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Research Article

An Analytical Study of the External Environment of the Coevolution between Manufacturing and Logistics Based on the Logistic Model

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This paper focuses on the external environmental capacity of the coevolution system of the manufacturing industry and logistics industry. This paper first constructs a dynamic model of the external environmental capacity of the coevolution system by using the logistic model and then simulates the effects of two factors: one factor is the institutional environment affected by the random interference factors of policy and the other factor is the industrial environment affected by the random interference factors of the industrial economy on the coevolution system. This paper discusses the cooperative mechanism of external random interference factors on system evolution, analyzes the nonlinear variation of external environmental factors with time, and gives the estimation method. Finally, we provide an example to prove our findings.

1. Introduction

In the historical process of the evolution of the social division of labor, the form of industrial organization presents an obvious evolutionary phenomenon. From the perspective of organizational ecology, the formation and evolution process of an organization is not the strategic choice and adaptation of decision-makers within the organization but the choice of the external environment. On the one hand, the impact of external environmental changes on organizational evolution will be recorded in the number of enterprises entering or exiting the population [1], which will change the population density, environmental capacity, and survival mode of the organization. On the other hand, environmental change produces industrial evolutionary action through the self-organization mechanism of the organization [2], and this evolutionary action is bound to have more or less impact on the environment. In other words, industrial evolution operates in a complex environment, and its essence has a very close interactive relationship with the environment.

The logistic differential equation has become the main tool for modeling physical, engineering, economic, and biological models [3, 4] because it provides more ability in estimating the natural behavior of the model, and it also provides higher degrees of freedom [5]. In addition, the logistic equation involves memory and genetic characteristics, which are essential to describe the behavior of the ecological model [6]. On the other hand, the logistic model can demonstrate the interaction relationship between two species since the earliest model was published by Verhulst [7] in 1838. May [8] added a linear term in the population environment capacity of the logistic growth equation. This linear term can be described as the density of the symbiotic population to the environmental capacity of the equation. The symbiotic function can be seen as a function to enlarge the population environment capacity. Lotka [9] and Vloterra [10] extended it to simulate the interaction between two populations. This mathematical model is called Lotka–Volterra (LV) model or predator-prey model. The LV model can be used to describe the dynamics of some realworld models. For example, Zhou and Wang [11] used the LV model to calculate the symbiotic relationship and symbiotic coordination degree of an industrial economy and industrial ecology in 30 provinces in China. Meng et al. [12] used the LV model to explore the symbiotic stability of two types of enterprise population: central enterprise population and satellite digital enterprise population in the digital economic ecosystem. Mao et al. [13] took the predator as an online bank and the prey as the third online payment system. Using the LV model, they quantitatively analyzed and predicted the impact of commercial banks' online payment systems on the development of third-party online payment systems. Mohammed et al. [14] used the LV model to simulate the dynamic behavior of New Coronavirus. However, most of these studies are deterministic external environmental capacity. The model does not consider the external environmental capacity of the interaction between the two groups. The external environment of the LV model shows randomness and affects the ecosystem in many forms [15–17]. For example, the external environment to be considered in industrial evolution includes resources and energy supply, environmental protection, other population functions, economic development, market, and political system changes, and the changes in time show a nonlinear functional relationship. The existing research does not estimate the impact of external random interference factors on systems coevolution.

To solve this problem, this paper uses a logistic equation to build an external environment capacity model of coevolution between manufacturing and logistics, and then the mathematical statistics method is used to estimate the internal environmental capacity and external random interference factors. Finally, this paper validates the feasibility and effectiveness of the model based on the data collected from the manufacturing and logistics industry in Shaanxi Province.

2. Methodology

2.1. External Environmental Capacity Model of the Coevolution between Manufacturing and Logistics. The industrial activities of manufacturing and logistics can be likened to the self-organization behavior of the biopopulation in the ecosystem. In the process of evolution, various populations are constantly exchanging material, energy, and information with the external environment so that the structure of the population has evolved into an orderly and stable state, which shows the self-organization regularity of the great nature. The relationship between population density and environmental capacity can be described by the logistic growth equation, as shown in the following:

$$\frac{\mathrm{d}N}{\mathrm{d}t} = rN\left(1 - \frac{N}{k}\right), \tag{1}$$

where N is the population density of time t. N refers to the individual quantity of each population unit space. It is the state variable describing the evolution process of the industrial system. r is called the natural growth rate of the population, which refers to the ratio of the natural increase in population to the total population, that is, the difference between the average birth rate and the average mortality rate of the population, which indicates that the population of individuals in the absence of inhibition of the maximum growth, reflecting the inherent characteristics of the species; K is the maximum capacity of the environment. It is the upper limit of population density. In other words, it represents the maximum population density that environmental resources can carry.

Hypothesis $N_1(t)$ and $N_2(t)$ are the population density of the manufacturing and logistics, respectively; r_1 and r_2 are the natural growth rate of the manufacturing population and the logistics population separately; and $K_1(t)$ and $K_2(t)$ are the separately maximum ambient capacity. The synergetic evolutionary kinetic model of two industrial populations is expressed as follows:

$$\begin{cases} f_1(N_1(t)) = \dfrac{\mathrm{d}N_1(t)}{\mathrm{d}t} = r_1 N_1(t)\left(1 - \dfrac{N_1(t)}{K_1(t)}\right), \\[2ex] f_2(N_2(t)) = \dfrac{\mathrm{d}N_2(t)}{\mathrm{d}t} = r_2 N_2(t)\left(1 - \dfrac{N_2(t)}{K_2(t)}\right). \end{cases} \tag{2}$$

The impact of external environmental changes on the internal population of the system can be simplified into two cases: one is the impact of the market on the efficiency of resource allocation so that the change of external random interference factors of environmental capacity affects the change of industrial population-scale and the other is to transfer the resource allocation of enterprises in the system, to change the scale of the existing industrial population from emerging industrial population to emerging industrial population [18]. On this basis, we continue to consider the synergy between manufacturing and logistics to expand the environmental capacity of the existing population system, to promote the change of population growth rate. We try to analyze the coevolution between the system and the external environment by extending the environmental capacity parameter in the logistic equation.

Hypothesis $\alpha_1 f_1(N_2)$ and $\alpha_2 f_2(N_1)$ separately represent increment values of the environmental capacity of S_1 and S_2, which results from the synergy between manufacturing population and logistics population separately. According to the logistic equation of the population growth of manufacturing and logistics, we have

$$\begin{cases} \dfrac{\mathrm{d}N_1(t)}{\mathrm{d}t} = r_1 N_1(t)\left[1 - \dfrac{N_1(t)}{K_1^0 + \alpha_1 f_1(N_2)}\right], \\[2ex] \dfrac{\mathrm{d}N_2(t)}{\mathrm{d}t} = r_2 N_2(t)\left[1 - \dfrac{N_2(t)}{K_2^0 + \alpha_2 f_2(N_1)}\right], \end{cases} \tag{3}$$

where k_1^0 and k_2^0, respectively, represent the size of environmental capacity with two population systems, i.e., $t = 0$ and $f = 0$; $K_1 = K_1^0$; $K_2 = K_2^0$.

So, we can obtain the environmental capacity model with a system based on (2), as follows:

$$\begin{cases} K_1(t) = K_1^0 + \alpha_1 f_1[N_2(t)] = f_1^k(N_2), \\ K_2(t) = K_2^0 + \alpha_2 f_2[N_1(t)] = f_2^k(N_1). \end{cases} \quad (4)$$

As the evolution process between manufacturing and logistics must be influenced by the random disturbance factors in the outside system, in this, we mainly consider two points, one is by the influence of the industrial system and the policy random disturbance factors due to the guidance of the system and policy forcing the rapid development of manufacturing and logistics, which promotes the change of internal organization structure and the transformation and upgrading of industrial structure; another is by the influence of the industrial economy random disturbance factor, which is reflected in the output value of the economy.

Based on this, we hypothesis that represents the external environmental change of system, and the change will cause the external environmental capacity K with the change in the system. I represents the institutional system environment random disturbance factor which on the external environmental capacity of the system coefficient of influence is β_1 and β_2, respectively. E represents the institutional economic environment random disturbance factor which on the external environmental capacity of the system coefficient of influence is γ_1 and γ_2, respectively. So, under the influence of the random disturbance factor of the exterior environment, the dynamics model of manufacturing and logistics should be amended to the following:

$$\begin{cases} \frac{dN_1(t)}{dt} = r_1 N_1(t)\left[1 - \frac{N_1(t)}{k_1^0 + \alpha_1 f_1(N_2) + \beta_1 f_1(I) + \gamma_1 f_1(E)}\right], \\ \frac{dN_2(t)}{dt} = r_2 N_2(t)\left[1 - \frac{N_2(t)}{k_2^0 + \alpha_2 f_2(N_1) + \beta_2 f_2(I) + \gamma_2 f_2(E)}\right], \end{cases} \quad (5)$$

where $I = f(t)$ and $E = f(t)$, respectively, represent the time function of industrial system environment and industrial economic environment with T-time change; $N_1(t)$ and $N_2(t)$ represent the population density of the manufacturing and logistics, respectively, and $N_1|_{t=0} = N_1^0$ and $N_2|_{t=0} = N_2^0$.

From (5), we can see the synergy between S_1 and S_2 and influence function about external random disturbance factors of the industrial system environment and the industrial economy environment, which affect the growth rate of the population by changing the K value of environment capacity. So, under the joint action of internal synergy force and external environment random disturbance factors, the dynamics model of external environment capacity should be amended again to

$$\begin{cases} k_1(t) = k_1^0 + \alpha_1 f_1(N_2) + \beta_1 f_1(I) + \gamma_1 f_1(E) = f_1^k(N_2, I, E), \\ k_2(t) = k_2^0 + \alpha_2 f_2(N_1) + \beta_2 f_2(I) + \gamma_2 f_2(E) = f_2^k(N_1, I, E). \end{cases} \quad (6)$$

2.2. Parameter Estimation of the Factors. For better parameter estimation, we choose any adjacent two years $[t_i, t_{i+1}]$ on the population growth curve of manufacturing and logistics, as the observation interval, and then the interval length is $\Delta t_{i+1} = t_{i+1} - t_i = 1$ in Figure 1.

It can be seen that the increment of the population density on the evolution curve $[t_i, t_{i+1}]$ is $\Delta N_1^{i+1} = N_1^{i+1} - N_1^i$, the average is $\text{aver}N_1^{i+1} = N_1^i - N_1^{i+1}/2$, and there is $\text{aver}N_1^{i+1} \in [\min N_1(t), \max N_1 | t_i \le t \le t_{i+1}]$.

So, the slope of a line with two endpoints on an arbitrary interval $[t_i, t_{i+1}]$ in Figure 1 curve is as follows: $\Delta N_1^{i+1}/\Delta t_{i+1} = \Delta N_1^{i+1}$.

At the same time, the curves in the interval $[t_i, t_{i+1}]$ are also the logistic curves of the environmental capacity which is k_i^{i+1}, and the slope of the curve is the growth rate of the manufacturing population density, that is, $dN_1(t)/dt = r_1 N_1(t)[1 - N_1(t)/k_1^{i+1}]$ when $t \in t_i, t_{i+1}$.

As the rate of change of the population density is not very large in the logistic curve of the interval $[t_i, t_{i+1}]$, it can be approximated that the slope of logistic curves is equal to the slope of the interval endpoint in the interval $[t_i, t_{i+1}]$.

So, approximately there is $\Delta y_1^{i+1} = r_1 N_1(t)\ [1 - N_1(t)/k_1^{i+1}] = r_1(t)\text{aver}N_1^{i+1}[1 - \text{aver}N_1^{i+1}/k_1^{i+1}]$.

The iterative formula for the environmental capacity of the manufacturing population can be obtained by the finishing arrangement, as follows:

$$k_1^{i+1} = \frac{r_1 \text{aver}N_1^{i+1}}{r_1 - \Delta N_1^{i+1}/\text{aver}N_1^{i+1}} = f_1^k(r_1). \quad (7)$$

As the environmental capacity of the manufacturing population density is greater than 0, i.e., $k_1^{i+1} > 0$, there is $r_1 - \Delta N_1^{i+1}/\text{aver}N_1^{i+1} > 0$, that is, to satisfy

$$r_1 > \frac{\Delta N_1^{i+1}}{\text{aver}N_1^{i+1}} \quad (i = 0, 1, 2, \ldots,). \quad (8)$$

Therefore, given one r_1 value is $\hat{r}_1$, we can obtain a set of estimates $\hat{k}_1^{i+1}$ $(i = 0,1,2, \ldots, n)$ between the partitions through (7), that is,

$$\hat{k}_1^{i+1} = \frac{\hat{r}_1 \text{aver}N_1^{i+1}}{\hat{r}_1 - \Delta N_1^{i+1}/\text{aver}N_1^{i+1}} = \widehat{f_1^k}(\hat{r}_1). \quad (9)$$

Substituting the above estimate value $\hat{r}_1$ and $\hat{k}_1^{i+1}$, we can obtain a set of logistic estimates $\hat{N}_1^{i+1}$ $(i = 0,1,2, \ldots, n)$, that is:

$$\hat{N}_1^{i+1} = \frac{\hat{k}_1^{i+1}}{1 + \left(\hat{k}_1^{i+1} - N_1^i\right)/N_1^i e^{-\hat{r}_1}} = \widehat{f_1^N}\left(\hat{r}_1, \hat{k}_1\right). \quad (10)$$

In the same vein, we can obtain a set of logistic estimates of the population density and environmental capacity of the logistics as follows:

$$\hat{N}_2^{i+1} = \frac{\hat{k}_2^{i+1}}{1 + \left(\hat{k}_2^{i+1} - N_1^i\right)/N_1^i e^{-\hat{r}_1}} = \widehat{f_2^N}\left(\hat{r}_2, \hat{k}_2\right), \quad (11)$$

$$\hat{k}_2^{i+1} = \frac{\hat{r}_2 \text{aver}N_2^{i+1}}{\hat{r}_2 - \Delta N_2^{i+1}/\text{aver}N_2^{i+1}} = \widehat{f_2^k}(\hat{r}_2). \quad (12)$$

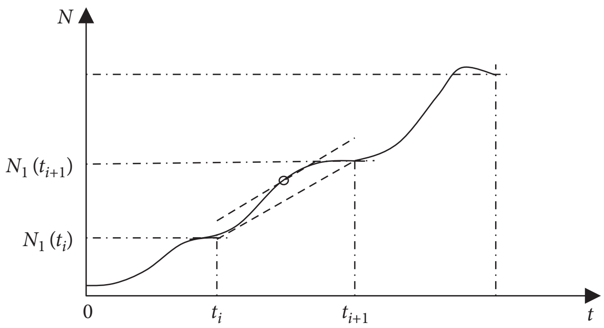

Figure 1: Population density evolution curve based on the logistic equation.

3. Examples Analysis

3.1. Data Selection. In order to verify the effectiveness and feasibility of the above models and methods, we select Shaanxi Province as the research object to study the estimation of the coevolution environmental capacity of the manufacturing industry and logistics industry. Because Shaanxi Province has not the value of manufacturing added statistics in the national economic accounting system and at the same time the logistics have not established a unified caliber to carry out added value statistics, in order to analyze the relationship of coevolution between the manufacturing and logistics of Shaanxi in a better way, in line with the principle of the availability of data and the consistency of statistical caliber, we use the industrial value-added (IVA) to measure the biomass of manufacturing to create the manufacturing population and use the transportation, warehousing, and postal services value-added to measure the biomass of logistics to create the logistics population, which will probe into the environmental capacity of the coevolution between manufacturing and logistics. Data originate from the "China Statistic Yearbook," "China Industrial Statistics Yearbook," "Shaanxi Statistic Yearbook," and "China Tertiary Industry Statistic Yearbook."

3.2. Numerical Estimation. For a given estimate, the variance of the estimated value of the manufacturing population density in each observation year is as follows:

$$d_j = s_j^2 = \sum_{i=0}^{n} \left(N_j^{i+1} - \widehat{N}_j^{i+1} \right)^2 = f_j^{s_j}\left(\widehat{r}_j\right) \quad (j = 1, 2). \quad (13)$$

We use the C++ program language to iterate over the infinite loop estimation $\widehat{r}_j$ towards the direction of variance reduction. When variance d_j cannot be reduced or it reaches the preset threshold, the corresponding estimate $\widehat{r}_j$ which is the natural growth rate r of the population can be calculated by substituting the natural growth rate into the Equation (8) to Equation (11) where the estimated value $\widehat{k}_j$ is the corresponding environmental capacity in each year.

According to the above methods, we can obtain the natural growth rate $r_1 = 0.2412$ and $r_2 = 0.1474$ and the environmental capacity estimates between manufacturing and logistics, as shown in Figure 2.

As shown in Figure 3, the environmental capacity changes with the increase of population density. These two variables show a trend of co-evolution. However, the external environmental capacity of the population shows unstable trends and shows mutations in some years node (such as 1987, 1993, and 2000), which indicates that the node is influenced by random disturbance. According to the situation of the industry system environment and economic environment of manufacturing and logistics in Shaanxi, we find the following fundamental reality:

(1) In 1987, this year is a new stage of China's economic development, which is transformed into the direction of marketization and privatization by the former wholly public-owned and planned. Affected by this, Shaanxi successively appeared machinery, building materials, textiles, printing and dyeing, papermaking, and other manufacturing industries, and the concept of logistics began to emerge, such as transport, warehousing, distribution, circulation processing, information processing, and other logistics links in the supply chain, which are gradually accepted by the enterprise.

(2) In 1993, the CPC "The third Plenary Session of the 14th CPC Central Committee" held which indicates that Chinese economy is transitioning from a planned economy to a market economy. All kinds of private enterprises began to appear and increase year by time; all kinds of industrial parks have been planning and constructed; the manufacturing market in Shaanxi starts booming; the manufacturing demand for the external service is increasing. As a result, we are moving towards a new developing era for logistics.

(3) In 2000, Chinese government launched "West Development Strategy of China." The strategy significantly accelerated economic development in Shaanxi. After China joined the WTO in 2002, there are more opportunities for China to collaborate with developed countries in the world, which drives the rapid growth of the heavy machinery, equipment, steel, molds and other raw materials. As a result, the automotive, metal smelting, general equipment, instrumentation engineering machinery, computer, communications, and electronic equipment and other manufacturing have also been developed rapidly. However, the benefits and service quality of logistics that underpin their external services are lagging.

Moreover, at the same time node, the sudden increase in manufacturing environment capacity also brought about a sudden increase in the environmental capacity of the logistics, but the logistics population did not grow, indicating that the node was negatively affected by external stochastic disturbance factors, such as the elimination of backward enterprises by economic development.

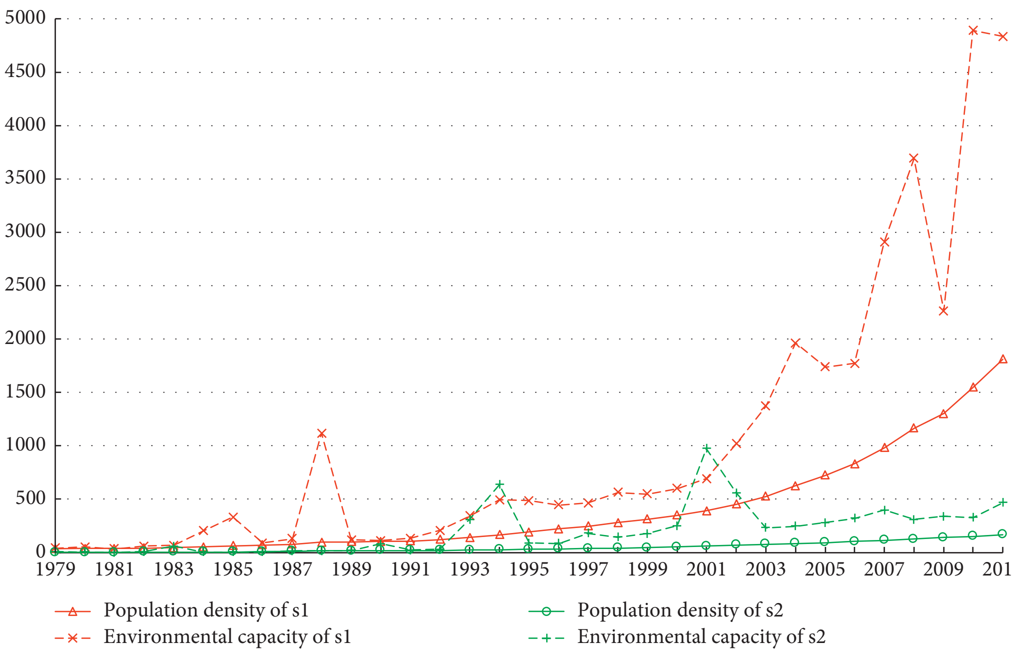

Figure 2: The relationship between S_1 and S_2.

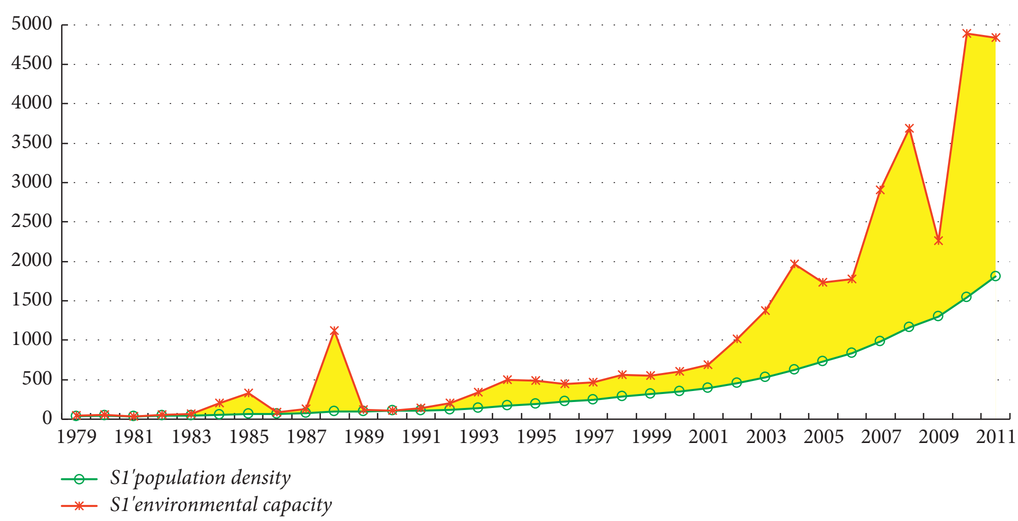

Figure 3: Relationship between K_1 and N_1.

3.3. External Environmental Capacity Estimation. Based on the above analysis, we can estimate the external environmental capacity model of coevolution between manufacturing and logistics in the following equation:

$$\begin{cases} k_1(t) = k_1^0 + \sum_{i=1}^{3} [\alpha_1(N_2)]^n + \sum_{i=1}^{3} [\beta_1(I)]^n + \sum_{i=1}^{2} [\gamma_1(E)]^n = f_1^k(N_2, I, E), \\ k_2(t) = k_2^0 + \sum_{i=1}^{3} [\alpha_2(N_1)]^n + \sum_{i=1}^{3} [\beta_2(I)]^n + \sum_{i=1}^{2} [\gamma_2(E)]^n = f_2^k(N_1, I, E). \end{cases} \quad (14)$$

We want to assure that the results of F-test, R^2, and t-test are significant. So we use progressive regression and tentative regression on $N_i(t)$, $i = 1, 2$, and $k_i (i = 1, 2)$, and get the following equations:

$$\begin{cases} K_1(t) = 25.531 - 10.877N_2(t) + 1.534(N_2(t))^2 - 2.455(I(t))^2 + 1.089(I(t))^3, \\ K_2(t) = -47.844 - 0.786(N_1(t))^2 + 12.487E(t), \end{cases} \tag{15}$$

where $t = 0, 1, 2, \ldots, T$ and $R^2 \geq 0.780$ $(F \geq 47.091)$, which illustrated that the fitting effect of the equations on the sample points is good. The sig. <0.01 shows that the regression equation is well predicted.

We discuss the relationship between the population density and the environment capacity of manufacturing and logistics, respectively, as shown in Figures 3 and 4.

The figure clearly shows the trend of changes in the external environmental capacity and the population of time, and it can be seen that Shaanxi manufacturing and logistics in the current development space is very large. It is at the growing stage of the logistics curve, but the growth rate is different. To further discuss the growth rate of the two, the first derivative of (14) with respect to t, we have

$$\begin{cases} f'(K_1) = \dfrac{\mathrm{d}k_1}{\mathrm{d}t} = \dfrac{\mathrm{d}N_2}{\mathrm{d}t} + \dfrac{\mathrm{d}I}{\mathrm{d}t} = -10.877 + 3.068N_2(t) - 4.910I(t) + 3.267(I(t))^2, \\ f'(K_2) = \dfrac{\mathrm{d}K_2}{\mathrm{d}t} = \dfrac{\mathrm{d}N_1}{\mathrm{d}t} + \dfrac{\mathrm{d}E}{\mathrm{d}t} = -1.572N_1(t) + 12.487. \end{cases} \tag{16}$$

The varying rate of ambient capacity varies between manufacturing and logistics as follows: the change rate of external environment capacity of manufacturing is a quadratic function, in which the synergy performance is a positive effect (3.068) from logistics, and the industry system environment performance is shown as a short-term positive effect, and there is a maximum value. However, the change rate of external environment capacity of logistics is characterized by a linear function, and synergy performance is a negative effect (−1.572), and the performance of the industrial system environment and the synergy of manufacturing is not obvious.

4. Results and Discussion

4.1. Manufacturing. The change of environment capacity of the manufacturing population is influenced by the synergy of its own enterprise's resource allocation, the synergy of logistics, and the industry system environment.

The K_1 equation embodies the complex process of manufacturing population evolution:

(1) The existing scale and market share of manufacturing enterprises provide huge environmental space for the growth of the manufacturing population. However, the synergy of the emerging logistics expands the environmental capacity of manufacturing and has formed a competitive relationship with it, which reduces the environmental capacity of manufacturing. From equation (16), we can find that the logistics population system has had a positive effect on the overall environmental capacity of the manufacturing population system from 1978 to 2011.

(2) The influence of the industrial system environment factor is to increase the policy to promote the development of manufacturing and expand its market space. However, due to the delay of policies on technology development, the expansion of the manufacturing market space has been suppressed. Therefore, the industrial system environment factor has a double effect. It can be found that from 1978 to 2011, industrial system environmental impact factor and the manufacturing population system environment capacity follow two quadratic curve trends. In other words, there is the maximum limit of environmental capacity.

4.2. Logistics. The change of environment capacity of logistics population is influenced by the cooperation of its own enterprise's allocation of resources, the synergy of manufacturing, and the industrial economic environment.

(1) The constant term in the K_2 equation represents the original environmental capacity of the logistics. The negative coefficient indicates that the environmental capacity of the logistics population evolution originates initially from the result of the manufacturing enterprise's allocation of resources. The manufacturing population system harms the overall environment capacity of the logistics population system during the years 1978–2011.

(2) The negative coefficient of $N_1(t)$ indicates that the synergy promoted by manufacturing to the logistics is not obvious, it originates from the inherent production and management model of the manufacturing, which does not create a broad market space for the logistics, and many logistics projects are constrained by the manufacturing, which makes the logistics development slowly.

The economic environment is a positive role, indicating the demand and contribution of the current economic development to logistics; from equation (16), we can find that the contribution of economic development along

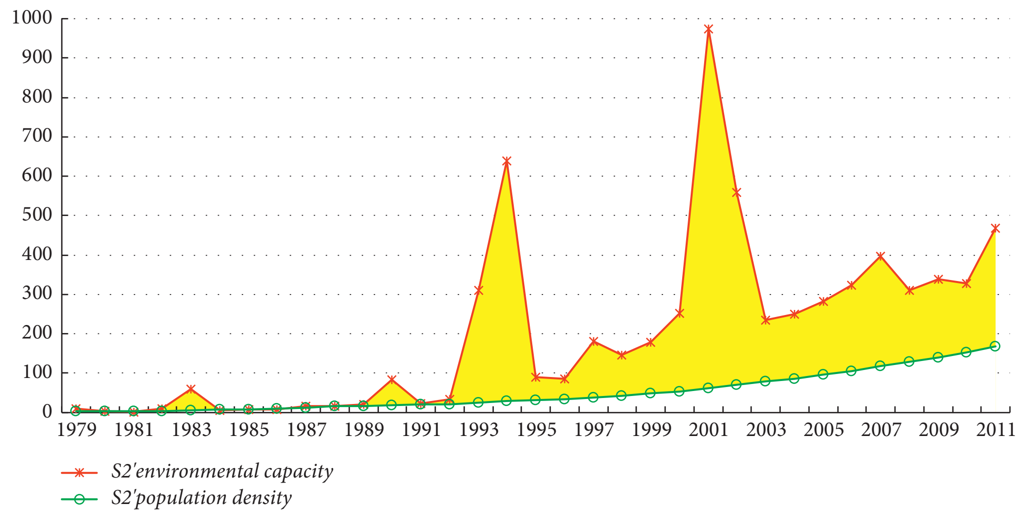

FIGURE 4: Relationship between K_2 and N_2.

1978–2011 to the environmental capacity of the logistics is positive.

5. Conclusions

The classical logistic equation illustrates the relationship of the individual population with time and environment, but the nonlinear function relation produced by the synergistic force between the two populations is not clear, and there is no exact expression. To solve this problem, we propose an improved logistic equation, to establish a system dynamics model of the coevolution between manufacturing and logistics and study the synergistic mechanism of external random interference factors on the coevolution system of manufacturing and logistics. The results show that the dual effects of policy system time lag and economic development demand affect the changes of manufacturing external environmental capacity and logistics ecosystem. This study reveals this internal mechanism. Through the analysis of external environmental capacity, it is further found that Shaanxi manufacturing and logistics are currently in the stage of commensalism and have not reached the ideal mature stage of mutualism. Our research extends the nonlinear environmental capacity of the LV model and its application fields. It is hoped that this study can provide enlightenment and help for follow-up research.

Data Availability

All underlying data that support the results can be found in "China Statistic Yearbook," "China Industrial Statistics Yearbook," "Shaanxi Statistic Yearbook," and "China Tertiary Industry Statistic Yearbook."

Conflicts of Interest

The authors declare that there are no conflicts of interest in the paper.

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