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Understanding the Rural Production Space System: A Case Study in Jiangjin, China

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Abstract: Rural China is experiencing a phase of rapid transition and new conflicts have arisen between the sharp shrink of rural production space and the high goal of rural economic development due to the spatial competition amongst multiple stakeholders and the disordered spatial allocation of rural production resources. To explore how conflicts can be alleviated, this study applies dissipative structure theory to the rural production space system (RPSS). It points out that RPSS belongs to the dissipative structure category, which exhibits a series of characteristics, i.e., an opening system, being far from equilibrium, a nonlinearity regime and random fluctuations. The information entropy principle is introduced to RPSS to build a quantitative analysis model and to quantify the variation in the entropy changes of RPSS. This study uses the Jiangjin District, located in southwestern Chongqing (China), as an example to analyze the entropy changes in its RPSS, by applying the quantitative analysis model, and to identify the reasons for these changes. Results are helpful in overcoming the spatial allocation of rural production resources and in providing a means to enable the sustainable transformation of RPSS.

Keywords: rural production space system; dissipative structure; quantitative analysis model; Jiangjin district of Chongqing; China

1. Introduction

The transformation of the global economy and society in the past few decades has escalated an exploitation of rural areas worldwide. Rural areas in many countries have experienced considerable space reduction due to rapid urban sprawl, thereby resulting in rural decline [1–3]. China, which has remained a predominantly agricultural developing country for centuries, has several modern metropolises with high economic growth levels. Nevertheless, more than 500 million inhabitants still live in rural China at present [4]. The huge rural population of China challenges its economic development and environmental protection. Rural production spaces have faced additional pressures, exerted by the need to protect cultivated land (from development) and the high goals of rural economic development in China. In addition, China's urban and rural growth and development is paradoxical, which makes urban–rural relationships extremely complicated. Accordingly, many stages may be identified from the history of China's development.

For more than 2000 years, the smallholder management system and the lack of physical infrastructure in rural China restricted rural development before the founding of the People's Republic of China in 1949. Since 1978, rural reforms have begun to change the basic management system in rural areas. For example, the separation of collective land ownership and land contract management rights gradually emerged with the implementation of production responsibility systems, such as fixed farm output quotas on a household basis. In 1984, the Chinese central government proposed the household contract responsibility system, in which the land contract term of each household was at least 15 years. This system fostered an institutional guarantee for the land ownership of individual farmers and was the most fundamental production and operation system in rural China. The market price fluctuations of agricultural products and the popularity of non-agricultural products hindered rural development with rapid economic growth and industrialization. The Chinese government introduced market mechanisms into the overall agricultural production system to address the problem. The establishment of the agricultural product market system through legislation enabled the agricultural production structure to comply with market demands. When China formally became a member of the World Trade Organization in 2001, the Chinese government adopted rural agricultural policies to meet international trade guidelines. Policies and regulations, such as rural finance, grain circulation system, taxes, and fees, were adopted in accordance with WTO rules. The rural land property right system was dramatically changed with regard to the policy of building a new socialist countryside. A new pattern of three-right separation, which involved dividing land contract rights into contract rights and management rights with regard to land ownership, was designed. Correspondingly, supporting policies were introduced by the Chinese government, which directly targeted rural construction and development. These policies addressed the rational use of land resources, the building of new agricultural management systems, and the development of various forms of moderate scale management, including the 'beautiful village' policy and the 'rural vitalization strategy' policy. The traditional models of rural economic development were drastically reformed in China.

Although considerable progress had been achieved by launching a series of representative policies since the rural reforms of 1978, rural development in China continues to face challenges, such as urban-rural integrated development, rural vitalization, and new challenges brought about by the policy of three-right separation of rural land rights. There was urgent need to build new mechanisms, develop modern agriculture, increase peasants' incomes, bridge the urban–rural gap, and accelerate sustainable rural economic development during the early 2000's. The principal contradiction faced by the Chinese society in this new era is between unbalanced and inadequate development and the people's ever-growing needs for a better life. In this context, the rural development conditions formed over decades and centuries will be broken. The rural production and operation processes are undergoing seismic shifts, from a naturally slow evolution to a mutation, which typically result from the joint external effects of rural industrial restructuring, development of rural tourism, rural human settlement improvement, movement, and traditional village protection. Consequently, the multifunctional feature of territorial function in the rural production space was evident. An understanding of the rural production space from any single perspective, such as economy, society or culture, is no longer sufficient to address the practical problems of rural development. Instead, the rural production space and its features should be regarded as a continuum [5]. The rural production space should be systematically studied to construct a theory system, which can provide theoretical supports for making rules regarding rural production activities.

Existing studies on rural production space have focused on rural agriculture in more developed areas, a single type of spatial layout of an industry or tourism [6], changes in demand for agricultural products [7] or eco-economy framings, rural development, sustainable rural–urban functionalities [8,9], and peasant household's behaviour choices, with regard to a willingness to change [10–12]. Diverse features of rural transition have stimulated research about uneven development based on post-productivism and multi-functionality [13–17]. Few studies have explored rural areas with land fragmentation, ecological fragility, and intensity of man-land interaction from a system perspective. Rural geography must highlight four aspects, namely, being strategic, systematic, scientific, and security-oriented [18]. The current research refers to system theory [19,20] and space production theory [21–24] to study rural production space in ecologically fragile areas. It introduces the concept of the rural production space system (RPSS) and RPSS is the representation of various possible results of the interaction between multiple rural subjects in rural production space and the geographical environment. It exhibits a certain structure and functional mechanism [25]. The scope and objectives of this study are a model establishment to describe the features and the evolution of RPSS. This study offers suggestions for identifying the best approach to turn theoretical research into applied research in order to help guide the development demands of rural space from a scientific basis.

The remainder of this paper is organized as follows: Section 2 presents the theoretical basis, the dissipative structure features, and a quantitative analysis model of RPSS. Section 3 describes an empirical study to analyze the evolution of RPSS. The last section discusses similar classical rural studies in China and the prospects for the future study of RPSS.

2. Theoretical Basis and Quantitative Analysis Model

2.1. Dissipative Structure Theory and Entropy Theory in Rural Studies

Dissipative structure' is a term coined by Russian-Belgian physical chemist Ilya Prigogine [26] to explain that organized, non-equilibrium structures occur within a thermodynamic system. A system, which is nonlinear, open, and far from equilibrium, constantly exchanges material and energy with its exterior. Once the external conditions change to reach a certain threshold value, the system may mutate to a non-equilibrium phase and transform from a chaotic state to an ordered state in terms of time, space or function. The system continues to exchange materials or energy with the exterior to maintain an ordered structure [27]. The dissipative structure applies the rationale of the formula of the second law of thermodynamics to calculate entropy flux, entropy production, and entropy change. Entropy was first introduced by Rudolf Clausius in 1867 [28]. Subsequently, Ludwig Boltzman [29] introduced the statistical interpretation of entropy as a measure of information uncertainty on physical systems. To include this physical quantity into an open system, Ilya Prigogine [30] divided entropy change into two parts, entropy flux and entropy production. In 1949, Shannon [31] proposed the concept of information entropy, which integrated probability theory, to apply concepts of uncertainty and chaos to measuring the information. The actual state value of a system always deviates from the average value and the range of such deviation is called fluctuation. The shape of fluctuation is structural information, which can be quantified through information amount and information entropy. The concept of entropy theory is an abstract notion of probability distribution, which can represent the probability of any research object. Therefore, dissipative structure theory and information entropy theory have been widely applied and extended to physical [32], chemical [33], biological [34], social [35], and economic [36] systems to describe the relationship between competition and cooperation amongst the elements of a system and the degree of disorder of a system or material movement.

Rural is one form of a human-land relationship regional system, with a series of characteristics, including an opening system, being far from equilibrium, a nonlinearity regime, and random fluctuations. Thereby, dissipative structure theory and entropy theory were applied into the studies of the rural system and its sub-system. Gu built eco-economic model on the basis of dissipative structure theory and entropy theory. He pointed that the relationship between the environment system and the rural ecosystem had positive and negative effects [37]. Zhang introduced the concept of construction management system for villages and small towns, analyzed four main points of its dissipative structure, i.e., entropy change of open systems, bifurcation theory and self-organization phenomenon, nonlinear interaction, and fluctuation, and conducted the bifurcate and entropy flow analysis of its evolution [38]. Recently, dissipative structure theory and information entropy theory were applied to analyzing the rural ecological environment protection problems [39], the innovating mechanism of rural organization [40], and studying the compound rural system composed of economy, ecology, and social fitting subsystems [41]. RPSS is one subsystem of the rural system, thereby it is rational to conduct its dissipative structure and its evolution through dissipative structure theory and entropy theory.

2.2. Dissipative Structure Features of RPSS

RPSS is an open system with constantly circulating material, energy flow, and information exchanges with other systems [42]. This circulation includes the output drive of the production-supply-marketing of agricultural products and rural tourism services under an external market orientation in rural, as along with the input pull of high-tech, sophisticated equipment, and management talents. During the interaction between RPSS and its exterior, new structures will be rebuilt because the interaction mode and strength amongst the internal elements of RPSS will change. Thus, the relationship between competition and cooperation amongst the internal elements of RPSS is non-linear in nature. The final states of the relationship will influence and determine the operation of RPSS. Therefore, RPSS should be regarded as a spatial continuum with a certain structure and functional mechanism. Regardless of how wide the territorial scope of this continuum is or how long the time sequence is, the basic factors of RPSS (a) represent the historical outcomes that result from the interaction between humans and the rural production space and (b) act on the basic components during the operation and reoperation of RPSS. Thus, different states of RPSS can be characterized on the base of the results of internal actions and external exchanges over time and space. These states manifest as coordinated and orderly development, chaotic chaos, or both. RPSS is derived with a general trend of order-disorder-new order under different space-time conditions. Therefore, all characteristics of RPSS indicate that it is virtually a dissipative structure and far from equilibrium.

RPSS is an open system whose evolution exhibits dissipative structure characteristics, i.e., the evolution from equilibrium to near equilibrium to far from equilibrium over time and space at certain points. The current research analyses the dissipative structural features of RPSS as follows:

1. Open System. RPSS exchanges energy and matter with its exterior, which is reflected in the diversity of input and output relations within a system and between a system and its external environment. By contrast, RPSS actively and continuously absorbs negentropy (i.e., reverse entropy) from the external environment by conducting material circulation, energy flow, and information transformation. This type of input is external market demand-oriented and manifests as support for policy, finance, and high-tech equipment. RPSS exports products and services to the exterior environment to promote orderly development. This output appropriately utilizes land resources to set up grain production areas, vegetable cultivation areas, and fruit forests. It also develops rural non-material cultural resources, such as unique dwellings or ancestral halls. The objective flow of input and output indicates that RPSS is an open system.
2. Far from Equilibrium. Systems that are subject to energy and matter flow can be driven far from equilibrium states, i.e., a 'nonlinear' regime. Exchanges amongst various flows within RPSS happen continuously. At the temporal scale, exchanges are dynamic factor flows caused by the unbalanced development speed of factors, such as natural resources, production subjects, and mechanical equipment, within a system. At the spatial scale, exchanges are dynamic economic flows caused by the agglomeration of potential economic differences that exist in the spatial layout of a rural industry. Hence, when RPSS is far from equilibrium, the operational state of RPSS changes over time through various flows within a system and between a system and its external environment.
3. Nonlinearity Regime. Three pairs of relationships in RPSS contribute to the formation of a nonlinear regime of man-land relationship, as follows: The relationships amongst factors, between factors and the system, and between systems and the external environment. All these relationships exhibit characteristics of mutual contact, coordination, and restriction. Rural multiple subjects are interrelated and interact through the utilization of labour force, land resources, and capital by media, such as agricultural production and marketing information, which are important component of rural economy. These mutual effects and feedback amongst the major internal factors of RPSS exhibit a nonlinear relationship, which helps RPSS evolve into an orderly and functional self-organization structure.

4. Random Fluctuation. As a result of random fluctuations or other random factors, such as slight inhomogeneities or imperfections, a system evolves into one of many possible states. In general, RPSS can achieve a stable equilibrium, at the macro level, over a certain period. At the micro level, however, the labour force, land resources, capital, and other driving factors keep flowing amongst multiple rural subjects. Therefore, the quantity and quality of products in a rural area also fluctuate. This fluctuation phenomenon at the micro level is called the micro fluctuation of a system. If new types of agribusinesses crop up, then their sudden presence can sharply break the balance of resource allocation, thereby resulting in huge (e.g., considerably larger than macro) fluctuations in RPSS. Micro fluctuations will not exert a substantial influence on a system, but a huge fluctuation can lead to a disruptive change in system structure.

2.3. Entropy Change Mode of RPSS

As an open system, RPSS possesses all features of dissipative structures, and its evolution is the entropy change process of RPSS. Thus, the evolution of RPSS can be analyzed through the entropy changes in a dissipative structure system (including entropy flux and entropy production). As a system that represents man-land relations, RPSS contains complex socio-economic and human–environment interaction factors. In addition, information entropy can provide the evolutionary rules for RPSS. RPSS facilitates material circulation, energy flow, and information transformation with the external environment, thereby leading to entropy exchange and the generation of entropy flow. The irreversible process within a system generates entropy, i.e., the deterioration of the quality of the internal environment and the construction of an ecological environment that produces entropy. Total entropy change occurs when a system is affected by external disturbances and internal fluctuation, which generates the evolution of RPSS. Given the contradictions of human–environment interactions within the evolution process of RPSS, RPSS can theoretically facilitate sustainable development by considering rural productivity improvement and environmental protection.

In accordance with the reference paper on the pressure-state-response approach that was originally presented by the Organization for Economic Co-operation and Development [43] and Lin's findings on urban ecosystem studies [44], the current work aims to resolve the information entropy of the four parts of RPSS, as follows:

1. Input supportive type of entropy ($\Delta_e S_1$);
2. Output pressure type of entropy ($\Delta_e S_2$);
3. Consumption metabolic type of entropy ($\Delta_i S_2$);
4. Regeneration metabolic type of entropy ($\Delta_i S_1$).

The symbol, formula, and meaning of the information entropy of RPSS are provided in Table 1. The entropy change model is shown in Figure 1.

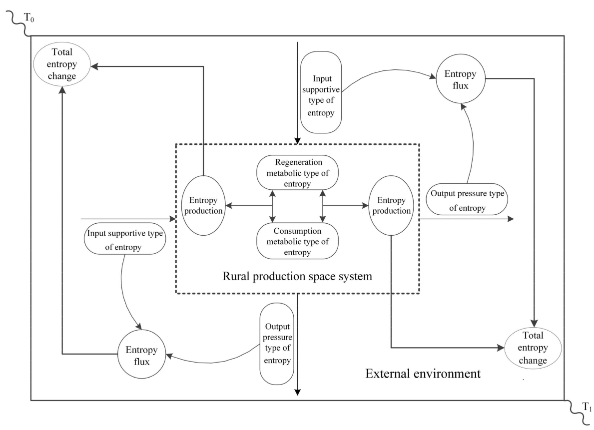

Figure 1. Entropy change mode of RPSS.

Table 1. Symbol, formula, and meaning of entropy flow, entropy production, and total entropy change of RPSS.

Items	Symbols or Formulas	Meaning
Input supportive type of entropy	$\Delta_e S_1$	Determine the supporting function of RPSS
Output pressure type of entropy	$\Delta_e S_2$	Determine the pressure exerted by rural production development on RPSS
Consumption metabolic type of entropy	$\Delta_i S_2$	Determine the negative effects of various production behaviours on the environment of RPSS
Regeneration metabolic type of entropy	$\Delta_i S_1$	Determine the environmental protection and pollutant treatment capability of human in RPSS
Entropy flux	$\Delta_e S_2 - \Delta_e S_1$	Determine the interactive effect of the activities of multiple subjects between the production and environmental protection of RPSS; reflect the carrying capacity of RPSS on rural production development; represent the coordination of RPSS.
Entropy production	$\Delta_i S_2 - \Delta_i S_1$	Determine the interactive effects of environmental pollution and purification on RPSS; reflect the regeneration capacity of RPSS on the metabolic process; represent the vitality of the system.
Total entropy change	$(\Delta_e S_2 - \Delta_e S_1) + (\Delta_i S_2 - \Delta_i S_1)$	Determine the evolution direction of RPSS; represent the degree of order and health condition of RPSS. A 'positive entropy' indicates an increase in the disorder degree of RPSS, whereas a 'negative entropy' indicates an increase in the order degree of RPSS.

2.4. Information Entropy Model of RPSS

In accordance with information entropy theory, the random variable X should be adopted to represent the characteristics of an uncertain system. For discrete random variables, if $X = \{x_1, x_2, \cdots, x_n\}(n \geq 2)$, then the probability of each value $P = \{p_1, p_2, \cdots, p_n\}(0 \leq p_i \leq 1,\ i = 1, 2, \cdots, n)$ and $\sum_{i=1}^{n} P_i = 1$. The information entropy of the system can be described as follows:

$$S = -\sum_{i=1}^{n} p_i \cdot ln(p_i) \tag{1}$$

where S denotes the information entropy of an uncertain system and p_i denotes the probability of a random variable X.

When evaluating n indicators of RPSS in m years, the information entropy of RPSS can be expressed as follows:

$$q_j = \sum_{i=1}^{n} q_{ij} (i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, m) \tag{2}$$

$$\Delta S = -\frac{1}{lnm} \sum_{i=1}^{n} \frac{q_{ij}}{q_j} \cdot ln \frac{q_{ij}}{q_j} \tag{3}$$

where q_{ij} denotes the standard values for raw data; q_j denotes the sum of the standard values of year j; ΔS denotes the input supportive type of entropy, the output pressure type of entropy, the consumption metabolic type of entropy, and the regeneration metabolic type of entropy; i represents an indicator, and j represents the year when the value of each indicator is evaluated.

3. The Empirical Study: Evolution of RPSS Using Information Entropy

3.1. Study Area

The county is the smallest unit for statistical data of the National Bureau of Statistics and other departments and, thus, querying and collecting data required for research based on county unit is easy. Differences exist amongst counties in resource endowment, economic development, cultural customs and policies. Counties also face different key issues, which can better reflect the entropy change process in RPSS and provide an ideal case for exploring the characteristics of entropy changes in RPSS. As a modern agricultural demonstration base and a pilot area of Chongqing for urban and rural comprehensive reforms, Jiangjin District has been actively promoting the integration of rural three industries and integrating efficient planting, demonstration and promotion, and research and development incubation. The development of agriculture in Jiangjin District is sustainable and its sustainability is continuously enhanced. A complex situation arises because of the influences of multiple factors, such as natural conditions, economic level, cultural differences, and rural production in the Jiangjin District, during the critical period of rural transformation and development. Therefore, this study selects the Jiangjin District of Chongqing as the research area to discuss a representative process of entropy changes in RPSS.

The Jiangjin District (105° 49′–106° 28′ E, 28° 28′–29° 28′ N) is at the tail end of the Three Gorges Reservoir Area in the southwestern part of Chongqing (Figure 2). This district covers an area of 3217.80 km^2 and has 6 subdistricts and 24 towns under its jurisdiction. The topography is predominantly hilly (78.2%), with a higher elevation in the south. By 2016, Jiangjin District had a population of approximately 1.62 million permanent residents and 0.59 million rural migrant residents, resulting from making a living and better education for their children. The number of rural employed persons was approximately 0.67 million, i.e., 53.50% of the total number of residents. Agricultural development in the Jiangjin District is transitioning from traditional to modern agriculture and considerable progress has been achieved towards modern agriculture in 2016. With regard to food security, the gross output of vegetables and fruits was 889 thousand tonnes and 275 thousand tonnes, respectively, thereby reflecting an increase of 17.20% and 123.88% from 2009, respectively. The gross output value of farming, forestry, animal husbandry, and fisheries reached 12.21 billion yuan. With the support of national macro-policies and funds, township enterprises and rural tourism grew dramatically in 2016, i.e., the township enterprise output value reached 21.79 billion yuan (RMB), 8.2 million visitors were served and the comprehensive income from rural tourism was 3.02 billion yuan (RMB). In developing Jiangjin District's rural economy, the local government adhered to the ecological red line and promoted rural ecological vitalization. In 2016, 125 rural environmental improvement projects were completed, the penetration rate of rural toilets reached 57.25%, and 9.66 million steres of rural wastewater was treated. In addition, the conservation of 150.7 thousand hectares of forest, the accumulation of 740 hectares of forest, a forest coverage rate of 47%, and a drought and flood protection rate of 23.97%, are conservation measures whose ecological benefits will positively impact rural production in the district. However, the following challenges remained: Serious agricultural non-point source pollution, land fragmentation, non-agricultural sector intrusion, poor infrastructure, and rural hollowing. These unique characteristics of the rural production space present a platform for studying the Jiangjin District.

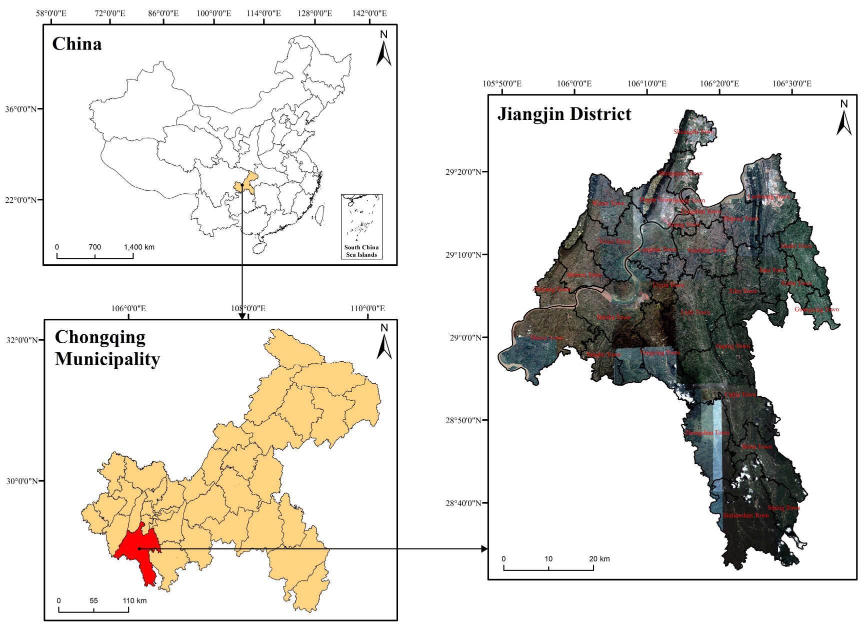

Figure 2. Study area.

3.2. Data Acquisition and Data Management

3.2.1. Data Resource

The data that support this study include socio-economic and eco-environmental data taken from the statistical data collected by the relevant departments of local authorities. The data include information collected between 2007 and 2016, i.e., a nine-year span. Socio-economic data, such as agricultural fertilizer and pesticide consumption, crop yield, expenditure for agriculture, forest and water conservation, income of rural residents, and total output value of township enterprises, were obtained from the Statistical Yearbook of Jiangjin and the Statistical Bulletin of National Economic and Social Development of Jiangjin, which record the input and expenditure of various undertakings, and the Agricultural Economic Report of Jiangjin, which records the basic situation of rural production. Comprehensive income from rural tourism and rural tourist numbers were obtained from the District Tourism Statistical Bulletin of Jiangjin, which records tourism consumption and income.

Eco-environment data, such as forest coverage, area of farmland returning to woodland, ratio of soil erosion control, and discharge solid waste pollution of township enterprise, were obtained from the Environmental Statistical Bulletin of Chongqing and the Environmental Quality Report of Jiangjin. Rural sanitary latrine penetration was provided by the Status Survey of Rural Sanitation of Jiangjin. The quantities of fertilizer pollution, crop straw pollution, and livestock and poultry breeding pollution are calculated data and the calculation formula is as follows:

- Quantity of fertilizer pollution = Quantity of chemical fertilizer(purity) × Inflow coefficient;
- Quantity of crop straw pollution = Crop yields × Straw yield coefficient × (1-Straw utilization ratio) × Nutrient content of straw × Inflow coefficient;
- Quantity of livestock and poultry breeding pollution = Total breeding × Coefficient of fecal discharge × Average fecal contaminant content × Inflow coefficient.

3.2.2. Establishment of the Index System of the Evolution of RPSS

In recent years, rural China has undergone a series of changes, i.e., a more diverse rural population, multiple agricultural industry forms and multi-functional land use. With the launch of the rural vitalization strategy program (2018–2022), flow and interaction amongst RPSS factors will accelerate, which, in turn, will drive the continuous evolution of the structure, form, and function of RPSS. Given these circumstances, this study establishes the index system of the evolution of RPSS based on the complex and diverse human–environment interaction of the Jiangjin District, which makes it unique. Consistent with the principles of representativeness and operability, 36 indicators from 4 aspects are selected to establish the index system for the evolution of RPSS (Table 2). The four aspects are as follows:

1. Indicators of the input supportive type of entropy (A_1–A_{10}) represent the productivity of the natural environment, the productivity of multiple rural subjects in RPSS and the supporting role of RPSS.
2. Indicators of the output pressure type of entropy (B_1–B_{10}) represent the ability of rural multiple subjects to utilize and release energy substances and to reflect the pressures undertaken by RPSS.
3. Indicators of the consumption metabolic type of entropy (C_1–C_8) represent the consumption metabolic capability of RPSS and reflect the negative impact on the environment due to the waste and pollutants discharged in rural production.
4. Indicators of the regeneration metabolic type of entropy (D_1–D_8) represent the regeneration metabolic ability of RPSS, the environment protection and pollution treatment ability of human beings and resilience to natural disasters per RPSS.

Table 2. Index system of RPSS evolution.

Indicator Type	Indicators	Units
Input supportive type (A)	Gross output of grain A_1	$\times 10^4$ t
	Gross output of vegetables A_2	$\times 10^4$ t
	Gross output of fruits A_3	$\times 10^4$ t
	Gross output of aquatic products A_4	$\times 10^4$ t
	Gross output of meat A_5	$\times 10^4$ t
	Primary industry gross domestic product A_6	$\times 10^8$ RMB
	Gross output township enterprises A_7	$\times 10^8$ RMB
	Comprehensive income from rural tourism A_8	$\times 10^8$ RMB
	Per capita net income of rural residents A_9	RMB
	Commercial rate of agricultural products A_{10}	%
Output pressure type (B)	Population of rural employees B_1	$\times 10^4$ person
	Rural tourist number B_2	$\times 10^8$ person
	Expenditure for agriculture, forest and water conservation B_3	$\times 10^4$ RMB
	Agricultural water consumption B_4	$\times 10^8$ m^3
	Agricultural fertilizer consumption B_5	t
	Usage of plastic film B_6	t
	Usage of pesticide B_7	t
	Power consumption of rural production B_8	$\times 10^4$ kW h
	Cropping index B_9	%
	Intensity of agricultural economic activity B_{10}	RMB/m^2
Consumption metabolic type (C)	Quantity of fertilizer pollution C_1	t
	Quantity of crop straw pollution C_2	t
	Density of livestock and poultry breeding pollution C_3	t/hm^2
	Agricultural source chemical oxygen demand C_4	t
	Agricultural source amino-nitrogen emission C_5	t
	Quantity of township enterprise wastewater effluent C_6	$\times 10^4$ t
	Pollutant quantity in flue gas of township enterprise C_7	$\times 10^4$ t
	Discharge solid waste pollution of township enterprises C_8	$\times 10^4$ t
Regeneration metabolic type (D)	Forest coverage D_1	%
	Area of farmland returning to woodland D_2	hm^2
	Ratio of soil erosion control D_3	%
	Rural sanitary latrine penetration D_4	%
	Harmless treatment quantity of rural production wastewater D_5	$\times 10^4$ m^2
	Ratio of rural environmental protection investment D_6	%
	Area ratio of ecological infrastructure land D_7	%
	Drought and flood resistant ability of grain D_8	%

3.2.3. Data Standardization

All types of entropy indicators were standardized during the establishment of the information entropy model and, thus, distinguishing positive indicators from negative indicators is not required in data standardization. Consequently, this study adopted the Z-score standardization method.

$$\boldsymbol{Z} = \frac{\boldsymbol{x} - \boldsymbol{u}}{\boldsymbol{\sigma}} \tag{4}$$

where $\boldsymbol{Z}$ denotes the standard value, $\boldsymbol{x}$ denotes the origin value, $\boldsymbol{u}$ denotes the mean value, and $\boldsymbol{\sigma}$ denotes the standard deviation of the indicators.

3.3. Results

From the standardized data of the selected indicators, in accordance with Formula (4), the four types of entropy values were calculated by Formulas (1)–(3). The entropy change results of the evolution of RPSS in Chongqing from 2007 to 2016 were calculated using Formula (4) in Table 1. The results in Table 3 show that the total entropy change of RPSS exhibits a downward trend due to the effects of entropy flux and entropy production. RPSS constantly evolves towards order and health and its structure and function evolve towards optimization to continuously enhance self-stability. The total entropy change shifted from positive to negative after 2014 for a series of rural environmental protection policies, such as the three-year action plan for the rehabilitation of the rural habitat environment, thereby considerably reducing the negative impact on the environment and enhancing the environment protection and pollution treatment ability of human beings and their resilience to natural disasters. The characteristics of the variations of entropy flux and entropy production are presented in Figures 3 and 4.

Table 3. Entropy change of RPSS of Jiangjin District from 2007 to 2016.

Items	Years									
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Input supportive type of entropy	0.404	0.421	0.424	0.425	0.429	0.434	0.437	0.444	0.446	0.450
Output pressure type of entropy	0.432	0.426	0.427	0.431	0.429	0.435	0.433	0.437	0.432	0.434
Consumption metabolic type of entropy	0.434	0.417	0.409	0.405	0.393	0.384	0.377	0.373	0.363	0.359
Regeneration metabolic type of entropy	0.327	0.336	0.339	0.341	0.350	0.348	0.354	0.346	0.355	0.357
Entropy flux	0.028	0.005	0.003	0.006	0.000	0.001	−0.004	−0.007	−0.014	−0.016
Entropy production	0.107	0.081	0.070	0.064	0.043	0.036	0.023	0.027	0.008	0.002
Total entropy change	0.135	0.086	0.073	0.070	0.043	0.037	0.019	0.020	−0.006	−0.014

3.3.1. Entropy Flux

Figure 3 shows that the input supportive type of entropy presents a trend of fluctuating upward from 2007 to 2016, including a sudden increase of 7% in 2008 and a constant growth from 2009 to 2016. The productivity of the natural environment, the productivity of multiple rural subjects in RPSS, and the supportive role of entropy improves continuously. The output pressure type of entropy tends towards a wave-like slow increase and is smaller than the input supportive type of entropy. The pressure of rural production activities on RPSS has increased, but the increase is considerably smaller than the growth of its supporting role. With the interaction of the two types of entropy, the entropy flux of RPSS exhibits an overall decreasing trend during this period, which indicates the enhanced carrying capacity and coordination of RPSS. After a sudden decline in 2008, the entropy flux smoothly decreased from 2008 to 2012 and abruptly dropped in 2013 when the entropy value changed from positive to negative.

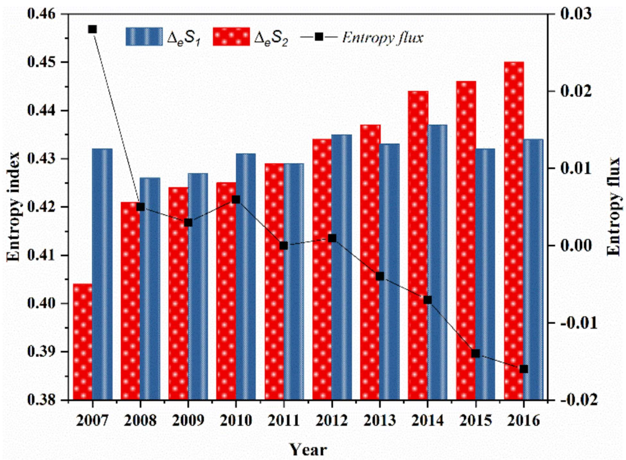

Figure 3. Variation of entropy flux of RPSS from 2007 to 2016 in Jiangjin.

We relied on Chongqing's unique socio-economic background to further explore the reason behind the variation of entropy flux. In 2007, Chongqing was designated a National Pilot Area of Comprehensive Supplementary Reforms of Coordinate Urban and Rural, which performed reform experiments in 10 key reform areas, including urban resources going to the countryside and agricultural industrialization, Jiangjin transformed from a prefecture-level city into a district of the Chongqing Municipality. These administrative changes resulted in a notable decline in the entropy flux from 2007 to 2008. In addition, a series of favourable actions and funds to promote investment in rural infrastructure, introduce new agricultural management subjects, and build a modern agriculture park was infused into agriculture production in the Jiangjin District. This advanced rural productivity could have facilitated a rapid growth in RPSS's supporting role. However, the development of rural production during this period may also have had negative effects on the environment, which increased pressure on RPSS. The interaction of the input support type of entropy and the output pressure type of entropy brought about a smooth variation of the entropy flux until 2012. In 2013, the government of Jiangjin worked hard to promote three industries' integration developments, thereby deepening the reform of the agricultural supply side and accelerating the construction of modern agriculture parks. To guarantee food security and the use of unique selenium-rich soil resources, the government vigorously developed selenium-rich characteristics to benefit agriculture and promoted agricultural development from a 'production guide' transition to a 'consumer oriented' one, from 'intensive cultivation' to 'mass production'. Simultaneously, under the aegis of the rural tourism development plan for Chongqing, the local authorities positioned rural areas for agriculture tourism development and undertook several measures to cultivate agritourism. By 2016, the comprehensive income from rural tourism in the Jiangjin District exceeded 30 billion yuan. The supporting role of RPSS was considerably enhanced by this accelerated growth rate. With the development of rural agritourism, local authorities responded enthusiastically to the national guidelines for ecological civilization construction, as decreed by the Chinese central government in 2012. They launched programs for the construction of beautiful villages, implemented strict control for fertilizer and pesticide use, encouraged the adoption of ecological agriculture technology, such as the utilization of straw and biogas, coordinated the development of the agricultural industry's structure, and built a new pattern of production, life, agricultural resources, and environment, with the ecological home project as the carrier. These moved not only reduced the pressure on the environments but also strengthened the carrying capacity of the system, which in turn led to the continuous decline of the entropy flux since 2013.

3.3.2. Entropy Production

The variation of entropy production (defined by the consumption metabolic type of entropy and the regeneration metabolic type of entropy) from 2007 to 2016 is shown in Figure 4. For 2007–2016, the consumption metabolic type of entropy continuously declined from 0.434 to 0.359, which indicated that the total amount of various pollutants stemming from the rural production process decreased. The regeneration metabolic type of entropy fluctuated upward, which reflected an enhanced level of ecological protection and environmental management in the Jiangjin District. The two types of entropy working together enabled the entropy production of RPSS to fluctuate downward, thereby demonstrating that the regeneration ability and vitality of RPSS were gradually enhanced.

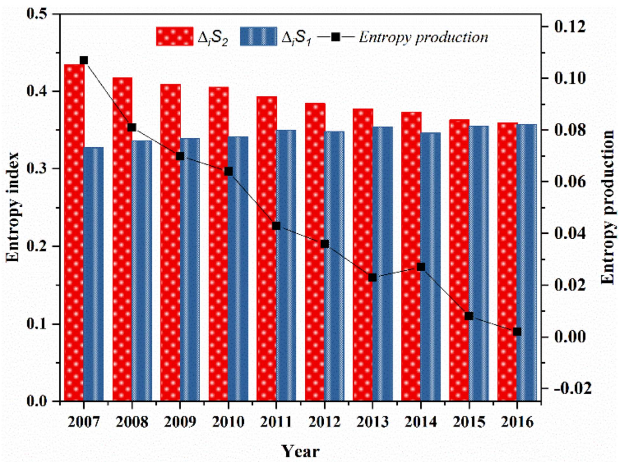

Figure 4. Variation of entropy production of RPSS from 2007 to 2016 in Jiangjin.

During the time frame of this study, from 2007 to 2016, local authorities implemented numerous measures to strengthen the management of agricultural non-point source pollution. These measures included setting up pollution monitoring points, delimiting zones for livestock and poultry rearing, banning firewood burning, and penalizing township enterprises on excessive pollution discharge. Compared with that in 2007, the quantity of livestock and poultry breeding pollution, agricultural source chemical oxygen demand, agricultural source amino-nitrogen emission, crop straw pollution, township enterprise wastewater effluents, and discharge solid waste pollution of the township enterprise decreased by 10.96%, 21.58%, 9.31%, 27.27%, 62.38%, and 96.17%, respectively, in 2016.

By eliminating the pollution of the natural environment in RPSS, the negative impact of production activities on the ecological environment was effectively controlled, which considerably decreased the consumption metabolic type of entropy. In addition, by increasing investment in environmental protection and promoting the construction of rural toilets (the 'toilet revolution' increased the popularity of sanitary toilets in rural areas), substantial progress has been made in rural human settlements in the Jiangjin District. In 2016, the penetration rate of hygienic toilets in rural areas rose by 249.09% and the harmless disposal of wastewater from sewage production in rural areas increased by 507.14%. With the implementation of a series of joint actions, such as building a shelterbelt system along the Yangtze River, returning farmland to forestland or grassland, promoting land conservancy, and controlling soil erosion, the environmental protection and pollutant treatment capacity of RPSS has been comprehensively enhanced, thereby ensuring the steady increase of the regeneration metabolic type of entropy. With the continuous decrease of the consumption metabolic type of entropy and the continuous increase of the regeneration metabolic type of entropy, the interaction of the two metabolic types of entropy may impact the continued decline of the entropy production of RPSS.

4. Discussion and Conclusions

4.1. Discussion

Before the millennium, Zhang [45] studied the rural space system and divided it into three sub-systems, as follows: The economic activity space system, the settlement space structure, and the social space structure. The succeeding research emphasized the spatial characteristics of rural settlements in the eastern developed area of China [46,47] and recently probed the accurate depiction of the rural space system, underlining a 'material space-social space-cultural space' multi-dimensional space perspective to research the rural space system, rather than an understanding of the material space singly [48]. By contrast, this study intends to build a research perspective to discuss the complex situation of production activities in rural China in the urbanization process. The results demonstrated that RPSS can be efficiently analyzed by dissipative structure theory and quantified through the information entropy method. This objective is consistent with the study on rural restructuring under the background of rapid urbanization to ultimately optimize structures, improve the functions within rural territorial systems, and realize the structural coordination and functional complementation between urban and rural territorial systems [49]. Following the concepts first defined by Woods [50], Long [51,52] proposed the strategy of pushing forward rural spatial restructuring in China, from the discussion of the measures of land use policy and land consolidation, in the process of building new countryside and emphasizing urban–rural integration development. This theory resulted in an approach from the three aspects of spatial, economic, and social restructuring [53].

Since Shannon proposed information entropy in 1948, it has been widely applied to study the operation disciplinarian in systems, along with the dissipative structure theory. Byeon applied dissipative structure theory and entropy theory to analyze the operation of a political system [54]. Li analyzed the entropy change process of entrepreneurs' creative behavior system through entropy theory and dissipative structure theory and analyzed its order degree in the different evolution stages [55]. Yang studied the evolution process of the urban system from disordered to order by using dissipative structure theory and the entropy change method [56]. It is an important method to understand RPSS. RPSS belongs to the dissipative structure category, with a series of characteristics, including an open system, being far from equilibrium, a nonlinearity regime, and random fluctuations. Thus, based on dissipative structure theory and entropy theory, the study builds a quantitative analysis model to quantify the variation of entropy flux and entropy production of RPSS. The results of the study are helpful to understand the complex transformation process in the material transport, information transfer, and energy exchange within the rural areas or between the rural areas. The study is highly consistent with the research on systems by mainstream scholars at home and abroad. Meanwhile, based on the understanding of RPSS, this study intends to focus on areas with lagging economics, broken terrain, and fragile eco-environments. The results guide their policy formulation to achieve the sustainability in these areas, according to the realistic development demands within rural production.

Thus, future research will include an empirical case study of multiple rural locations to test the validity and reliability of the theoretical framework of RPSS and the specific factors, structures, and functions of RPSS. Progresses of rural geography research on the tracks of political–economic structures and social construction have stimulated innovations in methodology and opened up opportunities for new interdisciplinary connections [57]. Interdisciplinary and multi-method studies on the interaction mechanism and the behaviour mechanism between humans and the environment in RPSS and the interactions amongst various stakeholders, along with the evolution of RPSS, must be performed.

4.2. Conclusions

In this study, dissipative structure theory is used to describe RPSS and its dissipative structure characteristics are systematically expounded. By introducing the information entropy principle, this study builds a quantitative analysis model to quantify the entropy change process of RPSS. This work applies the model in the example of Jiangjin District, Chongqing (China) to analyze the variation of the entropy flux and the entropy production of its RPSS and suggests strategies for RPSS to develop from disorder and guide the sustainable development for rural production.

(1) RPSS belongs to the dissipative structure category, with a series of characteristics, including an opening system, being far from equilibrium, a nonlinearity regime, and random fluctuations. The evolution process of RPSS is a direct consequence of the entropy changes of RPSS and it shows the complex human–environment interaction of rural production activities. Therefore, entropy theory can be used to understand the input and output of matter, energy, and information in RPSS and provides a method for expounding RPSS systematically to realize sustainable rural developments.
(2) RPSS is affected by many factors that can be divided into input supportive type of entropy, output pressure type of entropy, consumption metabolic type of entropy and regeneration metabolic type of entropy, in accordance with entropy theory. RPSS presents different states under the interaction of humans and the environment, i.e., the combined effects of entropy production and entropy flow.
(3) The four types of entropy can be used to characterize the interaction of the influencing factors of RPSS in the study area. Factors supporting rural development, such as sufficient funds, favorable policies, and good infrastructure, were input into RPSS of Jiangjin and interacted with each other, presenting that the input supportive type of entropy presents a trend of fluctuating upward from 2007 to 2016. Entropy generation and entropy flow can characterize the interaction process between humans and the environment. The entropy flux of RPSS showed an overall decreasing trend and the entropy production of RPSS fluctuates downward in Jiangjin from 2007 to 2016. The results indicated the rural output benefits were higher than the negative benefits on villages on the base of the consumption of resources per unit when stakeholders strengthen the protection of the rural environment and reduce rural pollution. These results can be used to explain the situation of the study area and guide the practice of rural production space development.

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