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Assessing the Economic Energy Level of the Chengdu–Chongqing Economic Circle: An Integrative Perspective of "Field Source" and "Field"

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Abstract: As a densely overlapping area under the national overarching development strategy, the Chengdu–Chongqing Economic Circle (CCEC) possesses a significant strategic location. However, compared with the other three growth pillars, the economic energy of the CCEC is still at a low level and in urgent need of improvement, which has to be implemented step by step in a systematic manner. At present, the focus remains on the two central cities—Chengdu and Chongqing. In contrast to the traditional evaluation of the regional economic energy level (EEL) solely from the "internal comprehensive development level", this paper takes an angle on the interdependence and co-existence of "field source" and "field" to construct a preliminary index system which accounts for the "external economic connection level" as well. We then calibrate and validate the proposed model from both statistical and empirical angles. Finally, by optimizing the model, this paper evaluates the EELs of the Chengdu–Chongqing twin cities by fuzzy integrals of comprehensive weights. The results show the following: (1) From the perspective of overall indicators, the EELs of Chengdu and Chongqing have been rising from 2000 to 2018. In 2019, due to deglobalization and the Sino-US trade war, both cities appeared to reach an inflection point. (2) In terms of horizontal comparison, the EELs of the two cities basically coincide with each other, in line with the positioning of Chengdu–Chongqing as the two leading cities in Western China. However, their EELs have been lagging behind those of Beijing, indicating more room for further improvement. (3) From the point of view of sub-indexes, Chongqing has the advantage in the "external economic connection level" while Chengdu has the advantage in the "internal comprehensive development level". The dislocation and complementarity of Chongqing and Chengdu has become an opportunity to break away from the stiff competition and jointly improve their EELs. (4) By comparing our evaluation with the traditional assessment, we note that the EEL tends to be misestimated if comprehensive factors regarding the "external economic connection level" are not taken into account.

Keywords: Chengdu–Chongqing economic circle; regional economic energy level; field source; field

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1. Introduction

The Chengdu–Chongqing Economic Circle (CCEC), as the key connecting node between the "Belt-and-Road Initiative" (BRI) and the Yangtze River Economic Belt, is not only a critical point of China's external circulation with Europe, Central Asia, Western Asia, Southeast Asia, and other countries; but also the dual-core engine of the central hub for internal circulation to the west of the Yangtze River Economic Belt and Hu Huanyong axis (a critical population distribution line in China). As the carrier of the economic dual circulation, as well as the priority area of the internal circulation, and the economic powerhouse of Western China, the construction of the CCEC possesses strategic importance and plays an integral part in the current international and domestic development. However, there still exist significant gaps, both in absolute and relative terms, in the economic energy levels (EELs) among the CCEC, the Beijing–Tianjin–Hebei region, the Yangtze River Delta, and the Guangdong–Hong Kong–Macao Greater Bay Area. Therefore, there is an urgent need to heighten the EEL of the CCEC.

In October 2020, when the master plan of constructing the CCEC was reviewed, the Political Bureau of the CPC Central Committee pointed out that "Chengdu and Chongqing as the dual core should properly handle the relationship between their central roles and the surrounding regions, strive to enhance their development energy levels and comprehensive competitiveness of Chengdu and urban Chongqing, promote the transformation of urban development from geographical expansion to enhance living standards, thereby spreading from urban to suburban areas for coordinated development of an integrated metropolitan cluster with neighboring cities and counties". This document highlights the key steps of improving the energy level of the CCEC by first upgrading the dual core of Chengdu and Chongqing, and then, expanding from urban centers to the surrounding areas. Subsequently, the CCEC will enter the stage of urban agglomeration, achieve integrated and balanced regional development, and form the fourth growth pillar for further stimulating the development of Western China and boosting economic dual circulation. This blueprint clearly lays out the steps of improving the EEL of the CCEC that should start from the dual-core of Chengdu and Chongqing and gradually expand to the whole area as reflected by the current development status and characteristics of the CCEC.

This paper thus focuses on assessing the EELs of the twin cities of Chengdu and Chongqing to identify the breakthrough point of their further upgrade. The existing literature typically evaluates regional EELs from a single dimension of "internal comprehensive development level" [1–6]. Furthermore, when the "internal comprehensive development level" is evaluated, existing research normally considers one [1,5] or two [2,3] aspects of production, living, and ecological environment and rarely conducts a comprehensive assessment, which is not conducive to the high-quality and sustainable development of the regional economy. At the same time, because the single dimensional evaluation ignores the level of regional external economic relations, it is not conducive to assessing how well the regional economy adapts to the trend of "flow space" owing to globalization. As such, this paper redefines the regional EEL and proposes a comprehensive evaluation framework to properly assess the regional economy facing globalized "flow space" [7] and high-quality sustainable development. This research is conducive to scientific and reasonable evaluation of the EEL and the result helps the Chengdu–Chongqing twin cities to improve their EELs for high-quality and sustainable development by following the trend of globalization. This research also sheds insights on how to connect the two cities to form an axis for further expansion to the surrounding areas, thereby realizing the gradual radiation and overall improvement in a point-axis-plane fashion and making the CCEC the fourth growth pole in China.

The rest of the paper is structured as follows. Section 2 reviews the existing literature to position this research in a proper context. Section 3 redefines the regional economic energy level and proposes a two-dimensional evaluation framework based on theoretical and practical angles and future development trends. Section 4 constructs a preliminary regional EEL evaluation model. Section 5 calibrates and validates the proposed model and applies the optimization model to evaluate the EELs of the Chengdu–Chongqing twin cities. The Section 6 sums up the results and presents a discussion. The conclusions and limitations are summarized in Section 7.

2. Literature Review

Energy level refers to the energy value of electrons moving in their original orbits. electrons with different energy values correspond to different energy levels. Electrons at different energy levels may transition, absorb, or release energy to the external environment. This phenomenon of diffusion and transition not only occurs in the micro physics world but also proves universal in human society and economics.

At present, the notion of energy "diffusion" and "transition" has been widely applied to regional economics research such as urbanization. For instance, Losch (1954) [8] contemplated that as a "spatial landscape", the whole operating system of a city acts like a "living organism" that not only absorbs energy from the outside but also releases energy to the external environment. Various resource elements gather and expand outside the city, promoting the economic flow and development of the whole city.

Sun (1998) [9] introduced the energy level into the study of urban functions and put forward the concept of urban energy levels. It is conceived that the urban energy level reflects the comprehensive strength of a city and represents the diffusion impact of one or more of its functions on the surrounding areas. The level of urban energy is positively related to the size of the external radiation space. Subsequently, the research on the energy level is extended to assess urban functional energy levels, urban connection energy levels, urban field energy levels, urban tourism energy levels, etc.

Research on urban functional energy levels capitalizes on Sun's ideas and other researchers' views. For instance, Han (2010) [10] pointed out that the urban energy level reflects the agglomeration and diffusion extents in the urban economy and the ability of promoting regional economic development. Upgrading the urban energy level is a process of improving its comprehensive functions and spatial reconstruction, including economic, potential, and support energy levels. Moreover, some scholars have constructed comprehensive evaluation index systems according to the concept of urban functional energy levels to conduct quantitative research on urban energy levels [11–14]. However, these comprehensive indexes for evaluating urban functional energy levels only consider the internal strengths of the city without accounting for its external agglomeration and diffusion capacity, which reflects a city's level of external economic connections.

Zhou (2005) [15] believes that in the context of globalization and informatization, the traditional geographical space has changed into the space of flows, and the assessment of urban energy levels is transformed from mainly depending on the urban size and economic strength (such as population size, regional area, economic output, etc.) to considering the connectivity and synergy of external economic relations. Wu et al. (2021) [16] analyzed the aggregation between cities from an angle of information flow. It is obvious that the notion of urban connection energy levels characterizes the urban dynamics of the space of flows, which reflects a city's external agglomeration and diffusion levels and captures its external economic connection level, but tends to overlook the city's stock of history or the comprehensive strength of its holistic economic landscape.

The urban field energy level introduces the electromagnetic field theory into urban studies to examine the interaction between cities. A field is a physical phenomenon or force effect in space [17], such as the electromagnetic field and the gravity field. According to the principle of electromagnetic induction revealed by British physicist Faraday: electricity and magnetism exist in the form of spatial fields that are distributions of certain forces. A "field source" is a point at the center that radiates energy outward [18]. Neither a field nor field source can exist alone. Without a field source, there does not exist a field in a certain space; if there is a field in the space, there must be a corresponding field source. When an object (a field source) exists in the space, it will generate forces (field) at each point around it. As such, a field and field source coexist and depend on each other [17]. These two concepts have been applied to regional economics research to examine the interaction of a region and its surrounding area. The field source in this context can be a region or a city, which changes according to the geographical space under consideration. Similarly, the field in this case refers to the interaction between regions or cities. Regions or cities and the interaction between them coexist and depend on each other. Ren (2005) [19] put forward the urban field theory by linking the electromagnetic principle with the urban energy level. Zhang (2016) [20] further pointed out that in the urban field, the effect of one city on another is similar to the effect of a charged particle on another in the electromagnetic field. This effect not only changes the quantity, but also affects the quality of urban economic development. This impact is similar to the interactions between magnetic fields and electric currents: the change of electric currents generates magnetic fields and the change of magnetic fields also generates electric currents. From this perspective, the interactions between cities are carried out through the changes of urban fields. Moreover, interactions between regions or cities are mainly reflected by the agglomeration and diffusion of various factors, which are the driving force for the evolution of regional spatial structure [21]. Jin et al. (2018) [22] argued that understanding regional economic agglomeration patterns is critical for sustainable economic development, urban planning and proper utilization of regional resources. As such, the urban energy level from the view of fields can be treated as a special kind of "external economic connection level" and reflects a city's interaction with other cities, which is of great significance to the sustainable development of regional economy, the evolution of regional spatial structure and urban planning. Moreover, it is a study of the absolute value of "external economic connection level", rather than the relative ranking of urban connection energy levels.

The urban tourism energy level is adapted from and has its root in the urban functional energy level. Lu et al. (2018) [23] proposed that "urban tourism energy level is a metric that reflects the diffusion impact of the urban tourism function on areas outside the city". Wang (2015) [24] claimed that existing assessments of the energy level of urban tourism development typically take a single angle of the field source without considering external cities or the interactions between the focal city and others from a field perspective, making the evaluation inevitably incomplete. As such, the regional EEL should be evaluated by considering both "field source" and "field".

However, the current research on the regional EEL solely focuses on the perspective of field source, namely the single dimension of "internal comprehensive development level". Based on the "field source" and "field" theory of interdependence, and the urgent need for high-quality sustainable economic development, as well as the future trend of globalization with the flow space, this single-dimensional framework not only deviates from the theory, but also fails to meet the need of the reality, or adapt to the future trend. To close the gap, this paper innovatively assesses the regional EEL by accounting for two interdependent dimensions of "internal comprehensive development level" and "external economic connection level".

3. An Evaluation Framework of Regional EELs

3.1. Definition of Regional EELs

By integrating the theories of energy levels, urban energy levels, and tourism energy levels, the regional EEL can be defined as: the degree of radiation impact of regional economic functions on areas outside the region by accounting for internal comprehensive development and external economic connections. Its evaluation indexes cover different aspects ranging from the field source to the internal comprehensive strength and the field or economic interactions between regions, which measure the external economic connection level and can be characterized by the regional agglomeration and diffusion capacity.

3.2. An Evaluation Framework of Regional EELs

3.2.1. Evaluation Indexes of Internal Comprehensive Development Levels

Due to the extensive and rapid growth of China's economy over the past decades and the traditional notion of emphasizing GDP, the internal comprehensive development level typically exhibits a series of problems such as waste of input factors, low economic efficiency, and serious environmental pollution [25]. Therefore, the core problem facing China's economy at this stage is how to shift from the stage of extensive rapid growth to high-quality development. High-quality economic development is a multi-dimensional concept involving economy, society, ecology, and other aspects [26,27]. Therefore, the selection of evaluation indicators of the regional economic development level must reflect the specific problems and characteristics of China's current economic development stage. As such, this paper expands the evaluation of the internal comprehensive development level of the regional economy to a multiple-dimensional framework and incorporates life and ecology into our research. This comprehensive consideration presumably makes up the single-dimensional inadequacy of the traditional research focusing on economic production only, which is unable to guide the direction of China's high-quality development at this stage.

3.2.2. Evaluation Indexes of Urban External Economic Connection Levels

Regional economic connection refers to the intra-regional and inter-regional interactions in technical economy, trade activities of raw materials and finished products, reflecting the agglomeration and diffusion of various factors. Among them, the inter-regional trade and interaction reflect a region's external economic connection level, which can also be expressed as the interaction of economic entities between regions. The level of economic connection not only illustrates the radiation capability of an economic powerhouse to the surrounding areas, but also shows the reception of the surrounding areas to the radiation of the economic powerhouse [28]. The relevant research methods mainly include the gravity model [29,30], urban flow intensity [31], locked connection within the city [32], input–output table [33,34], proportional method [35], etc. In view of the subjectivity of the gravity model, the questionable adaptability of urban flow intensity to the industrial development stage, and the limitations of data reliability and authority in the locked connection within the city, this paper adopts the proportional method in combination with the domestic inter-provincial trade volume in the input–output table.

4. Preliminary Construction of a Regional EEL Evaluation System

4.1. Design Principles and Assumptions of the Regional EEL Index

The construction of a proper index system should follow the principles of comprehensiveness, scientificity, and data reliability and availability. Based on these principles, after reviewing the relevant literature from abroad and at home, this paper makes three assumptions when constructing the index system.

Assumption 1: Based on the "field source" and "field" theory of interdependence and co-existence, this paper assumes that it will be more scientific to evaluate the EEL from the two dimensions of "internal comprehensive development level" and "external economic connection level" than traditional evaluation methods. If the EEL is assessed from the traditional single dimension of "internal comprehensive development level", such as only from the perspective of the production level, it will lead to misestimation.

Assumption 2: On the evaluation of the internal comprehensive level, this paper assumes that the evaluation from the perspectives of production level, life level, and ecological level will be more comprehensive and systematic, which is conducive to identifying the specific problems existing in the sustainable and high-quality development of the regional economy.

Assumption 3: On the description of the external economic connection level, due to availability and quantifiable data, this article assumes that the interaction between information flow and technology flow in "flow space" is mainly attached to goods and personnel, etc. Therefore, the level of external economic connection is assessed from the material, personnel, and capital flows.

4.2. Design Process of the Regional EEL Index

4.2.1. The Internal Comprehensive Development Level

In the past, scholars typically evaluated the internal comprehensive development level of regional economy from an angle of social production levels. The ensuing evaluation index system is generally mature and accounts for such aspects as the economic scale, economic structure, and people's life levels [36,37]. By reviewing the relevant indicators that have been adopted by existing research [2,6,38–41], we note that they have considered the indices such as GDP, total population, per capita GDP, total investment in fixed assets of the whole society, the proportion of the secondary industry, the proportion of the tertiary industry, urbanization rate, retail sales of consumer goods, per capita disposable income of urban residents, and per capita disposable income of rural residents, to name a few. Capitalizing on extant research, this paper first classifies these indices into three categories:

Production level (P), life level (L), ecological level (E), and then, refines and supplements some indicators.

4.2.2. The External Economic Connection Level

The level of external economic connection represents the external agglomeration and radiation capacity of a region, which is mainly evaluated by the total amount of external economic interactions, that is, the total amount of factor flows. In this paper, "external economic connection Level" is decomposed into outer interaction level (O) and internal interaction (I), which represent international and domestic interaction, respectively. Whether from an O (global) or I (domestic) angle, an export-oriented economy (external economic connection level) is reflected in the interaction and exchange of goods, personnel, capital, technology, information and other factors [7,42]. As mentioned above, because of intangibility of information and technology, they are difficult to quantify statistically. We assume the technical and informational interactions are mainly attached goods and personnel, so the level of external economic connection in this paper is assessed from the material, personnel, and capital flows. In light of the availability of statistical data, the sum of inflow and outflow was chosen to measure the flow of goods. The total amount of import and export was applied to assess the outer interaction level, and the inter-provincial volume of trade from the input–output table is adopted to gauge the internal interaction level (I), that is, the total amount of domestic inter-provincial inflow and outflow. Due to the availability of data, only inflow data are used to evaluate the levels of personnel and capital flows, which represent the region's agglomeration capability for personnel and capital in the internal and external interactions.

4.3. A Preliminary Framework of a Regional EEL Evaluation System

The proposed evaluation system of the regional EEL is shown in Figure 1, which includes 29 indices in five layers. Except for the negative indicators of the urban–rural Engel coefficient, the proportion of urban–rural disposable income, industrial wastewater, waste gas and waste discharge, the rest are positive indicators.

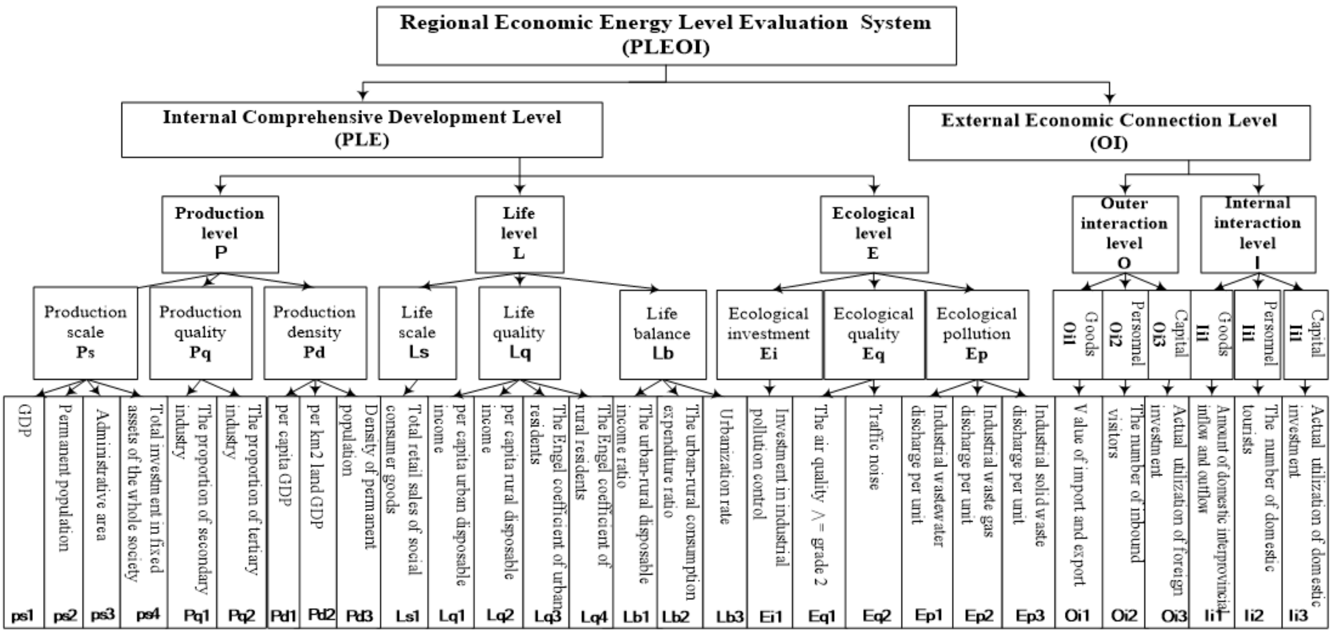

Figure 1. A preliminary framework of the regional EEL evaluation system.

5. Quantitative Evaluation of the EEL of Chengdu and Chongqing

The regional EEL evaluation index system constructed in Section 4 expands the traditional single-dimensional framework in the extant literature into a new evaluation model.

Therefore, the scientificity and rationality of the index system should be tested before its use. Firstly, this paper adopts Cronbach's α to test the internal reliability coefficient of the model and perform the first screening of the index system. Secondly, this paper employs a confirmatory factor analysis to further test the structural validity of the screened index system. Testing and optimization of the reliability and validity of the model can only prove the model's suitability statistically, but it remains unknown whether it is reasonable empirically. As such, this paper further uses a comprehensive weighted fuzzy integral method to quantify Chengdu, Chongqing, Tianjin, and Beijing's EELs, thereby testing the model's empirical rationality through horizontal comparison. Finally, this paper applies the statistical and empirical evaluation model to guide the planning practice of the CCEC.

5.1. Data Source and Evaluation of the EEL Evaluation of Chengdu and Chongqing

According to the proposed regional EEL evaluation system in Figure 1, the target layer is to assess the regional EEL, and the criteria layer consists of the internal comprehensive development level and external economic connection level. This paper collects the statistical data of Chongqing, Chengdu, Beijing, and Tianjin corresponding to 29 indicators in the criteria layer during 2000 to 2019. The data are drawn from the National Bureau of Statistics, urban statistical yearbooks, Culture and Tourism Commission, Investment Promotion Bureau, Ecological Environment Bureau, statistical bulletins, work reports of the relevant governments, investment guides, input–output tables, etc. Moreover, the reason for collecting the data of Tianjin and Beijing is to verify the reliability and validity of the sample size and the subsequent regional EEL evaluation model as well as validate the empirical test after model construction. In total, we collected 2320 ($4 \times 20 \times 29$) data points of these four cities. At the same time, taking the data in each year as sample points, a total of 80 (4×20) sample points are collected for the four cities across the 20 years.

We note the following four points on data collection in this paper:

① Different data sources. When differences exist in different statistical yearbook sources at the national and municipal levels, this paper adopts the latest municipal statistical yearbook data of Chongqing, Chengdu, Tianjin and Beijing in 2020 as our source.

② Missing indicator data. For missing indicator data, we apply the interpolation method to fill the gap. If missing data show an essentially increasing trend, an equal difference sequence is used for interpolation. For instance, we follow this interpolation approach to fill missing data of domestic inter-provincial inflows and outflows of the four cities collected from the input–output tables. For missing data showing non-increasing trend such as the ecological quality index, we use the average value for interpolation. For instance, we lack data of the number of days when air quality in the four cities reached at or above Grade 2 between 2000 and 2003, so the average value interpolation is applied to fill in the gap.

③ Sample selection for horizontal comparison. Ideally, we should have selected a representative city from each of the other three growth pillars such as Shanghai, Beijing, and Guangzhou. However, given the availability of data, we can only find the input–output tables of provincial-level jurisdictions (except Shanghai) under the central government statistics. Therefore, we do not have data for Guangzhou or Shanghai but are able to collect the relevant data for Tianjin and Beijing for about 8 years in 2000, 2002, 2005, 2007, 2010, 2012, 2015 and 2017. As such, this paper ultimately selects these two cities in the Beijing–Tianjin–Hebei region as horizontal benchmarks and expanded sample cities. Furthermore, since there are no public statistics on the domestic capital utilization for Beijing, we assign the average of the data for Chongqing, Chengdu, and Tianjin to Beijing. On the other hand, as the political and economic center of China, it is highly likely that Beijing has higher domestic capital utilization than the average of these cities. Therefore, the EEL of Beijing tends to be underestimated.

④ To illustrate the statistical characteristics of the original data collected in this paper, indicators Pq2 (the proportion of tertiary industry) and Lb3 (the urbanization rate) representing the production quality and the balance of people's livelihood are selected from the

29 indicators to display in Figure 2. It shows how the index data of the four cities change in the past 20 years. The ranking stays constant among the four cities: Beijing (1), Tianjin (2), Chengdu (3), and Chongqing (4) in Lb3, indicating that the imbalance between "big city" and "big countryside" is prominent in Chongqing. In Pq2, Beijing is still far ahead, and Chengdu stands firmly in the second place. Tianjin rises faster and narrows its gap with Chengdu. It shows that Chongqing, as an old industrial base, has shortcomings compared to the other three cities in terms of high-technology and high-service industries.

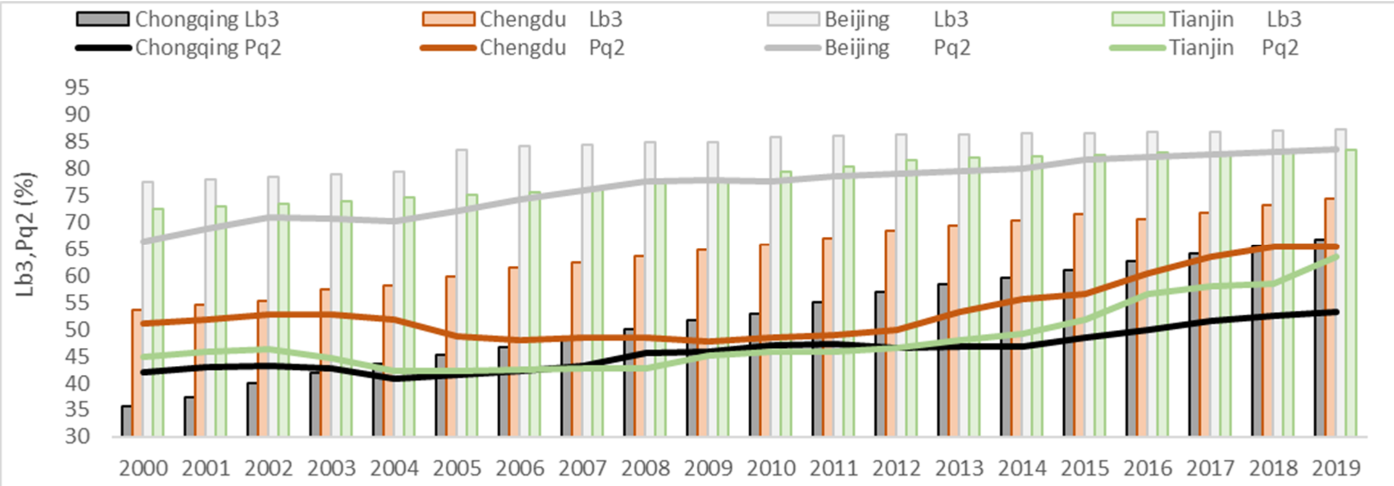

Figure 2. Evolution of Lb3 and Pq2 in the four cities from 2000 to 2019.

5.2. Quantitative Evaluation of the EEL of Chengdu and Chongqing

5.2.1. Dimensionless Processing of Data

In order to eliminate the influence of different dimensions, the original data should be standardized first. This paper applies a linear proportional transformation formula as follows:

$$\text{Positive indicators}: \ Y'_{ij} = \frac{x_{ij}}{\max(x_{1j}, x_{2j}, \ldots, x_{ij})} \tag{1}$$

$$\text{Negative indicators}: \ Y'_{ij} = \frac{\min(x_{1j}, x_{2j}, \ldots, x_{ij})}{x_{ij}} \tag{2}$$

In Equations (1) and (2), Y'_{ij} represents the standardized dimensionless value of the j-th index in the i-th year; x_{ij} represents the original value of the j-th index in the i-th year; $\max(x_{1j}, x_{2j}, \ldots, x_{ij})$ indicates the maximum value of the j-th indicator. After applying Equations (1) and (2), we normalize the raw data for the three cities (60 samples) and four cities (80 samples) according to Equation (3) to obtain the final data.

$$r_{ij} = \frac{Y'_{ij}}{\sum_{i=1}^{m} Y'_{ij}} \quad (1 \le i \le m, 1 \le j \le n) \tag{3}$$

m is the number of the evaluation objects and n is the number of the evaluation indices.

5.2.2. Reliability and Validity Evaluation of the EEL Index System on Chengdu and Chongqing

(1) Reliability Analysis

The reliability analysis in this paper refers to the internal reliability and verifies whether a group of indicators measure the same concept and test the internal consistency of index items [43,44]. The most frequently used internal reliability coefficient is Cronbach's α. According to Peterson (1994) [45], when the value of Cronbach's α is more than 0.7–0.8, the testing reliability is quite good, and a value between 0.8–0.9 indicates that the reliability is very good [39]. In addition to the overall reliability of Cronbach's α, the index system can be further processed by testing individual indices and eliminating those with low reliability. This study uses the corrected item total correlation (CITC) of the revised indices to select candidates for elimination based on two criteria: ① the value of CITC should greater than or equal to 0.4; ② the Cronbach' α item deleted (CAID) increases significantly [46].

According to the above principles, this paper uses SPSS 26.0 to analyze the reliability of the sample with 80 data points, as shown in Table 1 below.

Table 1. Overall reliability analysis of regional EELs.

Samples (PCs.)	Cronbach' α
80	0.960

Source: This study.

Table 1 shows that Cronbach' α value is 0.960, indicating that the sample data has excellent reliability. Meanwhile, the optimization results of indicators are detailed in Table 2.

Table 2. Individual index optimization of the regional EEL.

Index	CITC	CAID	Cronbach α	Whether the Indicator Is Reserved
Oi1	0.905	0.956	0.960	✓
Oi2	0.879	0.957	0.960	✓
Oi3	0.852	0.957	0.960	✓
Ii1	0.867	0.958	0.960	✓
Ii2	0.967	0.956	0.960	✓
Ii3	0.969	0.956	0.960	✓
Ps1	0.987	0.956	0.960	✓
Ps2	0.824	0.960	0.960	✓
Ps3	0.390	0.961	0.960	×
Ps4	0.963	0.956	0.960	✓
Pq1	−0.606	0.962	0.960	×
Pq2	0.806	0.960	0.960	✓
Pd1	0.990	0.956	0.960	✓
Pd2	0.982	0.956	0.960	✓
Pd3	0.757	0.960	0.960	✓
Ls1	0.912	0.956	0.960	✓
Lq1	0.967	0.956	0.960	✓
Lq2	0.973	0.956	0.960	✓
Lq3	0.549	0.960	0.960	✓
Lq4	0.746	0.960	0.960	✓
Lb1	0.772	0.960	0.960	✓
Lb2	0.785	0.959	0.960	✓
Lb3	0.854	0.960	0.960	✓
Ei1	0.039	0.968	0.960	×
Eq1	−0.273	0.963	0.960	×
Eq2	0.110	0.961	0.960	×
Ep1	0.945	0.956	0.960	✓
Ep2	0.838	0.958	0.960	✓
Ep3	0.912	0.956	0.960	✓

Source: This study.

The results in Table 2 illustrate that the CITC values of Ps3 (the administrative area), Pq1 (the proportion of the secondary industry), Ei1 (the investment in industrial pollution control), Eq1 (the # of days of air quality $\geq$ Grade 2) and Eq2 (traffic noise) are less than 0.4, and the CAID is larger than the Cronbach's α prior to deletion. We therefore need to delete them and the remaining 24 indicators are kept in the evaluation system.

(2) Validity Analysis

Validity refers to how effectively tools or methods can accurately measure the objects. Validity is the most important factor in evaluations as it directly affects the result of the whole study [47]. Content validity and structure validity are usually the two aspects of this analysis [48].

Content validity refers to whether the proposed indicators can adequately represent the content to be measured [49]. As the overall index framework and individual index selection of this study are obtained by combining and integrating existing research in the literature, demonstrating its content validity.

Structural validity indicates that the measurement results can properly reflect the correspondence between a certain structure and the measured values. Obviously, this paper needs to focus on the test of structural validity. The most ideal structural validity analysis method is to use a factor analysis to measure the structural validity of the evaluation index system. Before conducting the factor analysis, it is necessary to check whether the sample data are suitable for this exercise.

According to Kaiser (1974) [50], a factor analysis is suitable when the measured KMO (Kaiser–Meyer–Olkin) is larger than 0.6 and the Chi-square value of the Bartlett test is significant. Using SPSS 26.0, KMO and Bartlett Test of Sphericity are carried out on the sample of 80 data points. The KMO value is 0.887 and Bartlett Test of Sphericity χ^2 is 5743.092, d. f. is 406, and the p-value is significant at 0.000 < 0.05, verifying that the sample data are suitable for a factor analysis.

Since the evaluation system of the regional EEL in this study has been constructed and the dimensions are known, an exploratory factor analysis (EFA) is not required, but a confirmatory factor analysis (CFA) is needed. The purpose of the CFA is to judge whether the measurement indicators on the potential dimensions can reflect the characteristics of the structure. Using Amos 26.0, this paper adopts the maximum likelihood estimation to carry out a single-factor CFA test and a first-order multi-factor CFA test of the five-in-one combination model (PLEOI) on the five dimensions of production, life, ecology, outer interaction level, and internal interaction level (P, L, E, O, I). The Amos result provides 25 indicators of fitting degrees as the judgment basis. Following Jackson and Gillaspy (2009) [51], this study reports the 11 most frequently used indicators in the literature as the standard as shown in Table 3. The specific fitting index values of single-factor and first-order multi-factor of the five-in-one combination model (PLEOI) can be found in Table 3 and the text in Figures 3 and 4.

Table 3. CFA model fitting standard and the testing values of each model.

Fitting Degree Index	The Fitting Standard		The Testing Values					
	Good Fitting	**Basic Fitting**	**P**	**L**	**E**	**O**	**I**	**PLEOI**
Chi-square (χ^2)	The smaller the better	NA	3.10	10.1	0	0	0	164.2
DF (degree of freedom)	NA	NA	3	8	0	0	0	92
Chi-square/df	1–3	<5	1.04	1.26	NA	NA	NA	1.79
p-value	>0.05	NA	0.38	0.26	NA	NA	NA	0.00
GFI (goodness of fit index)	>0.9	>0.7	0.98	0.96	1	1	1	0.84
AGFI (adjusted GFI)	>0.9	>0.7	0.92	0.90	NA	NA	NA	0.70
CFI (comparative fit index)	>0.9	>0.7	1	1.0	NA	NA	NA	0.98
RESEA (root mean square error of approximation)	0.05–0.08	0.1 [52]	0.02	0.06	NA	NA	NA	0.10
NFI (normalized fit index)	>0.9	>0.7	1.0	0.98	NA	NA	NA	0.95
IFI (incremental fit index)	>0.9	>0.7	1.0	1	NA	NA	NA	0.98
TLI (Tucker–Lewis index) is also known as NNFI	>0.9	>0.7	1.0	0.99	NA	NA	NA	0.96

Source: Jackson and Gillaspy (2009) and the data of this study.

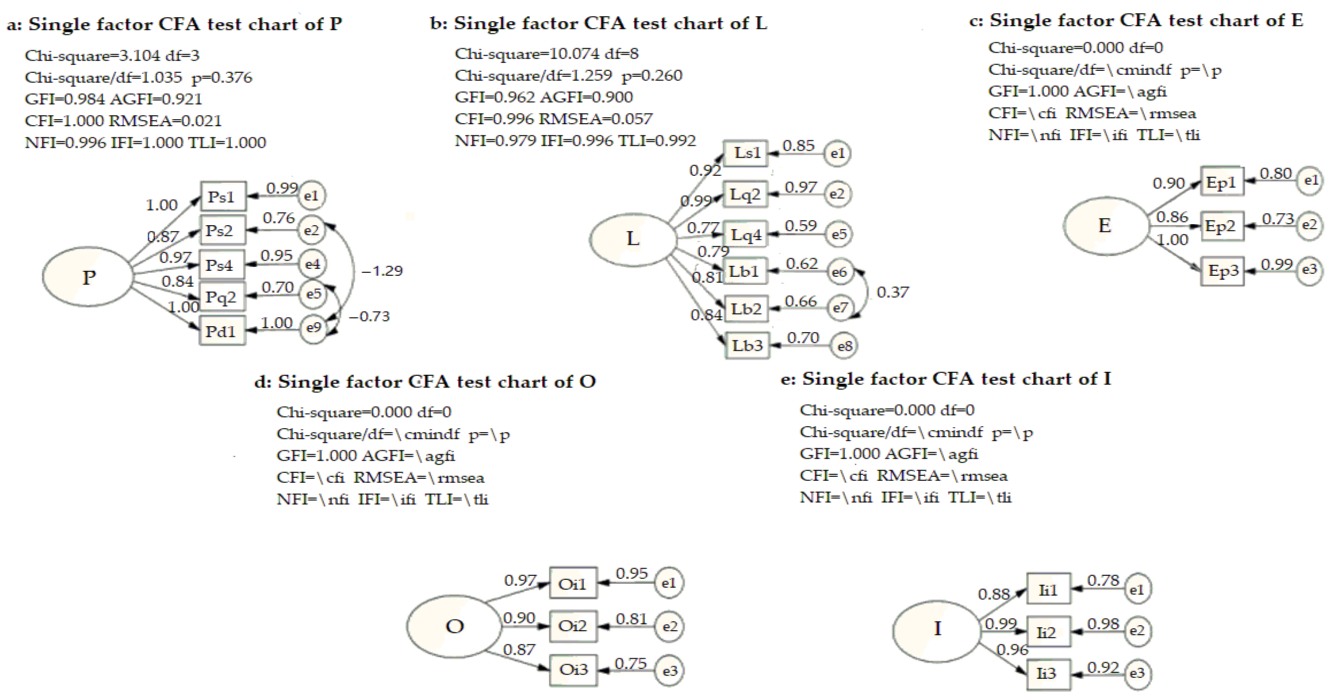

Figure 3. Single factor CFA test chart of P, L, E, O and I.

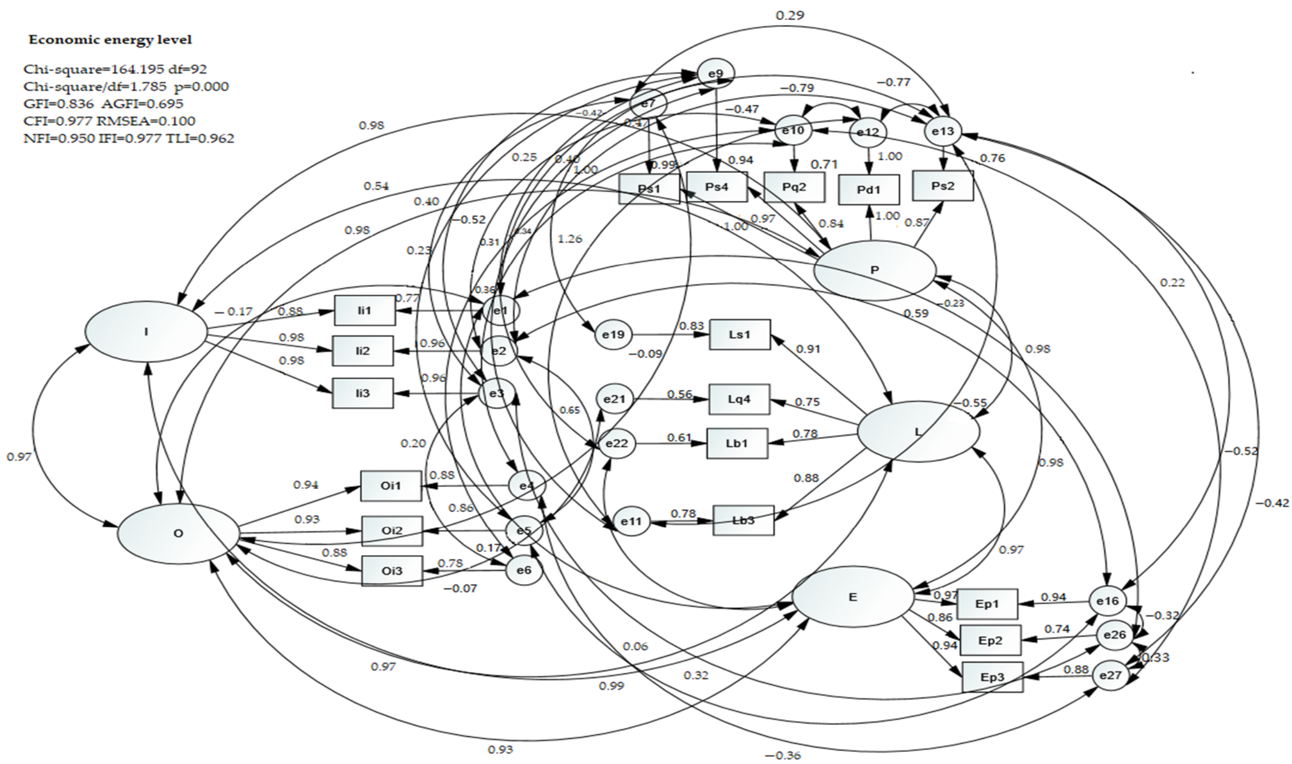

Figure 4. PLEOI first-order multi-factor of the five-combination model CFA test chart (80 samples).

From Table 3 and Figure 3, we conclude that: ① From the final results of the model, the fitting degrees of the five single-factor CFA models meet the requirement. It is worth noting in Figure 3c–e that only the values of GIF = 1 are shown for the ecological level, outer interaction level, and internal interaction level structure plane and other fitting degree indexes are not shown in the text in the upper left corner of the figure. This indicates a saturation model and proves that there is an ideal state between the latent and explicit variables, pointing to very high fitting degrees of the ecological level, outer interaction level, and internal interaction. ② From the perspective of individual indicators, it can be seen from the aggregation of the indicators in the five aspects that the number of indicators is further reduced to 20 from 24 obtained in the previous step as Pd2, Pd3, Lq1 and Lq3 fail to pass the test and are thus removed. Based on the remaining 20 indexes, the first-order multi-factor CFA test of the five-in-one combination model is carried out. The model results are shown in Figure 4.

From Figure 4 and Table 3, one can see that ① the rural disposable income per capita (Lq2) and the proportion of urban and rural consumption expenditure (Lb2) do not pass the first-order multi-factor CFA test, but the remaining 18 out of the 20 indicators pass the test at the individual indicator level. ② From the final results of the model, good fittings are achieved for the five-in-one combination model. The corresponding fitting degree indexes are shown in Table 3 with those passing the test highlighted in bold. Among them, AGIF (0.70) and RMSEA (1.00) are basically fitted, GFI (0.84) is well fitted, and so are Chi-square/df (1.78), CFI (0.98), NFI (0.95), IFI (0.98) and TLI (0.96). Given our limited samples, as the value of IFI is not affected by the size of samples, its value is especially important for this research paper.

The aforesaid discussions reveal that the model constructed in this paper has good structural validity and its indicators have been further optimized from 20 to 18, which indicators are shown in Table 4.

Table 4. Evaluation index system of regional EEL.

OI						**PLE**											
O			**I**			**P**					**L**				**E**		
						Ps			**Pq**	**Pd**	**Ls**	**Lq**	**Lb**		**Ep**		
Oi1	Oi2	Oi3	Ii1	Ii2	Ii3	Ps1	Ps2	Ps4	Pq2	Pd1	Ls1	Lq4	Lb1	Lb3	Ep1	Ep2	Ep3

Source: This study.

However, it should be noted that the structural equation model with a high goodness of fit does not necessarily mean the correctness of the model, nor does it explain the applicability of the model in practice. It only shows that the actual data collected in this paper present a high degree of fit into the proposed model statistically. Next, we carry out a quantitative evaluation of the regional EELs of Chengdu, Chongqing, Beijing, and Tianjin through the model calibrated by statistical data, then empirically evaluate the rationality of the index system through comparison. Furthermore, as it passes the empirical test, this quantitative result offers practical guide for analysts and policy makers.

5.2.3. Evaluation of the EEL of Chengdu and Chongqing by Fuzzy Integrals of Comprehensive Weights

Due to inherent vagueness and uncertainty in the independence among the indicators in the final regional EEL evaluation index system, this paper uses the fuzzy integral method that can handle interdependent indicators. Fuzzy integral is based on fuzzy mathematics, which can effectively deal with the problem of vagueness and uncertainty in the system. As a nonlinear mathematical tool, it can solve difficult evaluation problems with interdependent factors [53]. In fuzzy integral, the important index fuzzy density is related to the weight of each index. To determine the weight of each index, this paper adopts a combination of subjective and objective methods where the objective weight is derived by the entropy weight and the subjective weight is obtained by expert scoring. By combining the objective and subjective weights, we can obtain the comprehensive weight, which can not only mitigate human-induced factors embedded in subjective weights, but also overcome the heavy reliance on the availability of data in objective weights. Consequently, the relevant models, formulas, data, and calculation process applied in this paper are furnished as below:

(1) Entropy Weight

Assuming that the number of evaluation objects is m and the number of evaluation indexes is n, the dimensionless standardized matrix of the original data is:

$$P = (P_{ij})_{m \times n},\ 0 \le P \ \le\ 1,\ \sum_{i=1}^{m} P_{ij} = 1,\ \text{where } i = 1, 2, \ldots m,\ j = 1, 2, \ldots n$$

$$\text{The information entropy of } x_j \text{ is } E_j = -k \sum_{i=1}^{m} p_{ij} \ln\left(p_{ij}\right),\ k = \frac{1}{\ln m}$$

$$\text{The information entropy of j is } W_j = \frac{1 - E_j}{n - \sum_{i=1}^{n} E_j} \tag{4}$$

(2) Comprehensive Weight

$$\beta_j = \frac{\alpha_{j \times W_j}}{\sum_{j=1}^{n} \alpha_{j \times W_j}}\ j = 1, 2 \ldots n \tag{5}$$

where α_j is a subjective weight, the evaluation index system in Table 4 is used following the Delphi method by interviewing 20 relevant experts in the economic field online and offline. They were asked to furnish their values back-to-back, then the average values of the expert scores are used as the subjective weights. W_j is an objective weight calculated by the entropy weight, and the comprehensive weight β_j is obtained by applying Equation (5), which is used as the fuzzy density in fuzzy integrals. Based on the transitivity between evaluation indexes, we calculate the relevant weights and the resulting evaluation value $g\ (X_i)$ for each indicator.

(3) λ Fuzzy Measure

A fuzzy measure is the prerequisite and key of applying the fuzzy integral method and the λ fuzzy measure is a frequently used method. It is defined as follows:

Definition 1: *If a fuzzy measure g satisfies the following additive property: if $A \cap B = \phi$, $g(A \cup B) = g(A) + g(B) + \lambda g(A)g(B)$, $\lambda \epsilon[-1,\infty)$, then g is called a λ fuzzy measure, denoted by g_λ.*

If $X = \{x_1, x_2, \ldots, x_n\}$ is a finite set, and the fuzzy density function of each variable x_i is $g(x_i)$, then g_λ can be written as:

$$\begin{gathered} g_\lambda\ (\{x_1, x_2,\ \ldots, x_n\}) = \sum_{i=1}^{n} g(x_i) + \lambda \sum_{i1=1}^{n-1} \sum_{i2=i1+1}^{n} g(x_{i1}) g(x_{i2}) + \cdots + \\ \lambda^{n-1} g(x_1) g(x_2), \ldots, g(x_n) = \frac{1}{\lambda} \left| \prod_{i=1}^{n} (1 + \lambda g(x_i)) - 1 \right| \\ \lambda \epsilon [-1, \infty),\ \lambda \neq 0 \end{gathered} \tag{6}$$

(4) Fuzzy Integrals

A fuzzy integral is a nonlinear function defined based on fuzzy measures, which does not need to assume independence among evaluation indexes. There are many ways of defining fuzzy integrals, such as the Suggeon fuzzy integral [54], the Weber fuzzy integral [55], and the Choquet fuzzy integral [56]. This paper applies the most widely used method of the Choquet fuzzy integral, which is defined as follows:

Definition 2: *Let $f(x_1) \ge f(x_2) \ge \cdots \ge f(x_i) \ge \cdots \ge f(x_n)$, the Choquet fuzzy integral of the f fuzzy measure g on X is given by:*

$$\int f d_g = f(x_n) g(X_n) + [f(x_{n-1}) - f(x_n)] g(X_{n-1}) + \cdots + [f(x_1) - f(x_2)] g(X_1) \tag{7}$$

where $f(x_i)$ is the standardized value of the evaluation object under indicator i. $g(X_i)$ represents the importance degree of indicator i when considering attributes $x_1, x_2, \cdots, x_n$ simultaneously. $g(X_1) = g\{(X_1)\}$, $g(X_n) = g\{(X_1, X_2, \ldots, X_n)\}$.

(5) Steps of Applying the Proposed Evaluation System

Relevant Data Processing

The original data used to calculate the EEL are those under the remaining 18 indicators that have passed the model verification for the four cities Chongqing, Chengdu, Beijing, and Tianjin for the 20 years, and the dimensionless processing is carried out in the same way as given in Section 5.2.1. However, when data are normalized, differing from the aforesaid reliability and validity tests where distinct normalization processes are applied for each of the four cities, we adopt a unified normalization procedure across the four cities for the whole sample of 80 data points in Equation (4). The rationale is that separate normalizations can only reflect the time series changes of an index within the same city and cannot carry out horizontal comparison to properly reflect the inter-city differences. On the contrary, when a unified normalization is applied, for index j, the eliminated column vectors in Y'_{ij} have the same modules, meaning that the real inter-city differences are retained for horizontal comparison. To verify that the empirical model is reasonable, the benchmark city of Beijing is added. We hope that the quantitative EELs can be compared horizontally to verify the reasonableness of the quantitative values. Therefore, the unified normalization is used here.

Description of Subjective and Objective Weights, Comprehensive Weight, and the Value of λ.

The objective weights are calculated by using the entropy weight method in Equation (4) and starting from the indexes in the bottom layer. The MPai software is employed to carry out the calculation. For example, the objective weights calculated for the third-level indicators (Ps1, Ps2, Ps4) are (0.349, 0.313, 0.339), while their subjective weights are (0.442, 0.267, 0.292) according to the average scores of the interviewed experts. Combining these subjective and objective weights, we derive the comprehensive weights as (0.459, 0.248, 0.294) according to Equation (5), which will be used as the fuzzy density in the fuzzy integral later.

After the fuzzy density is obtained, the fuzzy measure can be calculated according to Equation (6). Before calculating the fuzzy measure, it is critical to determine an appropriate value of λ first. Relevant research shows that the evaluation result focuses on balancing among indicators when the value of λ is assumed to be positive, but the evaluation result tends to account for both particularity of certain indicators and the balance among indicators when λ is less than 0 and approaches 0 [57]. In our proposed evaluation index system, we have to consider both the overall balance across indicators at all levels and some special preferences for certain indicators. For instance, for the three sub-indicators, Ls, Lq and Lb, of the life levels (L) indicator, we should not only consider the balance among the three dimensions, but also account for the special problems that should be solved at present such as people's livelihood coordination (Lb). To sum up, we should accommodate both balance and particularity in this index system. Given that the extant literature typically assumes $\lambda = -0.5$ in such a situation [58], this paper also adopts $\lambda = -0.5$ for indicators at all levels.

For instance, for (Ps1, Ps2, Ps4), λ is taken as −0.5 to calculate the fuzzy measure, which is then normalized to calculate the Choquet fuzzy integral according to Equation (7). The resulting values correspond to the upper index value Ps, the production scale values of Chongqing, Chengdu, Beijing and Tianjin from 2000 to 2019.

Other indicators are similarly calculated step by step from the bottom to the top by using Matlab programming. Table 5 shows the results of the subjective and objective weights, comprehensive weights, and the priority order of the calculations for different indexes.

Table 5. Weight and calculation order of each index level.

Index	Objective Weight	Subjective Weight	Comprehensive Weight	Corresponding Upper-Level Indicators			
				Second Level	First Level	Criterion Layer	Target Layer
Ps1	0.349	0.442	0.459	Ps			
Ps2	0.313	0.267	0.248				
Ps4	0.339	0.292	0.294				
Lb1	0.703	0.563	0.753	Lb			
Lb3	0.297	0.437	0.247				
Ps	0.322	0.335	0.322		P		
Pq	0.364	0.368	0.400				
Pd	0.313	0.297	0.278				
Ls	0.532	0.299	0.488		L		
Lq	0.263	0.397	0.321				
Lb	0.205	0.304	0.191				
Ep1	0.349	0.300	0.326		E		
Ep2	0.247	0.420	0.323				
Ep3	0.402	0.280	0.351				
Oi1	0.322	0.375	0.362		O		
Oi2	0.319	0.293	0.280				
Oi3	0.359	0.333	0.358				
I i1	0.410	0.369	0.449		I		
I i2	0.215	0.318	0.203				
I i3	0.375	0.313	0.348				
P	0.276	0.350	0.293			PLE	
L	0.274	0.340	0.282				
E	0.450	0.310	0.424				
O	0.418	0.445	0.365			OI	
I	0.582	0.555	0.635				
PLE	0.688	0.615	0.779				PLEOI
O I	0.312	0.385	0.221				

Source: This study.

(6) Calculation Results

Benchmark Empirical Test in Beijing:

This paper validates the reasonableness of the model design by introducing the benchmark city of Beijing for horizontal comparison. Following the aforesaid calculation steps, this paper quantifies the EEL evolution diagram of Chongqing, Chengdu, and Beijing for the twenty years as shown in Figure 5.

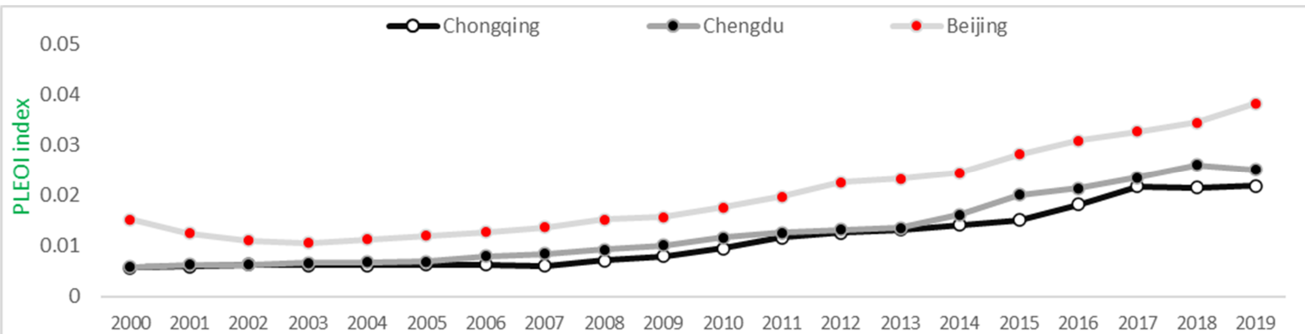

Figure 5. Evolution of the EELs of Chongqing, Chengdu, and Beijing from 2000 to 2019.

From the comparative rankings of the three cities, the EEL of Beijing has always ranked first during the 20 years from 2000 to 2019, which is obviously consistent with the reality. As the capital of China, Beijing is the political, cultural, and economic center of the whole country and its EEL is consistently higher than those of Chengdu and Chongqing across the 20 years, validating empirically the reasonableness of the EEL evaluation system constructed in this study. Moreover, it can be seen from the above that due to the availability of the data on domestic capital utilization, there is still an underestimation of Beijing's EEL. Even the underestimated EEL is higher than those of the Chengdu–Chongqing twin cities, further illustrating the rationality of the model. In addition, the EELs of the three cities all show a general rising trend across the 20 years, reflecting the development reality of the three cities. Furthermore, the two energy level lines of Chengdu and Chongqing approximately coincide with each other, which is also consistent with their dual leading position in economic development in the West. Nevertheless, Chengdu scores slightly better than Chongqing, especially in recent years. In summary, the case study reveals that the regional EEL evaluation system constructed in this paper is consistent with the actual qualitative judgment, so we can conclude that the PLEOI model has passed the empirical test.

EEL Evolution Diagram and Analysis of Chengdu and Chongqing

As the evaluation model constructed in this paper passes both statistical and empirical tests, the quantitative results derived from this model can be applied to study the evolution characteristics, laws, and key issues of the EELs of Chengdu and Chongqing.

First of all, from the perspective of the evolution of the overall objective layer and the criteria layer, Chongqing and Chengdu's evolution diagrams of the internal comprehensive development level (PLE) and external economic connection level (OI) and EEL (PLEOI) are shown in Figures 6 and 7, respectively.

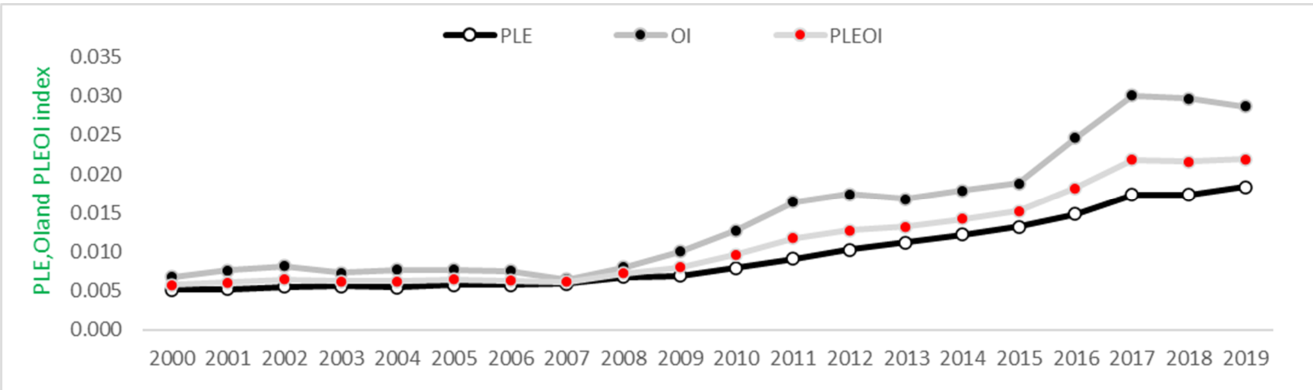

Figure 6. Energy level evolution of Chongqing at all levels in 2000–2019.

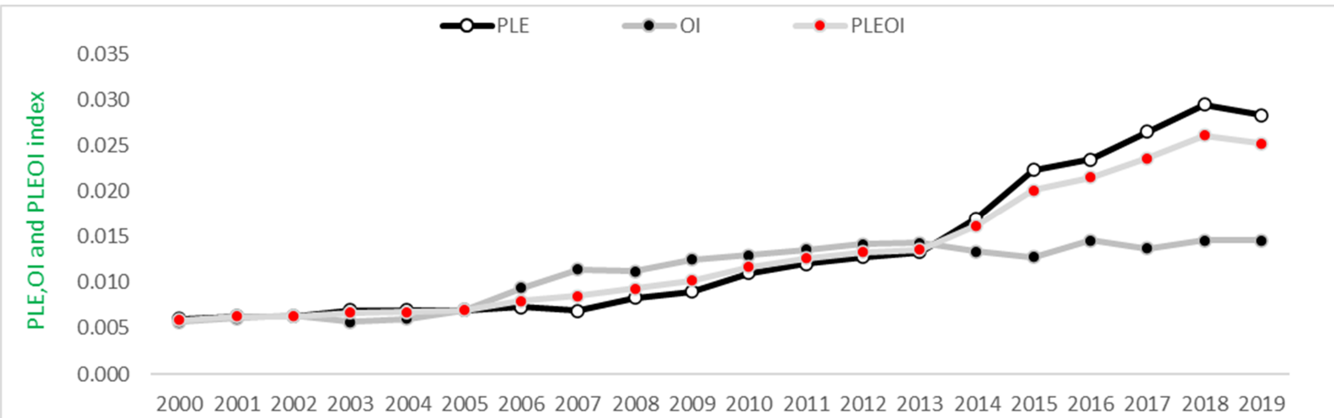

Figure 7. Energy level evolution of Chengdu at all levels in 2000–2019.

Figure 6 shows that Chongqing's external economic connection level (OI) has been consistently outperforming its internal comprehensive development level (PLE) at the sub-indicator level. Particularly during 2015–2017, the OI value has increased from 0.019 to 0.030, corresponding to a rapid developing stage. This dramatic growth is attributed to the outpouring of energy when Chongqing was positioned as the "inland opening-up height" under the BRI in 2013. From the aggregate index perspective, the EEL of Chongqing stayed at around 0.006 from 2000 to 2005, which was in a steady and slow growth period. It increased to the level of 0.006–0.010 from 2006 to 2010, which was the initial growth period. It was further elevated to the level of 0.010–0.022 during 2010–2018, corresponding to a fast-growing period, especially the rapid growth in 2015–2017. The main driver is the rapid development of OI under the BRI. As for 2018–2019, the EEL of Chongqing hovered horizontally at around 0.022. This stagnation is due to the deglobalization and the Sino–US trade war, driving down the OI in Chongqing and eventually leading to the horizontal movement of its EEL.

As we can see in Figure 7, firstly, Chengdu is different from Chongqing in sub-indicators as its internal comprehensive development level (PLE) and external economic connection level (OI) moved in opposite directions. Initially, they contributed to the overall index relatively equally. In the intermediate stage, OI contributed more, and then PLE surpassed OI and contributed more in recent years. After the "BRI" was launched in 2013, the OI of Chengdu remained steady in sharp contrast to the rapid growth of Chongqing's OI. The reason is that Chongqing has taken more active roles in external and internal interactions at the external economic connection level. On the other hand, the internal comprehensive development level of Chengdu has been rapidly growing, reaching a maximum of 0.030 after BRI was launched. In terms of OI and PLE, Chengdu and Chongqing tend to move in opposite directions, showing complementary advantages and distinct divisions of labor between the dual core in the CCEC. From this perspective, opportunities appear plenty for Chongqing and Chengdu to achieve complementary integration in the future with Chengdu serving the interior areas and Chongqing the exterior regions.

Secondly, Chengdu maintained an EEL of 0.006 between 2000 to 2002 from the overall index angle. From 2003 to 2013, this level rose from 0.007 to 0.014, which was in the stage of slow growth. During 2013–2018, Chengdu experienced a fast-growing period and its EEL increased to 0.014–0.026, reaching the rapid growth stage. The main reason is also attributed to the "BRI", differing from Chongqing, the main growth rate of Chengdu is due to the internal comprehensive development level that benefits from rapid development of the production level (P), life level (L), and ecological level (E).

Moreover, if we look further into the data and consider things only from the perspective of the production level (P) in the primary index level, it is essentially equivalent to the main index system used in the traditional evaluation of regional EELs. By taking Beijing and Tianjin as benchmark cities for horizontal comparison, the evolution diagram is obtained for the four cities on P as shown in Figure 8. At the same time, by using Tianjin as the benchmark city, we obtain the evolution diagram of PELOI of the four cities by quantifying the regional EEL system constructed in this paper as shown in Figure 9.

From Figures 6–8, we can find that in 2019 the Chengdu–Chongqing twin cities are similar in terms of P, but Chongqing lags behind Chengdu once PLE is considered comprehensively. This reversal indicates that the sustainable and high-quality development of Chongqing's economy lies in improving the two subdivisions of L and E.

From Figures 8 and 9, we can see that except for 2019 due to China–United States trade war, the ranking order of the four cities stays constant: Beijing (1), Tianjin (2), Chongqing (3), and Chengdu (4) in the production level. As for the EEL, the ranking of Tianjin stayed at No. 2 before 2010, but began declining afterwards, falling from No. 2 to No. 4 gradually. After the "BRI" in 2013, Chongqing and Chengdu as the dual core of the CCEC and the new opening-up height in Western China seized the strategic opportunity and staged a quick catchup, causing to fall behind.

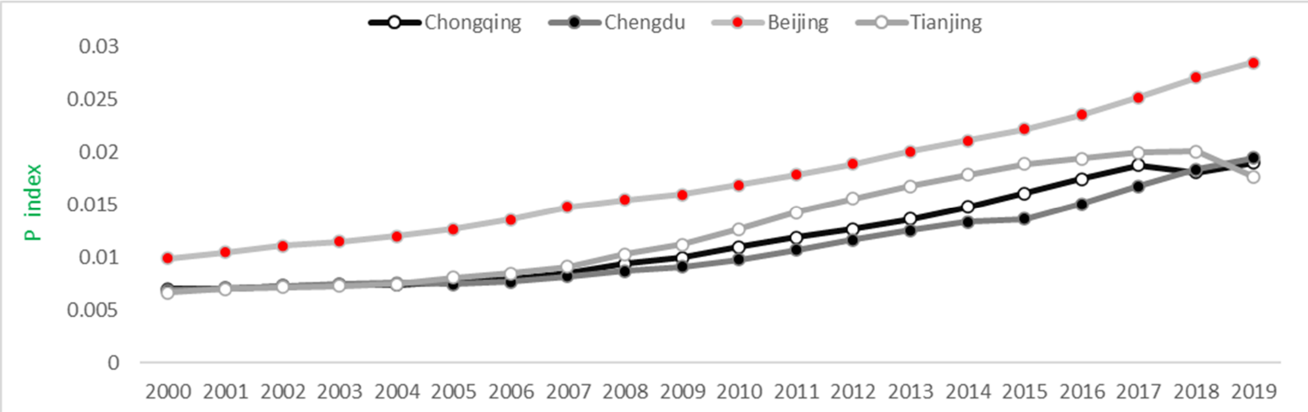

Figure 8. Evolution of the production level of the four cities in 2000–2019.

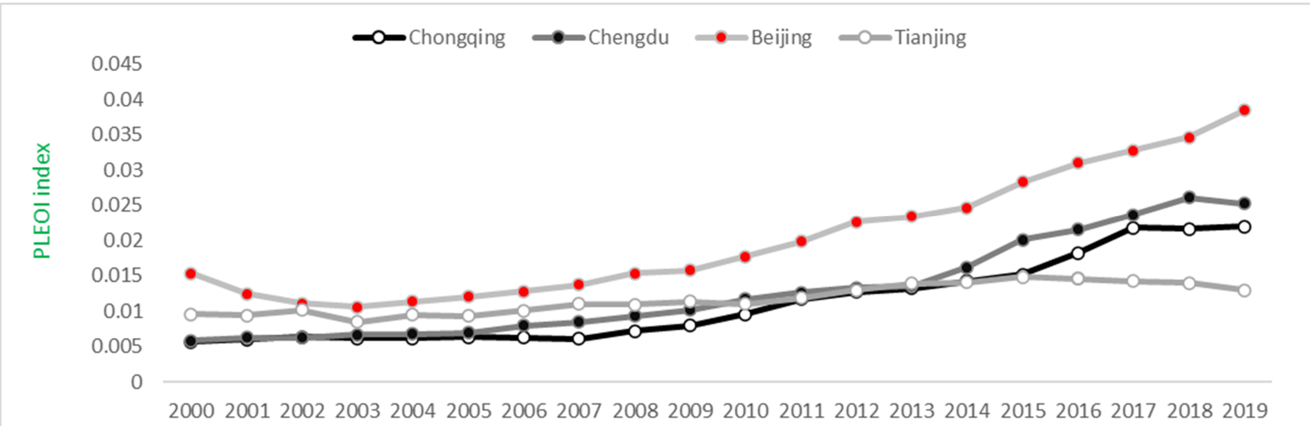

Figure 9. Evolution diagram of the EEL of the four cities from 2000 to 2019.

Our empirical study reveals that if the traditional index system is adopted to evaluate the regional EEL, misleading comparative results might be obtained. For instance, Tianjin as a national advanced manufacturing research and development base generally scores quite high under the traditional evaluation index system. However, when other factors are considered, Tianjin's position drops owing to its weak performance in external and internal interactions as well as ecological levels. After the BRI in 2013, Chengdu and Chongqing greatly benefit from this new development strategy. By comparing our evaluation with the traditional assessment, we note that the EEL tends to be misestimated if comprehensive factors regarding the "external economic connection level" are not taken into account.

6. Discussion

(1) The paper focuses on the evolutionary law of the indexes of PLE and OI of Chengdu–Chongqing twin cities. OI in Chongqing has always been ahead of its PLE and constitutes the main driver of its EEL. In Chengdu, on the contrary, PLE has an advantage in the later stage and has become the main driver of its the EEL. The evolution trends of PLE and OI in Chongqing are basically synchronized: They mutually influence each other, rise and fall simultaneously, and satisfy the theory of interdependent and co-existence of its "field source" and "field". However, the evolution trends of PLE and OI in Chengdu are not necessarily synchronized, and are sometimes even in reverse order, indicating that its "field source" and "field" are not only interdependent but also have the possibility of mutual transformation.
The city as an aggregated "spatial landscape" is itself a product of interaction. Different cities have distinct initial endowments, leading to different evolutionary paths. As a mountainous city, Chongqing has poor interaction with the interiors, resulting in

the unbalanced reality of "big city " and " big countryside " and insufficient internal integration. However, as a western inland city, Chongqing is directly connected by the golden waterway of the Yangtze River, which fosters an export-oriented economy and a high level of interaction with the outside world (the dual circulation). After the "BRI" in 2013, it has been further strengthened to release its energy of "a new opening-up height in Western China" through "Yuxinou Railway" and "the New Western Land–Sea Corridor" resulting in a higher level of OI. In addition, a higher OI is manifested by more personnel flow, goods flow, and capital flow, which eventually contribute to such factors as technology, consumption, and investment in the internal comprehensive development level (PLE), pushing up the internal integration and improvement and PLE.

In terms of Chengdu, as a plain basin, the interaction between the interiors is much easier than Chongqing, so the internal regional balance is higher than that of Chongqing, and the level of PLE is also higher than that of Chongqing. As a strong "field source", its radiation capacity is higher than that of Chongqing, but OI in Chongqing is stronger than that of Chengdu. This is due to the fact that our underlying assumption of consistent or negligible radiation resistance does not apply to Chengdu. As an inland city, Chengdu is neither near the border nor close to a major waterway such as the golden waterway of the Yangtze River endowed to Chongqing. As such, Chengdu's outward radiation resistance is much higher than that of Chongqing. At present, the dual international airports in Chengdu operate to reduce radiation resistance, which is the reality that PLE feeds back OI. However, the airline mainly solves the problem of the flow of personnel and high-tech products. Chengdu is still at a natural disadvantage in the external circulation of general products.

The industrial structure coefficients between Chengdu and Chongqing are highly consistent, implying stiff competition between Chengdu and Chongqing in certain industries. On the other hand, from the angle of the CCEC, when Chengdu and Chongqing two central cities are considered holistically, these two cities possess complementary advantages: Chongqing has the advantage in the "external economic connection level" (OI) while Chengdu has the advantage in the "internal comprehensive development level" (PLE). The complementarity of Chongqing and Chengdu ushers in an excellent opportunity to break away from the stiff competition between them and foster joint improvement of their EELs.

(2) After introducing the two benchmark cities, Beijing and Tianjin, we note the following: Firstly, for the PLE in Beijing, Tianjin, Chengdu and Chongqing, if only P is considered or the EEL is evaluated purely from the traditional production level, misleading estimations of EELs may be the result as this approach tends to overestimate old industrial bases with traditional manufacturing-oriented industries such as Tianjin and Chongqing. At the same time, it tends to underestimate the roles of life levels and ecological levels, which motivates us to propose our holistic evaluation frame-work in this research. Moreover, from the perspective of the high-quality and sustainable development of the regional economy, Tianjin and Chongqing need to focus on the improvement of L and E. As for the OI, due to the significant impact of globalization in Western China, especially after the "BRI" was implemented, inland opening-up is gradually accelerating and staging a quick catchup. Our proposed integrative evaluation system from the perspective of "field source" and "field" properly captures this trend and predicts a smaller gap in the economic energy level EEL between Eastern and Western China than that under the traditional evaluation method.

(3) Judging from the overall indicators of PLEOI (EEL), along the timeline, the EELs of Chengdu and Chongqing have been rising from 2000 to 2018. In 2019, due to deglobalization and the Sino–US trade war, both cities appeared to reach an inflection point. In terms of horizontal comparison, the EELs of the two cities basically overlap and stick to each other, in line with the positioning of Chengdu–Chongqing as the two leading cities in Western China. However, their EELs have been lagging behind those

of Beijing, indicating more room for further improvement. After 2013, Tianjin's EEL gradually declined, falling behind the Chengdu–Chongqing twin cities, and the gap with Beijing's EEL is getting bigger and bigger, indicating that the economic integration of the Beijing–Tianjin–Hebei region needs to be strengthened, and Beijing is still in the siphoning state in the area.

7. Conclusions and Limitation

This paper proposes an evaluation framework for the regional EEL from the perspective of "field source" and "field". The novelty of this research is reflected by a holistic incorporation of the internal comprehensive development level and external economic connection level. We then apply this proposed approach to assess the EELs of Chengdu and Chongqing in the CCEC. The calibrated model passes the dual test of statistical and empirical validation, showing the reasonableness of the proposed regional EEL evaluation system based on "field source" and "field". Subsequently, this paper applies the optimized model to obtain the EELs of the Chengdu–Chongqing twin cities, which helps to foster their high-quality and sustainable development under the general trend of globalization. Moreover, this research also sheds insights on how to connect the two cities to form an axis for further expansion to the surrounding areas, thereby realizing gradual radiation and overall improvement in a point-axis-plane fashion and making the CCEC the fourth growth pillar in China.

By comparing our evaluation with the traditional assessment, we note that the EEL tends to be misestimated if comprehensive factors regarding the "external economic connection level" are not taken into account. At the same time, if the "internal comprehensive development level" does not consider the life level and ecological level, we will not be able to properly identify the obstacles to the sustainable and high-quality development of regional economy along these two dimensions.

As Castells (2010) stated, "flow space" includes technology, information, capital flow, personnel, and goods flow. This paper only considers the flow of personnel, goods, and capital, under the underlying assumption that the information and technology flows are attached to personnel and goods flows. However, this assumption has certain limitations, especially in the current 5G communication technology and post-pandemic era, which greatly affect the flow of personnel. In addition, information flow has become a significant dimension that deserves special consideration in measuring OI. As such, a worthy future work is to further expand our framework by explicitly accounting for information and technology flows.

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