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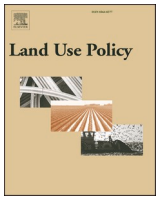

The development of multifunctional agriculture in farming regions of China: Convergence or divergence?

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ABSTRACT

The multifunctionality paradigm, in particular, represented a facilitator of sustainable agricultural development. There arises a question of whether or not the different areas would evolve in a common direction. This study attempts to examine the dynamics and performances of multifunctional agriculture (MFA) in farming regions of China by using the multi-criteria comprehensive appraisal method and convergence analysis. The integrated function and multifunctionality of agriculture in the Huang-Huai-Hai Plain are assessed, based on which the evolving trend is investigated. The findings reveal that from 1990 to 2015, the multifunctionality of agriculture in the Huang-Huai-Hai Plain was strengthened, displaying clear agglomeration in larger metropolitan regions, which has been a characteristic of MFA in regions with a thriving economy. The supply function for agricultural products arose during 1990–2000, then maintained steady, while suffering a recession in Beijing-Tianjin-Hebei urban agglomeration and Jiaodong Peninsula. The function of social security generally continued to increase, presenting a spatially surging trend from north to south and from east to west. The function of facilitating agricultural economic development was also enhanced, especially in the clusters including the Beijing-Tianjin urban agglomeration, the Jiaodong Peninsula, and the northern Jiangsu Province. The function of ecological conservation displayed obvious spatial heterogeneity, and the functional index manifests no apparent variation. The σ coefficients of each functional index indicate that path dependence, which excludes the function of social security when there are regional disparities, is a crucial characteristic of the evolution process of the MFA subdimensions. Areas with low multifunctionality do not grow faster than areas with high multifunctionality, and they are differentiated in terms of their performance. The "catch-up effect" is clearly apparent when external forces intervene, as evidenced by the absolute and conditional β convergence. These findings have important ramifications for the creation of policies that, in line with the market rationality of territorial division, encouraging MFA in peri-urban and economically developed areas while fostering large-scale and industrialized farming in distant areas.

1. Introduction

The multifunctionality of farming activities signifies the shift from a productivist to a post-productivist agricultural regime (Rodríguez Sousa et al., 2020; Long, 2020, 2022). China's agricultural development paradigm stated to transform from production to provision of multiple services and functions by agriculture as the rapid economic growth, urbanization, as well as agricultural intensification, have led to sustainability crisis and diversified demands of urban and rural residents for agriculture (Long, 2022; Rallings et al., 2019; Song and Robinson, 2020). The No.1 Policy Document of 2018 and Rural Vitalization Plan of China's central government stressed the importance of multifunctional agriculture (MFA), which signifies that policy and accompanying practice have started to focus on the multiple goods and services (food and non-food) produced by agriculture. Correspondingly, China's agricultural support policies are moving towards a multifunctional paradigm (Long et al., 2022; Liu et al., 2020). For example, the agricultural subsidies are not merely provided for motivating grain production, also

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used for encouraging distinctive agricultural production and farm-based tourism.

The common propositions of the different definitions of MFA refer to agriculture as a multi-output activity embracing various goods, products, and services, which provides a theoretical lens to characterize agricultural systems. The OECD's (2001) "working definition" stated that the critical elements of multifunctionality are the existence of multiple commodities and non-commodity outputs that are jointly produced by agriculture. Tilzey (2003) argued that MFA seeks to capture the multiple benefits and services connected with agricultural systems that should benefit human and non-human nature alike. Considering the dynamics of MFA development, Renting et al. (2009) proposed an inclusive definition from a transition-oriented approach, which recognizes that MFA doesn't refer to a static state-of-affairs, but can be considered as a transitional and dynamic process.

The assessment of agricultural function is the fundamental work of depicting the multifunctional character of agricultural development. One group of literature proposed approaches in which multiple dimensions were taken into account. A multivariate approach is one of the most usual techniques to evaluate the multiple dimensions of MFA. Gómez-Sal et al. (2003) incorporated three or more dimensions in their approach to agricultural landscapes assessment. Some works focused on certain agricultural functions, such as grain production, ecological services, agricultural externality, and biological diversity. Another group of studies investigated MFA from a comprehensive perspective and attempted to assess the agricultural function by using an integrated model. In terms of the theoretical framework, Madureira et al. (2007) established an all-inclusive assessment framework for the non-commercial output of an agricultural landscape. Besides, case studies have been conducted at different scales (Ma et al., 2021). Othman (2004) observed the multifunctionality of agriculture in terms of social, cultural, and food security functions at the farm and national levels. As for regional case studies, Li et al. (2005) assessed the function of an agricultural ecosystem in Hubei Province, China. Despite a growing body of research being implemented with a special focus on quantifying the multifunctionality of agriculture, much work still awaits investigations into the spatiality of multifunctionality, especially in traditional farming regions, and there is currently insufficient research into the characteristics of the multifunctional region.

The ways of the unfolding of MFA are spatially heterogeneous and diverse. Different regional characteristics will construct differentiated actions of agriculture, and shape diversified trajectories of MFA development. Some studies have been concerned with the territorial differentiation of MFA, and the spatio-temporal dynamics of MFA development based on the multi-criteria assessment techniques. Wilson (2009) established a conceptual framework for the spatiality of MFA, which, however, has not been applied to an empirical assessment. The spatiality of MFA is often elaborated in research on peri-urban areas (Hrabak and Konecny, 2018) with high potential for MFA development. Consumer perspectives and demand for farm products are stressed in these studies (Syrovátková et al., 2015). In Chinese literature, some papers depicted the regional heterogeneity by classifying MFA into several sub-functions, including food production, job provision, economic development, biodiversity, etc. (Gao and Peng, 2021; Fang et al., 2019; Tan et al., 2018; Jiang et al., 2022). Generally, assessments of MFA practices that focus on the spatial dimension have been quite limited. Although some literature performed a trade-off analysis between criteria groups (economic and ecological) and made a comparison between different development scenarios (Huylenbroeck and Coppens, 1995; Zhang et al., 2019), the literature reveals a paucity of information concerning how the sub-functions develop, in other words, the directions that MFA follows. In sum, there is insufficient information concerning the dynamics and the tendency of MFA development and how external forces influence the trajectories. These are the gaps that we seek to fill.

Therefore, the aim of the present article is two-fold. First, we attempt to supply principles and tools useful for a comprehensive evaluation of agriculture, which contributes to the quantification of multiple evaluative dimensions of MFA. Second, the dynamics of MFA are investigated by convergence analysis. We try to examine whether the convergence tendency exists under the influence of external socio-economic interventions.

2. Conceptual underpinnings

The notion of multifunctionality originated in the context of European Union (EU) agricultural policy as a way to characterize the non-production goods arising from European agriculture and, ultimately, to defend domestic subsidies for systems that provide these "non-trade distorting" services (Freshwater, 2002; Hollander, 2004). It is usually perceived to be that which encompasses and supports all commodities and non-commodities goods and services that result from agricultural activities. Another argument for US agriculture emphasizes its role in generating more advantageous economic, sociocultural, and environmental externalities that support rural development (Song et al., 2022). These two discourses share the view that agriculture is an economic activity that, beyond its primary function of supplying food and fibre, provides various non-market benefits to the society (Hediger and Knickel, 2009). The outputs incorporate diverse range of socio-economic and cultural benefits, such as those related to food security and animal welfare, a basic level of rural employment that contributes to the viability of rural areas, the non-use and intrinsic values of cultural heritage, etc., as well as the environmental benefits, such as recreational amenities and aesthetic values of the rural landscape, non-use values of biodiversity and habitat protection, important ecosystem and watershed functions, etc. Multifunctionality and ecosystem service both focus on the "functions" generated by ecosystem processes, while multifunctionality is more interdisciplinary. Multifunctionality also encompasses non-ecosystem outcomes from interactions between socio-ecological systems, such as a strengthened feeling of community and an enhanced standard of living in an agricultural setting (Brummel and Nelson, 2014). Ecosystem services of agricultural landscapes generally include three categories-provisioning, supporting/regulating, and cultural/landscape aesthetic services. Furthermore, it is impossible to isolate MFA from rural transformation process (Robinson and Song, 2019). The most representative uses of rural space in regional Australia are described by Holmes' modes of occupancy typology (Holmes, 2006), which are particularly relevant to the diversity of agriculture-related benefits. These serve as references for categorizing the functions of agriculture.

As a geographically conditioned process (Holmes, 2006), the conceptualizations of multifunctionality should, therefore, be closely intertwined with issues of scale. At the regional level, rural multifunctionality issues assume a more important role than agricultural production and its related issues (Holmes, 2006), as it is merely one of the dimensions of the economic sector. Unlike the farm level, regional-level multifunctionality highlighted the synergistic and comprehensive representations of multiple outputs generated by agricultural activities rather than the individual decision-making processes such as diversification and intensification or other multifunctional practices at the smallest spatial unit (Wilson, 2008; Hediger and Knickel, 2009). It is recognized that the production function is the pivotal function, referring to other functions as externalities, or services (job provision, aesthetics, recreation, etc.). Several dimensions of the outcomes or benefits from MFA have been debated, including food supply (Wiskerke, 2009), local jobs (Evans, 2010), culture (Paarlberg et al., 2002), rural life (Vejre et al., 2007), landscape and biodiversity conservation (Renting et al., 2009; Roth et al., 2008), etc. Some literature focus on the mono-functional assessment, such as ecological services (Palm et al., 2014), biological diversity (Roth et al., 2008), and agricultural landscape (Flick et al., 2012). Another group of theoretical and empirical studies examined the multifunctionality of agriculture from an

integrated perspective. Madureira et al. (2007) proposed a multi-attribute valuation approach to the agricultural non-commodity outputs.

MFA coincides with economic development. Economic growth can catalyze the shifts in societal expectations on agriculture. Production-oriented agriculture is closely linked to a low level of economic development. It occurs when farmers grow food crops to meet the needs of themselves and their families on smallholdings. At this stage, the primary function of agriculture is satisfying the basic physiological needs, which is the biological component for human survival, according to Maslow's hierarchy of needs. As agricultural production transforms into integrated and more complex market chains, the agriculture is becoming more productive and intensified. While differentiated demands by consumers promote the creation of additional value for agriculture, integrating agricultural production increases with environmental and biodiversity preservation. Therefore, the characterization of the combinations of functions evolves with societal demands in connection with economic development level. It has been suggested by several authors that agricultural transitional paths should be viewed as a multifunctional spectrum, with productivist and non-productivist action and thought as its two ends (Hollander, 2004; Holmes, 2006). Regional economic development level plays a key role in conceptualizations of weak, moderate and strong multifunctionality, as the interlinkage of agriculture with diverse societal demands can be seen as a possible contributing factor towards strong multifunctionality. According to the neoclassical growth theory, income disparities between nations will eventually converge because wealthy nations on the technological frontier can only advance by embracing new technologies, while developing nations have the potential to do so by catching up to developed nations in specific industries and reallocating resources from low- to high-productivity sectors (Gollin et al., 2013; Fukase and Martin, 2017). As the economy grows, the multifunctionality of regional agricultural growth will undergo a dynamic convergence tendency, displaying a trend comparable to that of regional economic development.

3. Methodology

3.1. Study area

The Huang-Huai-Hai Plain is one of the major farming regions in China, spanning five provinces (Jiangsu, Anhui, Shandong, Henan, and Hebei) and two municipalities (Beijing and Tianjin) (Fig. 1). It produces 70% of China's wheat and 30% of its maize, while its arable land area, population, and grain output account for 20.6%, 22.5%, and 30.8% of the nation's total, respectively (NBSC, 2016). The number of rural labor forces expanded from 428.9 million in 1990 to 532.5 million in 2017, but the proportion of rural employment in agriculture decreased considerably. The dynamics of demand from urban consumers and central city development is transforming the agricultural landscape. The Huang-Huai-Hai Plain is therefore seen as an appropriate national representation when discussing the dynamics of MFA development.

The reasons for selecting the Huang-Huai-Hai Plain as our study area are as follows: a. It is undergoing a transition from traditional agriculture to modern agriculture, which is underpinned by advanced technology, large-scale farming, etc., and has progressed towards a sustainable high efficient agriculture. b. Many cities, including Beijing,

Fig. 1. The location of the study area.

Tianjin, Jinan, Shijiazhuang, and Zhengzhou, demonstrate particular desires for expanding the agricultural functions (sightseeing, leisure, and affinity with nature to citizens). c. The differentiation of socio-economic and natural conditions provides a suitable environment for the heterogeneity of multifunctional development. Overall, the agricultural development of the Huang-Huai-Hai Plain has been a process of expanding its roles from just producing food to the combination of characteristics including food production, ecological balance, and societal development.

3.2. Assessing indicators for MFA

Quantifying the multifunctionality of agriculture starts with creating an index system of assessment. Considering the agricultural system is an assemblage of components, which consists of three broad families or divisions-social, economic, and natural systems, it is broadly accepted to divide agricultural functions into social, economic, and ecological dimensions. Given the characteristics of farming regions, we underline the agricultural product supply function.

- The function of agricultural products supply is embodied in the outputs of agricultural production, which can be characterized by the grain production capacity and the output value (Tran et al., 2022). They can be quantified in terms of grain output per acre of farmland and grain output per capita. The majority of agricultural production in farming areas is made up of grain crops, which is essential for ensuring China's food security (Huang et al., 2015).
- Economic function attributes were assessed analytically using the value of commodity outputs, which have been measured within two dimensions economy (the production of marketable grain food, the contribution to GDP). Hence, agricultural production outputs, which mean the market value of grain and non-grain products, can be quantified by both the indexes of the gross output value of agricultural products per capita (Peng et al., 2015), the share of agricultural production in GDP (Daniel and Perraud, 2009), as well as the agricultural mechanization (Hodbod et al., 2016).
- The social function is essential, especially in the processes of rural divergence. Social representations (i.e. employment, welfare, level of income, comforts, and services available) fall within a social optimal mix of functions in agricultural landscapes (Abler, 2004; Dubois and Carson, 2020; Brummel and Nelson, 2014), since they determine an impact on the rural society, contributing to the welfare and the civil improvement of its members (Song et al., 2022).
- The ecological function of agricultural landscapes is particularly important for landscape protection and environmental sustainability, as it is one of the key ingredients of the MFA regime. It is widely acknowledged that ecological function can be assessed from the perspective of ecological foundation and ecological stress (Tran et al., 2022; Undersander et al., 2002). Ecosystem service and biodiversity conservation indicate the quality of the agriculture ecosystem. Ecological stress is the opposite of the positive function, which refers to the damage to the natural ecosystem during agricultural production activities. This can be measured by fertilizer application (Zhang et al., 2019).

Building on the above-mentioned conceptual underpinning, an indicator system for the assessment of MFA is established. A detailed explanation of the assessment of attributes is given in Table 1.

3.3. Integrated function and multifunctionality assessment of agriculture

To assess the sub-functions and agricultural multifunctionality, min-max normalization was employed to process the data, and the weights for each indicator were determined by a comprehensive approach, which integrates two subjective methods (AHP (Park and Han, 2002) and the Delphi method (Dalkey and Helmer, 1963)) and one objective method (Entropy method (You et al., 2018)). Finally, the weights were determined by the mean value of the results of the abovementioned three methods, thus avoiding subjectivity and making the results more scientific. The agricultural multifunctionality index (AMFI) can be calculated as the following formula:

$$\mathrm{AMFI} = \sum_i Q_i * W_i \tag{1}$$

Table 1
The indicators of measuring the multifunctionality of agriculture.

Functions	Criteria	Indicators	Calculations	Weight
The function of agricultural product supply (APSF)	Agricultural production output	Grain yield per acre of cultivated land (kg/hm^2)	Gross grain output divided by the area of cultivated land	0.2949
		The per capita share of grain yield (kg/person)	Gross grain output divided by the total population	0.3992
		Proportion of cultivated land (%)	Gross cultivated land area divided by total land area	0.1453
		Multiple crop index	Dividing harvested area by cropland area	0.1607
The function of facilitating agricultural economic development (AEDF)	Growth in agriculture	Agricultural value-added per capita (yuan/ person)	Gross agricultural value added divided by the total population	0.5082
		Labor productivity for grain production	Gross grain production divided by the total rural labor	0.2488
		Agricultural mechanization level (kW·h/hm^2)	Total power of agricultural machinery divided by gross farmland area	0.2430
The function of social security (SSF)	Safeguarding farmers' livelihoods.	Job provision	The proportion of people engaging in the agricultural sector	0.6273
		Per capita farmland area (hm^2/ person)	The total farmland area divided by the total rural labor	0.1441
		Per capita net income (yuan/ person)	The total income from wage and salary, agricultural production, property, and transfer income divided by the total rural population	0.2287
The function of ecological conservation (ECF)	Environment stress	Application intensity of chemical fertilizer (kg/ hm^2)	The total amount of chemical fertilizer input divided by gross cultivated land area	0.1932
	Water supply	Water supply capacity	The amount of water resources divided by the total land area	0.2485
	Ecological condition	Value of ecosystem service	Estimating the number of people who are willing to pay to preserve or enhance the services by using land-use types	0.1099
		Ecological dominance of cultivated land	The paddy field area is divided by gross farmland area (denoting the ecological background condition)	0.3411
		Biodiversity index	Calculated based on the environmental quality evaluation standards	0.1074

Where AMFI represents the agricultural multifunctionality index, Q_i denotes indicator i, and W_i indicates the weight of indicator i. Using the same formula, the sub-function index is likewise determined.

3.4. Convergence analysis

There are two notions of convergence appearing in the classical literature, σ convergence, and β convergence (Cui et al., 2020). We focus on these two measures for examining the cross-sectional dispersion within counties in the study area. As noted earlier, σ convergence measures the behavior of cross-sectional dispersion of a particular variable over time, and it can be defined as a group of counties (the basic units) converging in the sense of σ. Thus, σ convergence was used to examine whether the sub-functions of the multifunctionality of agriculture tend to be converging under the existing differences in natural conditions, resources endowment, etc. (Gezici and Hewings, 2004). The formula is as follows:

$$\Sigma_t = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\ln F_{i,t} - \frac{1}{n}\sum_{i}^{n}\ln\left(F_{i,t}\right)\right]^2} \quad (2)$$

Where σ_t represents the σ coefficient of year t; $F_{i,t}$ indicates the sub-function index of i in year t; n represents the number of the regions; If σ_{t+1} is less than σ_t, it denotes that the corresponding sub-function index is converging. This also means that certain function index tends to be similar under the condition that there exist differences in natural conditions.

Absolute β convergence examines whether the counties with a low agricultural function index would be able to grow at a faster rate than the higher one and thereby catch up with the higher counties. Imagine that we have data on the function index for a cross-section of counties between periods t and $t+T$. If we estimate the following regression (Sme Tkowski and Wójcik, 2012):

$$\frac{1}{T}\ln\left(\frac{F_{i,t+T}}{F_{i,t}}\right) = \alpha + \beta_i \ln F_{i,t} + \varepsilon_{i,t} \quad (3)$$

Where $F_{i,t}$ and $F_{i,t+T}$ are the function index i at time t and $t+T$, α is the constant intercept, $\varepsilon_{i,t}$ is the error term. Other things being equal, if β is less than zero, the corresponding function index will show an absolute converging trend. In other words, it means the low function index tends to have a faster growth rate than the high index region, demonstrating that the function index in different regions will eventually tend to the same steady-state level.

The conditional β convergence is based on the absolute β convergence, which incorporates the control variables that influence the changes in the function index and accounts for the features of regional heterogeneity, ensuring that the function index converges to a steady state value in all regions. The β convergence model is set as follows (Sme Tkowski and Wójcik, 2012):

$$\frac{1}{T}\ln\left(\frac{F_{i,t+T}}{F_{i,t}}\right) = \alpha + \beta_i \ln F_{i,t} + \mu_1 UR_{i,t} + \mu_2 PEC_{i,t} + \mu_3 UCL_{i,t} + \varepsilon_{i,t} \quad (4)$$

Where, $UR_{i,t}$ represents the urbanization rate of unit i in year t, $PEC_{i,t}$ indicates the per capita electricity consumption in rural regions of unit i in year t, and $UCL_{i,t}$ denotes the proportion of urban construction land in total land area of unit i in year t. The model shows that, if the coefficient β is less than zero, it means that there exists conditional β convergence; otherwise, it does not exist. In this paper, we set T as 1 to maximize the utilization of the samples, and ensure the continuity of the time series of regression. Urbanization rate, per capita electricity consumption in rural regions and the proportion of urban construction land all indicates the degree and scale of urbanization, which reflects the societal demands. An exploration of societal demand for the different functions of agriculture needs to consider the regional contexts in which these societies are embedded. These metrics are sufficient to reflect societal demand for the various agricultural functions. The rate of urbanization is a direct indicator of how people move between rural and urban areas. The intensity of both residential and commercial activities is demonstrated in the per capita power usage. The percentage of land used for urban construction indicates the extent to which the area has been developed.

3.5. Data

Multiple-source data incorporating socio-economic data and land use data were used for assessing the sub-functions and the multifunctionality of agriculture. Socio-economic data was derived from China County Statistical Yearbook (1990, 2000, 2010, and 2015), and the data for land use was obtained from Landsat TM and ETM true color composite images after geometric rectification and supervised classification (GB/T21010–2007), the data spatial resolution of which is 30 m × 30 m. The total annual volume of water used in this study was obtained from the dataset of the National Water Census (1 km x 1 km) (2005) published by the *Ministry of Water Resources of the People's Republic of China*. In addition, the data regarding the storage of water was expressed by the weighted average based on the background information of each year.

4. Results and analysis

4.1. Spatial differentiation of the multifunctionality of agriculture

4.1.1. The function of agricultural product supply

Eastern Henan, northwest Shandong, and the Jiaodong Peninsula have high agricultural product supply function indices, whereas northeast Hebei, Anhui, and northern Jiangsu have comparatively low indices (Fig. 2). In 2000, counties with a function index above 0.4 covered the majority of the counties, with just a few coastal areas still exhibiting low production function, compared to 1990, when the area with high agricultural production function had risen dramatically. With a mean function index of 0.46 and 0.47, respectively, there was no discernible difference in the spatial distribution patterns between 2010 and 2015. The fact that agricultural output increased in 1990 and became more and more dependent on agricultural chemicals despite advancements in agricultural technology and farming facilities explains why agricultural production capacity was lower than it had been in the previous three periods. The average regional usage of chemical fertilizers increased by 122% between 1990 and 2015, from 227.32 kg/hm^2 to 50.46 kg/hm^2, and constantly exceeded international standards.

4.1.2. The function of facilitating agricultural economic development

From 1990–2015, the function of facilitating agricultural economic development was enhanced in general, presenting obvious regional differences (Fig. 2). Counties with a function index greater than 0.3 in 2000 increased by 33.3% compared with 1990, and the area with a high index expanded from Jiaodong Peninsula to Beijing, Tianjin, and southern regions. The distribution of the function index in 2010 was identical to that in 2000. In 2015, a small number of high-function-index areas such as Weifang and northern Jiangsu had been shrunk. The high-function-index areas of facilitating agricultural economy have formed three agglomerations-Beijing-Tianjin urban agglomerations, Jiaodong Peninsula, and northern Jiangsu. Agriculture, a disadvantaged industry, continued to face relatively modest growth in the farming area even while agricultural labor productivity and mechanization levels in regions remained rising. Urbanization and industrialization were highly correlated with agricultural expansion. Demand-driven agricultural commercialization and industrialization in economically developed regions' urban peripheries is fueled by the production of agricultural and auxiliary products like vegetables, livestock, poultry breeding, etc., which embodies the expansion of high-function-index areas in the peripheries of the Beijing-Tianjin urban cluster and coastal regions.

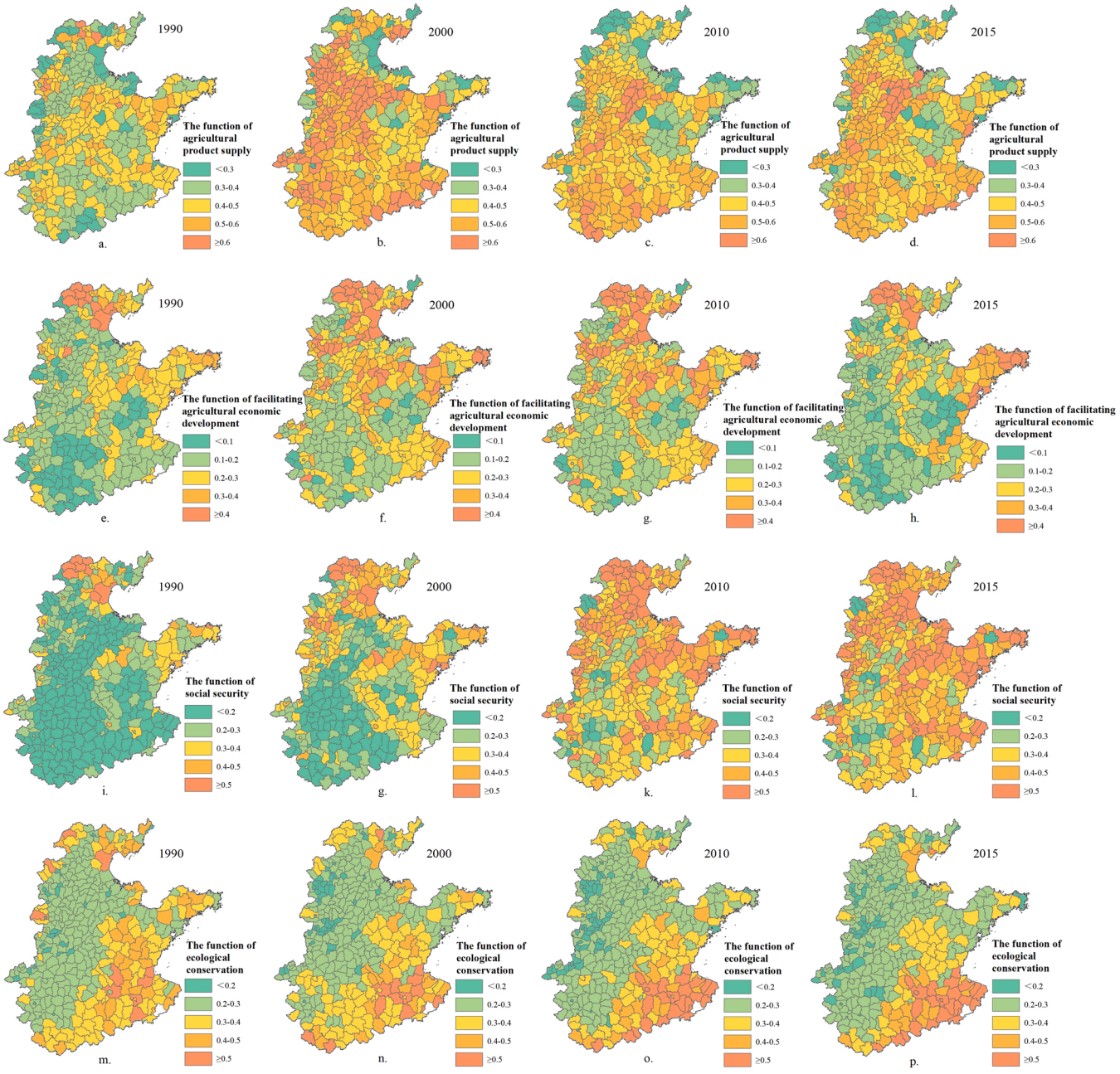

Fig. 2. The evolution of the multiple agricultural functions.

4.1.3. The function of social security

The social security system continued to improve between 1990 and 2015, and regions with a high function index showed an upward trend that is spreading from the north to the south and from the east to the west. In the traditional farming areas where wheat, corn, and other bulk grains are farmed predominantly, the function of guaranteeing livelihood security fell between 1990 and 2010 as a result of rising grain planting costs and poor farming productivity. Since 2010, the increase in farm subsidies, the minimum purchase price policy for grain, and the temporary purchase and storage policy have had a direct impact on the revenue of farmers. The demand for agricultural products stimulated by urban-rural transformation and rapid development would also help to increase farmers' motivation for production.

4.1.4. The function of ecological conservation

The ecological conservation function in the Huang-Huai-Hai region presented distinctive regional characteristics and maintained a stable distribution pattern in the period from 1990 to 2015. The ecological function index of the western and central regions of the Huang-Huai-Hai Plain was comparatively low and exhibited an increasing tendency. While the role of agricultural product deliveries in this region increased gradually. Despite the fact that the agricultural production function in northern Jiangsu and northern Anhui had been improved, the ecological conservation function remained at a high level, primarily due to the abundant farmland resources and ideal climate and rainfall conditions, which resulted in the favorable ecosystem service and high water reserves.

4.1.5. A comprehensive index of agricultural multifunctionality

From 1990–2015, the comprehensive index of agricultural multifunctionality increased over time, as did the degree of concentration. In addition, high-level areas continued to expand and showed signs of

rotation and transition (Fig. 3). Even while the index of agricultural multifunctionality in the Beijing-Tianjin urban cluster, Jiaodong Peninsula, and northern Jiangsu declined slightly in 1990, it remained at a high level, while low-level areas were concentrated in Hebei and northern Anhui (Fig. 3). From 1990–2000, the index of traditional farming regions, such as Hebei, eastern Henan, and northern Anhui, increased dramatically, and counties with a comprehensive index more than 0.3 accounted for 78% of the region (Fig. 3e). The multifunctionality of Hebei's agriculture had also been greatly boosted between 2010 and 2015, and the MFA development pattern was constant during this time. The Jiaodong Peninsula, northern Jiangsu, and the Beijing-Tianjin unban cluster continued to hold a leading position in terms of multifunctionality in the areas driven by the traditional agricultural economy, while the spatial agglomeration trend of transformation in the multifunctionality of agriculture generally dropped first and then rose.

4.2. Analysis of the spatial convergence of MFA development

4.2.1. σ convergence

The temporal trends of the coefficients of various sub-functions exhibit varied trajectories, as seen in Fig. 4. The σ coefficient of the supply function for agricultural products exhibits a definite increasing trend with apparent oscillations, indicating a tendency for first diverging, then convergent, and then diverging behavior. In general, this indicates the widening gap between regions in the supply function of agricultural products also means that the regional division of production is gradually strengthened. The supply function of agricultural products shows a similar temporal trend with the function of facilitating agricultural economic development, which is related to the parallelism between these two functions. It is also evident that the Huang-Huai-Hai region's agricultural growth continues to be significantly influenced by the planting industry. The divergence trend of agricultural economic development is not distinguishable when compared to the supply function of agricultural products, indicating that the pattern of agricultural development is still influenced by the path dependency of regional agricultural industrial development. The role of guaranteeing social security demonstrated notable convergence, and the inter-

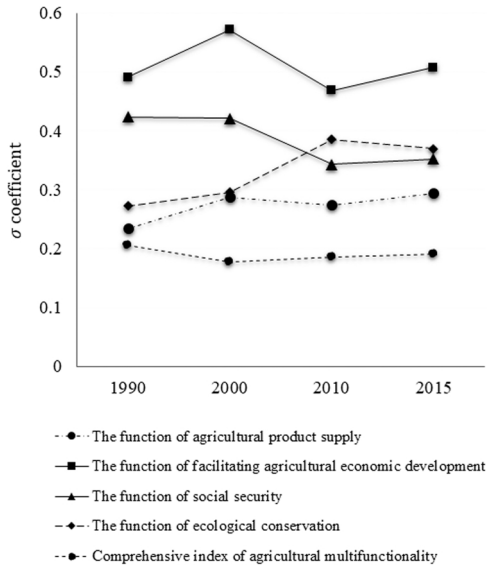

Fig. 4. The σ coefficients of MFA development in the Huang-Huai-Hai Plain.

regional gap is continuing to diminish. Due to the non-agriculturalization of work, a common trend in regional development is the weakening of the function of agricultural employment carrying, which leads to the gradually rising management scale of cultivated land. The income gap in most counties has steadily expanded in terms of the entire region, and the gap has gradually shrunk, despite the fact that it is constantly growing for rural inhabitants living between metropolitan suburbs and traditional agricultural districts. The aforementioned factors exhibit a common direction of development, producing a pattern of gradually closed regional gaps in the social security function. The σ convergence coefficient of the ecological security function sees the trend of rising first and then declining, and generally displays a tendency of divergence before convergence. Even when there are minor human disturbances, regions with poor ecological conditions often respond more strongly than areas with favorable ecological conditions, leading

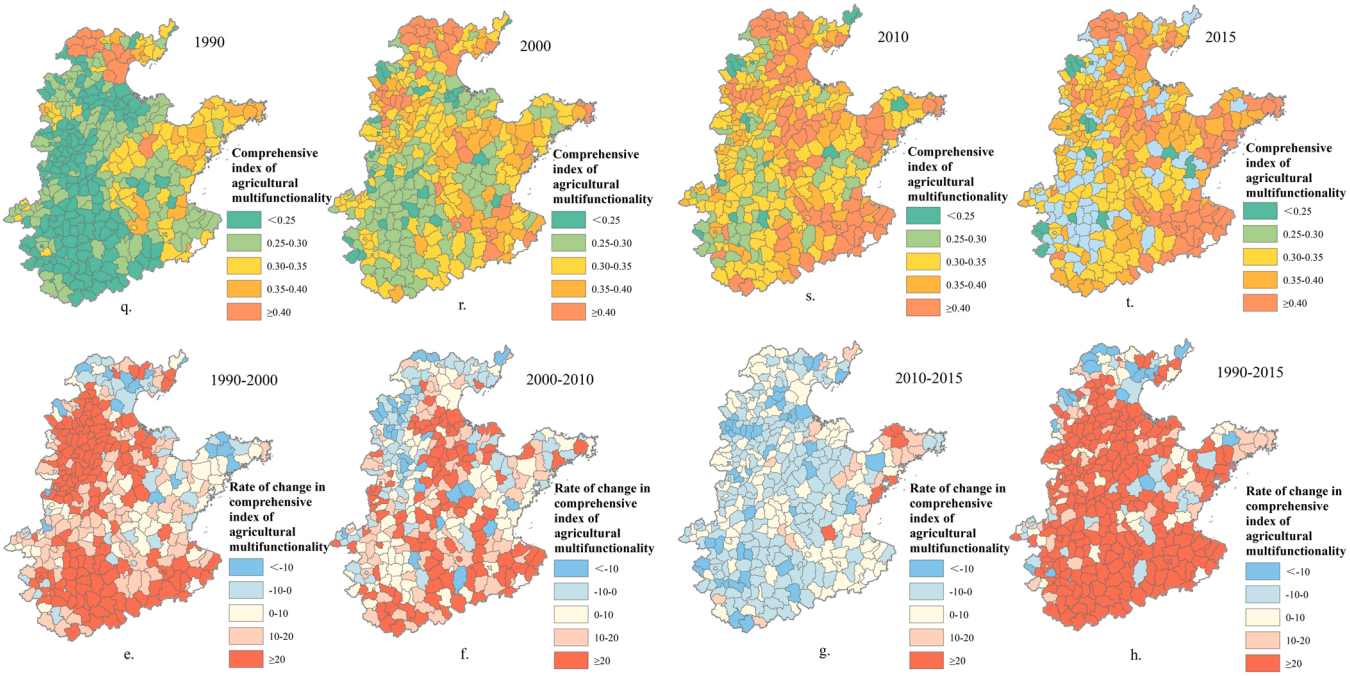

Fig. 3. The spatial-temporal pattern of MFA development from 1990 to 2015 in the Huang-Huai-Hai Plain.

to widening inter-regional gaps. This is because the function of ecological conservation is highly dependent on the regional natural basis. The ecological function gap between regions is reduced and the direction of evolution converges when human perturbations reach a specific threshold and are also intensely reacted to in areas with better ecological circumstances. Despite the variations in MFA development over time, the index of comprehensive functions generally shows a slight downward trend, indicating that the gap is gradually closing.

4.2.2. *Unconditional and conditional* **β** *convergence*

The absolute β convergence analysis shows all functional indexes passed the Hausman test, and the null hypothesis that there are no systematic differences between the random effect model and fixed effect model is rejected. Thus, the results of the fixed effect model are effective. According to the estimation results in Table 2, each functional index shows convergence with else conditions all being equal, and there is a catch-up effect in backward areas. Specifically, the absolute convergence β estimation of each functional index performed well, all being significantly negative at the 1% confidence level. The absolute value of the convergence β coefficients of the agricultural product supply function and the facilitating agricultural economic development function is higher than the other functional indexes, indicating that their catch-up effect develops faster than the other functional indexes. That is, compared to the other functional indices, the regional gaps of these two functions decrease more quickly. Overall, there was a decreasing tendency over time in the regional differences of each functional index. The regions with lower functional indexes gradually converge to the areas with higher functional indexes, exhibiting a propensity of change from "heterogeneous" to "homogeneous", and eventually tend to the same steady-state of growth.

The fluctuation of the function indexes does not, however, occur in the ideal situation of uniform regional socio-economic variables and calls for careful study of the limitations imposed by various regional development histories. Consequently, by establishing the control variable, the primary variables influencing the convergence of areas were investigated. The proportion of rural construction land, the rate of urbanization, and the amount of electricity consumed per person in rural areas were added as controlled variables based on the absolute convergence model to reflect the intensity of regional economic development, urbanization, and the level of interference from human activities, respectively.

Overall, after adding controlled variables, the βcoefficients of each functional index remained negative, which indicates that the spatial differences present a gradually decreasing trend over time (Table 3). The per capita power consumption and the pace of urbanization, respectively, revealed substantial positive and negative connections with the supply function of agricultural products. The amount of mechanization and modernization of agriculture that can be roughly correlated with per-capita electricity used in rural areas shows that industrialization of agriculture played a significant impact in boosting output and productivity levels. Multiple facets highlight the contributions of urbanization on agricultural output. On the one hand, the shortage of rural labor force resulting from rural outmigration frequently resulted in the intensive usage of cultivated land. In contrast, urban sprawl reduced agricultural production space by encroaching on farmland. In terms of the function of facilitating agricultural economic development, the development level of the agricultural industry was directly related to its contribution to agricultural economic growth. Thus, there was a certain correlation between the function of facilitating agricultural economic development and the supply function of agricultural products. Urbanization, on the other hand, achieved the initial agglomeration through the advancement of agricultural technology and input of agricultural production, which increased the efficiency of agricultural production. By raising the operating scale and income of the rural population through the spatial redistribution of the population, urbanization has a favorable impact on the enhancement of the social security function. The negative impact of rural construction land on social security function was mostly attributable to farmers' expansion of rural construction land, which frequently displaced cultivated land resources. In addition, the large proportion of rural construction land indicates a dense rural population, which has a direct impact on the per capita scale of farmland management. The rise of the agricultural industry had a substantial influence on ecological protection, mostly as a result of the excessive use of artificial fertilizers. The ecological function was most highly linked with natural conditions, thus external elements such as regional, social, and economic development stages were not yet important. In general, regional industrial development and urbanization levels facilitated the integration of regional differences and played positive roles in the development of MFA, whereas the impact of human disturbance on MFA development was frequently negative, such as the occupation of cultivated land.

5. Discussion

5.1. *Possible causes of convergence process in MFA development*

The aforementioned findings show that, in the context of diverse resource endowments, climatic conditions, topographical conditions, etc., only the function of guaranteeing social security witnessed an evident tendency towards convergence. There was no apparent convergence tendency in other indicators. Particularly after taking into account controlled variables, convergence was seen, suggesting that counties will only converge when they share structural traits. Environmental variables, external socioeconomic activities, and policy influences all contribute to the development of MFA (Long et al., 2020). In essence, MFA development may be defined as the process by which various stakeholders utilize agricultural resources in distinct ways in order to get access to products and services. Therefore, σ convergence in MFA development is hindered by the interregional disparities. Under the assumption that all other conditions are absolutely homogeneous and

Table 2
Estimated values of absolute β convergence of MFA development in the Huang-Huai-Hai Plain.

Variables	The function of agricultural product supply	The function of facilitating agricultural economic development	The function of social security	The function of ecological conservation	A comprehensive index of agricultural multifunctionality
C	0.62 * **	0.27 * **	0.20 * **	0.19 * **	0.27 * **
	(51.97)	(34.92)	(26.95)	(22.21)	(36.06)
β	-1.28 * **	-1.29 * **	-0.44 * **	-0.66 * **	-0.78 * **
	(− 50.74)	(− 36.25)	(− 18.68)	(− 22.54)	(− 33.13)
R^2	0.78	0.65	0.33	0.42	0.61
F	2574.07	1314.37	348.94	507.86	1097.68
P	0.00	0.00	0.00	0.00	0.00
Hausman test (chi2)	673.87 * **	1244.49 * **	314.90 * **	697.30 * **	1205.26 * **

Note: * ** , * *, and * show the level of Significance at 1%, 5%, and 10% respectively, and the standard error of each coefficient is in brackets.

Table 3
Estimated values of conditional β convergence for MFA development in the Huang-Huai-Hai Plain.

Variables	The function of agricultural product supply	The function of facilitating agricultural economic development	The function of social security	The function of ecological conservation	A comprehensive index of agricultural multifunctionality
C	0.60 * **	0.22 * **	0.20 * **	0.20 * **	0.27 * **
	(29.94)	(9.88)	(10.58)	(14.74)	(23.98)
β	-1.27 * **	-1.27 * **	-0.48 * **	-0.64 * **	-0.80 * **
	(− 47.22)	(− 33.66)	(− 17.53)	(− 21.32)	(− 30.37)
Per capita household electricity consumption in rural region	0.15 * **	0.06 * **	0.02	-0.04 * **	0.03 * *
	(7.27)	(2.59)	(0.91)	(− 2.75)	(2.14)
Urbanization rate	-0.10 * **	0.22 * **	0.24 * **	-0.002	0.07 * *
	(− 3.59)	(7.14)	(8.56)	(− 0.14)	(4.39)
The proportion of rural construction land	0.04	-0.05	-0.11 * **	-0.023	-0.003 *
	(1.64)	(− 1.52)	(− 3.91)	(− 1.35)	(− 1.83)
R^2	0.81	0.67	0.41	0.42	0.62
F	735.88	368.36	124.59	129.95	291.96
P	0.00	0.00	0.00	0.00	0.00
Hausman test (chi2)	612.52 * **	4048.05 * **	600.12 * **	695.55 * **	433.63 * **

Note: * ** , * *, and * show the level of Significance at 1%, 5%, and 10% respectively, and the standard error of each coefficient is in brackets.

when control variables are included, all functional indices exhibit β convergence. The degree and direction of each control variable's influence on various agricultural functions differs greatly, suggesting that exogenous force interventions assist in bridging the gap between regional agricultural development and promote the shift from the dominance of a single function to the joint development of several functions. The evolving agricultural policies and the paradigm of agricultural development are dynamically coupled (Prändl-Zika, 2008) (Fig. 5). At an initial stage of development, "taking grain as the key link"-the emphasis on grain production means that the maximization of grain yield is the ground objective, and the supply function of agricultural products and the function of facilitating agricultural growth are reinforced. Large-scale intensive or industrial farming is encouraged once the benefits of the household responsibility system are depleted (Song and Robinson, 2020). Smallholder farmers are increasingly being marginalized as agribusinesses and other large-scale operators grow in popularity and the central government continues to place a focus on expanding and modernizing agriculture. During this time, productivity-focused agriculture was the norm in terms of agricultural practices. The "New Countryside Construction Program" and "Rural Vitalization and Integrated Urban-Rural Development" programs are being implemented to draw attention to the many values of rural areas

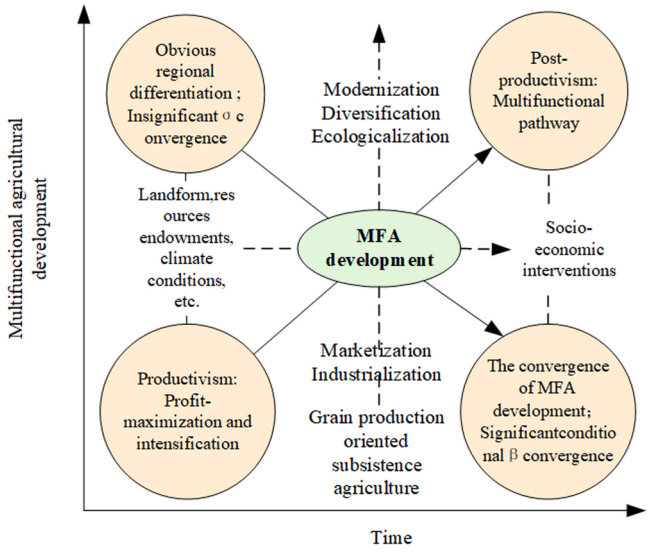

Fig. 5. The mechanism of the convergence of MFA development in the Huang-Huai-Hai Plain.

(Zang et al., 2020). The transition of the development approach attaches more emphasis to the equilibrium and integration of production, ecological protection, and living function. In peri-urban areas, the urban demand for rural goods and services represents a driving factor to adapt farming activities in a multifunctional way. In response to the post-productive, consumption-oriented requirements of the urban society, agritainment, rural homestays, ecological agriculture, and other activities and diversification approaches consist of the mixed picture of MFA. Generally speaking, on the one hand, the supply and facilitating economic growth function of agriculture were improved due to increasingly specialized and intensive management techniques, and on the other hand, the function of social security was simultaneously reinforced by rising income and dense population. As a result, agricultural multifunctionality has gained popularity.

5.2. Should there be universal encouragement for multifunctional intervention in agricultural governance?

According to the conceptualization of MFA, the transformation of the agricultural development towards multifunctionality is based on a radical reorganization of three basic ways of using agricultural space: production (farming), consumption, and protection. One of the manifestations in China of the ongoing agricultural transformation is the shift from productivity-oriented goals to a more complex mix of economic benefits, social security, and environmental protection (Song and Robinson, 2020). MFA has been encouraged under strong government policy directives from the early 2000 s. The central government proposed the guidelines in the CCCPC (Central Committee of Communist Party of China) No.1 document in 2007 to achieve the sustainability goals-"developing agricultural multiple functions and improving the industrial system of modern agriculture (Ye, 2015)". Recent decades have witnessed the continuous emphasis on MFA in the various statements from central government, featured in broad strategy documents. However, failures occur in many regions despite the received massive investment from the government, which implies that the state promotion of multifunctionality is not effective everywhere. The MFA should be developed in accordance with market norms, and it is not applicable everywhere. This raises the question of what areas should be supported for MFA promotion. Peri-urban fringes have increasingly supplied the burgeoning cities with food, especially vegetables, as well as the unique farming landscape that provides amenity services. Induced by the demand of urban customers, farmers in urban-rural fringes have diversified to survive (Ploeg and Ye, 2010), often combining intensive farming with enterprises, notably tourism, and activities ancillary to farming depending on the multifunctional rural landscapes (Song and Robinson, 2020; Zasada, 2011). In contrast, remote rural areas with less demand

for non-production services are not suitable for farm-based tourism, which creates an environment of production-oriented farming. From a territorial perspective, MFA is necessary to be arranged following the rationale of regional specialization. Considering the ample farmland endowments and the drawbacks of long distance to the urban market, the agriculture characterized by profit-maximization and intensification will continue to support grain production rather than the agricultural multifunctional activities linked to recreation, and leisure time. Thus, the territorialization of productivist and post-productivist agricultural activities, in other words, the regional division of agricultural activities could promote the productivity of the agricultural-based sector (Liu and Zhou, 2021). Arranging the leading agricultural activities by considering the comparative advantages is conducive to boosting the efficiency of the utilization of agricultural resources. Highlighting the post-productivist was strongly based on the regional conditions, and the corresponding policy interventions should also be diversified. Compared with the market-driven Australia settings, public support and funding are highlighted in China to encourage positive multifunctional outcomes- environmental sustainability, increasing agricultural resilience, reducing socio-environmental risks in the agricultural sector, etc (Fielke and Wilson, 2017). Cultural difference also matters, which has significant influences on the priorities of each agricultural system. China's farming legacy and successful agricultural systems are widely recognized and promoted. This is unlike some western countries, where despite efforts to recognize and safeguard agricultural historical values and promote ecologically friendly produce, farms and farmers continue to decline. Therefore, state-assisted multifunctional agriculture through direct subsidisation is more appropriate for rewarding positive outcomes in China.

5.3. Uncertainties and future research

Several major uncertainties when using Multi-Criteria Comprehensive Appraisal Method should be highlighted. First, the multiple measurements in one indicator should be carefully considered, because some of the indicators simultaneously express different sub-functions. Second, the ecological function cannot be fully depicted constrained by the difficulties in data availability and seeking appropriate qualification methods. On a county scale, it is not possible to include many important indicators in measuring and mapping different sub-functions. For example, the functions of providing scenic beauty and cultural landscapes are difficult to quantify. It is worth pointing out the limitations that should be addressed in further improvements in computer science. Big Data Technologies have shown the potential of using social media for collecting data on recreational activities (Wood et al., 2013).

Moreover, a lengthy history of agriculture in China has played a significant role in the development of the country's distinctive farming culture, which is the set of norms and values developed over time by farmers in order to satisfy the requirements of agricultural production and facilitate their livelihoods. Farmers have developed a farming culture that is "timely (ying shi), appropriate (qu yi), proper (shou shi), and harmonious (he xie)". This has led to a long history of many different types of agricultural production systems. These farming practices are tightly associated with the location, the weather, and also influence the manner in which individuals get along. However, it is commonly acknowledged that the cultural function of agriculture is inherently hard to quantify because of its complexity, localization, and inextricable association with the features of agricultural production conditions (Dickinson and Hobbs, 2017; Willcock et al., 2017; Tew et al., 2019). The lack of cultural indicators is a major constraint that necessitates an examination using behavioral geography or sociological methods (Paracchini et al., 2014; Zandersen et al., 2014).

Another challenge is that there is no available principle or guideline for selecting the most representative criteria for the characterization of the sub-functions of agriculture, requiring more innovative frameworks with appropriate indexes (Hou et al., 2014). Meanwhile, the scale effect should also be taken into consideration, which may result in the inaccuracies of different scales. It is necessary to narrow the evaluation units to plots or households, as well as to enlarge the scale to larger units, enriching the knowledge of the scale effects of agricultural multifunctionality.

6. Conclusions

The multifunctional development paradigm provides an approach that strengthens and modernizes China's agricultural development. Agricultural integrated function assessment and convergence analysis were employed to shed light on the dynamics of MFA. This study takes the case of the Huang-Huai-Hai Plain, which is a typical representative of farming regions with diversified patterns of agricultural production and obvious regional disparity, to assess its multifunctionality determined by the associations of different functions, as well as answer the question of whether one can observe convergence or divergence of MFA development.

The findings presented in this article have proven that (1) MFA has been generally strengthened from 1990 to 2015, and areas with high multifunctionality present increasing agglomeration effects, especially in the fringe areas surrounding the economically prosperous urban areas. Some regions with low functional index converted to areas with high functional index, extending the regions with high multifunctionality. (2) Path dependence is a crucial characteristic of the development of all MFA dimensions, with the exception of the function of social security, provided that there are large regional variances. The "catch-up effect" is evident in MFA development when exogenous influences are at play. Each control variable's influence on each functional index has a different direction and magnitude which proves that appropriate external interventions should be made depending on the circumstances. (3) The progression of multifunctionality corresponds to the stages of socioeconomic development and is influenced by both natural conditions and the external interventions. Paralleling the MFA development is a dynamically evolved rural and agricultural policy regime. The intervention of "exogenous forces" helps bridge the gap in regional MFA development, thus broadening and deepening activities of MFA growth.

The raising multifunctionality in China's farming regions implies the transition in thinking about the objectives of agricultural production, which is primarily concerned with re-ordering the use of agricultural space in terms of production, consumption, and protection. Actually, for this process to work, both the farmers, the new agricultural operators, the governments, etc., must reach to reciprocal agreements. However, China's agriculture sector is confronting great problems and challenges including the exodus of the able-bodied rural population to cities, the marginalization of farmland, overdependence on fertilizer application, etc., which prevent the transformation towards MFA. Therefore, adjusting the prices of agricultural products based on market rationality and encouraging entrepreneurial farms may be better choices for promoting MFA in farming regions. Meanwhile, large-scale and industrialized farming should also be encouraged in the vast plain regions with abundant farmland resources, to maintain productivity and secure food supply. Regional variations in the prioritization of multifunctional outcomes will be crucial for developing strategies to capitalize on the competitive advantages of specific agricultural settings. To sustain and contribute to the prosperity of some locations, regionally-specific agricultural planning may be necessary.

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