res. Ekonomska Istraživanja* **2016**, *29*, 643–664. [CrossRef]
19. Hong, H.K.; Liao, H.P.; Wei, C.F.; Xie, D.T. Health assessment of a land use system used in the ecologically sensitive area of the Three Gorges reservoir area, based on the improved TOPSIS Method. *Acta Ecol. Sin.* **2015**, *35*, 8016–8027.
20. Yan, J.; Zhuo, R.; Xie, D.; Zhang, Y. Land use characters of farmers of different livelihood strategies: Cases in three gorges reservoir area. *Acta Geogr. Sin.* **2010**, *65*, 1401–1410.
21. Ni, J.P.; Gao, M.; Wei, C.F. Watershed sediment yield and effect of spatial scale based on high resolution digital elevation model and GEOWEPP. *Acta Pedol. Sin.* **2010**, *47*, 1–6.
22. Huang, X.J.; Ma, Q.F. The material metabolism response of regional land use change. *Trans. Chin. Soc. Agric. Eng.* **2008**, *S1*, 6–11.

23. Xiao, X.C.; Ni, J.P.; He, B.H.; Xie, D.T. Estimation of Agricultural Nonpoint Source Pollution Loads and Regional Differentiation in Chongqing Section of the Three Gorges Reservoir Region. *J. Basic Sci. Eng.* **2014**, *22*, 634–645.
24. Zhang, G.N.; Shao, J.A.; Wang, J.L. Spatial and Temporal Variations of Agricultural Non-point Source Pollution in the Three Gorges Reservoir Area of Chongqing. *J. Natl. Resour.* **2015**, *30*, 1197–1209.
25. Chen, M.P.; Chen, J.N.; Lai, S.Y. Inventory analysis and spatial distribution of Chinese agricultural and rural pollution. *China Environ. Sci.* **2006**, *26*, 751–755.
26. Seto, K.C.; Fragkias, M. Quantifying spatiotemporal patterns of urban land use change in four cities of China with time series landscape metrics. *Landsc. Ecol.* **2005**, *20*, 871–888. [CrossRef]
27. Zanten, H.H.E.V.; Mollenhorst, H.; Klootwijk, C.W.; Middelaar, C.E.V.; Boer, I.J.M.D. Global food supply: Land use efficiency of livestock systems. *Int. J. Life Cycle Assess.* **2015**, *21*, 1–12. [CrossRef]
28. Szabó, S.; Bertalan, L.; Ágnes, K.; Novák, T.J. Possibilities of land use change analysis in a mountainous rural area: A methodological approach. *Int. J. Geogr. Inf. Sci.* **2016**, *4*, 1–19. [CrossRef]
29. Charnes, A.; Hornes, K.E.; Hazleton, J.E.; Ryan, M.J. A hierarchical goal programming approach to environmental land-use management, 1998–2002. *Geogr. Anal.* **1975**, *7*, 121–130. [CrossRef]
30. Zhao, X.B. Quantitative Analysis of Land Use Efficiency in China. Ph.D. Thesis, Liaoning University, Shenyang, China, June 2013.
31. Pan, D.; Ying, R.Y. Agricultural Total Factor Productivity Growth in China under the Binding of Resource and Environment. *Resour. Sci.* **2013**, *35*, 1329–1338.
32. Xie, H.L.; Wang, W. Spatiotemporal differences and convergence of urban industrial land use efficiency for China's major economic zones. *J. Geogr. Sci.* **2015**, *25*, 1183–1198. [CrossRef]
33. Feng, X.L.; Huo, X.X. Total factor productivity of apple industry in China considering non-point source pollution and its spatial concentration analysis. *Trans. Chin. Soc. Agric. Eng.* **2015**, *31*, 204–211.
34. Bryan, B.A.; Crossman, N.D.; Nolan, M.; Li, J.; Navarro, J.; Connor, J.D. Land use efficiency: Anticipating future demand for landsector greenhouse gas emissions abatement and managing trade-offs with agriculture, water, and biodiversity. *Glob. Chang. Biol.* **2015**, *21*. [CrossRef] [PubMed]
35. Caves, D.W.; Christensen, L.R.; Diewert, W.E. The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica* **1982**, *50*, 1393–1414. [CrossRef]
36. Nishimizu, M.; Page, J.M. Total Factor Productivity Growth, Technological Progress and Technical Efficiency Change: Dimensions of Productivity Change in Yugoslavia. *Econ. J.* **1982**, *92*, 920–936.
37. Färe, R.; Grosskopf, S.; Norris, M.; Zhang, Z. Productivity growth, technical progress, and efficiency change in industrialized countries. *Am. Econ. Rev.* **1994**, *84*, 66–83.
38. Wen, T.; Wang, X.H.; Dong, W.J. Performance evaluation and improvement path of government educational resources allocation: A case study of Chongqing city. *J. Southwest. Univ. Soc. Sci. Ed.* **2013**, *39*, 48–56.
39. Wang, K.; Wei, Y.M. Sources of energy productivity change in China during 1997–2012: A decomposition analysis based on the Luenberger productivity indicator. *Energy Econ.* **2016**, *54*, 50–59. [CrossRef]
40. Stegman, A.; Mckibbin, W.J. Convergence and Per Capita Carbon Emission. *Brook. Discuss. Pap. Int. Econ.* **2005**, *167*, 1–69.
41. Ezcurra, R. Is There Cross-country Convergence in Carbon Dioxide Emission? *Energy Policy* **2007**, *35*, 1363–1372. [CrossRef]
42. Liu, H.J.; Zhao, H. Study on the regional difference of carbon dioxide emission intensity in China. *Stat. Res.* **2012**, *6*, 46–50.
43. Azizi, H.; Akbari, E.; Amiri, N. Remote Sensing and Land Use Extraction for Kernel Functions Analysis by Support Vector Machines with ASTER Multispectral Imagery. *Iran. J. Earth Sci.* **2012**, *4*, 85–94.
44. Cho, G.S.; Gantulga, N.; Choi, Y.W. A comparative study on multi-class SVM & kernel function for land cover classification in a KOMPSAT-2 image. *KSCE J. Civ. Eng.* **2016**. [CrossRef]
45. Qin, X.H.; Peng, L.; He, J. Satisfaction evaluation of rural environmental sanitation in Chongqing city based on urban and rural areas. *J. Southwest. Norm. Univ.* **2013**, *38*, 136–141.