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Study on Rural Development Evaluation and Drivers of Sustainable Development: Evidence from the Beijing-Tianjin-Hebei Region of China

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Abstract: Rural areas are the basic units of social development and contain residents' production and living activities, so understanding the nature of rural development has essential theoretical and practical significance. This paper first constructs a rural development evaluation index system, then analyzes the changes in the development level and development pattern of rural areas in Beijing, Tianjin and Hebei from 2009 to 2020 in five aspects: prosperous industry, eco-friendly, civilized countryside, effective governance, and affluent living, and then further explore the changes in their comprehensive rural development level and development pattern. Finally, the main drivers of sustainable development in rural areas and their dynamic impacts are studied and analyzed using the boosted regression trees method. The research results show that: (1) from 2009 to 2020, all five aspects of rural development in the Beijing–Tianjin–Hebei rural areas have progressed to different degrees, among which the development level of affluent living has progressed very significantly and is the primary driver of sustainable rural development in the region; (2) the development level of rural areas in the Beijing–Tianjin–Hebei region has improved in general, but the development speed of major agricultural areas such as Baoding, Xingtai and Handan slower; (3) improving rural medical and health conditions, narrowing the urban–rural gap, and activating farmers' vitality are the main ways to promote sustainable rural development. The results of the study help to gain an in-depth understanding of the rural development in the Beijing–Tianjin–Hebei region and also have important reference significance for sustainable rural development in other countries or regions.

Keywords: rural development; sustainability; Beijing-Tianjin-Hebei; entropy method; boosted regression trees; drivers

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1. Introduction

The rural area is the basic economic and social unit of every country, covering the production and living behavior of rural residents, so the development of the rural area is related to the improvement of the living standard of every rural resident, but many problems have emerged in the process of rural development, such as poor health care conditions [1], an increasing urban–rural development gap [2], ecosystem pollution [3], etc. Governments and scholars have made many efforts to solve the problems in the process of rural development and achieve sustainable rural development [4]. For example, Streimikis [5] proposed a new indicator framework for agricultural sustainability assessment to achieve coherence between sustainable development, climate, and agricultural policies in the EU; Watmough [6] studied the potential role of satellite data in monitoring the progress of poverty reduction in rural areas and conducted an empirical analysis of rural Kenya.

China has about 300 million agricultural producers and operators, providing agriculture-related products and services to 1.4–1.5 billion people. Thus, rural development in China is related to improving the living standards of hundreds of millions of people [7]. Since the reform and opening up, people's lives in rural areas of China have progressed to some extent. However, due to the strategy of the Chinese central government to prioritize urban development, the development of rural areas has lagged far behind that of urban areas, resulting in an increasing gap between urban and rural development and a prominent urban–rural conflict [8]. To change the backwardness of rural areas and promote sustainable rural development, the Chinese central government proposed a rural revitalization strategy in 2017, aiming to promote sustainable development of rural areas in terms of economy, environment, culture, and living, improving the living standards of rural residents and enhancing the people's sense of access [9]. At the end of 2020, the Chinese central government announced that China's rural problem of absolute poverty in rural areas had been solved [10], but the gap between rural and urban areas and between rural and rural regions is still very obvious. How to better promote sustainable rural development is still a question researchers need to think about.

Rural development has regularity, and at the same time, it has unique regional characteristics and development processes, which is the connotation of regional differentiated development in rural areas [11]. Therefore, the study of rural development should be based on specific regional contexts and should explore the general laws of rural development [12]. China is a vast country with complex development of various internal regions, among which the Beijing–Tianjin–Hebei region is a typical traditional Chinese rural area with the coexistence of metropolis and countryside, significant differences in regional development, and apparent urban–rural conflicts, in line with the characteristics of most regional development [13]. In this paper, Beijing–Tianjin–Hebei rural areas are selected as the study area. Firstly, based on the entropy method, we analyze the changes in rural development level and development pattern from 2009 to 2020 from five perspectives: prosperous industry, eco-friendly, civilized countryside, effective governance, and affluent living, and then further explore the comprehensive development level of rural areas. Finally, the main drivers of sustainable development in rural areas are investigated based on the boosted regression trees method.

In summary, the objectives of our study are: (1) to understand the changes in development levels and development patterns in various aspects of rural areas in Beijing, Tianjin, and Hebei regions from 2009 to 2020; (2) to study the influence of multidimensional factors, examine their relative importance, and also dissect the dynamic processes of these factors to identify the drivers of sustainable rural development. The findings of this paper will help deepen the knowledge and understanding of rural development theory and have important implications for sustainable rural development in other countries or regions.

2. Literature Review and Theoretical Analysis

Research on rural development is long-standing and has been widely discussed in various fields. The World Bank proposed rural development as a strategy aimed at improving the economic situation and social life of the rural poor [14]. Lewis [15] proposed the dualistic development theory, that rural development should be integrated with urban development. The primary role of the countryside is to provide agricultural products and related services to the city, so rural development should be based on agriculture [16,17]. Rozelle [18] and Song [19] argue that the development of non-agricultural industries is the main reason for promoting rural development. Through the development of non-agricultural industries, more rural laborers are employed, which raises the income level of rural residents and promotes sustainable rural development. Wang [20] argues that rural development involves a range of disciplines, including not only agriculture, economics, and sociology, but also rural ecology. Terluin [11] provides an overview of rural development research in developed countries and argues that rural development research has undergone three main stages of transformation: exogenous, endogenous, and mixed exogenous/endogenous. Modernization of the agricultural sector was the focus of rural development policies in European countries until the 1980s in real life. That is, the exogenous approach to development was the dominant model during that period [21]. By the mid-1980s, regional location factors provided a link between the endogenous development approach and endogenous growth theory, and the focus of rural policy shifted from exogenous to endogenous development [22]. Since the 21st century, many scholars have argued that regional rural development is underpinned and driven by a complex set of internally and externally generated interrelationships and interactions that shape the relative economic, social, cultural, and environmental attractiveness and competition of rural spaces [23]. Thus, an integrated theory of rural development that combines exogenous and endogenous theories has gained wide acceptance. In the context of globalization, rural development actors are often involved in internal and external local networks. Still, the size, direction, and strength of the networks may vary from region to region, resulting in different levels of rural development [24].

The rural area is the main battleground for solving problems related to farmers, agriculture, and the countryside. As a developing country with a large agricultural population, China still has many issues in the rural development process, resulting in a slower pace of rural development [12]. Fortunately, in recent years, the Chinese central government has introduced a series of incentives to promote the development of rural areas [25]. Researchers in various fields have also explored sustainable rural development. Based on the key factors affecting rural development, Long [26] elaborates on the connotation of rural revitalization and land improvement in the new era and their relationship. Mao [27] argues that industrial integration is an important initiative to accelerate rural economic development and plays a crucial role in narrowing the urban–rural gap. Guo [28] investigates the role of rural finance on rural development and proposes a set of financial innovation countermeasures to promote rural economic development. Qiao [29] investigates the effects of institutional environment and technological progress on different types of agricultural economies. Luo [30] explored the mechanisms of emergence and evolution of particular rural areas. Sato [31] conducted a quantitative study of village development changes. Village development has attracted a wide range of attention in the fields of geography, sociology, political economy, and finance [32].

Previous studies have focused on addressing one aspect of rural development, yet evaluating one aspect of rural development may also involve synergies with other aspects. In addition, existing literature usually conducts qualitative analysis or case studies of rural development processes at the village level, and the findings are not general. Meanwhile, with China's rapid economic development, a large amount of data has been generated, and traditional economic methods are unsuitable for dealing with big data. To address the above problems, this paper constructs a comprehensive evaluation index system for rural development, takes the Beijing–Tianjin–Hebei region of China as the research sample, and conducts a research analysis on the level of rural development and its main drivers of sustainable development based on the entropy method and the boosted regression trees method. Figure 1 illustrates the structure of our theoretical approach.

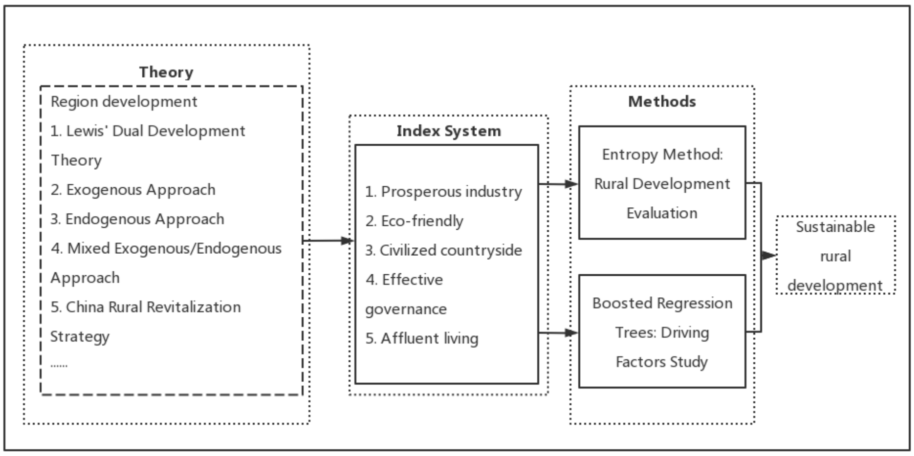

Figure 1. Theoretical structure of methods.

3. Materials and Methods

3.1. Data and Study Area Overview

This study uses panel data from 2009 to 2020 from 13 cities in the Beijing–Tianjin–Hebei region (Beijing, Tianjin, Shijiazhuang, Tangshan, Qinhuangdao, Handan, Xingtai, Baoding, Zhangjiakou, Chengde, Cangzhou, Langfang, and Hengshui). The data sources are China Statistical Yearbook, China Rural Statistical Yearbook, China Urban Statistical Yearbook, Beijing Statistical Yearbook, Tianjin Statistical Yearbook, Hebei Economic Yearbook, and Hebei Rural Statistical Yearbook. To ensure comparability of the values of the indicators in the time series, the value-added and other relevant data used in this paper are calculated using 2009 as the base period. Missing values are taken as the average of the data from the two most recent years.

The Beijing–Tianjin–Hebei region is China's "Capital Economic Circle", located at the center of Northeast Asia's Bohai Sea Rim (see Figure 2). It is the largest and most dynamic economic region in northern China. However, the region has a complex internal context that includes not only Beijing, the world's top tier city as assessed by the world's urban research institute GaWC [33], but also the poverty belt around Beijing and Tianjin as proposed by the Asian Development Bank [34]. Therefore, this context makes the Beijing–Tianjin–Hebei region a good sample for studying rural development and a reference for rural development in other countries or regions.

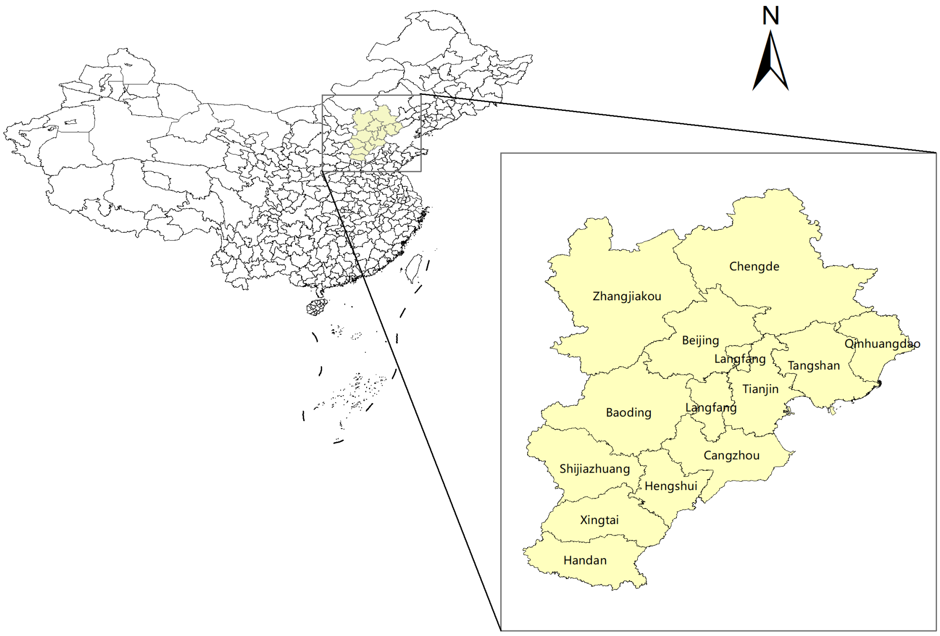

Figure 2. The geographical location of the Beijing–Tianjin–Hebei region.

3.2. Index System

The development of rural areas is the result of the synergistic evolution and joint action of multiple factors, so the construction of the evaluation index system should consider various aspects of rural development. The general requirements of the rural revitalization strategy proposed by the central government of China are prosperous industry, eco-friendly, civilized countryside, effective governance, and affluent living [9]. Among them, the prosperous industry is the cornerstone of rural revitalization, eco-friendly is the guarantee of improving the quality of rural development, the civilized countryside is the soul of rural construction, effective governance is the core of good governance in rural areas, and affluent living is the goal of rural revitalization. These five aspects are full of content and have clear logical progression relationships. Therefore, the study of rural development level and development mode from these five perspectives can help us better understand the laws of rural development. Then, we summarized 18 specific indicators (see Table 1) that best reflect the development of rural areas in Beijing, Tianjin, and Hebei by reading relevant literature [11,15,18,19,21,22] and relevant statistical yearbooks of the region, based on the logical relationship between indicators and the principle of data availability.

- Prosperous industry requires cultivating new industries and business models and improving the industrial system based on developing production in rural areas to make the rural economy more prosperous [35]. This paper assesses the level of prosperous industry from four perspectives: natural resources, agricultural modernization, production efficiency, and agricultural industrialization.
- Eco-friendly requires the development of a green economy and the treatment of environmental pollution to make the rural living environment more comfortable [36]. This paper assesses the level of eco-friendly from four perspectives: agricultural pollution, air quality, pollution control, and energy consumption.
- Civilized countryside requires promoting the development of rural culture, education, health care, and other undertakings, and improving basic public services in rural areas [37]. This paper assesses the level of the civilized countryside from four perspectives: basic education, healthcare, amateur life, and civilization creation.
- Effective governance requires strengthening and innovating rural social governance to make it more scientific and efficient and better meet the needs of rural residents. This paper assesses the level of effective governance from three perspectives: traffic, farmer vitality, and human resources.
- Affluent living requires making farmers' lives more prosperous and fulfilling with the new goal of building a moderately prosperous society in all aspects and the new goal of building a strong socialist modern state in two steps. This paper assesses the level of affluent living from three perspectives: farmers' income, consumption, and the urban–rural gap.

Table 1. Comprehensive index system for the evaluation of rural development.

Dimension	Variable	Description	Property [1]
prosperous industry	Natural resources	Arable land per capita (hm^2)	+
	Modernization	Agricultural machinery power (kW/hm^2)	+
	Production efficiency	Labor productivity (CNY/Person)	+
	Industrialization	Ratio of agricultural products processing value to agricultural output	+
Eco-friendly	Agricultural pollution	Fertilizer application per hectare (t)	−
	Air Quality	CO_2 emissions per capita (t)	−
	Pollution Control	Greenery coverage (%)	+
	Energy consumption	Electricity consumption per capita (kW·h)	+
Civilized countryside	Basic Education	Average number of elementary school students per teacher	−
	Healthcare	Number of medical beds per 1000 people	+
	Amateur life	Percentage of expenditure on culture and entertainment (%)	+
	Civilization creation	Public library book collection per capita	+
Effective governance	Traffic	Proportion of villages connected to public transportation (%)	+
	Farmer Vitality	Proportion of rural employees to rural population (%)	+
	Human Resources	Average age of education of rural workers (year)	+
Affluent living	Farmers' Income	Per capita disposable income of rural residents (1000 CNY)	+
	Consumption level	Engel coefficient (%)	−
	Urban-Rural Gap	Ratio of urban and rural residents' income	−

[1] In the variable property, "+" means the larger the value the better, and "−" means the smaller the value the better.

3.3. Entropy Method

Originally derived from the thermodynamic concept in physics [38], entropy reflected the degree of chaos in the state of a system and was later introduced into information theory [39], where it is widely used in socio-economic, engineering, and other research fields. The entropy weight method is an objective weighting method that eliminates the subjective human factor and maximizes the information in the data itself [40]. Generally speaking, the basic idea of the entropy weight method is to determine the objective weight according to the size of the variability of the indicator. That is, if the information entropy of an indicator is smaller, it indicates that the greater the variability of the value of the indicator, the more information it provides, the more significant the role it plays in the comprehensive evaluation, and the corresponding weight is more prominent, and conversely, the smaller the weight [41]. Assuming there are m cities, n evaluation indicators, and T years, the main steps of the entropy weight method are summarized as follows [42,43]:

Step 1, build the initial global evaluation matrix, x_{ij}^t represents the t-th year, the i-th city, and the j-th index value:

$$X = \{x_{ij}^t\}_{mT*n} \quad (1)$$

Step 2, the evaluation matrix X is converted into the normalized matrix Y as follows: Normalized matrix for positive indices:

$$y_{ij}^t = \frac{x_{ij}^t - x_{j\min}}{x_{j\max} - x_{j\min}} \quad (2)$$

Normalized matrix for negative indices:

$$y_{ij}^t = \frac{x_{j\max} - x_{ij}^t}{x_{j\max} - x_{j\min}} \quad (3)$$

Step 3, the entropy e_j of the j-th index is defined as follows, where $p_{ij}^t = \frac{y_{ij}^t}{\sum_{t=1}^{T}\sum_{i=1}^{m} y_{ij}^t}$:

$$e_j = \frac{-\sum_{t=1}^{T}\sum_{i=1}^{m} p_{ij}^t \ln p_{ij}^t}{ln(mT)} \quad (4)$$

Step 4, the weight w_j of the jth index is defined as follows:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{n} 1 - e_j} \quad (5)$$

Step 5, calculate the comprehensive evaluation score of city i in year t :

$$s_i = \sum_{j=1}^{n} w_j y_{ij}^t \quad (6)$$

3.4. Boosted Regression Trees

After measuring and comparing the level of rural development in the Beijing–Tianjin–Hebei region, we applied boosted regression trees (BRT), a machine learning algorithm that combines the advantages of regression trees and boosting [44], to identify the drivers of sustainable rural development. Similar studies generally use linear regression or probit regression models [21,45]. However, these methods often have drawbacks, such as the inability to handle different predictor variables and to identify very complex and nonlinear variable associations.

Regression tree is a model that relates the independent variable to the dependent variable through recursive binary partitioning [46,47] and boosting is an adaptive approach that combines many simple models to further improve predictive performance [48]. The boosted regression trees contain important advantages of both algorithms, so the final boosted regression tree can be understood as an additive regression model in which the individual terms are simple trees fitted in a forward, staged fashion [44]. Additionally, as a machine learning method to improve prediction, the BRT model focuses more on the residuals in the response process and adds a new tree at each step to minimize the loss function [49].

In summary, the BRT model is a linear combination of hundreds of trees, which has the advantages of being able to handle predictor variables with different types and distribution characteristics, insensitive to outliers, and accommodating missing data. Given our desire to understand the relationship between explanatory variables and sustainable rural development and to find a more objective technology than the economic approach, the BRT model was chosen for this paper.

4. Results and Analysis

4.1. Entropy Method Result Analysis

Based on the entropy method, we firstly portrayed the development level and development pattern of rural areas in the Beijing–Tianjin–Hebei region in five aspects: prosperous industry, eco-friendly, civilized countryside, effective governance, and affluent living, and finally analyzed the comprehensive development level of rural areas in the Beijing–Tianjin–Hebei region.

4.1.1. Prosperous Industry Development

Figure 3 shows the changes in the development pattern of industrial prosperity in rural areas of the Beijing–Tianjin–Hebei region from 2009 to 2020. In 2009, the city with the highest level of rural industrial prosperity development in the Beijing–Tianjin–Hebei region was Shijiazhuang, followed by Langfang, Handan, Hengshui, Tianjin, Qinhuangdao, Zhangjiakou, then Xingtai, Chengde, Beijing, Tangshan, and the cities with a poor level of development were Baoding and Cangzhou. In 2020, the cities with the highest level of rural industrial prosperity development were Zhangjiakou and Shijiazhuang, followed by Chengde, Hengshui, Qinhuangdao, then Handan, Xingtai, Langfang, and Tianjin, while Cangzhou, Tangshan, and Beijing are the three cities with general development levels of rural industries, and Baoding has the worst development level of flourishing rural industries.

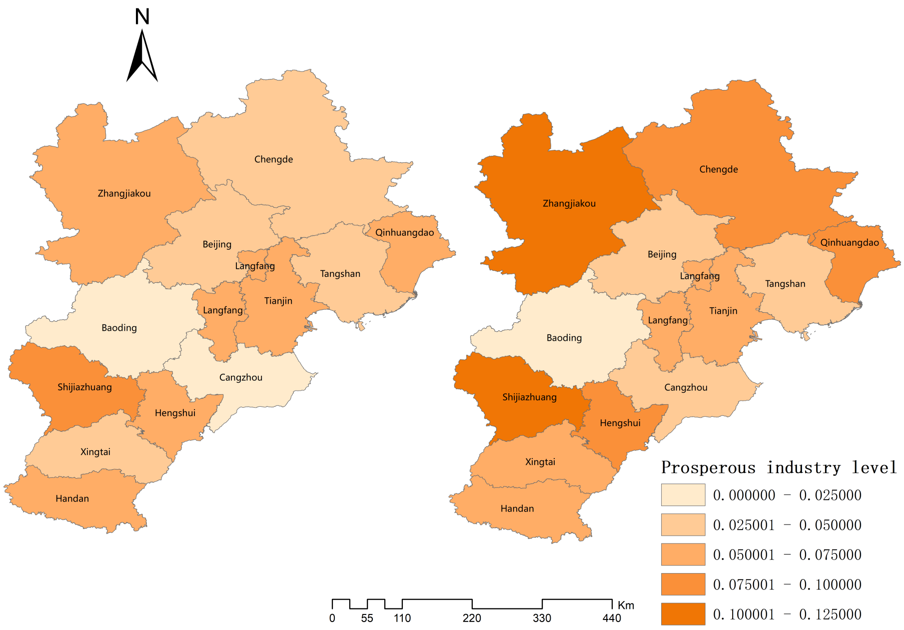

Figure 3. Prosperous industry development level of Beijing–Tianjin–Hebei region in 2009 (**left**) and 2020 (**right**).

From 2009 to 2020, some cities in the Beijing–Tianjin–Hebei region have improved their rural industrial prosperity development levels, such as Zhangjiakou, Chengde, Qinhuangdao, and Shijiazhuang, but Beijing, Langfang, Tianjin, and Baoding have not improved their development level. Industrial prosperity is inseparable from rural development and is the basis for achieving the strategic goals of rural revitalization and agricultural modernization [35]. However, rural development faces the problem of limited space for the growth of the arable land area, and agricultural productivity is an important factor affecting rural development [50]. Our data show that the labor productivity of Beijing, Tianjin, and Baoding is lower than the rural labor productivity of other cities, so to promote the development of thriving rural industries, we must first improve the labor productivity of rural areas and improve the level of agricultural modernization as important measures to improve agricultural productivity [51], so government departments can promote the prosperous development of rural industries by introducing advanced technological equipment and other measures. Agricultural industrialization is also a necessary path for rural development [52].

4.1.2. Eco-Friendly Development

Figure 4 shows the changes in the level and pattern of eco-friendly development in rural areas of the Beijing–Tianjin–Hebei region from 2009 to 2020. In 2009, the cities with the highest level of eco-friendly development in rural areas of the Beijing–Tianjin–Hebei region were Tianjin and Langfang, followed by Shijiazhuang, Tangshan, Qinhuangdao, Beijing, and Handan, followed by Hengshui, Xingtai, and Chengde, and the cities with poor development are Zhangjiakou, Baoding, and Cangzhou. In 2020, the city with the best development was Langfang, followed by Shijiazhuang, then Hengshui, Tianjin, Beijing, Handan, Qinhuangdao, Chengde, and Xingtai, then Tangshan and Zhangjiakou, and the cities with the worst development are Cangzhou and Baoding.

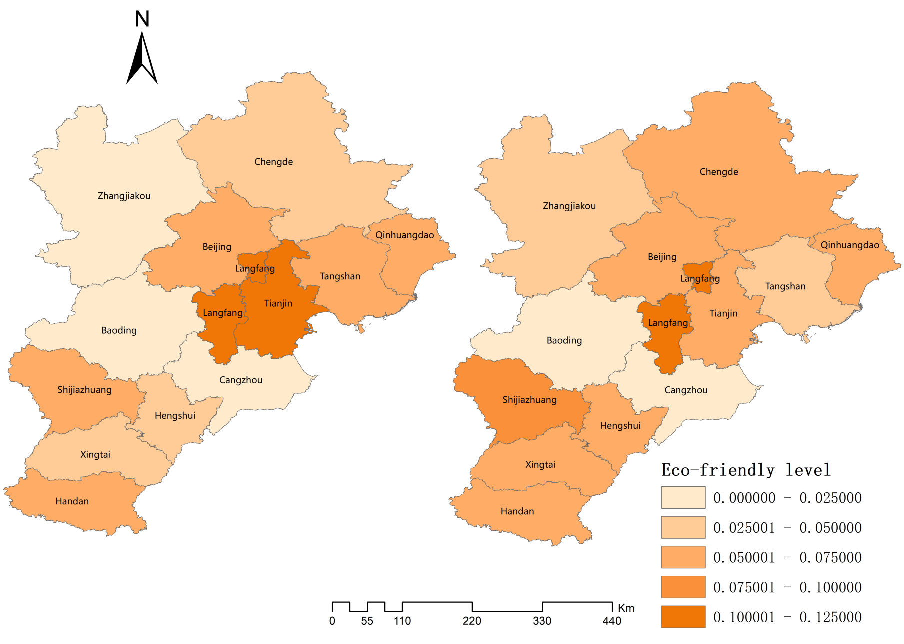

Figure 4. Eco-friendly development level of Beijing–Tianjin–Hebei region in 2009 (**left**) and 2020 (**right**).

From 2009 to 2020, the ecologically livable development pattern and development level of Beijing–Tianjin–Hebei rural areas have not changed significantly. Hengshui, Chengde, and Zhangjiakou have improved their development level but have made little progress, while Tianjin, Tangshan, and Qinhuangdao have produced a regression in their development level. China has for a long time implemented a model of economic development at the expense of the environment [53], and this model has indeed vigorously developed the Chinese economy, but energy consumption has had a huge impact on the ecological environment while improving the living standards of rural residents, so energy transition is increasingly seen as a good opportunity for economic development in rural areas [54].

The Chinese central government has issued a series of policies to address the rural energy transition [36]. Agricultural fertilizer inputs play an important role in securing farmers' income and increasing agricultural production, but their possible negative impacts on the agricultural ecology are often overlooked [55].

4.1.3. Civilized Countryside Development

Figure 5 shows the changes in the level and pattern of civilized countryside development in rural areas of the Beijing–Tianjin–Hebei region from 2009 to 2020. In 2009, the city with the highest development of rural civilization in the Beijing–Tianjin–Hebei region was Beijing, followed by Tianjin. The 11 cities in Hebei were generally poor in rural civilization. In 2020, the city with the better rural civilization was still Beijing, followed by Tianjin, Shijiazhuang, Zhangjiakou, Chengde, Qinhuangdao, and Handan, and the poorer cities are Langfang, Xingtai, Hengshui, Tangshan, Cangzhou, and Baoding.

From 2009 to 2020, the civilization of Beijing's rural areas progressed significantly, and the civilization of Hebei Province's cities, such as Zhangjiakou, Chengde, Shijiazhuang, and Tangshan, was gradually established. The building of civilization in rural areas includes both the promotion of rural culture, education, health care, and other businesses, as well as the ability of rural residents to have leisure time and access to knowledge [37,56,57]. Figure 5 shows the results of the efforts made by the Chinese government.

4.1.4. Effective Governance Development

Figure 6 shows the changes in the level and pattern of effective governance development in rural areas in the Beijing–Tianjin–Hebei region from 2009 to 2020. In 2009, the cities with the highest level of effective development of rural governance in the Beijing–Tianjin–Hebei region were Zhangjiakou, Handan, Chengde, Qinhuangdao, and Langfang, followed by Shijiazhuang, Hengshui, Xingtai, and Tianjin, and the less developed cities are Beijing, Baoding, Tangshan, and Cangzhou. By 2020, Shijiazhuang has improved its effective level of rural governance and become the best-developed city in the Beijing–Tianjin–Hebei region, followed by Handan, Xingtai, and Qinhuangdao, then Hengshui, Zhangjiakou, Langfang and Tianjin, then Chengde, and finally Baoding, Cangzhou, Tangshan, and Beijing.

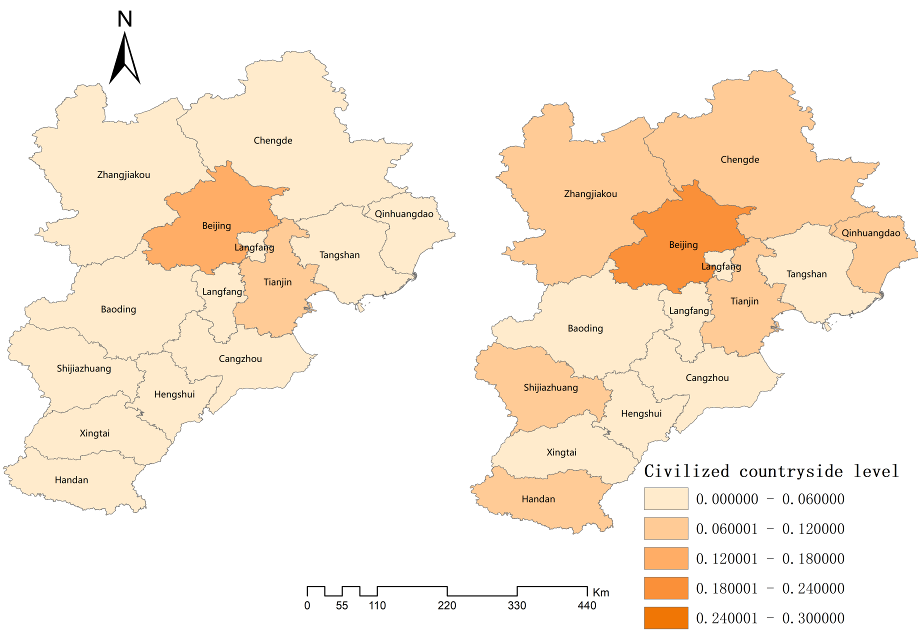

Figure 5. Civilized countryside development level of Beijing–Tianjin–Hebei region in 2009 (**left**) and 2020 (**right**).

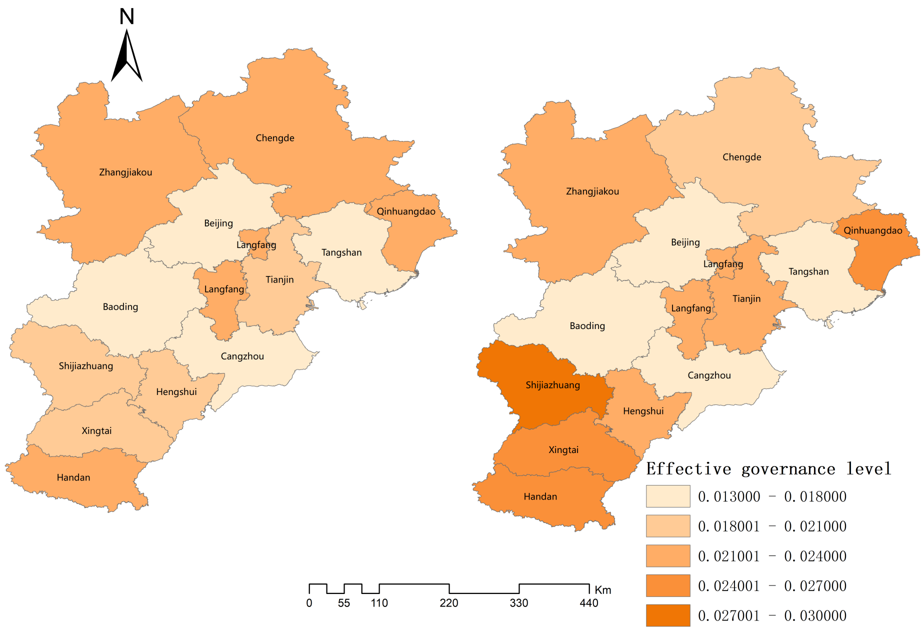

Figure 6. Effective governance development level of Beijing–Tianjin–Hebei region in 2009 (**left**) and 2020 (**right**).

The pattern of effective development level of governance in rural areas of Beijing, Tianjin, and Hebei from 2009 to 2020 has not changed, with the biggest improvement being in Shijiazhuang. Rural governance is a rural reform strategy that combines top-down macro-management of rural areas by the modern state and bottom-up self-transformation of traditional villages [58]. In this paper, we measure the level of grassroots governance in rural areas using transportation, rural residents' dynamism, and human resource levels. The strategic planning of rural revitalization in China has planned a new order of rural governance, and this model is effective in raising farmers' income, improving their quality of life, narrowing the urban–rural gap, and promoting modern rural development [59].

4.1.5. Affluent Living Development

Figure 7 shows the changes in the development level and pattern of living affluence in rural areas in the Beijing–Tianjin–Hebei region from 2009 to 2020. In 2009, the cities with a better development level of living affluence in rural areas in the Beijing–Tianjin–Hebei region were Tianjin, Xingtai, Beijing, Handan, Hengshui, Langfang, Qinhuangdao, Zhangjiakou, and Shijiazhuang, while Baoding, Chengde, Cangzhou, and Tangshan had Poorer. By 2020, the level of development of living affluence in rural areas in the Beijing–Tianjin–Hebei region as a whole has made greater progress, among which Langfang, Shijiazhuang, Beijing, and Qinhuangdao have made significant progress, followed by Zhangjiakou, Handan, Tianjin, Chengde, Xingtai, Hengshui and Tangshan, and Cangzhou and Baoding have developed to some extent, but at a slower pace than the others.

The development level of living affluence in rural areas of Beijing, Tianjin, and Hebei from 2009 to 2020 is the most obvious progress among the five dimensions, with Langfang, Shijiazhuang, and Tangshan being more prominent. For a long time, the unbalanced urban–rural relationship and socioeconomic disparities have caused inefficient resource allocation and also seriously affected the long-term development of rural areas [60]. To solve these problems, the government has issued a series of policies in the areas of rural credit, environment, and e-commerce to narrow the urban–rural gap, promote the development of rural areas, and improve the living standards of rural residents [2,61,62].

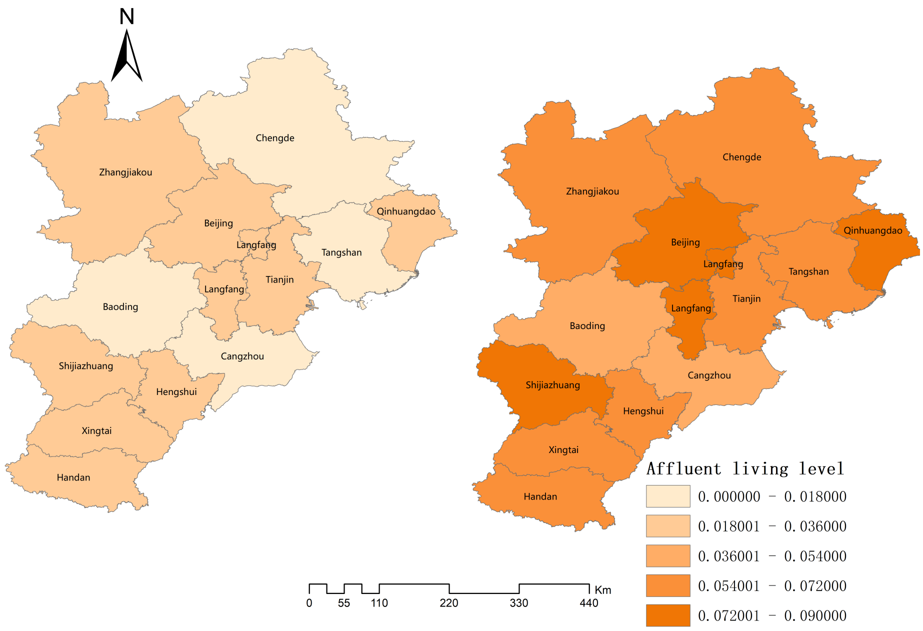

Figure 7. Affluent living development level of Beijing–Tianjin–Hebei region in 2009 (**left**) and 2020 (**right**).

4.1.6. Comprehensive Evaluation of Rural Development

Figure 8 shows the changes in the level and pattern of rural development in the Beijing–Tianjin–Hebei region from 2009 to 2020. The cities with the best rural development in 2009 were Tianjin, followed by Beijing and Langfang, then the eastern region of Hebei: Tangshan and Qinhuangdao, and the southern region of Hebei: Handan, Shijiazhuang, Xingtai, and Hengshui, and the most underdeveloped regions were Zhangjiakou, Baoding, Cangzhou, and Chengde. The more underdeveloped rural areas are mainly concentrated in the Beijing–Tianjin ring, consistent with He [63]. The level of rural development in the Beijing–Tianjin–Hebei region has improved very significantly by 2020, and the regional development pattern has changed significantly. The cities with higher levels of rural development are Shijiazhuang, Beijing, Tangshan, and Zhangjiakou, followed by Chengde, Langfang, Cangzhou, Tianjin, Hengshui, and Qinhuangdao, with the more backward cities becoming Handan, Xingtai and Baoding.

From 2009 to 2020, the level of development of rural areas in the Beijing–Tianjin–Hebei region has progressed by leaps and bounds, especially in the cities of Zhangjiakou, Chengde, and Cangzhou. We analyze the reason for the significant progress in the development level of Zhangjiakou's rural areas is that the success of the joint application for the Winter Olympics in Beijing in 2015 has strongly driven the construction of its non-agricultural industries and infrastructure. This phenomenon indicates that the implementation of the rural revitalization strategy since 2017 has been effective, and at the same time, to further promote the development of rural areas in backward regions, the government must pay great attention to the problem of urban–rural economic disparity and vigorously improve the income level of rural residents. Firstly, pay attention to the rural industrial structure and encourage rural residents to participate in various production activities to increase their income; secondly, introduce advanced agricultural technologies to improve the level of agricultural modernization; and accelerate the construction of infrastructures such as education, medical care, and transportation in rural areas.

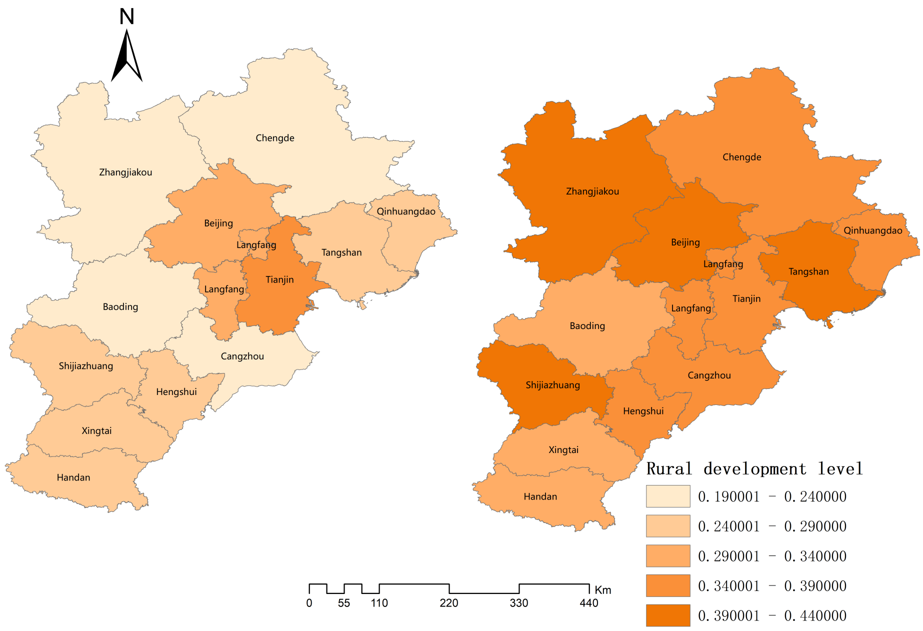

Figure 8. Rural development level of Beijing–Tianjin–Hebei region in 2009 (**left**) and 2020 (**right**).

4.2. Boosted Regression Trees Results Analysis

4.2.1. Model Pre-Processing

The total output value of agriculture, forestry, animal husbandry, and fishery is the total amount of all products of agriculture, forestry, animal husbandry, and fishery expressed in monetary terms and the value of various supporting service activities carried out for the production activities of agriculture, forestry, animal husbandry and fishery [64]. It reflects the total scale and results of agriculture, forestry, animal husbandry, and fishery production in a certain period. It is an important indicator to observe the production and development rate level of agriculture, forestry, animal husbandry, and fishery. Therefore, in this paper, we use the total output value of agriculture, forestry, animal husbandry, and fishery production per capita to represent rural development and then use it as the dependent variable to fit the BRT model and explore the main driving factors of sustainable rural development.

This study uses 18 indicators in five dimensions of the indicator system (see Table 1) as independent variables to explore the drivers of sustainable rural development, including, “Natural resources”, “Agricultural Modernization”, “Production efficiency”, “Agricultural Industrialization”, “Agricultural pollution”, “Air Quality”, “Pollution Control”, “Energy consumption”,“Basic Education”, “Medical care”, “Amateur Life”, “Civilization creation”, “Traffic”, “Farmer Vitality”, “Human Resources”, “Farmers’ Income”, “Consumption level”, and “Urban–Rural Gap”. Then we use the Pearson test to check the correlation coefficients between the various variables (see Figure 9). We eliminate the variables with strong correlations (correlation coefficient greater than or equal to 0.6) [65]. The matrix of correlation was prepared based on “corrplot” package in R software version 4.1.1 [66]. It was observed that there were six strongly correlated pairs of variables: “Production efficiency” and “Development level”(r = 0.94), “Agricultural pollution” and “Agricultural Modernization” (r = 0.72), “Amateur Life” and “Traffic” (r = 0.62), “Traffic” and “Development Level” (r = −0.60), “Human Resources” and “Healthcare” (r = −0.80), “Consumption level” and “Urban-Rural Gap” (r = 0.75). Finally, “Production efficiency”, “Agricultural pollution”, “Amateur Life”, “Traffic”, “Human Resources” and “Consumption level” were eliminated by comparing the mean values of correlation coefficients with other variables.

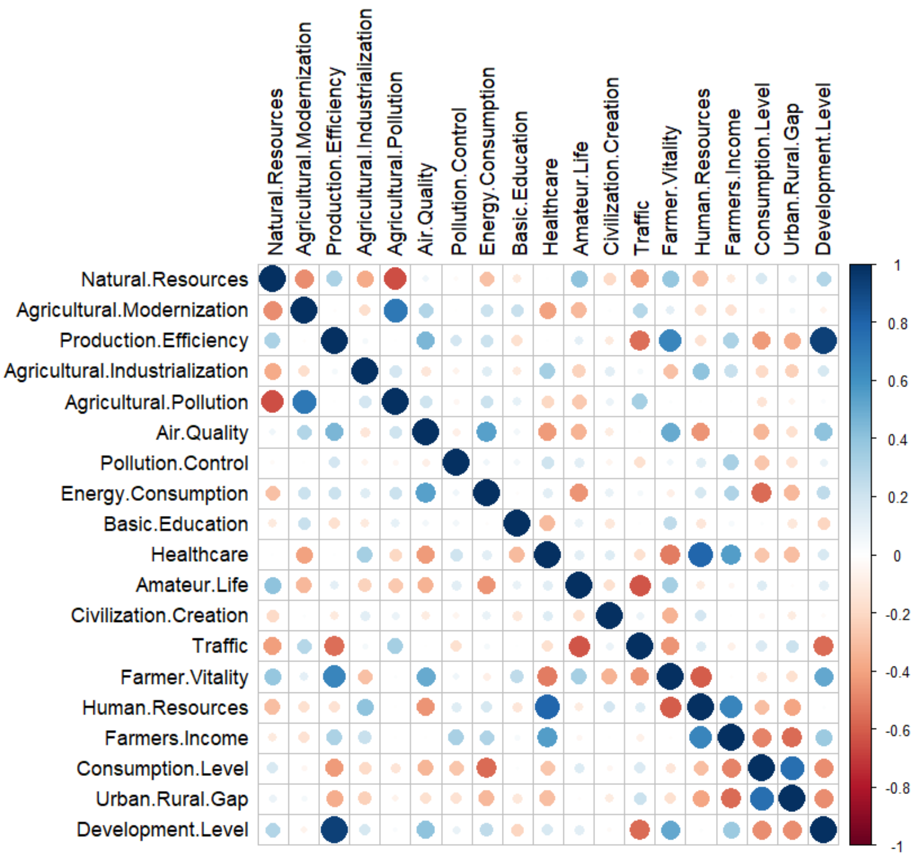

Figure 9. Pearson's correlations test among various variables.

The BRT models were operated in the R Statistical Software (R version 4.1.1) with the package "dismo" [67]. This research fitted a model with a "laplace" distribution with a suggested bagging fraction value of 0.75 [67]. Then, to find the optimal fitting under the "bias-variance trade-off" [68], we use the mean value of MSE obtained from 100 times 5-fold cross-validation method as criteria with lr = 0.2, 0.1, 0.05, 0.01 and tc = 4, 5, 6 (see Table 2), and model with the lowest MSE being the fittest.

Table 2. Parameter selection of BRT models.

Tree Complexity (tc)	Learning Rate (lr)	Mean MSE	Standard Error
4	0.01	6.236	0.269
4	0.05	4.839	0.230
4	0.10	4.895	0.258
4	0.20	4.952	0.313
5	0.01	5.918	0.238
5	0.05	5.029	0.183
5	0.10	4.446	0.209
5	0.20	4.891	0.236
6	0.01	5.655	0.236
6	0.05	4.536	0.220
6	0.10	4.655	0.150
6	0.20	4.484	0.248

4.2.2. Analysis of Results

With the lowest cross-validation Mean MSE (4.446 ± 0.209), the optimal model was found (or determined) to have an lr of 0.10, tc of 5, and a total of 149 decision trees, see Figure 10. The relative influence and marginal effects of the 12 factors are further discussed based on the boosted regression tree model.

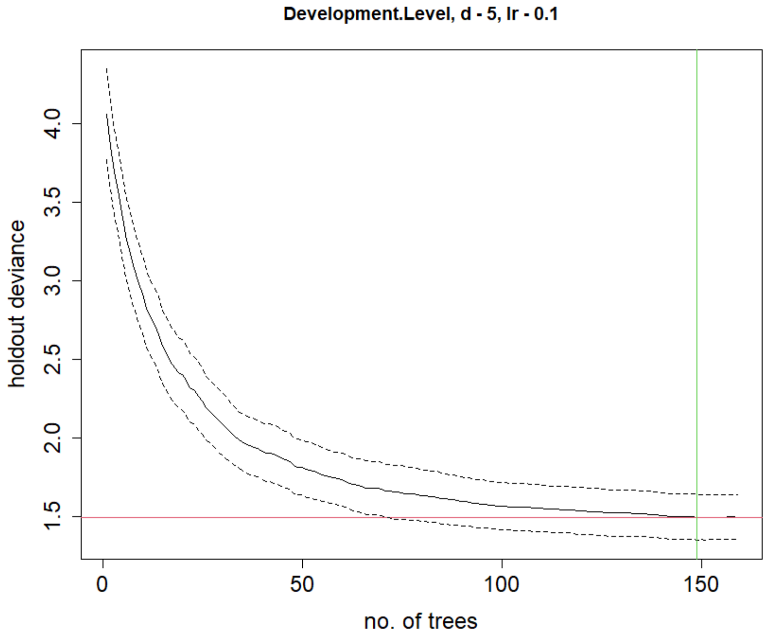

Figure 10. The holdout deviance of optimal lr and tc. The red line corresponds to the holdout deviance of the optimal parameters and the green line corresponds to the number of trees.

The relative influence of each predictor variable on rural development is shown in Figure 11: healthcare was the most important independent variable in the model (relative influence equal to 12.1%), followed by the urban–rural gap (10.1%), farmer vitality (9.9%), basic education (9.8%), air quality (9.3%), nature resources (8.1%), energy consumption (7.8%), pollution control (7.4%), civilization creation (6.9%), agricultural industrialization (6.4%), farmers' income (6.2%), and agricultural modernization (6.0%).

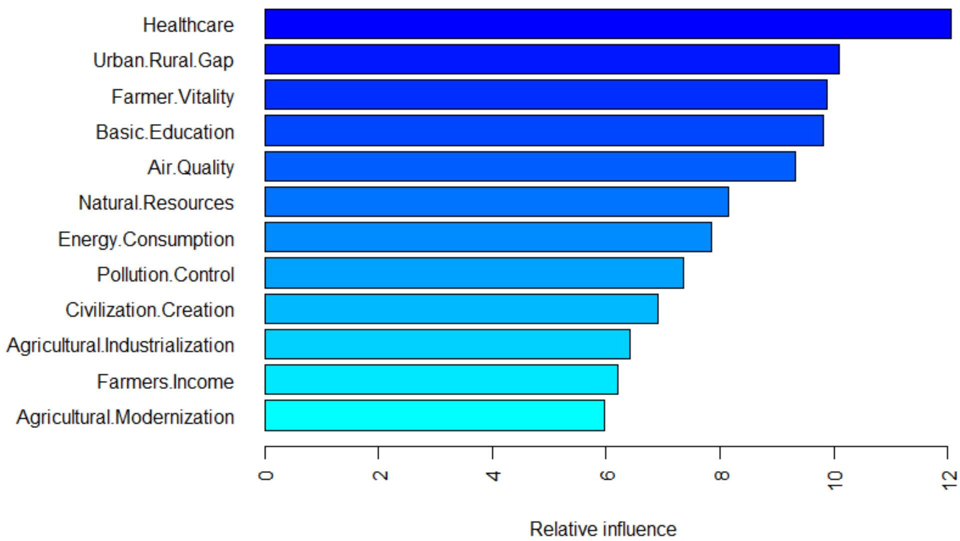

Figure 11. The relative influence of indicators on rural development.

The partial dependence plots (see Figure 12) display a marginal effect, identifying the driving factors of sustainable rural development at a particular stage. Among them, healthcare has the biggest influence on sustainable rural development. 12.1% of the rural development level is determined by health care, and its marginal effect curve has a non-linear relationship with rural development. The effect curve of increasing the number of medical beds per 1000 people on the rural development level tends to rise and then fall, and 19 beds are the optimal value. More medical beds mean more funds are invested in rural medical and health care, thus maximizing the demand for basic medical and public health services for rural residents and promoting rural development. At the same time, one issue that should be noted in the resource investment process is preventing waste of resources. The second larger driver is the rural–urban gap, which determines the 10.1% rural development level and has an overall negative correlation. The larger the urban–rural gap, the more it constrains rural development. The urban–rural development gap, especially the income gap between urban and rural residents, has been one of the constraints on rural development, and the Chinese government has made many efforts to resolve this contradiction [60]. Farmer vitality determines 9.9% of the level of rural development and has a positive correlation with it overall, implying that more rural practitioners would better contribute to rural development. With the implementation of a series of agricultural and rural human resources programs in China [69], the enthusiasm for returning to the rural areas for employment and entrepreneurship continues to increase nationwide, injecting new vitality into rural development. Basic education determines 9.8% of the level of rural development. It has an overall negative correlation with it, meaning that the more students per teacher's burden inhibit the development of the rural areas. At this stage, the main problem facing rural China is the lack of teachers [70], and rural teachers are the main body of rural education, as well as the participants and main force of rural revitalization, so the construction of rural teachers should be continuously strengthened to help rural revitalization. Air quality determines 9.3% of rural development level and has an overall positive correlation with it, implying that more CO_2 emissions will promote the development of rural areas. Natural resources determine 8.1% of the rural development level. They are generally positively correlated, implying that more arable land area per capita promotes rural development, which is contradictory to the study of Qin [21]. The reason may be that more arable land area does not impose a greater burden on farmers due to the higher level of agricultural mechanization in the Beijing–Tianjin–Hebei region. Energy consumption determines 7.8% of the rural development level and has an overall positive correlation with it, implying that more rural residents' per capita electricity consumption will promote rural development. Rural energy is an important material basis for rural economic and social development and can provide effective support for achieving agricultural production, rural ecological and environmental management, and improvement of farmers' living conditions [36]. Pollution control determines 7.4% of the rural development level and has a non-linear relationship with it and has a peak indicating that a green coverage of 40.1% is most favorable for rural development, below which it leads to increased pollution, and above which it compresses the living space of rural residents. The creation of civilization determines 6.9% of the level of rural development and is positively correlated with it, implying that more public library resources are beneficial for rural development, but it is not necessary to increase the number of resources to prevent underutilization. Agricultural industrialization determines 6.4% of the rural development level and is positively correlated with it, implying that the higher the degree of agricultural industrialization is, the more beneficial the rural development is. Agricultural industrialization implies a more mature industrial integration experience and development model and has advantages in various aspects such as technology, production, management, and market, which is the most powerful subject to promote the integration of three rural industries and rapidly improve the modernization level of agricultural industry chain supply chain [52]. Farmers' income determines 6.2% of the level of rural development and is positively correlated with it, which means that the higher the level of farmers' income, the better it is for rural development. The income level of farmers directly determines the living standard of farmers [62], and practical and effective measures should be taken to increase the farmers' income so that the majority of farmers have a more tangible sense of happiness in production and life. The level of modernization of agriculture determines 6.0% of the level of rural development and is stable in terms of its impact on rural development, probably because the degree of integration between agricultural modernization and rural agriculture is not yet sufficient, so it does not show a positive effect on rural development. Achieving modernization of agriculture and rural areas is a major task in building a modern country in an all-around way. It is necessary to introduce advanced technologies, modern equipment, and management concepts into agriculture, improve agricultural production efficiency, and promote comprehensive upgrading of agriculture, the progress of rural areas, and the development of farmers.

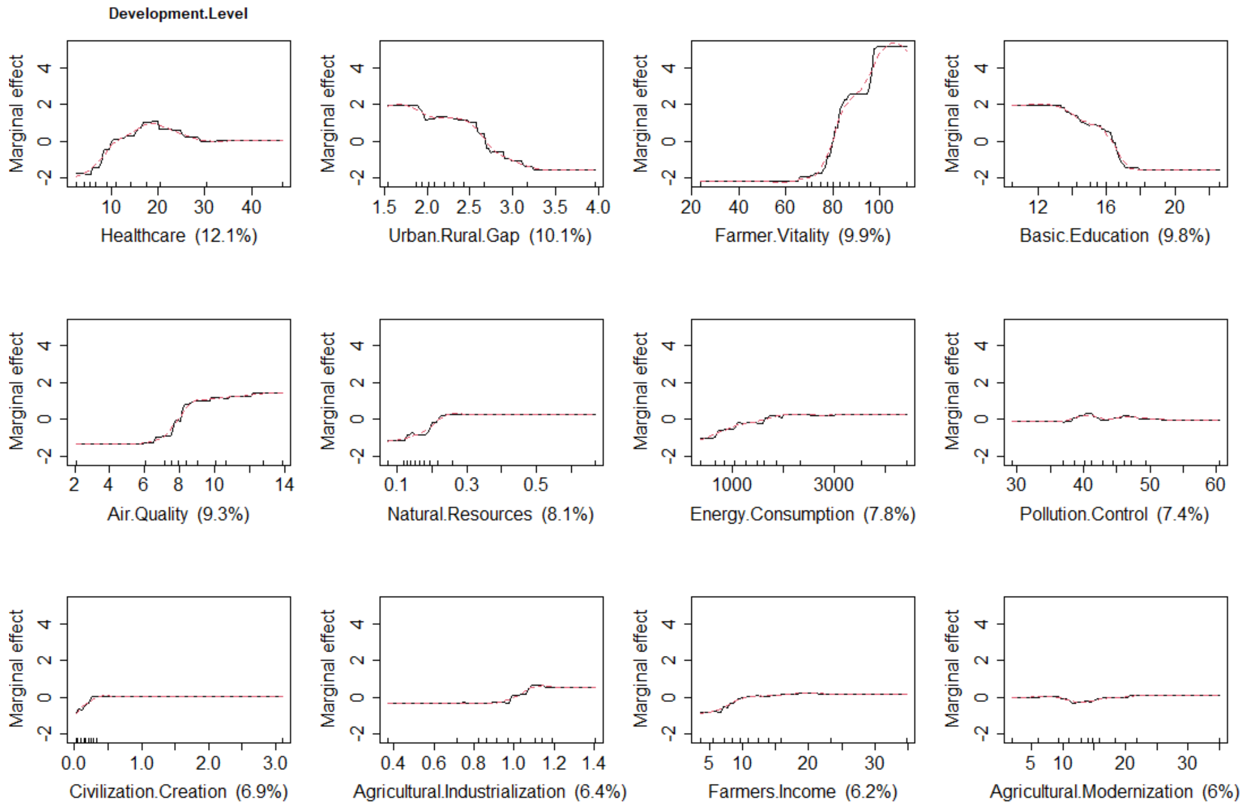

Figure 12. Marginal influence curves for drivers in the BRT model. The black lines indicates the marginal effect of each variable. The red lines were a smoothed representation of the plot. The parentheses percentages were each driver's relative influence on the rural's development. Rug plots at the bottom of the plots showed the distribution of the value of this driver.

5. Discussion

This paper integrates traditional economics methods and machine learning methods to understand the changes in the level and pattern of rural development in the Beijing–Tianjin–Hebei region from 2009 to 2020, as well as to gain an understanding of the drivers of sustainable rural development. Taking the rural areas of Beijing, Tianjin, and Hebei as the basic unit, this study constructs a rural development evaluation index system and analyzes it in terms of industrial revitalization, ecological livability, rural style civilization, effective governance, and living affluence, which helps government departments or research scholars to have a comprehensive understanding of rural development in the region and has important implications for sustainable rural development in other regions. In future rural development practice, this evaluation index system can be used for in-depth analysis and evaluation of the dynamic change process of rural revitalization strategy. Of course, in the process of continuous promotion of rural revitalization strategy, there will be new situations, and it is also necessary to fine-tune and further improve the evaluation index system according to the realistic needs, to effectively track and evaluate the rural development and revitalization process, which helps to truly understand the actual rural development and promote the formulation and adjustment of relevant policies, to promote the comprehensive development and revitalization of the countryside. This paper also has some limitations, despite our efforts to collect a comprehensive dataset, we still lack some representative indicators. For example, the situation of rural grassroots government can be added to the effective governance dimension. Additionally, this paper lacks micro data on rural development, which is a disadvantage of using statistical yearbooks, so in future studies, subjective indicators of rural residents can be included in the indicator system by combining questionnaires. We hope that future research will build on our study and use a broader dataset to study sustainable rural development.

6. Conclusions and Policy Analysis

6.1. Conclusions

Based on the entropy method, we first assessed the changes in the development level and development pattern of rural areas in 13 prefecture-level cities in the Beijing–Tianjin–Hebei region from 2009 to 2020 from five perspectives: prosperous industry, eco-friendly, civilized countryside, effective governance, and affluent living, then assessed the comprehensive rural development level in the region. Finally, the main driving factors of sustainable rural development are explored based on the boosted regression trees algorithm, and the dynamic influence of these factors is also examined.

We found that from 2009 to 2020, the five dimensions of rural areas in the Beijing–Tianjin–Hebei region (prosperous industry, eco-friendly, civilized countryside, effective governance, and affluent living) have all progressed to different degrees, with the most obvious progress in the development level of affluent living of rural residents. This is the goal of the rural revitalization strategy, which is to continuously improve the income of rural residents and narrow the income gap between urban and rural residents so that the farmers can join the people of the whole country to enter the overall well-off society and make steady progress toward the goal of common prosperity.

From 2009 to 2020, the comprehensive development level of Beijing–Tianjin–Hebei rural areas has improved greatly, among which Baoding, Xingtai, and Handan are the three cities with lower rural development levels in the region, and they are the main agricultural areas in the region, so we should focus on these areas in the process of rural revitalization strategy implementation.

By exploring the drivers of sustainable rural development, we found that the main drivers of sustainable rural development are medical and health conditions, urban–rural gap, and rural residents' vitality. Therefore, to promote sustainable rural development, government departments can design policies from three perspectives: improving medical and health conditions in rural areas, reducing the urban–rural gap, and activating rural residents' vitality. Meanwhile, we found that at this stage, rural residents' vitality, air quality, natural resources, energy consumption, civilization creation, agricultural industrialization, farmers' income, and agricultural modernization have a positive impact on sustainable rural development; a larger urban–rural gap and a larger number of students per teacher will harm sustainable rural development; the number of beds per 1000 people is 19, and the green coverage rate is 40.1% are the most favorable to sustainable rural development.

6.2. Policy Analysis

Overall, the development level of rural areas in the Beijing–Tianjin–Hebei region has improved significantly during the study period. However, there are still phenomena of unbalanced and insufficient development in the region, and the road to rural revitalization development is still a long way to go. According to the data of our survey, the main problems at present are as follows: firstly, the inadequate rural infrastructure, especially the poor production facilities, has seriously restricted the development of rural industries; secondly, the development gap between urban and rural areas is large, and there is less communication between the two, which is not helpful to realize the integrated development of urban and rural areas; thirdly, the lack of supporting power of elements such as financial resources, talents, and technology in rural areas, which leads to difficulties in upgrading rural industrial development; finally, the weakness of rural grassroots organizations in backward areas and the problems of aging and unreasonable knowledge structure of village cadres have seriously restricted the development of the rural economy.

To solve the above problems, the central government of China has classified villages into four types: clustering and upgrading, suburban integration, characteristic protection, and demolition and relocation, in the Rural Revitalization Development Plan (2018–2022) to promote rural revitalization in a categorical manner, which provides important guidance to promote the development of rural areas. The clustering and upgrading villages are the existing larger central villages and other general villages that will still survive. They account for most of the village types and are the focus of rural revitalization, and more resources and policies will be aimed at these villages in the future development process so that they can be better developed. The suburban integration type villages are the villages in the suburban areas of cities and the locations of county towns. They have the advantages of becoming urban backyards and have the conditions to transform into cities. Nowadays, many cities have already matured, so after the slowdown of urban economic development, cities in China have shifted their development focus to rural areas, and to better develop rural areas, villages near the suburbs of cities are classified as "suburban integration" to achieve integration with cities. The characteristic conservation villages refer to villages with rich natural and historical, cultural characteristics, such as famous historical and cultural villages, traditional villages, villages with minority characteristics, and famous landscape tourism villages, which are important carriers of manifesting and inheriting excellent Chinese traditional culture. So, based on respecting the life form and traditional habits of the original inhabitants, we will accelerate the improvement of village infrastructure and public environment, rationalize the use of characteristic village resources, develop rural tourism and characteristic industries, and form a benign mutual promotion mechanism of characteristic resource protection and village development. There are two types of villages in the demolition and relocation category: the first is the areas that are completely unsuitable for living and developing products, and these areas can only improve the living standards of residents through ecological migration and relocation, and the second is the villages that have lost a large amount of rural population and are hollowed out; the production function of these villages can be retained, and the land can be concentrated to develop modern agriculture.

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