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Does urbanization reduce the multi-functional value of cultivated land? Evidence from China

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The contradiction between urbanization and cultivated land conservation needs to be resolved urgently. The coupling of cultivated land production, compound utilization and ecological protection is a hot topic for policymakers and researchers. Based on the panel data of 31 provinces in China from 2002 to 2018, this paper estimated the impact of urbanization on the quantity and structure of cultivated land functional value using a fixed effect model. The results show that the multi-functional value of cultivated land fluctuates in time series. There was obvious synergistic relationship among different functions of cultivated land, and the synergistic relationship was gradually weakened. Urbanization did not decrease the multi-functional value of cultivated land, and the producing function of cultivated land was improved most obviously. The value of producing function and social security function in main-producing areas is the most obvious response to urbanization. The culture of main marketing areas has the highest response to urbanization, and urbanization has reduced the ecological function of grain main marketing areas. Urbanization has reduced the diversified types of cultivated land, and the function positioning of cultivated land is gradually obvious. Therefore, policymakers should pay attention to the dialectical relationship between the total amount and structure of multi-functional cultivated land and implement regional differentiation policy of multi-functional cultivated land utilization.

KEYWORDS
urbanization, cultivated land, multifunction, value accounting, fixed effect model

1 Introduction

Cultivated land is the basic resource for human survival and highly-compound ecosystem. It has typical functional characteristics and plays an important strategic role in ensuring food security, maintaining ecological balance, and ensuring sustainable rural development. With the rapid advancement of urbanization, every country is actively dealing with how to find a balance between urbanization and cultivated land conservation (Wu et al., 2018). Some scholars predict that China's urbanization level will rise to 70% by 2030 (Bai et al., 2014). There are already many scholars discussing the topics related to urbanization and green development (Yang et al., 2021; Shi et al., 2022; Xin et al., 2022a). Due to the vulnerability of agricultural natural resources, rapid urbanization has led to irreversible changes in cultivated land resources, and the trend of its depletion is gradually emerging (Liu et al., 2017). The Chinese government has been actively working to improve the problem of cultivated land loss. As an important resource element for rural development, the utilization of cultivated land function has become an important way to improve the quality of agricultural growth and promote sustainable development. It also has a series of new-age missions such as improving the environment of human settlements, eradicating poverty and revitalizing rural areas (Zhou et al., 2020). Therefore, it is of great significance to correctly evaluate the functional value and law of cultivated land for promoting its sustainable utilization.

The concept of cultivated land multi-functionality originates from agricultural multi-functionality. In the beginning, the function of cultivated land was mainly for food production and carrying biological diversity. Since the reform and opening up, China has undergone a huge socio-economic transformation. This development has affected the allocation of cultivated land resources and optimized its functional demand pattern (Lai et al., 2020), which has forced the functional connotation of cultivated land to be gradually enriched. In the process of urbanization, stakeholders such as the government, urban residents and farmers have different demands on cultivated land resources. People must adapt to the real threat of urbanization by adjusting the function of cultivated land with the limited resource endowment. Residents' perception of cultivated land has shifted from a single production function to a systematic multi-functional one, and its non-market value has become more prominent. In turn, the restructuring of residents' needs has led to a change in the function and structure of cultivated land. Traditional agriculture mainly emphasizes cultivated land to serve as a production factor, which leads farmers to value its production function. However, with the continuous development of modern agriculture, the connotation of the functional value of cultivated land has become more diverse. In addition to production functions, other functions of cultivated land are being started to be valued. Scholars have begun to argue that the production-oriented function of traditional agriculture has changed to a consumption-oriented function (Brandt and Vejre, 2004). The primary purpose of cultivated land resources is to meet the residents' demand for the consumption of agricultural products and to provide farmers with income and other security needs. It must also assume ecological functions such as soil and water conservation, climate regulation, adaptation to landscape, aesthetic and recreational needs. (Zasada, 2011; Aubry et al., 2012; Song et al., 2013; Ma et al., 2020). For example, rural tourism was declared as a key approach to rural development in 2014 (Wang and Yotsumoto, 2019). We summarize the value of cultivated land based on its connotation of it, which can be categorized into four categories: production value, ecological value, cultural value, and social value (DeFries et al., 2004; Wiggering et al., 2006; Liu and Zhang, 2013).

Under the change of times and the guidance of the government, the multi-function of cultivated land has responded positively to urbanization. However, it is undeniable that the contradiction between urbanization and cultivated land conservation has not been solved. How to balance the compound utilization of cultivated land and its ecological protection has long been a hot spot of concern for policymakers and theoretical researchers (Xi et al., 2012; Jiang, 2013; Skog & Steinnes, 2016). Many studies have explored the spatial and temporal characteristics of inclusive development in the new era, and some scholars have also described the cultivated land characteristics and evolutionary trends based on quantitative results of its functions (Xin et al., 2022b; Zhang et al., 2019). However, it is noteworthy that there is a lack of studies analyzing the response of cropland to urbanization from the perspective of functional synergy. The innovations of this paper can be summarized as three points in view of the shortcomings of existing studies. Firstly, we analyze the mechanisms and manifestations of the positive and negative effects of urbanization on cultivated land conservation from the perspective of objective processes, which reveals the laws of urbanization on the functional value of cultivated land. Secondly, this paper accurately identifies the key functions of cultivated land and constructs a scientific accounting system for the functional value of cultivated land, which enhances the credibility of the study. Thirdly, this paper analyzes the comprehensive impact of urbanization on the aggregate function value of cultivated land from both total and structural perspectives. Moreover, we explore the impact of urbanization on the evolution of functional structural characteristics of cultivated land and discuss the effective approaches to protect cultivated land.

In summary, this paper analyzes the impact of urbanization on the productive, ecological, cultural and social security functions of cultivated land. Meanwhile, this paper attempts to enrich the research findings by examining the heterogeneity between different functional areas and discussing the response functional structure of cultivated land on urbanization. The rest of the article is structured as follows: the second part is the literature review and research hypothesis; the third part is the accounting steps and statistical analysis of the multi-functional value of cultivated land; the fourth part is the data source and model description; the fifth part is the model analysis results; the last part is the conclusions and policy implications.

2 Literature review and research hypothesis

2.1 Literature review

To examine the impact of urbanization on the functional value of cultivated land, our primary task is to clarify the connotation of multi-functionality of cultivated land. Secondly, we should sort out the relationship between urbanization and cultivated land change.

Regarding the measurement and application of the functional value of cultivated land, scholars have done a lot of researches in both its definition and quantitative measurement. The concept of " cultivated land function" was first introduced in the field of agriculture. The typical characteristic of both urban and rural agriculture is multi-functionality (Zasada, 2011). Relying on the classification logic of agricultural multi-functionality, scholars' research began to extend to the fields of land use, ecosystem services and rural development. Naturally, the concept of multi-functionality was also applied to the evaluation of the functional value of cultivated land. The main function of cultivated land is to produce grains or other agricultural products from the most rudimentary perception (Moustier, 2004). However, the function of cultivated land is no longer limited to production, and it also has derived functions such as ecological service function and social function with the advancement of urbanization. For example, its cultural function value has also gradually received attention from scholars and society. Based on the basic connotation of the multi-functionality of cultivated land, academics have commenced theoretical discussions and quantitative studies on the ecological value, social security value and economic value of it. It is obvious that the multi-functional positioning of cultivated land plays an important role in connecting urban and rural needs (Weber and Seher, 2006). Drawing on the evaluation logic of agricultural multi-functionality, the main existing methods are the unit-equivalent factor method, the indicator system representation method, the hierarchical analysis method and the monetization method (Costanza et al., 1997; Marques-Perez et al., 2014; Peng et al., 2015; Madureira et al., 2007;

Yu et al., 2019; Zhou et al., 2017; Zhao et al., 2022). Among them, the monetary method can visually quantify the value components of cultivated land. Thus some classical valuation methods have been formed, such as the market comparison method, opportunity cost method, market value method and shadow engineering method.

Focusing on the relationship between urbanization and the value of cultivated land, scholars have two main views. The first view is that urbanization occupies cultivated land and has a negative impact on it (Huang et al., 2005; Xi et al., 2012). On the one hand, this is expressed as a loss in the amount of cultivated land. On the other hand, the reduction in rural human capital also brings about a decrease in the efficiency of cultivated land utilization (Jiang et al., 2013; Skog and Steinnes, 2016). Although the exact figure of total land area loss is still controversial, a part of scholars believe that the productivity of newly reclaimed cultivated land is lower than that of the converted land (Döös, 2002; Yan et al., 2009). The second view is that urbanization will not threaten the supply of cultivated land and will have a positive impact on its utilization. First of all, there is a close relationship between the level of urbanization and intensive land use whether for rural land or urban land. In order to improve land productivity, the Chinese government insists on deepening the scale of farming operations and promoting the reform of planting structures, which brings about the intensive use of cultivated land (Zhang et al., 2019). Secondly, scholars who hold this view are more concerned with the harmonious relationship between urbanization and changes in cultivated land. They argue that urbanization gives cultivated land values other than production. For example, the derivation of cultural and recreational functions can compensate for the shrinking output caused by the reduction of cultivated land to a certain extent(Gómez-Sal et al., 2003).

The relevant literature has laid the foundation for understanding the relationship between urbanization and the multi-functional value of cultivated land. However, the current research is deficient in two aspects. Environmental issues have been a hot topic and scholars have been active in verifying the impact of different policies on it (Liu et al., 2022; Wu et al., 2021; Meng et al., 2022; Cheng et al., 2022). The number of studies that specifically focus on the relationship between urbanization and cultivated land is limited. In terms of research content, many studies are restricted to the analysis between urbanization and cultivated land area, which does not sufficiently reflect the multifaceted effects of urbanization on cultivated land. How to explore the far-reaching relationship between urbanization and the quality of cultivated land requires us to find a new entry point to study its conservation from the perspective of functional coordination and functional enhancement. In terms of research perspectives, current research on quantitative accounting of cultivated land functions focuses more on the spatio-temporal examination of its current status, characteristics and evolutionary trends. Some scholars also focus on the hierarchical nature of cultivated land functions and the "competition-synergy" relationship between different functions, or further explore the transformation theory of them. However, studying the response mechanism of functional value of cultivated land from the perspective of urbanization is relatively rare.

2.2 Research hypothesis

The impact of urbanization on the function of cultivated land is multiple and complex, with both negative and positive effects on it. On the one hand, the urbanization process will have a negative impact on the function of cultivated land, which is manifested in a decrease of quantity and quality or an increase of pollution. Firstly, as the basic carrier of urban development, the demand for non-agricultural land increases with the urbanization process. Due to the difference in the utilization value of cultivated land and non-agricultural land, people tend to seek greater economic benefits by relying on non-agricultural land, which directly causes the reduction of cultivated land area. Secondly, the opportunity cost of agricultural labor is increasing with the influx of population to the cities. Farmers tend to increase the input of fertilizers and pesticides to offset the loss of labor. This will bring about the pollution of cultivated land, which manifests itself in the depletion of its productive and ecological functions. On the other hand, urbanization also positively affects the function of cultivated land through mechanisms that enhance its utilization efficiency and expand its functions. Firstly, the scale effect of urbanization increases the productivity of labor and technology, which has a positive effect on the restoration of low-quality cultivated land and the development and reclamation of reserve land resources. Moreover, the increased intensification of land enables each unit of non-agricultural land to absorb more people, which makes it possible to occupy less non-agricultural land when the population continues to gather in cities. It may indirectly slow down the future occupation rate of cultivated land and achieve the implicit protection of its functions. The third is that the loss of rural population may push farmers to choose to grow grain crops with a higher rate of mechanical operation, which can fill the labor supply gap. The change of agricultural cultivation structure will improve the production and security functions of cultivated land, and it will affect the ecological and cultural functions. Through the above analysis, urbanization has both positive and negative effects on the function of cultivated land, and there is a dialectical relationship between them. We believe that the positive compensatory effect of urbanization on the function of cultivated land may be stronger than the negative abatement effect. Therefore, Hypothesis I is proposed.

Hypothesis I: Urbanization will not reduce the functional value of cultivated land.

Based on the reconfiguration of agricultural labor factors and rural structure, the impact of urbanization on the functional value of cultivated land should be further studied. Because of the vast size of China, the level of urbanization, the structure of production factors, and the "human-land" relationship in different regions differs significantly.The structure of cultivation may vary from province to province, subject to regional orientation. The crops cultivated can be broadly classified into three categories: grain crops, cash crops, and horticultural crops. Food crops include rice, wheat and corn. Cash crops include soybeans, cotton, sugarcane, oil, tobacco and other economically efficient crops. Horticultural crops include various vegetables, fruits and flowers. The different physiological characteristics of crops lead to large gaps in the amount and proportion of inputs such as labor, land, machinery, and biochemicals. For example, compared with food crops, cash crops have lower fertilizer utilization and higher fertilizer input intensity. In terms of labor inputs, horticultural crops usually have the highest labor requirements, while field food crops have lower labor requirements. In terms of machinery inputs, the mechanization rate of field food crops is higher than that of cash crops and horticultural crops. In addition, the types of crops suitable for cultivation vary between provinces. For example, most cash crops and horticultural crops are dry crops. In contrast, cultivated land in the northeast and parts of the south is often predominantly paddy land. The input elements will be influential in the productive, ecological, cultural and security functions of cultivated land. Therefore, Hypothesis II is proposed.

Hypothesis II: The impact of urbanization on cultivated land function is heterogeneous among different food function areas.

Focusing on the structural evolution of cultivated land functions, we find that urbanization has an important influence on it, which is also reflected in the heterogeneity between different food function areas. In the early stage of urbanization, there was less transfer of rural labor to the non-farm sector, and the scale of farmland and farmers' behavior were less influenced by the market. The main purpose of farming is to maintain their own food supply. This situation is less dependent on mechanical inputs and pesticides and fertilizers, which helps to protect the diversity of farmland systems and reduce the environmental load on farmland. At this stage, the functional positioning of cultivated land is unclear, and the value distribution among various functions is relatively balanced. With the development of urbanization, farmers' production behavior began to be influenced by the market, and rural labor began to migrate between the agricultural and non-agricultural sectors. The intensity of chemical and mechanical inputs increased, leading to an increase in land productivity. The production and food security functions of cultivated land increased obviously in this period. With the further promotion of urbanization, massive agricultural laborers migrate into cities. The functional needs of residents in different areas for cultivated land are more variable. People's demand for diversified food has increased, and they also put forward more requirements for living environment, rural culture, and short-distance tourism and leisure. This offers the possibility of developing new agricultural complexes and ecological agriculture in rural areas. In developed areas, the increased environmental awareness of residents and the strengthening of rural environmental regulation have led to a remarkable increase in the cultural function of cultivated land functions. During this period, the layout of production in different areas has led to changes in the production, ecological and social security functions of local cultivated land. Urbanization has brought about changes in the "human-land" relationship. The ratio and combination of the different functions of cultivated land have been changing, and there is competition and coordination between the different functions. The functions of cultivated land in a typical area have begun to be specialized. Therefore, Hypothesis III is proposed.

Hypothesis III: Urbanization has reduced the diversity of regional cultivated land functions.

3 Accounting and analysis of the multi-functional value of cultivated land

3.1 Accounting of multi-functional value of cultivated land

Based on the analysis of the multi-functional of cultivated land and the availability of data, this paper concludes that the key service functions of cultivated land should include productive function, ecological function, cultural function and social security function. The producing function refers to the supply of agricultural products to society through the use of cultivated land, which is mainly expressed as the food-producing function of cultivated land. The ecological function, from the perspective of ecosystem services of cultivated land, mainly includes positive functions such as support and regulation, and also includes the environmental pollution brought about. The study specifically accounts for the ecological function value of cultivated land in five aspects: gas regulation, environmental purification, water containment, biodiversity support function, and negative environmental function. The cultural function is reflected in the service value of cultivated land to provide leisure landscape for human beings. The social security function is based on the value of economic output of cultivated land, which provides livelihood security for farm households. After identifying the key service functions of cultivated land, this paper specifically selects eight functions that have received more attention from scholars: food producing, gas regulation, environmental purification, water conservation, biodiversity, agricultural pollution, social security, and aesthetic landscape (Yu et al., 2019). In this paper, a quantification model is used to assess the value of each function of cultivated land, and the specific accounting steps are as follows.

(1) Food Producing Function value: Ensuring food security is the long-term goal of China's agricultural policy, and producing food is the primary function carried by cultivated land. As major crops, rice, wheat, corn, soybeans, cotton, oilseeds, sugar beets, sugar cane and vegetables accounted for an average of more than 95% of the sown area. The yield reduction method is used to account for the yield of our main agricultural products, and this result is used to characterize the functional value of food producing on cultivated land.

$$FP = \sum_{i=1}^{n} [(P_i \times y_i \times S_i] \tag{1}$$

Among them, P_i is the price of the main product in RMB per kg. y_i is the yield per unit area of crop i in kg/hm2. S_i is the planted area of crop i in hm2.

(2) Atmospheric Regulation Function value: Crops grown on cultivated land can fix CO2 and release O2 through photosynthesis to regulate the carbon and oxygen balance in the atmosphere, which is the most basic function of plants. In addition, cultivated land also contributes to other greenhouse gases, such as methane emissions from rice fields during growth. A cost approach is used to account for the gas regulating function of cultivated land:

$$AR = AR_1 + AR_2 \tag{2}$$

Among them, AR_1 is the value of the carbon and oxygen regulation function performed by cultivated crops through photosynthesis.

$$AR_1 = \sum_{i=1}^{n} (a_c \times NPP_i \times C_c \times S_i) + \sum_{i=1}^{n} (a_o \times NPP_i \times C_o \times S_i) \tag{3}$$

$$NPP_i = \frac{Y_i \times (1 - r_i)}{e_i \times S_i} \tag{4}$$

Among them, a_c、 a_o are the amount of CO2 that can be fixed and O2 released by 1 kg of plant, which are taken as 1.63 kg and 1.2 kg according to the photosynthesis equation. NPP_i is the net primary productivity of crop i. C_c and C_o are the carbon sequestration cost and oxygen release cost, respectively, which are taken as RMB 260.9 per t and RMB 376.47 per t. y_i is the crop yield in kg. r_i is the water content of the crop, and e_i is the economic coefficient of the crop.

AR_2 is the negative functional value of the carbon release generated by the cultivated land system for gas regulation.

$$AR_2 = \lambda \times EF_j \times AD_j \times C_C \quad (5)$$

Among them, λ is the conversion factor of methane to standard C. According to the IPCC Fourth Assessment Report, each ton of CH_4 is equivalent to the greenhouse effect produced by 6.818 tons of standard C. EF_j is the emission factor of different types of rice (single-season rice, double-season early rice and late rice) in kg/ha. AD_j is the sown area of the corresponding subtype of rice in ha.

(3) Environmental Purification Function value: Cultivated crops are able to purify pollutants in the environment through adsorption, barrier, and transformation. The environmental purification function of cultivated land is now accounted for by the cost method.

$$EP = Q_k \times C_k \times S_k \quad (6)$$

Among them, Q_k is the amount of SO2, NO2, HF and dust that can be absorbed per unit area, and based on the results of existing studies (Yu et al., 2019), the values are taken as 45 kg/hm2, 33.31 kg/hm2, 0.33 kg/hm2 and 1,500 kg/hm2, respectively. C_k is the treatment cost of SO2, NO2, HF and dust, and the values are taken as RMB 0.6 per kg, RMB 0.6 per kg, RMB 0.9 per kg and RMB 0.17 per kg. S_k is the area of cultivated land in hm2.

(4) Water Conservation Function value: Cultivated crops and soils are capable of retaining, absorbing and storing precipitation, thus regulating and improving the regional water cycle and regional hydrological conditions. The water holding function of cultivated land is accounted for by the shadow engineering method.

$$WC = \left[\sum_{i=1}^{n} (W \times Si \times \alpha_i) + S_k \times h \times \rho \times g\right] \times C_w \quad (7)$$

Among them, W is the annual precipitation of the area in mm. α_i is the rainfall interception rate of crop i. S_i is the sown area of the main grain products (rice, wheat, corn) and soybean in China in hm2. ρ is the soil capacitance, and the overall soil capacitance in China conforms to the normal distribution characteristics with an average value of about 1.32 g/cm3W h is the soil thickness, taking the tillage layer depth of 0.2 m.g is the soil moisture content, taking 22.3%. C_w soil is the reservoir cost, taking the value of RMB 6.1107 per t.

(5) Biodiversity Support Function value:TEEB (The Economics of Ecosystems and Biodiversity) considers the habitat function and support function of cultivated land as the basis for all other services. Cultivated land has a pivotal influence on the maintenance of biodiversity. The value of biodiversity support functions of cultivated land is accounted for based on the ecosystem service value equivalent factor approach.

$$BS = D \times (\gamma_1 \times S_1 + \gamma_2 \times S_2) \quad (8)$$

$$\mathrm{D} = \frac{(Y_r \times V_r + Y_w \times V_w + Y_c \times V_c)}{S_r + S_w + S_c} \quad (9)$$

Among them, D is the net profit of food production per unit area of cropland ecosystem. In this paper, D is taken as 1 standard equivalent factor of ecosystem service value quantity in RMB per hm2. γ1 and γ2 were the biodiversity value equivalent factors for dryland and paddy fields, respectively, taken as 0.13 and 0.21. Y_r, Y_w and Y_c were the yields of rice, wheat and maiz e in kg, respectively. V_r, V_w and V_c are the profit of rice, wheat and maize, respectively. It is calculated by subtracting the production cost from the average selling price. S_1 and S_2 are the area of dryland and paddy field in hm2.and S_r, S_w and S_c are the sown area of rice, wheat and maize in hm2.

(6) Negative Environmental Function value: Under the background of rapid urbanization, the excessive use of chemical fertilizers and pesticides in agricultural production will lead to the deterioration of the ecological environment of cropland system. The market value method is used to calculate the economic loss from the over-application of pesticides and fertilizers. It is used to express the negative environmental functions resulting from the production of cultivated land.

$$NE = -\left[\left(Q_f - \theta\right) \times P_f \times \mathrm{S} + \mathrm{Q}_p \times \omega \times P_p \times \mathrm{S}\right] \quad (10)$$

Among them, Q_f and Q_p are the amount of fertilizer and pesticide applied in kg/hm2. P_f and P_p are the market prices of fertilizer and pesticide in RMB. θ is the environmental safety que value of fertilizer application, taken as 250 kg/hm-2. ω is the residual rate of pesticide in soil, taken as 25%. S is the total planted area of rice, wheat, corn, soybean, cotton, oilseed, sugar beet, sugarcane and vegetables in hectares.

(7) Cultural Service Function value

$$CS = \lambda \times S_k \times D \times \delta \quad (11)$$

Among them, λ is the value equivalent factor of cultural service function per unit area of cultivated land ecosystem. D is the value of cultivated land ecosystem service with 1 standard equivalent factor in RMB per hm2. Due to the difference in the level of economic development, the residents of different regions have different levels of demand and consumption capacity for the cultural service functions of natural resources. The ratio of local GDP *per capita* to national GDP *per capita*, δ, was used as the correction factor. Use δ to correct the social security service function of cultivated land in different years in each province and city.

(8) Social Security Function value: farmers are able to get livelihood rely on the producing function and turnover rent of cultivated land security when facing unstable employment. The social security function value of cultivated land is now accounted for by the cost of land in the production process of cultivation, taking into account the actual situation of agricultural development in different provinces in different years.

$$SS = \sum_{\mathrm{i}=1}^{n} (R_i + D_i) \times S_i \quad (12)$$

Among them, R_i and D_i are the cost of flow land rent and depreciation of self-camp for crops rice, wheat, corn, soybean, cotton, oilseed, sugar beet, sugar cane and vegetables, respectively, in RMB per mu. S_i is the planted area of major crops in acres.

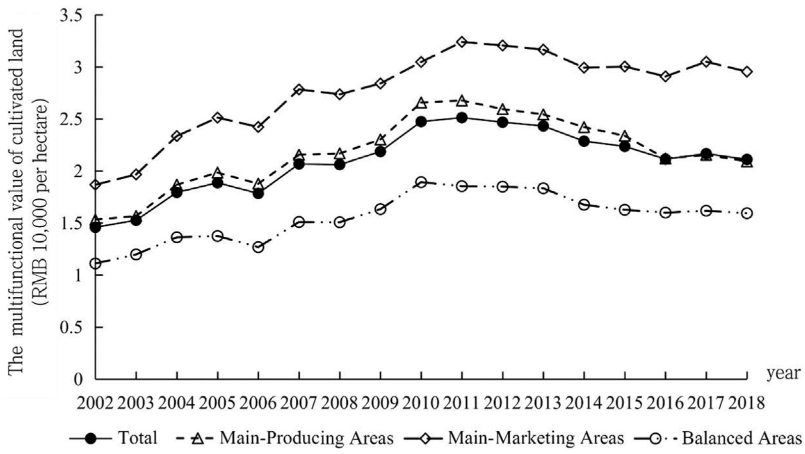

FIGURE 1
Trend of multifunctional change of cultivated land in 2002–2018.

3.2 Analysis of results

According to the foregoing theoretical analysis, this paper first conducts a preliminary statistical analysis on the multi-functional value of cultivated land in different grain functional areas. Figure 1 shows the functional value of cultivated land in the whole country from 2002 to 2018. In order to ensure national food security, the Chinese government has divided the country into grain main-producing areas, main-marketing areas and producing and marketing balance areas. The main-producing areas aim to further improve their grain production capacity and provide the country with a major source of commodity grain. The goal of the main-marketing areas is to stabilize the existing self-sufficiency rate of grain. Production and marketing balance areas should continue to ensure that the region's basic balance of food production and demand, some areas suitable for production should restore and improve food production capacity gradually. The main-producing areas include 13 provinces: Liaoning, Jilin, Heilongjiang, Inner Mongolia, Hebei, Shandong, Anhui, Jiangsu, Jiangxi, Henan, Hunan, Sichuan and Hubei. The main-marketing areas include 7 provinces: Beijing, Shanghai, Tianjin, Zhejiang, Hainan, Guangdong and Fujian. Grain production and marketing balance areas include 11 provinces: Shanxi, Guangxi, Chongqing, Yunnan, Guizhou, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. As we can see from the graph below, the main-producing areas, the main-marketing areas, and the producing and marketing areas showed an upward trend of fluctuation. There are differences in the multi-functional value of cultivated land in different subdivisions: the multi-functional value of cultivated land in the main grain marketing area is the highest, followed by the main producing area, and the producing and marketing balance area is the lowest. Meanwhile, the fluctuation status of the functional value of cultivated land in different grain functional areas varies between years. On the one hand, the different policy orientations of different food functional areas directly affect the degree of manifestation of their cultivated land functions; on the other hand, the resources endowment of cultivated land and the conditions of social development in different regions are different, which leads to the different demands of the stakeholders on the function of cultivated land. The results of descriptive statistics show that the impact of urbanization on the function of cultivated land is different in different grain functional areas.

Each function of cultivated land is independent and interconnected, and there are competing and promoting synergistic relationships among different functions. The Spearsman rank correlation coefficients between different functions of cultivated land in 2002 and 2018 are calculated to quantitatively determine the degree and direction of association between functions of cultivated land and analyze the "balance-synergy" relationship of functional cultivated land. Table 1 shows that there is a significant synergistic relationship among the functions of cultivated land, but there are differences in the synergistic situation among different types of functions. Among them, the synergistic relationship between producing and cultural functions, producing and social security functions, and ecological and social security functions are stronger, while the synergistic relationship between cultural and social security functions is weaker. With the advancement of urbanization, the synergy of cultivated land functions tended to weaken from 2002 to 2018, with the most obvious decline in the synergy of " producing -ecology" functions. This is a preliminary indication that the urbanization process not only affects the functional value of cultivated land in total but also brings about a structural evolution of cultivated land functions.

4 Data and model

4.1 The benchmark model

In order to test the impact of urbanization on the multi-functionality of cultivated land, the following models are constructed in this paper for investigation:

$$V_{it} = \alpha_0 + \alpha U_{it} + \sum \beta_j Control_{jit} + \mu_i + \gamma_t + \varepsilon_{it} \tag{13}$$

Among them, V_{it} is the multi-functional value of cultivated land. U_{it} is the level of urbanization in the t-year. $Control_{jit}$ is a series of control

TABLE 1 Multi-functional correlation of cultivated land in 2002 and 2018.

Year	Prod-eco function	Pro-cul function	Prod—social function	Eco-cul function	Eco-social function	Cul-social function
2002	0.7315***	0.7323***	0.7560***	0.4512**	0.9633***	0.4181**
2018	0.4855**	0.7468***	0.7476***	0.3202*	0.7653***	0.5472**

(1)The values in the table are the Spearsman correlation coefficient
(2)***, **, * stand for the significance levels at 1%, 5% and 10%, respectively.

TABLE 2 Descriptive statistical results for each variable.

Variable	Definition	Mean	Std. Dev	Min	Max	Obs
Value	Multi-functional value of cultivated land	2.0912	0.8053	0.6456	4.6021	527
urbanization	Urbanization rate	0.5098	0.1559	0.1991	1.0193	527
ind-structure	The proportion of the added value of secondary and tertiary industries in GDP	0.8825	0.0624	0.6210	0.9968	527
Income	Per capita disposable income of rural residents	0.7520	0.5098	0.1462	3.0375	527
palnting-structure	The proportion of food crops	0.6175	0.1130	0.3385	0.8845	527
machine	Total power of farm machinery	7.7370	4.2302	0.5850	26.6720	527
irrigation	The proportion of effective irrigated area to cultivated area	0.5497	0.2431	0.1369	1.2079	527
facility	Completed investment in water conservancy construction	5.7316	0.4884	4.4582	6.7620	527
damage-defence	The proportion of the affected area minus the affected area	0.4948	0.1415	0.1000	0.9767	527
conservation	Soil and water conservation management area	2.3043	0.6160	0.1818	3.1467	527
multi-cropping	The proportion of the total sown area of crops to the cultivated area	1.3439	0.4376	0.4877	2.4271	527
water-resource	Total water resources	6.6336	0.6506	4.5647	7.6773	527
land-resource	Area of cultivated land/number of primary-industry employees	0.5717	0.4430	0.1401	2.8334	527

variables. μ_i is an individual-fixed effect, γ_t is a time-fixed effect, and ε_{it} is a random perturbation term.

4.2 Variable selection

The explained variable of this paper is the multi-functional value of cultivated land. According to the connotation of multi-functional value of cultivated land, it should contain four dimensions: producing function, ecological function, cultural function and social security function. In this paper, eight representative indicators including food production, gas regulation, environmental purification, water conservation, biodiversity support, environmental pollution, cultural and leisure services, and social security are selected to reflect the multi-functionality of cultivated land. The opportunity cost method, market value method and shadow engineering method are used to quantify the service value of cultivated land. Meanwhile, in order to avoid being affected by the cultivated land area, the multi-functional value of unit cultivated land area is used as the explained variable.

The core explanatory variable of this paper is the level of urbanization. The measurement methods of urbanization can be roughly divided into two categories: the single index method and the comprehensive index method. Population urbanization and land urbanization are common single indicators. The population proportion index method is a common calculation method because of its direct algorithm and clear concept. Its representative indicators include the proportion of permanent population, the proportion of registered population, the proportion of non-agricultural employment, etc. After the concept of new urbanization was proposed, the comprehensive index method of urbanization, which takes population, land, economy and environment as the main dimensions, has gradually attracted the attention of the academic circle. The advantage of the comprehensive index method is that it can reflect the level of urbanization in an all-round and multi-angle way. However, a general index system has not been formed in the academic circle. Population agglomeration is the primary feature and support of urbanization. Based on such considerations, this paper uses the proportion of permanent residents to measure the urbanization level and test the impact of urbanization on the multi-functional value of cultivated land. On this basis, this paper takes population urbanization, land urbanization, economic urbanization and employment urbanization into consideration, calculates the comprehensive urbanization index from four dimensions, and tests the robustness of the model.

In this paper, control variables are set from four dimensions: economic factors, agricultural production conditions, cultivated land utilization capacity and resource endowment. It includes 10 variables including industrial structure, farmer income, agricultural machinery power, irrigation efficiency, farmland water conservancy infrastructure, disaster resistance, soil and water management, multiple cropping index, water resource endowment and average cultivated land area. The screening is based on the following principles and their descriptive statistical characteristics are presented in Table 2.

TABLE 3 Benchmark regression results.

Variable	(1)	(2)	(3)	(4)	(5)
	Multi-function	Prod	Eco	Cul	Sec
urbanization	3.0728*** (0.3972)	1.4491*** (0.3388)	0.7733*** (0.0969)	0.0808*** (0.0181)	0.7698*** (0.0848)
ind-structure	1.3947** (0.6065)	0.9644* (0.5172)	−0.0005 (0.148)	0.0853** (0.0277)	0.3454** (0.1294)
income	−0.1168** (0.0526)	−0.2144*** (0.0449)	−0.0268** (0.0128)	−0.0202*** (0.0024)	0.1447*** (0.0112)
palnting-structure	1.6946*** (0.2614)	0.3330 (0.2229)	1.1620*** (0.0638)	0.0571*** (0.0119)	0.1426** (0.0558)
machine	0.0664*** (0.0071)	0.0541*** (0.0061)	0.0028 (0.0017)	0.0013*** (0.0003)	0.0109*** (0.0015)
irrigation	−0.201 (0.1986)	−0.3513** (0.1694)	0.1147** (0.0485)	0.0172* (0.0091)	0.0184 (0.0424)
facility	0.0189 (0.0522)	0.0335 (0.0445)	−0.0212* (0.0127)	0.0022 (0.0024)	0.0044 (0.0111)
damage-defence	0.4842*** (0.0714)	0.3927*** (0.0609)	0.0276 (0.0174)	0.0156*** (0.0033)	0.0483** (0.0152)
conservation	−0.2333*** (0.0654)	−0.1097* (0.0558)	−0.0866*** (0.016)	−0.0021 (0.003)	−0.0349** (0.014)
multi-cropping	0.9367*** (0.0763)	0.3988*** (0.0651)	0.4187*** (0.0186)	−0.042 (0.0035)	0.1234*** (0.0163)
water-resource	0.2289** (0.0887)	0.2163** (0.0756)	−0.0006 (0.0216)	0.0100** (0.004)	0.0031 (0.0189)
land-resource	0.0964 (0.0868)	0.0359 (0.074)	0.0887*** (0.0212)	0.0047** (0.004)	−0.0329* (0.0185)
_cons	−4.7801*** (0.8349)	−3.3025*** (0.7120)	−0.4023** (0.2037)	−0.2127*** (0.0381)	−0.8626*** (0.1782)
Year Fe	Yes	Yes	Yes	Yes	Yes
Province Fe	Yes	Yes	Yes	Yes	Yes
N	507	507	507	507	507
r2_a	0.723	0.501	0.775	0.344	0.890

(1) The values in parentheses are robust standard errors.
(2)***, **, * represent the significance level of 1%, 5% and 10% respectively.
(3)Prod, Eco, Cul and Sec are abbreviations for the productive, ecological, cultural and social security functions of cultivated land, respectively.

(1) Since the secondary and tertiary industries have a high employment occupancy rate, the industrial structure will affect the regional non-agricultural employment and land output rate. In this way, the industrial structure will indirectly affect the functional value of cultivated land. The income of farmers affects the investment ability of farmers to grow grain, which may enhance the value of tillage function by improving the production efficiency of cultivated land. From another perspective, the increase of farmers' income may accelerate the possibility of agricultural marginalization, which will lead to the reduction of the functional value of cultivated land. In this paper, industrial structure and farmers' income are selected to represent regional economic factors.
(2) As an important condition for ensuring grain production, agricultural production conditions directly affect grain production capacity and the comprehensive utilization efficiency of cultivated land. In this paper, agricultural mechanical power, irrigation efficiency and water conservancy facilities were selected to characterize agricultural production conditions.
(3) The utilization mode and level of cultivated land have an effect on the production and environment of cultivated land. It can affect the food production, environmental conservation, ecological maintenance, cultural services and other functions of cultivated land by influencing the input ratio of cultivated land elements, the utilization intensity of cultivated land and the types of crops planted. In this paper, planting structure, disaster resistance, soil and water management and multiple cropping index were selected to represent the cultivated land utilization.
(4) The natural background conditions of a region directly affect the realization degree of the value output of local cultivated land resources. In this paper, water resource endowment and cultivated land area per labor are selected to represent the resource endowment status of the region.

5 Empirical analysis

5.1 Benchmark regression

Table 3 reports the impact of urbanization on the function of cultivated land. The estimation results in column (1) show the impact of urbanization on the accounting results of the multi-functional value of cultivated land. The results in columns (2)–(5) respectively show the impact of urbanization on the producing function, ecological function, cultural function and social security function of cultivated land. According to column (1), the impact of urbanization on the multi-functional value of cultivated land is significant at the significance level of 1%, and the coefficient is 3.0728. Specifically, for every 1% increase in the level of population urbanization, the multi-functional value of farmland per hectare will increase by RMB 0.0307 million.

The above empirical results show that the positive effect of urbanization on the multi-functional value of cultivated land is greater than the negative effect. The development of urbanization has significantly increased the multi-functional value of cultivated land, which verifies hypothesis 1. On the one hand, the economic benefits brought by urbanization play a direct positive role in improving the stock of cultivated land and restoring reserve cultivated land resources. On the other hand, the agglomeration and scale effect of urbanization promote the intensive use of urban land, which enables the non-agricultural land of urban units to accommodate more population. It indirectly slows down the rhythm of non-agricultural cultivation of cultivated land and guarantees the continuous growth of the functional value of cultivated land. In addition, on the basis of the investment of more funds and technology, agricultural production efficiency has been continuously improved, and the structure and layout of farmland utilization have been continuously optimized. This makes up for the loss of production and ecological functions caused by the flow of population to non-agricultural sectors and achieves the effect of increasing the total functional value of cultivated land.

The multi-function of cultivated land is the multiple output and service effect in the utilization of cultivated land resources. We take the producing function, ecological function, cultural function and social security function of cultivated land as the explained variables for regression analysis. The estimated results are shown in columns (2)–(5) of Table 3. It can be seen that urbanization has a significant positive impact on the producing function, ecological function, cultural function and social security function of cultivated land, and this result is consistent with the regression result of the benchmark model. The development of urbanization is the driving force to promote the functional transformation of cultivated land use. The promotion of urbanization has led to the upgrading of the consumption structure and level of agricultural products. The demands of urban and rural residents are no longer limited to specific agricultural products, but are upgrading to non-commodity services such as cultural landscapes and ecological services. These changes caused farmers to change the input structure of agricultural labor force, land, biological chemicals and other factors under the conditions of the established endowment of cultivated land resources. The empirical results show that with the change of cultivated land use structure brought by urbanization, the producing function value, ecological function value, cultural function value and social security function value of cultivated land are all improved. Among them, the producing function is the most obvious response. For every one percentage point increase in the urbanization rate, the productive function value of each hectare of cultivated land will increase by RMB 0.0145 million.

Focusing on the control variables, we can find that the industrial structure variables have a positive effect on the realization of the multi-functional value of cultivated land, but have no obvious effect on the ecological function of cultivated land. The increase of farmers' income reduces the multi-functional value of cultivated land, which means that the increase of labor opportunity cost is not conducive to the manifestation of the functional value of cultivated land. The increase of the proportion of grain sown area can effectively improve the ecological function, cultural function and social security function of cultivated land. Agricultural production condition is the key to grain production capacity and plays a positive role in improving the multi-functional value of cultivated land. The improvement of disaster resistance ability alleviated the blow of natural disasters on grain production and had a significant positive effect on the manifestation of multi-functional value of cultivated land. The variables of soil and water management are significant and the coefficient is negative. The large area of soil and water management indicates that the local ecological endowment of soil and water conservation is not good, which is not conducive to the manifestation of the multi-functional value of cultivated land. The multi-cropping index reflects the utilization intensity of cultivated land, which is conducive to better producing and security functions of cultivated land, and maximizes the environmental purification function of unit cultivated land. The water resource endowment variable is significant and the coefficient is positive, indicating that the more abundant water resources, the higher the multi-functional value of cultivated land.

5.2 Heterogeneity analysis

There are differences in the endowment of cultivated land resources, social development conditions and the demand of relevant stakeholders for the multi-function of cultivated land in different food functional areas. Based on grain function zoning, the impacts of urbanization on different functions of cultivated land should also be heterogeneous. This paper investigates the responses of the producing, ecology, culture and security functions of cultivated land to urbanization in the main grain-producing area, the main-marketing area and the producing and marketing balance area. The results are shown in Table 4. It can be found that in different functional areas, cultivated land producing function is significantly positively affected by urbanization, and the degree of impact is the most obvious, which is consistent with the estimated results of the national samples.

The input and utilization types of cultivated land elements will affect the producing, ecology, culture and security functions of cultivated land. In terms of function, cultivated crops can be roughly divided into three categories: food crops, cash crops and horticultural crops. Food crop includes rice, wheat and corn. Cash crop includes soybean, cotton, sugarcane, oil, tobacco and other crops with higher economic benefits. Horticultural crop includes all kinds of vegetables, fruits, flowers and so on. On the one hand, due to the different physiological characteristics of different crops, the amount and proportion of inputs such as labor, land, machinery and biological chemicals vary greatly. For example, cash crops have lower fertilizer utilization rate and higher fertilizer input intensity compared with food crops. From the perspective of labor input, Horticultural crops usually have the largest labor demand, while field food crops have less labor demand. For mechanical input, the mechanized operation rate of field food crops was higher than that of cash crops and horticultural crops. On the other hand, different crop types have different impacts on cultivated land types. For example, most cash crops and horticultural crops are dry crops, while the cultivated land in some regions in the northeast and most regions in the south tends to be dominated by paddy fields.

As can be seen from Table 4, the producing function and social security function value of major grain-producing areas have the most obvious response to urbanization. For every one percentage point increase in the urbanization rate, the productive value of farmland per hectare will increase by RMB 0.0149 million. First of all, the main food-producing areas are dominated by food crop cultivation, and

TABLE 4 Heterogeneity test results.

Variable	Main-producing area				Main- marketing area				Producing and marketing balance area			
	Prod	Eco	Cul	Sec	Prod	Eco	Cul	Sec	Prod	Eco	Cul	Sec
urbanization	3.928***	0.873***	0.105***	1.488***	3.935***	−0.042	0.327***	0.583**	3.217***	1.162***	0.115***	0.602***
	(0.613)	(0.207)	(0.035)	(0.127)	(0.945)	(0.279)	(0.072)	(0.244)	(0.637)	(0.203)	(0.024)	(0.168)
ind-structure	−0.467	−0.190	0.089**	0.138	5.138***	0.240	0.108	1.181***	1.816**	−0.127	0.128***	0.432**
	(0.659)	(0.223)	(0.038)	(0.137)	(1.247)	(0.368)	(0.095)	(0.322)	(0.739)	(0.235)	(0.028)	(0.195)
Income	−0.805***	0.006	−0.038***	0.078***	−0.115	−0.039*	−0.019***	0.149***	−0.752***	−0.096***	−0.034***	0.136***
	(0.085)	(0.029)	(0.005)	(0.018)	(0.074)	(0.022)	(0.006)	(0.019)	(0.109)	(0.035)	(0.004)	(0.029)
palnting-structure	0.215	1.213***	0.024	−0.570***	−0.122	0.974***	0.101***	−0.073	−0.311	0.609***	−0.001	0.062
	(0.447)	(0.151)	(0.026)	(0.093)	(0.430)	(0.127)	(0.033)	(0.111)	(0.349)	(0.111)	(0.013)	(0.092)
Machine	0.073***	0.003	0.002***	0.011***	0.004	−0.003	0.001	0.014***	0.029***	0.000	0.001***	−0.002
	(0.008)	(0.003)	(0.000)	(0.002)	(0.015)	(0.004)	(0.001)	(0.004)	(0.007)	(0.002)	(0.000)	(0.002)
Irrigation	0.228	0.231*	0.056**	0.481***	0.167	0.236***	0.016	−0.009	−0.600***	0.192***	−0.008	0.052
	(0.404)	(0.137)	(0.023)	(0.084)	(0.267)	(0.079)	(0.020)	(0.069)	(0.199)	(0.063)	(0.008)	(0.053)
Facility	0.219***	−0.012	0.011***	0.021	−0.027	0.036	−0.005	−0.005	0.029	−0.072***	−0.001	−0.002
	(0.062)	(0.021)	(0.004)	(0.013)	(0.084)	(0.025)	(0.006)	(0.022)	(0.057)	(0.018)	(0.002)	(0.015)
damage-defence	0.318***	0.017	0.012**	0.023	0.417***	−0.011	0.017**	−0.066**	0.162**	0.047**	0.012***	0.083***
	(0.085)	(0.029)	(0.005)	(0.018)	(0.113)	(0.033)	(0.009)	(0.029)	(0.071)	(0.023)	(0.003)	(0.019)
conservation	−0.022	−0.109*	0.004	−0.115***	−0.595***	−0.109**	−0.024*	0.016	0.022	−0.006	0.001	0.012
	(0.167)	(0.057)	(0.010)	(0.035)	(0.186)	(0.055)	(0.014)	(0.048)	(0.046)	(0.015)	(0.002)	(0.012)
multi-cropping	0.366***	0.431***	−0.014**	0.026	0.624***	0.401***	−0.005	0.209***	−0.067	0.255***	0.013**	0.226***
	(0.106)	(0.036)	(0.006)	(0.022)	(0.129)	(0.038)	(0.010)	(0.033)	(0.146)	(0.047)	(0.006)	(0.039)
water-resource	0.215**	0.063**	0.010**	−0.026	0.017	−0.024	−0.006	0.009	0.153	0.038	−0.000	−0.031
	(0.089)	(0.030)	(0.005)	(0.019)	(0.134)	(0.039)	(0.010)	(0.034)	(0.122)	(0.039)	(0.005)	(0.032)
land-resource	0.112	0.047	0.010*	0.016	0.475	0.081	−0.020	−0.005	−0.037	0.010	0.010**	−0.047*
	(0.091)	(0.031)	(0.005)	(0.019)	(0.311)	(0.092)	(0.024)	(0.080)	(0.098)	(0.031)	(0.004)	(0.026)

(Continued on following page)

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TABLE 4 (*Continued*) Heterogeneity test results.

Variable	Main-producing area				Main- marketing area				Producing and marketing balance area			
	Prod	Eco	Cul	Sec	Prod	Eco	Cul	Sec	Prod	Eco	Cul	Sec
_cons	−4.514***	−0.733**	−0.277***	−0.285	−6.461***	−0.168	−0.217**	−1.727***	−3.059***	−0.074	−0.145***	−0.636**
	(0.959)	(0.324)	(0.055)	(0.199)	(1.265)	(0.373)	(0.096)	(0.326)	(1.149)	(0.366)	(0.044)	(0.303)
Year Fe	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province Fe	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	221	221	221	221	100	100	100	100	186	186	186	186
r2_a	0.715	0.837	0.459	0.957	0.770	0.899	0.590	0.932	0.562	0.520	0.604	0.919

(1) The values in parentheses are robust standard errors.
(2)***, **, * represent the significance level of 1%, 5% and 10% respectively.

they have higher policy pressure to stabilize production and ensure food security. Growing food crops has obvious labor-saving characteristics, which can be compensated by machinery substitution and improving the grain-to-crop ratio, thus not hindering the manifestation of the functional value of cultivated land. Therefore, urbanization has a significant positive impact on the producing and social security functions in the main grain-producing regions. Secondly, urbanization has a more significant impact on the cultural function value of cultivated land in the main grain marketing areas than in the main grain producing and balancing areas. This is mainly due to the high level of economic and social development in the main grain-marketing areas. In these areas, the demand of urban and rural residents for agricultural landscape, leisure and high-quality agricultural products is growing at a rapid pace. At the same time, multi-functional agriculture that integrates leisure, tourism and travel has emerged. Under such conditions, the cultural function of cultivated land is significantly enhanced. In addition, it is worth noting that urbanization has diminished the ecological function of cultivated land in the main-marketing areas. With a low food self-sufficiency rate and a high dietary structure and consumption level of residents in the main marketing area, the proportion of cash crops and horticultural crops grown on cultivated land in this region is much higher than that in the main grain-producing area and the producing and marketing balance area. Urbanization has led to a continuous increase in the demand for cash crops represented by flowers in the region. As this type of crops requires more water and fertilizer, it will bring the problems of fertilizer waste and groundwater pollution. Therefore, urbanization shows a negative impact on the ecological function of the main marketing area.

5.3 Robustness check

In the initial model, this paper examines the effect of population urbanization on the multi-functional value of cultivated land. We replace the explanatory variables to conduct robustness tests and further examine the effect of comprehensive urbanization rate on the multi-functional value of cultivated land. We construct a comprehensive urbanization index evaluation model from four dimensions: population urbanization, land urbanization, economic urbanization and employment urbanization. Land urbanization is characterized by "urban built-up area/administrative area". Social urbanization is characterized by "year-end actual road area/administrative area". Employment urbanization is characterized by "the sum of rural private employment and self-employment/rural population".

In this paper, we calculate the weights of different dimensions of urbanization by entropy weighting method. We will not expand the specific steps of entropy weighting method specifically. The multi-objective linear weighting function method is used to calculate the comprehensive urbanization rate, and the specific formula is as follows:

$$P_{it} = \sum_{n=1}^{4} \left(X'_{nit} \times \eta_n \right) \tag{14}$$

Among them, P_{it} is the composite index of urbanization; X'_{nit} is the standardized result of different urbanization rates; η_n is the weight of different dimensional urbanization indicators.

In Table 5, column (1) represents the regression results for the full sample, and columns (3)–(5) represent the regression results

TABLE 5 Robustness test regression results.

Variable	National sample	Different functional areas sample		
	(1)	(2)	(3)	(4)
composite urbanization	0.629***	1.017***	0.232*	0.970***
	(0.065)	(0.109)	(0.123)	(0.125)
Ind-structure	1.875***	1.186*	8.484***	2.244***
	(0.552)	(0.712)	(1.563)	(0.806)
Income	−0.396***	−0.908***	0.009	−0.795***
	(0.066)	(0.108)	(0.122)	(0.120)
Palnting-structure	1.339***	0.103	1.247**	0.849**
	(0.258)	(0.544)	(0.592)	(0.387)
Machine	0.065***	0.082***	0.033*	0.032***
	(0.007)	(0.010)	(0.020)	(0.008)
Irrigation	0.127	1.138**	0.980***	−0.330
	(0.194)	(0.471)	(0.336)	(0.220)
Facility	0.088*	0.272***	0.065	−0.011
	(0.048)	(0.072)	(0.110)	(0.059)
Damage-defence	0.484***	0.387***	0.378**	0.296***
	(0.069)	(0.100)	(0.150)	(0.078)
Conservation	−0.226***	0.014	−0.658***	0.026
	(0.063)	(0.186)	(0.246)	(0.051)
Multi-cropping	0.882***	0.764***	1.069***	0.525***
	(0.074)	(0.123)	(0.164)	(0.160)
Water-resource	0.185**	0.259**	−0.017	0.162
	(0.086)	(0.104)	(0.179)	(0.135)
Land-resource	0.238***	0.457***	0.490	−0.010
	(0.083)	(0.115)	(0.412)	(0.106)
_cons	−5.249***	−7.062***	−9.020***	−4.403***
	(0.795)	(1.092)	(1.672)	(1.257)
Year Fe	Yes	Yes	Yes	Yes
Province Fe	Yes	Yes	Yes	Yes
N	507	221	100	186
r2_a	0.740	0.855	0.825	0.752

(1) The values in parentheses are robust standard errors.
(2) ***, **, * represent the significance level of 1%, 5% and 10% respectively.

for the grain main-producing areas, main-marketing areas, and grain producing and marketing balance areas, respectively. It can be concluded that both under the national sample and under the sub-functional area sample, the calculated composite urbanization rate also has a significant positive effect on the multi-functional value of cultivated land. This is consistent with the direction of influence of the benchmark model.

5.4 Further analysis

In order to reveal the impact of urbanization on the multi-functional in value of cultivated land, this paper further analyzes the response of the multi-functional structure of cultivated land to urbanization. The structure of cultivated land refers to the combination of various functions of cultivated land, which is used

TABLE 6 Effect of urbanization on the multi-functional structure of cultivated land.

Variable	National sample		Different functional areas sample		
	(1)	(2)	(3)	(4)	(5)
Urbanization	−1.354***	−1.259***	−0.843**	−1.564***	−2.406***
	(0.093)	(0.142)	(0.341)	(0.290)	(0.375)
Ind-structure	—	−0.559**	−1.586***	−0.241	−1.080***
		(0.218)	(0.563)	(0.306)	(0.409)
Income	—	0.077***	0.059*	0.150***	0.366***
		(0.019)	(0.032)	(0.043)	(0.066)
Palnting-structure	—	−0.589***	−0.613***	−1.066***	−0.315
		(0.094)	(0.177)	(0.225)	(0.235)
Machine	—	−0.019***	−0.026***	−0.018***	−0.011**
		(0.003)	(0.005)	(0.004)	(0.004)
Irrigation	—	−0.079	−0.120	−0.105	−0.039
		(0.071)	(0.122)	(0.189)	(0.108)
Facility	—	−0.033*	−0.041	−0.020	−0.007
		(0.019)	(0.034)	(0.028)	(0.031)
Damage-defence	—	−0.210***	−0.144***	−0.155***	−0.183***
		(0.026)	(0.045)	(0.043)	(0.041)
Conservation	—	0.063***	−0.008	0.104	0.011
		(0.023)	(0.076)	(0.083)	(0.025)
Multi-cropping	—	−0.433***	−0.453***	−0.445***	−0.404***
		(0.027)	(0.058)	(0.052)	(0.049)
Water-resource	—	−0.118***	−0.130***	−0.014	−0.158**
		(0.032)	(0.048)	(0.050)	(0.069)
Land-resource	—	−0.133***	−0.171*	−0.212***	−0.036
		(0.031)	(0.103)	(0.045)	(0.049)
_cons	2.422***	4.973***	5.946***	4.352***	5.721***
	(0.048)	(0.299)	(0.529)	(0.496)	(0.639)
Year Fe	Yes	Yes	Yes	Yes	Yes
Province Fe	Yes	Yes	Yes	Yes	Yes
N	527	507	185	153	169
r2_a	0.298	0.777	0.805	0.833	0.823

(1) The values in parentheses are robust standard errors.
(2)***, **, * represent the significance level of 1%, 5% and 10% respectively.

to represent the diversity and homogeneity of multi-functional cultivated land. Simpson's reciprocal index is used to measure the multi-functional structure index of cultivated land:

$$SRI_{it} = \frac{1}{\sum(V_{kit}/N)^2} \tag{15}$$

Here, SRI_{it} is the Simpson's inverse index of the multi-functional value of cultivated land in province i in year t V_{kit} is the functional value of cultivated land of category k. It is measured in million RMB per ha. N is the type of cropland function in the study area.

The Simpson's inverse index of the multi-functional value land was used to represent the structural characteristics of cultivated. We used it as the explanatory variable for regression analysis, and the estimated results are shown in Table 6. Column (1)–(2) represents the regression results for the full sample, and columns (3)–(5) represent the regression results for the grain main-producing areas, main-marketing areas, and grain producing and marketing balance areas, respectively. We can find that the impact of urbanization is significantly negative under the national sample and under each functional area sample. In other words, urbanization has reduced the diversity of cultivated land types, and the uniformity of different functional values has decreased. The reason may be that the functional attributes of farmland begin to change along with human needs and utilization levels, and the different functions of farmland are derived and transformed (Jiang et al., 2017).

Under certain technical conditions, the process of urbanization will cause changes in the endowment of cultivated land in different functional areas. How cultivated land is used will certainly bring about the evolution of the types of functions of cultivated land. Generally speaking, at the primary stage of urbanization development, the positioning of cultivated land functions is not clear. Cultivated land comprehensively assumes the functions of ensuring production, ecological regulation and environmental conservation. The value distribution among the various types of functions of cultivated land is quite balanced. The advancement of urbanization has provided impetus for the accelerated development of factor markets and commodity markets. The use of cultivated land has also advanced in the direction of pursuing economic output. Although there is a tendency for non-agricultural use of cultivated land, urbanization has also brought about an increase in food productivity. At this stage, the producing and security functions of cultivated land are obviously enhanced, but the ecological regulation function begins to weaken. With the further development of urbanization, people's understanding of the usefulness of cultivated land resources has become more diversified. In addition to producing agricultural products and maintaining ecological balance, cultivated land has gradually begun to assume the aesthetic and recreational functions of landscape culture for residents. In summary, with the development of urbanization, the connotation of cultivated land function has been enriched and evolved. The functional orientation of cultivated land in different regions is inevitably differentiated, which is the main reason for bringing about a decrease in the uniformity of the functional structure of cultivated land.

6 Conclusions and policy implications

This paper estimates the effects of urbanization on the total and structure of the functional value of cultivated land using a fixed-effects model based on panel data for 31 provinces in China from 2002–2018. At the same time, we examine the heterogeneity among cultivated land functions and between regions. The paper draws the following conclusions.

First, the accounting results of the functional value of cultivated land in China show a general trend of fluctuation and increase. There is an obvious synergistic relationship among the functions, and this synergistic relationship tends to weaken in the time series. Urbanization did not bring about a decline in the functional value of cultivated land, but rather a significant increase in its functional value. In terms of the results of different functions, the production function of cultivated land is most obviously enhanced. Second, the results of different functional areas show that the production function and the value of social security function in the main-producing areas respond most obviously to urbanization. The culture of the main-marketing areas responds most obviously to urbanization, and urbanization reduces the ecological function of these areas. Third, urbanization has reduced the diversity of cultivated land types. The uniformity between the functions of different cultivated land is reduced, and the functional orientation is gradually obvious. Based on the above findings, this paper puts forward suggestions for policy formulation as follows.

Firstly, policymakers should pay attention to the relationship between the total amount of cultivated land functions and its structure. Our study finds an obvious interaction between different functions of cultivated land. Therefore, it is important to strengthen the total amount of functional value of cultivated land, while it is also necessary to improve the synergy of functional diversity. Under the background of rapid urbanization, it is critical to focus on the integrated development of cultivated land functions in order to promote sustainable growth of agricultural economy.

Secondly, according to the results, the response of cultivated land functions to urbanization is heterogeneous in different regions. The government should implement regional policies on multi-functional use of cultivated land to further fit the leading functions of each main functional area. For example, in the main agricultural products producing areas with better soil quality, the large-scale operation of cultivated land should be promoted to enhance the production function of cultivated land. The transfer of agricultural labor should be reasonably controlled to enhance the ecological function and social security function of it. In districts where ecological functions are clearly available, the government should deeply explore the non-commodity functions and service functions of the cultivated land resources. These areas should actively strengthen the ecological compensation of cultivated land and enhance its "green" value while developing modern agricultural markets. In areas with better economic development, local governments can orderly build a number of citizen farms and leisure farms as a way to meet the demand of urban residents for ecological landscape and cultural functions of cultivated land. These districts need to pursue further development of the ecological landscape and cultural functions of cultivated land.

Thirdly, our research shows that the functional orientation of cultivated land in different regions is becoming more and more apparent. Considering that stakeholders have different demands on cultivated land resources, government departments should carry out targeted social services for guidance. For example, farmers are the most direct subjects of cultivated land utilization. The primary job of the government for farmers is to provide socialized agricultural services in the process of population urbanization. Specific measures include organizing technical training on scientific fertilization and scientific cultivation for them. For large-scale farmers, the government needs to further improve their knowledge and ability to manage their land. In this way, it can raise the output of cultivated land and promote its value so that the agricultural economy can grow sustainably. For companies, the government can attract them to the agricultural sector by organizing new business extension activities. The government can be a channel for agricultural promotion to make them aware of the advantageous development of the multi-functionality of cultivated land. The development of modern agriculturalization rooted in multi-functional cultivated land can finally be realized through the implementation of a wide range of socialization activities.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: National Bureau of Statistics.

Author contributions

WS is responsible for data verification, searching literature and proofreading the manuscript.

DL is responsible for data collection, literature review, methodology, code and paper writing.

Conflict of interest

Author WS was employed by the company Shanghai Weicheng Enterprise Credit Information Co, Ltd.

The Remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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