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Article

Management on Transfer Pricing of Farmland Based on the Supply–Demand Mismatches for Multifunction: A Case Study from China

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Abstract: Realizing the multifunctional value of farmland is essential for regulating the pricing of farmland transfers and stabilizing the rural land market. However, in China, the mismatch between supply and demand leads to improper resource allocation, weakens the explicit value of farmland, and causes unreasonable transfer pricing mechanisms that threaten agricultural production and food security. This study develops an analytical framework to examine the relationship between farmland multifunction and transfer pricing from a supply–demand perspective. An evaluation index system is constructed, considering the physical, value, and material quantities. This study uses the matching index method and bivariate spatial autocorrelation to analyze the supply–demand match of farmland multifunction from 2014 to 2021 and its relationship with transfer prices. Additionally, management methods and strategies for dynamic zoning-based pricing under multifunctional matching trade-offs are proposed. The results show that: (1) There is significant heterogeneity in the supply and demand matching degree of different farmland functions in both space and time. The production and ecological functions of farmland are oversupplied, while the living functions are undersupplied. (2) Different spatial autocorrelation relationships exist between the degree of supply and demand matching of farmland functions and farmland transfer prices. Specifically, the supply and demand matching degrees of the production and living functions show a significant negative spatial correlation with farmland transfer prices. In contrast, the ecological function shows a significant positive spatial correlation with farmland transfer prices, which are continuously strengthening over time. (3) Based on the supply and demand matching situation of different farmland functions and the spatial autocorrelation of farmland transfer prices, nine types of regions are delineated for farmland functions. Among them, the surplus-coordinated development areas have the most cities, accounting for about 40%, with a wide distribution range. This study proposes zoning-based pricing instruments and management strategies. This research provides valuable insights for developing countries seeking to alleviate conflicts in multifunctional land use, enhance the sustainable protection of land resources, and improve land resource assessment frameworks.

Keywords: farmland multifunction; supply and demand; zoning; farmland transfer prices

Citation: Wu, L.; Ren, G. Management on Transfer Pricing of Farmland Based on the Supply–Demand Mismatches for Multifunction: A Case Study from China. *Land* **2024**, *13*, 1372. https://doi.org/10.3390/land13091372

Academic Editors: Weiguo Fan, Xuechao Wang and Ranjay K. Singh

Received: 25 July 2024
Revised: 22 August 2024
Accepted: 26 August 2024
Published: 27 August 2024

1. Introduction

Farmland is a key resource for human survival and development. As of 2021, farmland accounts for only 10.8% of the planet's land area [1] but contributes to most of the food of the world's 8.2 billion people and provides multifunction, mainly including the production of ecological and social security functions [2–4]. However, globally, farmland faces challenges such as low utilization efficiency and extensive management practices, which severely threaten food security and social stability. Over the past decade, the condition of global land and water resources has deteriorated sharply with increasing pressure on resources and the environment. The single-function management model of farmland can no longer meet the food demand of nearly 10 billion people globally by 2050 [5]. Therefore, many countries have adopted various methods to enhance farmland utilization efficiency and rationalize resource allocation and management. Western European and North American countries have developed advanced farmland multifunction management models focused on conservation and development. This approach emphasizes the non-productive functions of farmland, such as landscape and ecological benefits, motivating farmers to engage in better management practices. Building on these ideas, China has created a localized farmland multifunction management model. By optimizing spatial planning, ecological compensation, land improvement, and other means, China provides valuable insights for developing countries on farmland utilization transformation.

The multifunctional management of farmland aims to solve externality issues in land use functions. It guides the rational use of these functions. The success of this approach depends on whether the multifunctional value of farmland can be returned to farmers through land prices. The study of the multifunctionality of farmland began with discussions on the multifunctionality of agriculture, land, and ecosystem services, as well as landscape functions. The multifunctional value of farmland includes more than just the production of basic agricultural products like grain. It also provides ecosystem services as well as social and cultural functional values. Europe places great emphasis on the value of ecosystem services provided by farmlands. It introduced the concept of High Nature Value Farmland in the CAP [6]. This was done to enhance the role of farming practices in biodiversity conservation [7–9]. In the Midwestern United States, the economic and environmental benefits brought about by no-till policies have translated into higher farmland value [10]. In India, the non-market value of farmland has received more attention. Social studies have found that different types of farmers assign different values to their land [11]. Research has shown that farmland is a crucial carrier for realizing agricultural multifunctionality. The multifunctionality of farmland corresponds closely to agricultural multifunctionality. Its value can be estimated by separating the benefits of agricultural multifunctionality from land revenue. These research findings lay the foundation for enriching pathways to realize the multifunctional value of farmland. They also help promote multifunctional land management.

Besides focusing on the essence of the multifunctional value of farmland, many studies have also focused on the classification of farmland functions, value assessment, and issues of trade-offs and coordination [10]. Influenced by the shift in research interest in Europe and the United States regarding the spatial patterns and matching of supply and demand for agricultural multifunctionality [12–15] and ecosystem services [16,17], the supply–demand relationship of farmland multifunction has gradually become a focal point. Many researchers have used semi-structured social surveys to measure urban and rural residents' perceptions, willingness, and behaviors regarding the multifunctionality of farmland. These surveys reflect the level of human demand for various functions [18]. Building on studies related to the matching of supply and demand for ecosystem services, the connotations of the matching status of farmland multifunctions have been further explored. Research has found that the combination of evolving ecosystem types and increasing social demands has led to changes in the supply–demand relationship of farmland multifunction [19]. The supply of farmland functions cannot fully match human needs, resulting in a significant temporal and spatial mismatch.

Many research studies have focused on multifunctional supply and demand characterization and matching of farmland conditions. These include expert experience methods [17], indicator systems [20], value methods [21], energy value methods [22,23], and mass methods [24]; demand characterization methods mainly include single or multiple indicator methods, demand surveys, and ecological models. Overall, these methods can be categorized as complex and simple calculations. Different methods have their own advantages and limitations. For example, energy value methods, mass methods, and ecological models involve relatively complex calculations and require numerous parameters; however, they have a certain level of objectivity. In contrast, demand surveys, expert experience methods, and value methods, although simpler to operate, are more subjective and have difficulty accurately characterizing the supply and demand of farmland multifunction. As mentioned earlier, the supply and demand of farmland multifunction involve the coupling of economic, ecological, and social systems. It requires the integration of various disciplines and datasets to quantify the supply and demand formed by the farmland resource system, thus enhancing the reliability, scientific accuracy, and data precision of the assessment results. Although existing research has established evaluation systems for farmland multifunction supply and demand, these systems primarily use indicator-based methods. They focus more on physical quantities or values and lack objective measurements of mass. Additionally, methods for depicting supply–demand matching conditions are still largely qualitative. Early qualitative methods for ecosystem service supply and demand matrices lacked objectivity. The inconsistency in units of farmland multifunction evaluation indicators significantly limits the effectiveness of the matching results.

Currently, there is still room for further research on farmland multifunction. From a research perspective, there is a lack of exploration of both ends of farmland multifunction supply and demand. Few studies have analyzed the intrinsic relationship between farmland transfer prices and the matching of farmland multifunction supply and demand. From a methodological standpoint, there are few comprehensive evaluations of farmland multifunction supply capacity that consider physical quantities, values, and mass. There is also a limited focus on evaluating the demand side of farmland. It would be more meaningful to conduct quantitative measurements, identify matching conditions, and study the temporal dynamics of farmland multifunction supply–demand from the perspective of supply–demand matching. Meanwhile, China's long-standing pricing methods and management strategies, which have focused on production functions, have severely suppressed the manifestation of the multifunctional value of farmland and hindered the development of multifunctional farmland management models. The inherent dual urban-rural structure, which leads to regional development imbalances, has also exacerbated the spatial mismatch in the supply and demand of farmland multifunction, driving complex supply–demand relationships. Additionally, the illusion of farmland prices caused by the evaluation of multifunctional values at both ends of the supply–demand spectrum affects the preferences of both parties involved in farmland transfers regarding the demand for farmland functions, significantly reducing the likelihood of farmland transfers. This further suppresses the realization of the multifunctional value of farmland, which is detrimental to the management of farmland multifunction. Influenced by China's property rights system, where ownership, use rights, and management rights of farmland are separated, it is urgent to rationally regulate land transfer prices through the realization of the multifunctional value of farmland.

This study includes the following research content: (1) From the perspective of supply and demand, establish a land multifunctional supply and demand matching index system. Innovatively evaluate the multifunctional supply and demand of land from aspects such as physical quantity, value quantity, and material quality, and use the matching index method to depict the matching status to eliminate errors caused by different units, grasping the multifunctional supply and demand and matching situation of the research area; (2) Analyze the relationship between the multifunctional supply and demand matching of land and prices, and clarify the impact mechanism of land multifunctionality on land transfer prices; (3) Innovate the zoning method, propose a new perspective on land spatial zoning-based on the relationship between supply and demand matching and transfer prices, aiming to achieve matching of multifunctional supply and demand, and provide practical policy recommendations for improving land use efficiency and developing a price management system.

2. Theoretical Analyses

Multifunctional management of farmland, as a systemic issue, has both supply and demand sides. On the one hand, the supply of multifunctional farmland arises from the inherent physical, chemical, and ecological properties of natural ecosystems. On the other hand, human social system activities are external drivers of the demand for multifunctional farmland [25]. The supply and demand situation of multifunctional farmland reflects the dynamic process of the bidirectional flow of farmland elements between natural ecosystems and human social systems. There are three main supply and demand situations: supply greater than demand (surplus), supply less than demand (deficit), and supply equal to demand (balance). Farmland, as a commodity, has a transfer price determined by the supply and demand situation of farmland [26]. However, considering the complexity of the evolution of farmland functions and their supply–demand matching, it is necessary to analyze the relationship between different functional supply–demand matching situations and farmland transfer prices (Figure 1).

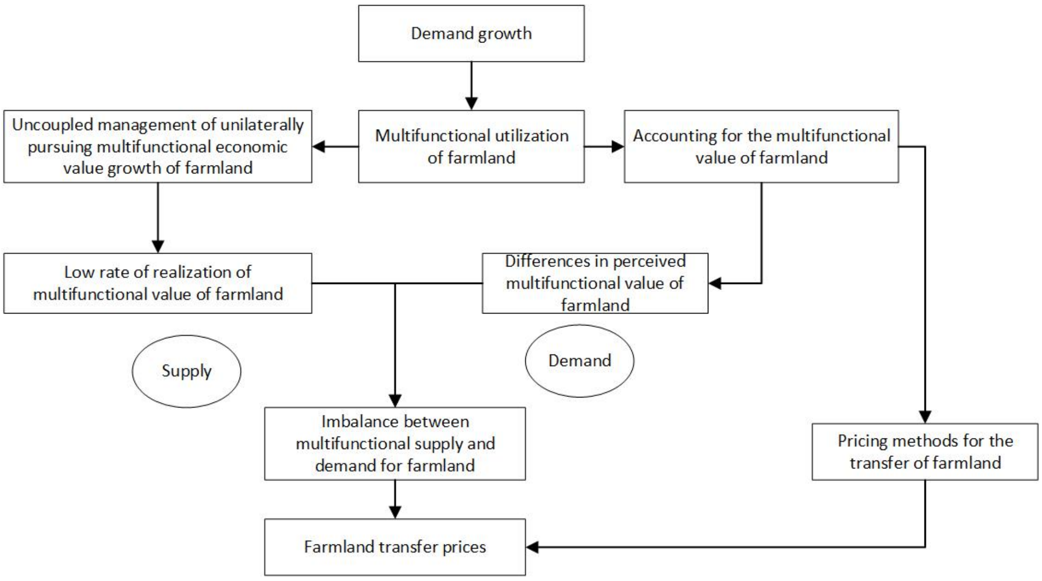

Figure 1. Theoretical framework for the supply–demand relationship and price of multifunctional farmland.

The supply–demand matching situation of multifunctional farmland has significant temporal and spatial characteristics. From a temporal perspective, human demand changes continuously with the evolution of socioeconomic development, and the multifunctionality of farmland accordingly becomes more explicit [27]. Over time, the supply and demand of farmland functions experience a dynamic process, from imbalance to balance, leading to corresponding changes in farmland transfer prices. Spatially, natural ecological characteristics and human social factors lead to significant spatial differences in the supply capacity of multifunctional farmland. Additionally, under the influence of different spatial contexts, the supply capacity of the same function may cluster or disperse, and the supply capacities of different functions may exhibit trade-offs or synergies, further enhancing the spatial heterogeneity of multifunctional farmland supply capacity [28]. These conditions collectively exacerbate the spatial polarization of fluctuations in farmland transfer prices.

The existing pricing of farmland transfers is primarily based on the production function of farmland, neglecting the realization of other functional values, leading to a mismatch in the supply and demand of multifunctional farmland. From the supply side of farmland functions, the farmland ecological function, such as carbon sequestration, soil conservation, and water source maintenance, have significant public interest characteristics. However, the value of these ecological products is difficult to reflect in the current market pricing mechanism. On the demand side of farmland functions, the differing perceptions of the multifunctional value of farmland between the transfer parties is the direct cause of the price illusion of farmland. In summary, the temporal and spatial differences in the supply and demand characteristics of multifunctional farmland combined with the functional limitations of farmland transfer pricing jointly lead to unreasonable current farmland transfer prices. Therefore, it is necessary to first quantify the supply–demand matching degree of multifunctional farmland, clarify the spatial and temporal distribution pattern of the supply–demand matching of multifunctional farmland, and then analyze its relationship with farmland transfer prices. This provides a basis for the spatial zoning of farmland functions, achieving scientific management, and long-term utilization of farmland.

3. Materials and Methods

3.1. Study Area

China is a major agricultural power that sustains 20% of the world's population, with just 9% of its farmland. Since the initiation of farmland transfer activities in 2002, the value of farmland in terms of food production, social security, ecological safety, and regional contributions has become increasingly prominent. Considering the availability of data and the feasibility of policy implementation, this study selects prefecture-level cities in China as the basic research unit. The main reasons are as follows: First, as an important administrative level in China, prefecture-level cities can provide relatively detailed and complete statistical data, ensuring the accuracy and consistency of data, which facilitates comparison and analysis. Second, as the intermediate level in China's five-tier administrative system, prefecture-level cities play a crucial role in farmland protection and management of the farmland transfer market. Additionally, due to data gaps in some provinces and cities, 329 prefecture-level cities are selected as the research units, and these basically cover the diverse geographical conditions, climate conditions, and economic development levels within China. This ensures that the research results are representative (Figure 2).

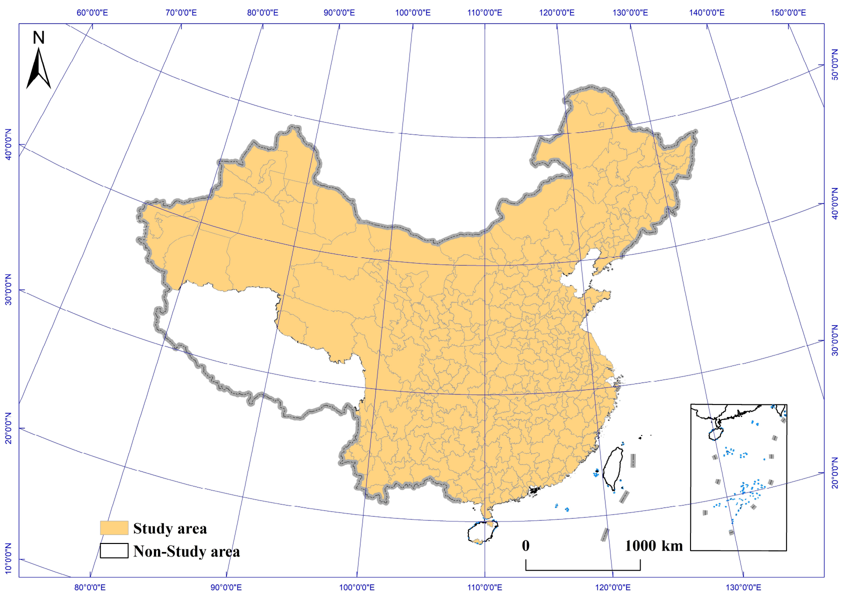

Figure 2. Study area.

3.2. Data Collection and Processing

This study uses multi-source data to analyze the supply and demand levels of farmland production, living, and ecological functions in Chinese prefecture-level cities. The data used to calculate the supply and demand levels of production and living functions come mainly from the China Economic and Social Research Big Data Platform, statistical yearbooks, and statistical bulletins of various provinces and cities. The vector and raster data used to calculate the supply and demand levels of the ecological function mainly come from various resource and environmental science data centers. All coordinates use the Albers_Conic_Equal_Area projection coordinate system. The specific data sources are shown in Table 1.

Table 1. Description of data sources and indicators.

Dimension	Data Use	Data Type	Data Year	Data Sources	Data Format
Farmland Production Function Supply and Demand	Food Supply	Grain Sowing Area	2014–2021	China Economic and Social Big Data Research Platform, Statistical Yearbooks of Various Provinces and Cities, Statistical Bulletins	Statistical Data/hectare
	Food Supply	Grain Output			Statistical Data/kilogram
	Food Demand	Permanent Population			Statistical Data/person
	Food Demand	Per Capita Grain Consumption of Urban Residents			Statistical Data/(kilogram/person)
	Food Demand	Per Capita Grain Consumption of Rural Residents			
	Food Demand	Urbanization Rate of Provinces and Cities			Statistical Data
	Food Demand	Engel Coefficient of Provinces			
Farmland Living Function Supply and Demand	Income Supply	Agricultural Output Value			Statistical Data/10,000 yuan
	Income Supply	Rural Population			Statistical Data/person
	Income Supply	Minimum Living Security for Rural Residents			Statistical Data (yuan/person)
	Income Demand	Per Capita Disposable Income of Urban Residents			
	Income Demand	Per Capita Disposable Income of Rural Residents			
Farmland Ecological Function Supply and Demand	Water/Carbon Supply and Demand	Administrative Boundaries	2023	Standard Map Service System	Vector Data
	Water/Carbon Supply and Demand	Land Use Data	2014–2021	CLCD 1990–2021 National Land Cover Data by Professors Yang Jie and Huang Xin, Wuhan University	Raster Data/30 m
	Water/Carbon Supply and Demand	Annual Precipitation		National Earth System Science Data Center Shared Service Platform	Raster Data/1 km
	Water Supply and Demand/Carbon Supply and Demand	Annual Evapotranspiration		National Earth System Science Data Center Shared Service Platform	
	Water/Carbon Supply and Demand	Root Restriction Layer Depth	2014	Research by Yan	
	Water/Carbon Supply and Demand	Plant-Available Water Content	2012	China Soil Dataset based on the World Soil Database (HWSD)	
	Water Supply and Demand	Proportion of Three Major Crops Area	2014–2019	National Ecosystem Science Data Center	
	Water Supply and Demand	Water Quota for Three Major Crops	2021	Ministry of Water Resources "Agricultural Irrigation Water Quota"	Quota Data
	Carbon Supply and Demand	Carbon Emissions	2014–2021	Emissions Database for Global Atmospheric Research (EDGAR)	Raster Data/0.1°

The data used in this study include three main types: raster data, vector data, and statistical data. The raster and vector data are mainly used to measure the supply and demand of farmland ecological functions. Statistical data are used to measure the supply and demand of farmland production and living functions. The first step in data collection is to retrieve indicators from the China Economic and Social Research Big Data Platform to measure the supply and demand of farmland production and living functions. This is supplemented with data from statistical yearbooks and bulletins of various provinces and cities. The second step involves accessing data from the National Earth System Science Data Center, the National Ecosystem Science Data Center, the World Soil Database, the Global Atmospheric Research Emissions Database, and other sources. To ensure data consistency and quality, the data undergoes preprocessing after collection. There are three main steps in this process: First, for statistical data, units are standardized, and for vector and raster data, coordinate systems and boundary ranges are unified. Second, missing values are handled using regression and Kriging interpolation methods. Third, raster data are converted into vector data based on China's prefecture-level cities as spatial units to enable integrated analysis with vector data.

3.3. Research Methodology

Firstly, this paper uses the value method, single indicator method, and physical quantity method to calculate the supply and demand of farmland production, living, and ecological functions. Secondly, the matching index method is used to calculate the supply–demand matching degree of each function of farmland. Thirdly, bivariate spatial autocorrelation is used to analyze the relationship between the supply–demand degree of multifunctional farmland and farmland transfer prices. On this basis, the supply–demand degree is revised, and the improved coupling coordination model is used to calculate the coordination degree of the supply–demand matching of multifunctional farmland (Figure 3).

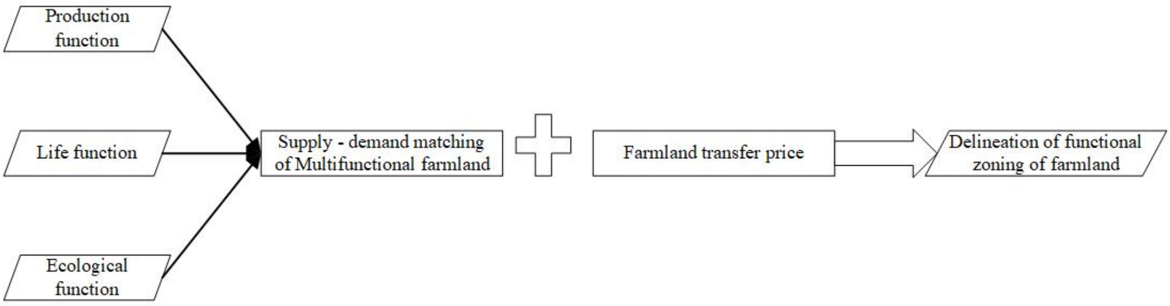

Figure 3. Research Methodology for the delineation of functional zoning of farmland.

3.4. Evaluation of Supply and Demand for Multifunctional Farmland

Under the coupling effect of the ecosystem and human system, the diversity of farmland utilization methods is determined. The achievement of sustainable development goals such as ecological protection, food security, and social stability poses various demands on farmland, collectively leading to the emergence of multifunctional characteristics of farmland. Currently, academia conducts research based on perspectives such as production function, living/social functions, and ecological functions, and adjusts the functions in detail according to different research purposes and characteristics of the study areas [29]. This paper adopts the classification method of production, living, and ecological functions for subsequent research for the following three reasons: (1) Enhance analytical comparability. The study area of this paper includes 329 prefecture-level cities in China. Choosing production-living-ecological functions helps avoid result biases caused by specific functional supply and demand differences, thereby enhancing the comparability of functional supply and demand matching across different regions. (2) Avoid indicator redundancy. A literature review revealed that the same indicators are used to evaluate different types of farmland functions. This may be due to previous multifunctional farmland evaluations, which are usually supply oriented and overly detailed in function division. This paper focuses on both the supply and demand of multifunctional farmland, selecting indicators from production, living, and ecological perspectives. This approach not only avoids redundancy in indicator selection but also comprehensively reflects the gap between farmland supply and demand, thereby achieving the goal of dynamically regulating farmland transfer prices. (3) Improve the usability of the results. The main focus of this paper is to explore the relationship between the supply and demand of multifunctional farmland and farmland transfer prices, and to conduct zoning-based on this relationship. The zoning results obtained from production, living, and ecological perspectives can provide a basis for the management of farmland transfer prices.

3.4.1. Farmland Production Function

The farmland production function is the core function [30]. Existing studies have selected indicators to evaluate the farmland production function from five perspectives: quality, area, cultivation conditions, yield, and output value. ① Farmland quality is mainly evaluated using some indicators from the farmland grading system, such as essential soil texture, soil organic matter content, and soil Ph [31]. ② Farmland area indicators are selected from the dimensions of total amount and proportion, such as farmland retention amount [25], crop/grain/economic crop planting area [32], land/farmland reclamation rate [33], and per capita farmland area [34]. ③ Cultivation conditions focus more on irrigation and drainage conditions and agricultural machinery levels [35]. ④ Farmland yield evaluates the production function mainly from the per unit and total yields of the different crops [36]. ⑤ Farmland output value measures the economic value of the production function mainly from the total output value, output value per unit of land, and contribution to GDP [20,37].

The supply of the farmland production function refers to the food production capacity of farmland resources under the coupling and linkage of different natural processes and socioeconomic backgrounds [4,38]. The demand evaluation of the farmland production function begins with the socioeconomic system or human needs. This paper selects the grain yield per unit area from the perspectives of area and yield to directly measure the supply of the farmland production function. Considering regional differences in food consumption, the Engel coefficient adjustment, population, per capita grain demand, and grain self-sufficiency rate are used to estimate the demand for the farmland production function.

(1) Grain supply. In this study, the sown area of grain and total grain output is selected to calculate the grain output per unit area to reflect the supply capacity of the production function of farmland, and the calculation formula is as follows:

$$FS = \frac{P}{S} \tag{1}$$

where FS is the supply capacity of farmland for the production function (kg/hm^2), P is the total grain production (kg), and S is the farmland area (hm^2).

(2) Food demand. In this study, the per capita food consumption of urban and rural residents, urban and rural resident population, area sown with food, and Engel's coefficient were selected to calculate the demand capacity of the farmland production function, and the formulas are as follows:

$$FD = \frac{(Pu * GDu + Pr * GDr) * \beta}{S} \tag{2}$$

$$\beta = \frac{x_i}{\overline{x}} \tag{3}$$

where FD is the demand capacity of the farmland production function (kg/hm^2), S is the farmland area (hm^2), and Pu is the permanent urban population (persons). Pr is the rural resident population (persons), GDu is the per capita food consumption of urban residents (kg/person), GDr is the per capita food consumption of the rural population (kg/person), β is the Engel's revised coefficient, x_i is the Engel coefficient of i, $\overline{x}$ is the regional average engel's revised coefficient.

3.4.2. Farmland Living Function

The living function of farmland mainly reflects its role in supporting the basic livelihoods of farmers by focusing on ensuring livelihoods and maintaining social stability. Indicators are selected from aspects such as food consumption, employment, and income. The Engel coefficient and per capita grain security rate are used to measure the level of grain required to meet basic living needs [39]. To measure the employment security level, on one hand, the level of agricultural employment and the labor force carrying capacity of farmland are directly depicted [40]. On the other hand, the level of agricultural mechanization, which affects labor employment, indirectly reflects the weakened living function of farmland in securing employment [41]. To select indicators for evaluating income security, indicators directly related to income, such as the per capita disposable income of rural residents and the difference/ratio between the per capita disposable income of urban and rural residents, are usually preferred [42]. At the same time, based on the principle of baseline thinking, the minimum living security level and pension security level of farmers are also important factors representing the income security level of farmland [43]. Additionally, some scholars believe that agricultural output value indirectly reflects the income level of farmers at the regional level [44].

The supply of the living function of farmland refers to the ability of farmland to provide economic sources and employment opportunities for farmers. The demand for the living function of farmland by farmers means that farmers can obtain a stable source of income by engaging in farmland operations. The essence of supply and demand for the living function of farmland is to obtain income for living expenses. Based on this, this paper mainly selects per capita agricultural output value and the minimum income security of rural residents to measure the supply level of the living function of farmland. The per capita disposable income of urban and rural residents is selected to represent the demand level of farmers for the living function of farmland.

(1) Income supply. In this study, the agricultural output value, size of the rural population, and minimum living standard for rural residents were selected to calculate the supply capacity of the living function of farmland, and the calculation formula is as follows:

$$LS = \frac{Ap}{Pr} + MLGr \quad (4)$$

where LS is the supply capacity of the farmland living function, Ap is the agricultural output (yuan), Pr is the rural population (persons), and $MLGr$ is the minimum subsistence guarantee for village residents (yuan/person/year).

(2) Income demand. In this study, the difference between the per capita disposable income of urban and rural residents is used to characterize the demand capacity for the living function of farmland, and the calculation formula is as follows:

$$LD = PDIu - PDIr \quad (5)$$

where LD is the demand capacity of the farmland living function, $PDIu$ is the per capita disposable income of urban residents, and $PDIr$ is the per-capita disposable income of rural residents.

3.4.3. Farmland Ecological Function

In reviewing the evaluation indicators of farmland ecological function, existing studies have focused on the extent of human-induced ecological damage and the farmland's ability to sustain its environment to portray ecological function indicators. On one hand, the ecological carrying capacity of farmland is directly measured through agricultural pollution indicators, such as the amount of fertilizer, pesticides, and agricultural film used per unit area of farmland [45]. Additionally, the ecological carrying capacity per capita is calculated using factors like per capita farmland area and yield [46], while landscape fragmentation and connectivity reflect the impact of human activities on farmland ecology [47]. On the other hand, the ecological maintenance function of farmland is mainly represented by calculating ecosystem service indicators such as ecological dominance, biodiversity, carbon sequestration and oxygen release, and soil and water conservation [48]. The cultural landscape function is indirectly reflected by the economic value generated by landscape culture, such as the total income from sightseeing and leisure tourism [32,49], while some studies directly evaluate it using landscape aggregation and evenness indices [50].

The supply of the ecological function of farmland mainly provides ecosystem services from a maintenance perspective, including carbon sequestration, oxygen release, and water conservation. The demand for the ecological function of farmland is difficult to measure directly and is mainly represented indirectly by the quality of conditions, such as air quality and water resources [29]. To avoid errors due to differences in the selection of indicators for supply and demand, this paper selects annual water production and carbon sequestration to calculate the supply of the ecological function of farmland. Crop water demand and carbon emissions are selected to calculate the demand for the ecological function of farmland. When measuring the supply of farmland ecological functions, the InVEST model's water yield and carbon sequestration modules are used to quantify the water supply and carbon supply within the farmland's ecological functions. When using the water yield module, the following data are sequentially loaded according to requirements: processed precipitation, evaporation, root-restricting layer depth, plant-available water content, land use/land cover raster data, biophysical table, Z parameter, and boundary data of the study area, before running the model. When using the carbon sequestration module, the processed land use/land cover raster data and carbon pool data are sequentially loaded according to requirements before running the model.

(1) Water Yield. In this study, the water production (annual water yield) module of the InVest model was used to quantify the capacity to supply water-producing services to farmland. The water yield model is based on the Budyko curve and average annual precipitation to determine the annual water yield for each raster, which is calculated by the following formula:

$$WS(x_i) = \left(1 - \frac{AET(x_i)}{P(x)}\right) \times P(x) \tag{6}$$

$$\frac{AET(x_i)}{P(x)} = 1 + \frac{PET(x_i)}{P(x)} - [1 + (\frac{PET(x_i)}{P(x)})^{\omega}]^{\frac{1}{\omega}} \tag{7}$$

$$PET(x_i) = K_c(l_{xi}) \cdot ET_0(x) \tag{8}$$

$$\omega(x) = Z\frac{AWC(x)}{P(x)} + 1.25 \tag{9}$$

$$AWC(x) = Min(Rest.later.depth, root.depth) \times PAWC \tag{10}$$

$$\begin{aligned} PAWC = 54.509 - 0.132 \times SAND\% - 0.003 \times \left(SAND\%\right)^2 - 0.055 \times SLIT\% \\ -0.006 \times \left(SLIT\%\right)^2 - 0.738 \times CLAY\% + 0.007 \times \left(CLAY\%\right)^2 \\ -2.688 \times C\% + 0.501 \times \left(C\%\right)^2 \end{aligned} \tag{11}$$

where $WS(x_i)$ is the annual water yield for land use type ith of the xth grid, which represents the water supply capacity of the farmland ecological function. $AET(x_i)$ is the annual average actual evapotranspiration for the land use type ith of the xth grid. $P(x)$ is the quantity of rainfall in the xth grid. $PET(x_i)$ is the potential vaporization for land use type ith of the xth grid. $?(x)$ is the natural climate—non-physical parameters of soil properties. $K_c(l_{xi})$ is the plant evapotranspiration coefficient for the land use type ith in the xth grid. $ET_0(x)$ is the potential evaporation for land use type ith of the xth grid. Z is an empirical constant (also known as a seasonal constant), which is used to represent local precipitation patterns and other hydrological characteristics. It is used to determine the Z-parameters concerning the same study area and the total water resources and water yield coefficients in the Water Resources Bulletin. $AWC(x)$ is the effective water content of plants. $PAWC$ is calculated based on the empirical estimation model proposed by Zhou [51], $SAND\%$ which is the sand content of the soil, and $SILT\%$ the powder content of the soil. $CLAY\%$ is the clay particle content of the soil. $C\%$ is the organic carbon content of soil. $Rest.later.depth$ refers to Yan's study to select 1 km Chinese soil depth map [52]. $root.depth$ and K_c are derived from biophysical reference tables and determined primarily from the available literature. Some of the raster-type input data for our study used in the InVest model water production module are as follows in Figure 4.

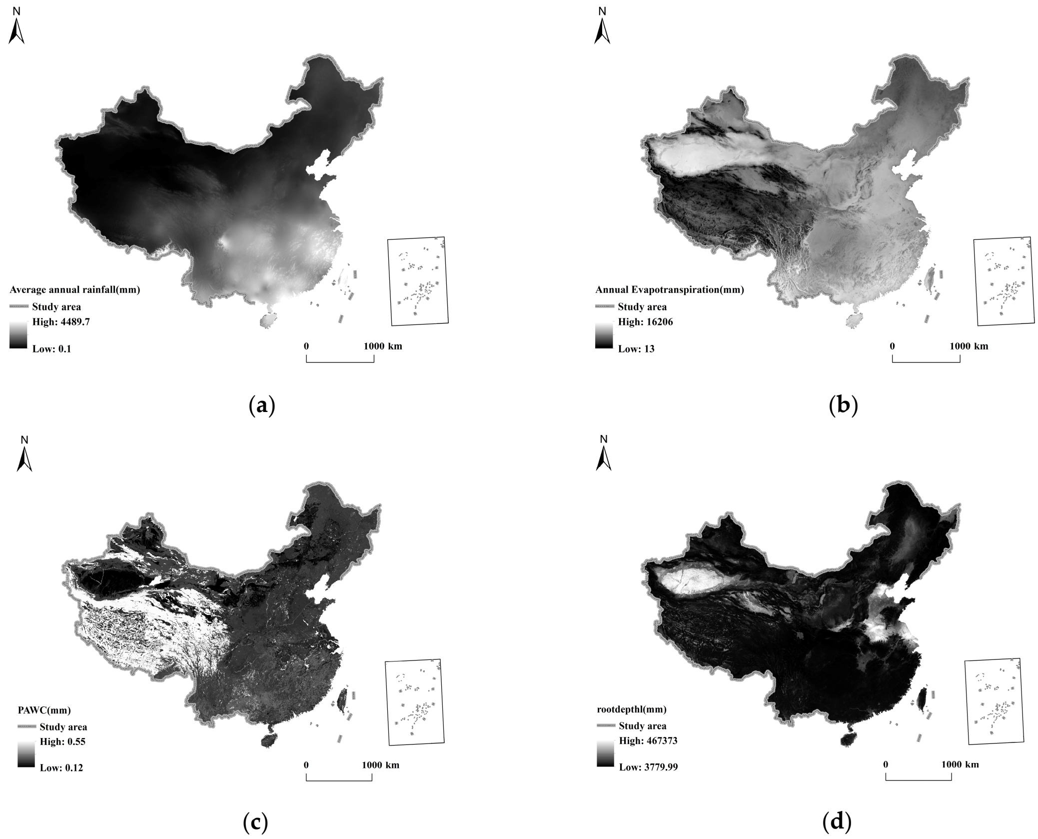

Figure 4. Relevant raster input data in the water yield calculation model. (**a**) Average Annual Rainfall; (**b**) Annual Evapotranspiration; (**c**) Root Depth; (**d**) Plant-Available Water Content.

(2) Water demand. The water demand for this study was measured based on the "Agricultural Irrigation Water Use Quotas: Rice", "Agricultural Irrigation Water Use Quotas: Maize", and "Agricultural Irrigation Water Use Quotas: Wheat" issued by the Ministry of Water Resources (MWR) in 2021, as well as the national 1 km planting distribution dataset of the three major grain crops issued by Luo Yuchuan et al. The calculation formula is as follows:

$$WD = \sum_{i=1}^{n} w_i \times s_i \quad (12)$$

where WD is the sum of the water requirements of the three major crops, and represents the water demand capacity of the farmland ecological function. w_i is the maximum water demand of the crop per hectare of the ith crop, and s_i is the area of the ith crop.

(3) Carbon storage capacity. In this study, the carbon storage and sequestration module of the InVest model was applied to quantify the carbon storage supply capacity of farmland. The carbon storage and sequestration model estimates the current carbon stored in the land based on the land use data and the stock of four carbon pools, i.e., aboveground biomass, belowground biomass, soil organic carbon, and dead organic matter carbon, and the formula of the model is as follows:

$$CS = C_{above} + C_{below} + C_{soil} + C_{dead} \quad (13)$$

where CS is the carbon storage, which represents the carbon supply capacity in the farmland ecology function. C_{above}, C_{below}, C_{soil}, and C_{dead} represent aboveground biomass, belowground biomass, soil organic carbon, and dead organic matter carbon, respectively, and were determined mainly based on the available literature.

(4) Solid carbon demand. The data of this study mainly comes from EDGAR, the Global Atmospheric Research Emissions Database, by extracting China's carbon emissions

data from 2014 to 2021 and utilizing ArcGIS 10.8 partitioning to statistically derive the carbon emissions data of each study unit to represent the carbon demand capacity of the farmland ecological function (CD).

3.5. Multifunctional Supply and Demand Division of Farmland

This study uses the Matching Index Method to measure the supply–demand matching degree of farmland multifunction. The matching degree is calculated based on the quantitative and spatially mapped evaluation of the supply (S) and demand (D) of farmland multifunction within spatial units (administrative units or grids). This degree represents the status of supply–demand matching for various functions. Compared with existing qualitative methods, it can systematically and quantitatively characterize the matching situation. The supply and demand quantity used to measure the matching degree can be a physically meaningful indicator or a dimensionless index value. The logic of constructing a matching index is to condense multidimensional and complex variable information into a comprehensive index, further enhancing the comparability of supply and demand matching results for analysis and decision-making. The multifunctional matching index method (FSDR) for farmland was used to calculate and classify the supply and demand of each function of farmland, and its formula is as follows [53]:

$$CSDM_i = \frac{S_i - D_i}{\frac{S_{max} + D_{max}}{2}} \tag{14}$$

where $CSDM_i$ is the match between the supply and demand of the ith unit. S_i and D_i represent the demand and supply of the ith unit. S_{max} and D_{max} are maximum supply and maximum demand, respectively, with positive values indicating surpluses, negative values indicating deficits, and zero indicating equilibrium between supply and demand. The number of 0 is relatively small; for this reason, this study takes the region of 0.1 up and down as the equilibrium region, i.e., ($-0.1 <$ CSDM < 0.1) and classifies CSDM > 0.3 as a significant surplus, $0.1 <$ CSDM < 0.3 as a slight surplus, $-0.3 <$ CSDM < -0.1 as a slight deficit, and CSDM < -0.3 as a significant deficit in five matching categories.

3.6. Impact of Farmland Price on the Supply–Demand Relationships of Farmland Multifunction

This study calculates bivariate global Moran's I and local Moran's I to explore the spatial association characteristics between the farmland multifunction supply–demand matching degree and farmland transfer prices. Since the study units in this paper are primarily administrative regions at the prefecture level in China, the spatial units for bivariate spatial autocorrelation analysis are prefecture-level cities. Global Moran's I examines the spatial correlation between farmland multifunction supply–demand matching degree and farmland transfer prices. Local Moran's I displays the spatial correlation within different spatial units. The formula for global spatial autocorrelation is as follows:

$$I = [\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}(x_i - \overline{x})(x_j - \overline{x})] / [S^2\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}] \tag{15}$$

Performing spatial clustering on local Moran's I yields a Local Indicators of Spatial Association (LISA) cluster map, which can be divided into five clustering types: high-high (H-H), high-low (H-L), low-high (L-H), low-low (L-L), and non-significant. The calculation formula is as follows:

$$I_2 = \frac{\left[(x_i - \overline{x})\sum_{j=1}^{n}\omega_{ij}(x_i - \overline{x})\right]}{S^2} \tag{16}$$

$$S^2 = \left(\frac{1}{n}\right)\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2 \tag{17}$$

In the formula, n represents the number of spatial units. x_i and x_j represent the observed values of units i and j, $\overline{x}$ is the mean value. When I is positive, it indicates that the two variables tend to increase or decrease together in space. Conversely, a negative I suggests that a high value for one variable often appears near a low value for the other. This study uses first-order neighborhood for spatial autocorrelation analysis. This is because it focuses directly on the spatial relationship between the target unit and its immediate neighbors. All adjacent units are considered, including those that share edges and corners. The Queen Contiguity was chosen as the neighborhood configuration type. To verify the robustness of the results, the permutation method was chosen to test the significance of Moran's I statistic. Significance was assessed by performing 999 permutations with randomized data.

4. Results

4.1. Analysis of the Spatial Pattern of the Match between Supply and Demand for Multifunctional Farmland

Based on the measurement of the multifunctional supply and demand capacity of farmland, the matching degree of supply and demand of farmland production function, ecological function, and living function was calculated. The average supply and demand degrees of farmland production function, ecological function, and living function in the study period of 2014–2021 are 0.22, −0.04, and 0.09, respectively. In terms of the positive and negative symbols, the supply of farmland production function and ecological function exceeds the demand, and the matching level of supply and demand is in surplus, while the matching level of supply and demand of the farmland living function is in deficit.

From the perspective of time evolution, the matching level of supply and demand of the farmland production function is always in surplus and tends to be balanced. The matching level of supply and demand for the farmland living function tends to increase and is close to a balance. The level of supply and demand for farmland's ecological function is fluctuating and increasing (Figure 5). Meanwhile, these three functions have a certain degree of spatial heterogeneity at the prefecture-level city scale. Therefore, ArcGIS 10.8 was utilized to quantitatively map the matching supply and demand of farmland production function, ecological function, and living function (Figure 6).

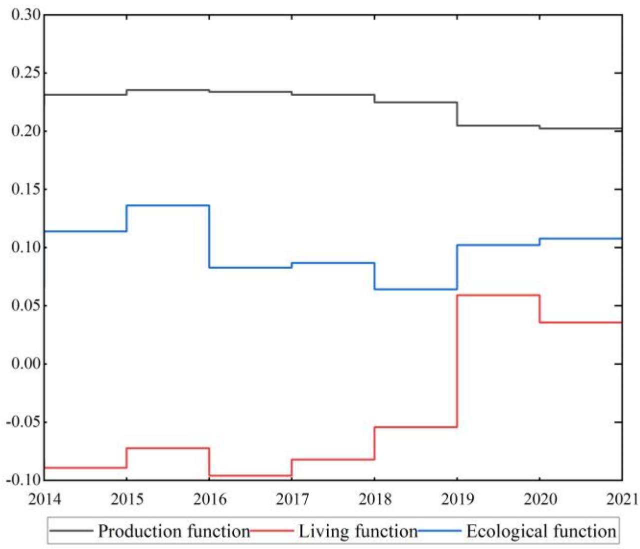

Figure 5. 2014–2021 supply and demand of Farmland functions.

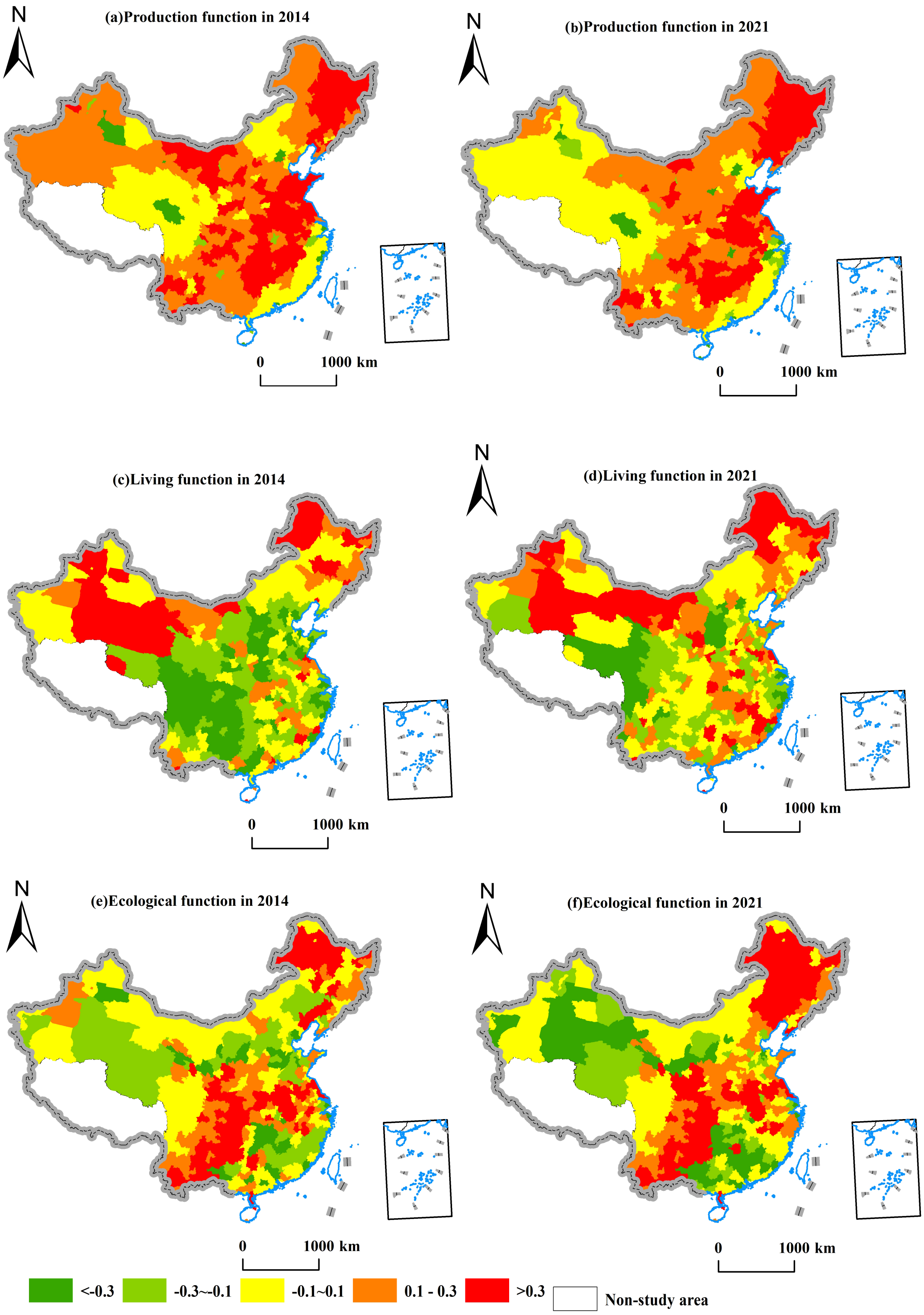

Figure 6. Spatial Distribution of Matching Supply and Demand of Farmland Functions, 2014–2021.

The surplus areas of the farmland production function (CSDM > 0.1) are mainly located in the Northeast Plain Region, North China Plain Region, and Yangtze River Economic Belt. These regions overlap with the 13 main grain-producing areas, a result related to the high supply of production function. Regions with significant surpluses (CSDM > 0.3) are concentrated in the Ningxia region and the Alashan League of Inner Mongolia, which have small populations and relatively low levels of economic development. Consequently, there is a surplus in the supply of farmland production due to relatively low demand. The deficit areas of the farmland production function (CSDM < −0.1) are mainly distributed in regions with poor farmland resources, such as first-tier and new first-tier cities like Beijing, Shanghai, Guangzhou, Wuhan, and Hangzhou. These areas are densely populated and have high food demand, exacerbating the mismatch between the supply and demand of farmland production function. The equilibrium area of farmland production function (−0.1 < CSDM < 0.1) is distributed in the southeast coastal and western inland areas. Overall, the supply and demand of farmland production functions are dominated by surplus. Over time, the number of cities with surplus is decreasing, while the balanced areas of supply and demand are increasing. However, first-tier cities remain in a serious deficit, with supply far from matching demand.

Farmland ecological function surplus areas (CSDM > 0.1) are mainly concentrated in the Yangtze River Economic Belt and northeastern part of Inner Mongolia, which have better ecological resources and a high ecological function supply. Significant surplus areas (CSDM > 0.3) are concentrated in Guizhou, western Hubei, and other cities. Deficit areas (CSDM < −0.1) are concentrated in the North China Plain and Central China, where supply is low and demand is high. The distribution of the ecological function supply and demand balance of farmland is more fragmented, being distributed in northern cities with low supply and low demand, and southern cities with high supply and high demand. Overall, the supply and demand for the farmland ecological function are dominated by surplus areas. Over time, the number of cities in surplus areas shows fluctuations, but the proportion of cities remains stable at an average of 44%. The proportion of deficit areas decreases from 24% to 22%, with one-third of the cities having better synergy in ecological supply and demand. However, cities in the central region still face serious mismatches in the ecological function of farmland.

The supply and demand levels of farmland living function were mainly in deficit. In 2014, most cities had a significant mismatch between the supply and demand of farmland living function, with supply being smaller than demand. Significant deficit areas (CSDM < −0.3) mainly covered most cities in Sichuan, Guangxi, Guizhou, and Shanxi, which are also major population outflow provinces and economically underdeveloped areas. Most cities in Shaanxi, Gansu, Hebei, Shandong, and Hunan were slight deficit regions (−0.3 < CSDM < −0.1). Cities in Heilongjiang, Jilin, Xinjiang, and other northern provinces, as well as cities in Fujian, Hubei, Yunnan, and other southern provinces, showed a surplus in the supply and demand match of farmland living function. However, cities in Putian, Quanzhou, and Xiamen, located in the eastern coastal region, are in a more serious deficit situation regarding the farmland living function. The supply–demand balance areas (−0.1 < CSDM < 0.1) are mainly distributed in the neighboring cities of the slight deficit cities. Over time, the number of cities in the deficit region shows a decreasing trend, with the proportion of deficit regions decreasing from 51% to 31%, the supply–demand balanced regions starting to increase, and the proportion of balanced regions increasing from 22% to 36%.

4.2. Impact of Multifunctional Farmland Supply–Demand Matching on Farmland Transfer Prices

To further explore the spatial correlation between multifunctional supply and demand matching of farmland and farmland transfer prices, GeoDa1.16 was used to measure the bivariate global Moran's I index for both (Table 2).

Table 2. Bivariate Global Moran's I Index.

	Production Function	**Living Function**	**Ecological Function**
Farmland transfer price in 2014	−0.162 (0.0251) ***	−0.220 (0.0271) ***	0.023 (0.0261)
Farmland transfer price in 2017	−0.172 (0.0260) ***	−0.209 (0.0264) ***	0.031 (0.0247) *
Farmland transfer price in 2021	−0.220 (0.0263) ***	−0.275 (0.0270) ***	0.049 (0.0253) **

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

From Table 2, it can be seen that the bivariate Moran's I index for the degree of supply and demand of the farmland production function, living function, and farmland transfer price are all negative in 2014, 2017, and 2021. They passed the test at the 95% significance level. This indicates a significant negative spatial correlation between them. Moran's I index for the supply and demand degree of farmland living function and farmland transfer price is slightly higher than that of the farmland production function. This negative correlation continues to increase. Conversely, Moran's I index for the degree of supply and demand of farmland ecological function and farmland transfer price was not significant in 2014. It shows a significantly positive correlation in subsequent years and tends to increase. This demonstrates a significant and growing positive spatial correlation between the supply and demand levels of farmland ecological function and farmland transfer price. Based on this, a bivariate local spatial autocorrelation LISA clustering map (Figure 7) was created to clearly show the local spatial relationship between the functions of farmland and the price of farmland transfer. By comparing the spatial distribution of LISA clustering of the supply and demand of different farmland functions and farmland transfer prices in 2014 and 2021, four types of areas were identified.

The first type is a high-value zone for both the supply and demand of farmland functions and farmland transfer prices. This is similarly distributed for both the production and living functions, mainly concentrated in Shandong, Jiangsu, and parts of Guizhou and Henan, with the number of high-value cities remaining relatively stable. Regarding the ecological function of farmland, high-value zones are mainly in Guizhou, with some in Jiangsu, Zhejiang, Shandong, and Henan. The number of high-value cities has increased from 37 in 2014 to 46 in 2021.

The second category is the low-value zone for both the supply and demand of farmland functions and farmland transfer prices. For the production function, these zones are primarily in Inner Mongolia, Xinjiang, and Qinghai. Jiangxi and Hunan have also become low-value zones for living and ecological functions. The number of cities in the low-value zone for the ecological function supply and demand and farmland transfer prices (43) is significantly higher than for the production and living functions (20 and 23, respectively).

The third category is the low-value zone for the supply and demand of farmland functions and the high-value zone for farmland transfer prices, mainly concentrated in southern Hebei, southern Jiangsu, and Zhejiang, and sporadically in Guizhou, Sichuan, and Guangdong. The number of cities in this category for ecological function decreased from 45 in 2014 to 37 in 2021.

The fourth category is the high-value zone for the supply and demand of farmland functions and the low-value zone for farmland transfer prices. The number of cities in this category for production and ecological functions (55 and 51, respectively) is significantly higher than that for living function (32). Most cities in Heilongjiang and Jilin are always in this category for production and living functions, while the cities in Jiangxi and Hunan do not fully exploit them despite having good production conditions, resulting in this classification. Similarly, Heilongjiang and Jilin have better ecological resources that have not been fully utilized, placing them in this category for ecological function.

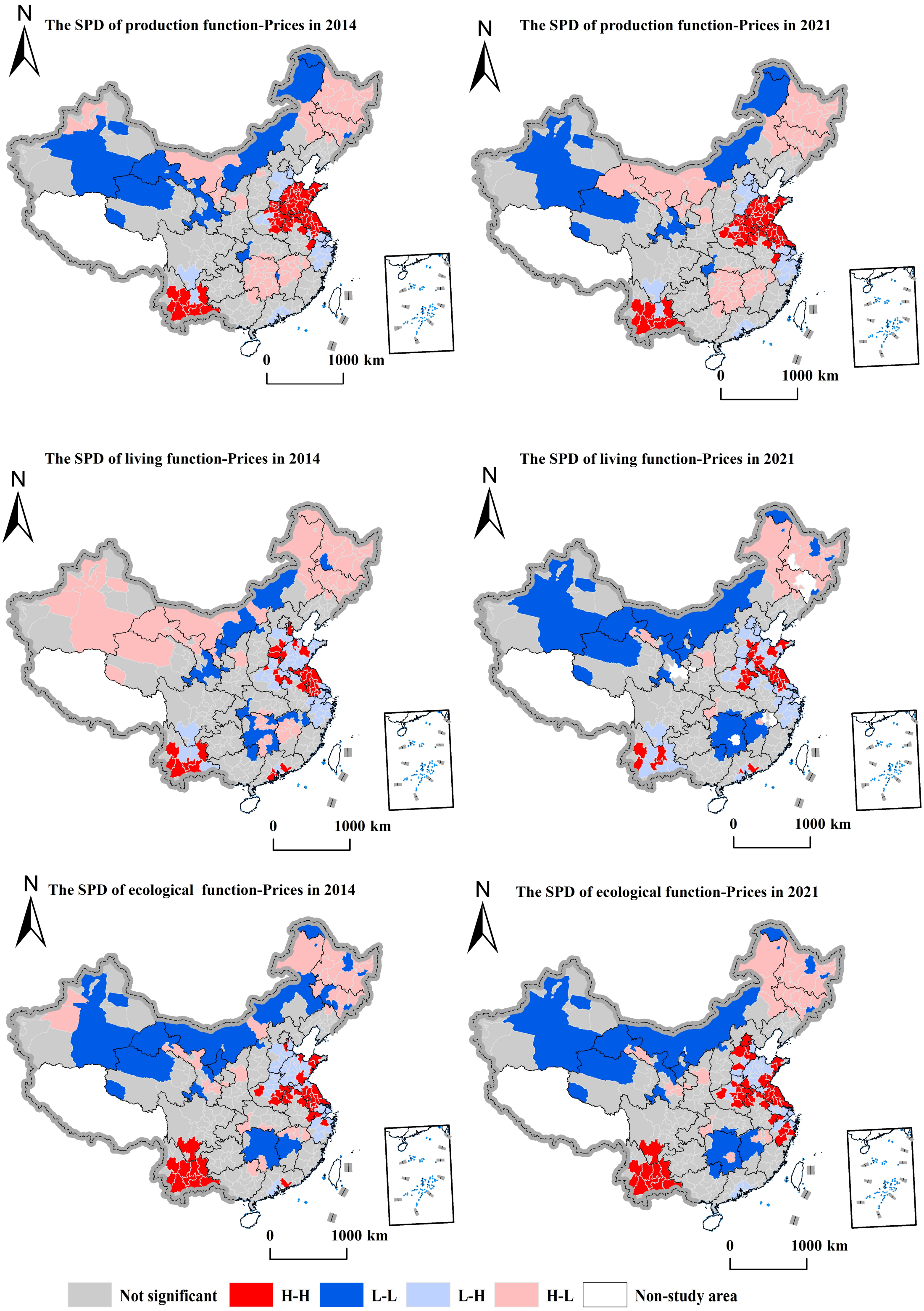

Figure 7. Bivariate local spatial autocorrelation LISA clustering plot.

4.3. Functional Zoning of Farmland Based on the Analysis of the Relationship between Multifunctional Supply and Demand of Farmland and Farmland Transfer Price

Based on the foregoing, it can be observed that there are different spatial autocorrelations between the degrees of supply and demand of various farmland functions and farmland transfer prices. This will be considered in the zoning of farmland functions to facilitate the subsequent implementation of differentiated price management for different farmland functional areas. In this study, we use the bivariate spatial autocorrelation Moran's I index to correct the degree of supply and demand and employ the improved coupled coordination model to calculate the degree of coordination. The utilization of farmland is then zoned according to the type of supply and demand for each function (Figure 8).

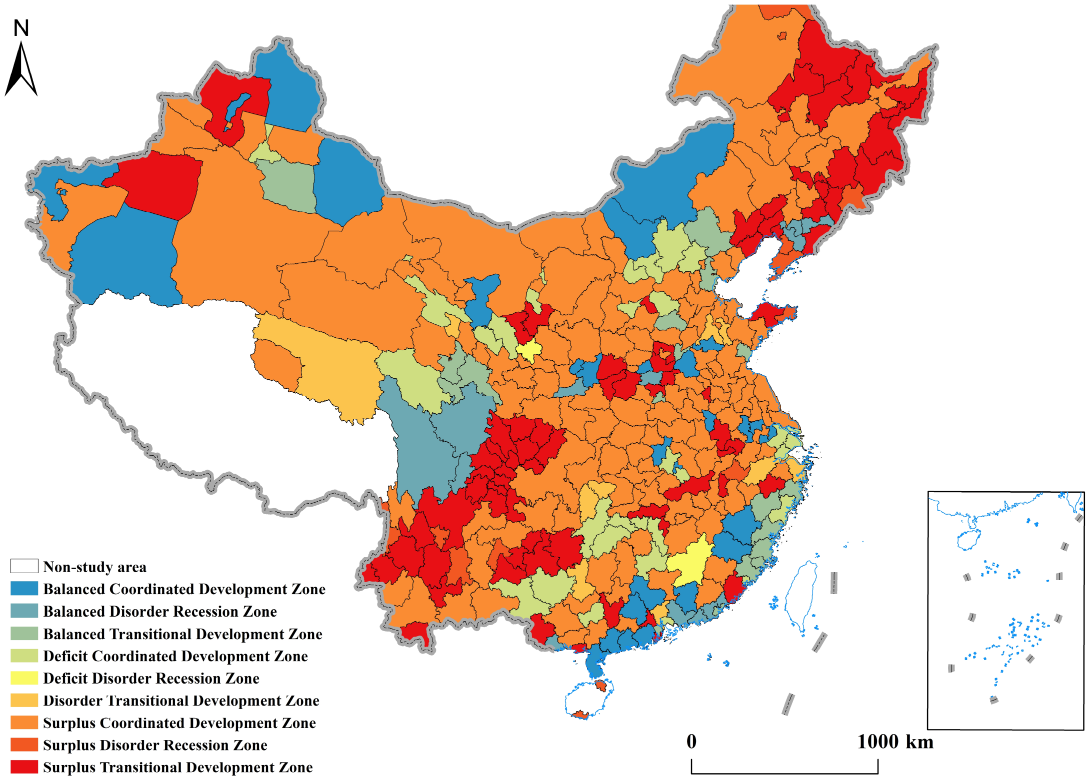

Figure 8. Results of functional zoning of farmland.

In terms of coordination, about 60% of the cities fall into the coordinated development category, with the transitional development category accounting for about one-third. From the perspective of supply and demand, the surplus type is predominant, with about 68% of the cities exhibiting a surplus in the supply and demand of farmland functions. For the coordinated development type, zoning should consider enhancing the advantage of balanced supply and demand for farmland functions in the region, and improving areas with surplus supply and demand. For the transitional development type, zoning should focus on maintaining the advantage of a balanced supply and demand of farmland and coordinating the development of areas with surplus supply and demand. For the dysfunctional decline type, zoning should concentrate on developing areas with supply and demand deficits and maintaining areas with balanced supply and demand to achieve the goal of the coordinated development of multifunctional farmland. Based on this, farmland is further divided into nine types of zones: balanced, coordinated development zone, deficit coordinated development zone, surplus-coordinated development zone, balanced transitional development zone, deficit transitional development zone, surplus transitional development zone, balanced dislocation recession zone, deficit dislocation recession zone, and surplus dislocation recession zone.

In the coordinated development category, the surplus-type coordinated development areas are mainly concentrated in the middle and lower reaches of the Yangtze River, where the economy is more developed and water and heat resources are abundant. The deficit-type coordinated development areas are mainly scattered in Hunan, Guangxi, Hebei, Shanxi, and other cities, where the supply and demand of farmland for living function are in a more serious deficit despite the surplus supply and demand of farmland for production function. In the transitional development category, the surplus transitional development areas are mainly concentrated in the northeast plains and the Yunnan-Guizhou Plateau region, where the surplus supply and demand of farmland production and ecological function are more significant, but the supply and demand of farmland living function are lower. In the dysfunctional decline category, the number of cities is fewer and more sporadically distributed. Balanced dysfunctional decline cities are mainly found in Sichuan and southern Liaoning.

5. Discussion

5.1. Spatial Patterns of Farmland Multifunction Supply–Demand Matching

Analysis of the farmland multifunction supply–demand matching reflects the degree to which the capacity of the farmland resource to provide products and services aligns with evolving social needs. It can provide fundamental information for farmland protection and farmland multifunction management [54]. The spatial patterns reveal that the supply and demand matching of farmland multifunction exhibits significant spatiotemporal variation. Overall, the supply of farmland production and ecological functions exceeds the demand, while the supply of the farmland living function falls short of the demand. This result is understandable. On the one hand, with the continuous improvement in agricultural technology, the supply capacity of farmland production function has significantly increased [55]. Food production has continuously increased. On the other hand, changes in dietary structure have expanded people's sole demand for food to a demand for various items like meat, eggs, milk, and vegetables [56], which has reduced the demand for crops to some extent. The supply level of the farmland ecological function exceeding the demand level is due to the low perception of the ecological function provided by farmland. In the context of insufficient rural livelihood security, farmland serves as the primary guarantee for farmers' livelihoods. The supply level of its living function struggles to meet the rapidly increasing consumption levels of farmers [57]. This understanding is derived from analyzing the supply–demand of farmland multifunction.

Similar to existing research, the supply of farmland multifunction exhibits clear spatial differentiation patterns [58]. Existing research mostly focuses on the supply side, enriching the understanding of farmland multifunction and establishing the relationship between farmland multifunction and value [59]. This provides a theoretical foundation for measuring farmland multifunction and accounting for their value [60]. However, it overlooks the mismatch between supply and demand caused by differing preferences among various stakeholders. Moreover, our research found that the North China Plain is characterized by an excess of farmland production function, while it has deficits in ecological and living function. Although farmland resources in the same area have similar characteristics, the mismatch in the supply–demand of different farmland functions is due to varying demand preferences. Additionally, under the implementation of food security policies, certain regions must grow grain crops instead of other cash crops. This results in a low supply but high demand for the farmland living function, causing an imbalance between supply and demand. Examples include major grain-producing areas like Sichuan, Hebei, Shandong, and Hunan. This finding aligns with existing research, which indicates that Hebei's farmland living function is notably low [61].

From the perspective of measurement methods, current research on the farmland multifunction primarily uses statistical data and comprehensive weighting methods to evaluate and calculate the farmland multifunction. It also analyzes the trade-offs/synergies between various functions. However, the quantitative indicators and methods used lack specificity, leading to situations where the same indicator measures different functions, such as the land reclamation rate being used to measure both production and ecological functions [62,63]. Additionally, from the perspective of evaluation purposes, existing research on farmland multifunction often focuses on the value of multifunctionality and the trade-off/synergy relationships from a supply perspective while neglecting the demand side and further exploration of changes in farmland multifunction from both supply–demand perspectives. Meanwhile, the quantitative indicators and methods used vary significantly in existing research, leading to the inability to compare the quantitative results horizontally and vertically. Although some studies have found that the production function supply in Wuhan is less than the demand, the production function supply–demand balance in Hangzhou is consistent with the results of this study [25,53]. These results are mostly based on a single point in time and do not involve dynamic research across multiple or continuous periods. Based on previous research, this study selects indicators for farmland production, ecological, and living functions from the perspectives of physical quantity, value, and material quantity. It integrates multiple data sources, including vector data, raster data, and statistical data. Different methods, such as the single indicator method, value method, and material quantity method, are used to calculate the supply–demand levels of farmland function. To avoid differences in the dimensions of supply–demand levels for different functions, the CSDM is chosen to measure the degree of supply–demand matching. Additionally, to further characterize the spatiotemporal evolution of farmland multifunction supply–demand matching, this study examines the spatial distribution of supply–demand matching from 2014 to 2021. It provides a more comprehensive analysis of the dynamic study of farmland multifunction supply–demand matching across continuous periods. By measuring the supply–demand matching of farmland multifunction, we can not only clarify the degree of matching between the capacity of the farmland resource system to provide products and services and the needs of socioeconomic development, but also provide more accurate information for the management of farmland multifunction.

5.2. Analysis of the Impact of Supply–Demand Mismatch on Farmland Transfer Prices

This study found that the matching of supply and demand for farmland multifunction profoundly affects farmland transfer prices, influenced by changes in China's primary social contradictions and the development of the land transfer market. This is because socioeconomic changes have led to shifts in the supply and demand of farmland multifunction, causing unreasonable fluctuations in farmland transfer prices, which poses higher demands for farmland multifunction management. On the one hand, the impact of land market changes during social development on farmland prices is self-evident. Since 2007, Ethiopia has experienced a significant increase in farmland demand due to soaring global grain prices and high grain costs [64]. Continuous social development has diversified the supply and demand for farmland function. In China, the dominant function of farmland has varied across different periods, leading to corresponding changes in farmland transfer prices. In the early stages of China's reform and opening-up, the production function of farmland gradually strengthened [65], and farmland transfer prices began to take shape. With agricultural structural adjustments and the deep implementation of pro-farmer policies, the production function continued to strengthen, and farmland transfer prices entered a high-growth phase [66]. As ecological civilization advances, the ecological function of farmland gradually becomes apparent, while the production function weakens due to low agricultural profits and changes in the dietary structure. On the other hand, the regional differences in the multifunctional supply capacity of farmland highlight the contradictions in its utilization. The varying levels of human demand across regions further affect the contradictions in the supply of farmland multifunction, leading to polarization in farmland transfer prices across different areas. Consistent with Song's study, the supply capacity for production and ecological function is strong in plain areas; farmland transfer prices are relatively high, whereas in mountainous areas, where the supply capacity for production and living function is weaker, farmland transfer prices are generally lower [67]. These spatial and temporal factors have gradually widened the gap between the supply and demand of farmland multifunction, leading to unreasonable fluctuations in farmland transfer prices. Therefore, it is necessary to explore the relationship between the balance of supply and demand for farmland multifunction and farmland transfer prices. This is not only an important direction for the practice of farmland multifunction management but also an urgent need in the field of farmland use transformation research.

Existing research on farmland transfer prices mainly focuses on price distribution and influencing factors. However, the externalities arising from the use of different farmland functions have varying degrees of impact on farmland transfer prices. It is necessary to explore the relationship between function supply and demand and prices from the perspective of farmland multifunction. Existing studies suggest that there are significant differences in farmland multifunction in China, with production, living, and ecological functions all exhibiting spatial clustering [58]. Additionally, farmland prices in China show significant spatial correlations and clustering [68]. Despite these spatial clustering characteristics, there has been little in-depth exploration of the relationship between these two aspects. This paper uses bivariate spatial autocorrelation analysis to further explore the relationship between the matching of farmland multifunction supply and demand and farmland transfer prices. The differences in multifunctionality supply and demand can profoundly affect the realization of farmland value.

The research shows that, overall, the supply–demand matching degree of farmland production and living functions is significantly negatively correlated with farmland transfer prices, and this negative correlation has continued to strengthen over time. The supply–demand matching degree of the farmland ecological function is significantly positively correlated with farmland transfer prices, and this positive correlation has continued to strengthen. This indicates that an imbalance in the supply and demand of farmland function can easily lead to uncoordinated responses in farmland value, which is consistent with previous research [59]. When the supply–demand matching of farmland production and living functions is in a surplus state, farmland transfer prices tend to be low. When the supply–demand matching of the farmland ecological function is in a deficit state, farmland transfer prices decrease accordingly. However, when the supply–demand matching of the farmland ecological function is in a surplus state, farmland transfer prices increase instead. This price increase may be due to a price illusion generated by the valuation of farmland multifunction, which is reflected in the realization of ecological product value. The LISA cluster spatial distribution map shows significant differences in the clustering patterns between farmland multifunction supply–demand matching and farmland transfer prices. For example, in terms of farmland production and living functions, high-value clusters of supply–demand matching and high-value clusters of farmland transfer prices are mainly concentrated in cities in Shandong, Jiangsu, and parts of Guizhou and Henan. However, in terms of farmland ecological function, most cities in Shandong are low-value clusters of supply–demand matching but high-value clusters of farmland transfer prices. Therefore, it is necessary to comprehensively consider the relationship between farmland multifunction supply–demand matching and farmland transfer prices and to conduct further regional studies to provide differentiated strategies for improving farmland transfer pricing.

5.3. Pricing Management of Farmland Transfer Based on Functional Zoning

Based on the spatial correlation characteristics between different levels of farmland function supply–demand and farmland transfer prices. This further confirms that the supply–demand gap in farmland multifunction leads to irrational fluctuations in farmland transfer prices. Therefore, based on the relationship between these two factors, farmland function zones should be delineated to coordinate and regulate the supply and demand of farmland multifunction in order to rationally realize the composite value of farmland and stabilize the level of farmland transfer prices.

Previous studies have mostly proposed zoning schemes based on the trade-offs and synergies of farmland multifunctional value, current farmland conditions, and agricultural production characteristics. The results of these zoning efforts can provide a basis for the use and management of farmland [37]. Additionally, in order to prevent the excessive capitalization of farmland, scholars have selected factors influencing farmland transfer prices and used geographic information technology to indirectly delineate the price zoning of Chinese farmland [69]. This has provided support for the present study. The current challenges in managing farmland transfer prices urgently require the establishment of new mechanisms to ensure that the multifunctional value of farmland is realized and returned to farmers. By considering the annual evolution of the coupling coordination model and the types of supply–demand matching. Nine major zones are ultimately delineated. Compared with the results of previous zoning studies, the zoning results of this study not only consider the relationship between the supply–demand matching degree of a single function and farmland transfer prices over continuous periods, but also comprehensively consider the coupling coordination relationship between multifunctional supply and demand. The zoning results can better allocate farmland resources and precisely optimize the methods and strategies for determining farmland transfer prices. For example, regions with better functional matching can adopt high-price strategies and urban land valuation methods. In contrast, regions with poor functional matching can adopt low-price strategies to increase transfer rates. At the same time, the zoning results fully ensure the integrity of administrative regions, making it easier to guide the improvement of farmland transfer pricing mechanisms within the same municipal area.

In terms of specific management practices, differentiated management strategies for farmland transfer prices should be formulated based on the characteristics of the functional zoning of farmland. For coordinated development types, zoning should first improve areas with an oversupply of multifunctional farmland. On the basis of maintaining the advantages of coordinated multifunctional development, the supply of farmland should be regulated. Efforts should be made to enhance residents' awareness of the multifunctionality of farmland, particularly its ecological function. This will increase the demand for ecological function in economic development. By providing ecological protection subsidies to farmland, the minimum farmland transfer price can be increased. This will help strengthen the construction of ecological landscapes in farmland. For supply–demand balanced areas, strict control over land use must be enforced. This ensures the quantity, quality, and ecological integrity of the farmland. Flexible pricing policies should be established to allow the market greater freedom to determine transfer prices. This further strengthens the coordination of the supply–demand balance of multifunctional farmland. For areas where supply is less than demand, the specific farmland function causing the imbalance should be precisely identified. This study found that the supply–demand deficit for the living function of farmland is particularly severe. The reason is that the supply capacity of the living support function of farmland has weakened over time [57]. This is especially true in areas restricted by ecological protection or grain production. In these areas, the supply of the living function is significantly lower than the demand. Therefore, corresponding agricultural subsidies should be provided to these areas. The farmland transfer price levels should be dynamically adjusted according to market demand. For transitional and declining areas, the main issue is the imbalance between the deficit in the living function and the surplus in production and ecological functions. In the pricing method, development strategies should be chosen based on the differences in supply–demand matching of farmland function. These strategies should strengthen the living function of farmland without damaging farmland resources or the ecological environment. At the same time, the continuous generalization of farmland function should be avoided. Therefore, it is necessary to determine farmland transfer pricing models according to the supply–demand matching of different farmland functions. For example, in the case of the production function, factors directly related to farmland production should be selected and used in a hedonic pricing model.

Implementing the above farmland transfer price management strategies based on different zoning situations can reasonably highlight the value of farmland multifunction to some extent and standardize farmland transfer prices. However, there still exists the challenge of reasonably attributing the highlighted multifunctional value of farmland. Therefore, it is necessary to fully consider the needs and expectations of different stakeholders. The attributes of the highlighted multifunctional value of farmland should be clarified according to the characteristics of the different farmland functions and zoning situations. The following approaches can be adopted during the implementation. First, identify the core stakeholders most affected by the supply–demand imbalance of farmland functions in different zones. For example, in areas where the supply of the production function of farmland exceeds demand, grain farmers' interests are most severely damaged [70]. Second, based on the core stakeholders' preferences and endowed characteristics regarding farmland functions, select an appropriate farmland transfer pricing model. Finally, the estimated prices obtained from the model are combined with the types of stakeholders involved in the transfer process to choose a reasonable pricing method. For example, if the transfer is between acquaintances, an autonomous agreement can be chosen based on the valuation results obtained from the farmland transfer pricing model. Additionally, appraisal professionals should continuously enhance their technical skills. Policymakers should strengthen the dynamic supervision of farmland transfer prices before and after the transfer process.

6. Conclusions

This study established an evaluation index system for the supply and demand of multifunctional farmland in China. It also mapped the supply–demand patterns of production, living, and ecological function of farmland across 329 prefecture-level cities from 2014 to 2021. The results further confirmed the significant spatiotemporal heterogeneity of the mismatch between the supply and demand of multifunctional farmland. The study also revealed the impact relationship between this mismatch and farmland transfer prices. Based on the interactive relationship between supply–demand and land transfer prices, management zones for land transfer pricing were delineated. The land transfer pricing methods were improved through functional zoning. This balance of supply and demand aims to alleviate the real-world issue of unreasonable fluctuations in farmland transfer prices.

The study showed that there is an oversupply of the production function in China's plains areas. There is a surplus of ecological function supply and demand in the Yangtze River Economic Belt and northeastern Inner Mongolia. However, the living function of farmland is undersupplied, especially in non-plain areas. The supply–demand degree of production and living function of farmland shows a significant spatial negative correlation with transfer prices. This correlation becomes more pronounced over time. In contrast, the spatial positive correlation between the supply–demand degree of the ecological function and transfer prices is continually strengthening. Additionally, the study found significant differences in the quantity and distribution of different land function areas. The surplus-type coordinated development zones account for the largest proportion, with balanced development zones mainly concentrated in the southeastern coastal areas. In contrast, the deficit-type disordered and declining zones include only a few cities.

To seek pathways for realizing the value of farmland multifunction. Attention must be paid to the supply–demand matching level of farmland functions. Starting from the spatial autocorrelation relationship between the supply–demand degree of farmland functions and farmland transfer prices. Dynamic regulation of both parties' preferences for the supply and demand of farmland functions is necessary. This can help address the issue of price illusion caused by the valuation of farmland multifunction. Additionally, attention should be paid to the supply level of each farmland function. Enhancing the awareness of both parties regarding the various functions of farmland is essential. Increasing the demand for various farmland functions in economic development is crucial. The price management system for different farmland zones should be improved. Exploration of improved methods for valuing land transfer prices is necessary. This will help reasonably tap into the value of farmland multifunction in different regions.

The spatial distribution of farmland supply–demand relationships tends to change with scale [25]. However, such research is limited by the constraints of existing data. Therefore, building a more systematic database and quantifying alternative indicators would be beneficial. This will better facilitate the exploration of the temporal dynamics of supply–demand relationships. Moreover, due to the complexity of the land system and the limitations of data availability. The indicator system used in this study to characterize the supply–demand of farmland multifunction still needs further improvement. The methods for selecting and measuring landscape and cultural supply–demand indicators in ecological function will be improved. The relationship between farmland supply–demand and transfer prices will be deeply studied among micro-scales, such as counties, villages, and households. This will promote the sustainable use of farmland and improve precise management mechanisms for farmland transfer prices.

Author Contributions: Conceptualization, G.R.; Investigation, G.R.; Methodology, L.W.; Software, L.W.; Supervision, G.R.; Writing–original draft, L.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

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

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