The Level of Agricultural Mechanization, the Scale of Agricultural Operation and the Income Gap Between Urban and Rural Areas

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Abstract

Agricultural mechanization is an effective way to improve farmers' income, and increasing farmers' income is the key means to narrow the income gap between urban and rural areas, and narrowing the income gap between urban and rural areas is one of the key factors to realize the integrated development of urban and rural areas. Based on the relevant statistical data of China from 2010 to 2020, a two-way fixed effect model was established to analyze the impact of agricultural machinery intervention on the income gap between urban and rural areas. The results show that the improvement of agricultural mechanization level has a significant positive impact on the convergence of urban-rural income gap. Its mechanism of action is to promote the increase of farmers' income and narrow the income gap between urban and rural areas, mainly through two paths: obtaining economies of scale through large-scale agricultural operation and providing agricultural machinery social services to improve operating income. Heterogeneity analysis showed that the improvement of agricultural mechanization level had a more significant effect on the convergence of urban-rural income gap in eastern China and non-main grain producing areas. Finally, it is suggested to develop mechanized agriculture according to local conditions, give diversified policy support to farmers to purchase agricultural machinery, improve the construction of socialized service system of agricultural machinery, ensure that land use rights can be transferred in an orderly manner, and further improve the relevant systems to support the development of large-scale agricultural operation.

Keywords: mechanized agriculture, scale operation, income disparity, Agricultural machinery leasing services, operating income

1. Introduction

The long-standing dual economic structure of urban and rural areas is one of the important factors leading to the widening of the income gap between urban and rural areas. In the report of the 20th National Congress of the Communist Party of China, it was emphasized that it is necessary to continue to enhance the coordination of urban and rural development, focus on solving the problems of agriculture and rural farmers ("three rural"), especially the problem of increasing farmers' income, organically connect rural revitalization, and promote the integrated development of urban and rural areas to reshape a new type of urban-rural relationship. However, at present, the phenomenon of unbalanced development between urban and rural areas and uneven income distribution is still obvious. According to the National Bureau of Statistics, the per capita disposable income of urban residents in 2023 will be 51,821 yuan, while that of rural residents will be only 21,691 yuan, and the income gap between urban and rural areas will reach 2.39 times. The development of modern agriculture and the promotion of farmers' income are regarded as the key ways to narrow the gap between urban and rural areas. At the 2022 Central Rural Work Conference, General Secretary Xi Jinping emphasized that it is necessary to "accelerate the construction of an agricultural power and promote the modernization of agriculture and rural areas", and the core of promoting agricultural modernization lies in improving the level of agricultural mechanization. According to the "2022 National Statistical Communiqué on the Development of Agricultural Mechanization", the comprehensive mechanization rate of crop cultivation and harvesting in China has reached 73.11%, the total power of agricultural machinery in the country has exceeded 1.1 billion kilowatts, and the number of rural agricultural machinery employees has reached 49.5998 million. Since the implementation of the subsidy policy for the purchase of agricultural machinery in 2004, the level of agricultural mechanization has continued to improve. Theoretically, the introduction of agricultural machinery as a "modernization element" can save costs, increase efficiency, and increase farmers' income [1]. In fact, the wage gap between urban and rural areas has raised the opportunity cost for rural labor to continue to engage in agricultural production, and a large number of rural working-age labor

force has shifted to non-agricultural employment. According to the 2023 Migrant Worker Monitoring Survey Report, the proportion of rural laborers going out to work will reach 59.3% in 2023, of which 44.6% are under the age of 40, and most of them are male, and the proportion under the age of 50 will reach 69.4%. This large-scale labor outflow has led to an aging and feminized rural employment structure, and the skills mismatch has made it difficult for some farmers to adapt to the new mode of production, and may encounter obstacles in the introduction and application of modern agricultural technology, affecting the process of agricultural modernization.

Large-scale agricultural operations are an important direction for the transformation of China's agricultural management system and mode, and an important way to improve the efficiency of agricultural production [2]. Large-scale agricultural operations promote the modernization and transformation of agricultural production by integrating land resources and optimizing resource allocation, achieving large-scale benefits. Labor outflow may lead to idle or inefficient use of land, loosening the "human-land relationship" in rural areas, and even the phenomenon of cultivated land abandonmeng in some areas, and large areas of abandoned land provide the possibility of agricultural mechanization and large-scale operation, but at the same time, it may also exacerbate the income gap between urban and rural areas. On the one hand, the investment in agricultural machinery in agriculture can effectively alleviate the problems of low agricultural production efficiency caused by the rise in agricultural labor costs and the shortcomings of production skills, and at the same time promote the adjustment of agricultural industrial structure, improve agricultural productivity, promote the transfer of labor, increase non-agricultural income, and narrow the income gap between urban and rural areas. On the other hand, due to factors such as unbalanced economic development between regions, differences in policy support, and different geographical environments, farmers in some areas have not been able to fully benefit from these changes, and may face the risk of declining income due to loss of land or employment opportunities, which will exacerbate the income gap between urban and rural areas. So, will mechanization and agricultural-scale operations affect the urban-rural income gap? How does it work? It is of great significance to discuss the above issues and explore the optimization path of relevant policies to promote agricultural modernization, realize rural revitalization and the urban-rural integration development.

Most of the existing studies have discussed the impact of agricultural mechanization level and agricultural large-scale operation on the income gap between urban and rural areas from the perspective of non-farm income and rural labor transfer. Some scholars believe that the improvement of agricultural mechanization will narrow the gap between urban and rural areas by increasing non-farm income. For example, [3]Zhi Huifang believes that the level of agricultural mechanization has a strong positive impact on the convergence of the urban-rural income gap, and its contribution rate gradually increases over time, but there is regional heterogeneity. [4] Liang Yawen found that provinces with a higher proportion of non-farm employment and a higher level of agricultural mechanization have a smaller urban-rural income gap. On the one hand, the improvement of agricultural mechanization has increased the possibility of rural households engaging in non-farm employment and increased the proportion of non-farm employment [5], and the wages of non-agricultural work are usually higher than the income obtained from agricultural labor. On the other hand, agricultural mechanization and large-scale development have promoted land transfer, improved the efficiency of agricultural operations, and increased farmers' wages and property income [6]. [7]Xiao Xiaoyu and Li Weimin argue that farmers can obtain stable rental income from land circulation after transferring their own land management rights. This part of the income is an important supplement to the labor income, which increases the source of property income for the peasants and narrows the income gap between urban and rural areas. However, [8]Zhang chen found that a high proportion of mechanization will bring higher agricultural machinery costs, offset the growth of non-farm income, and is not conducive to the narrowing of the income gap between urban and rural areas.

Some scholars believe that the level of agricultural mechanization will affect the income gap between urban and rural areas through labor transfer. Due to the high wage level in the city, a large number of rural laborers are attracted to work in the city, pursuing higher income and living standards, and narrowing the income gap between urban and rural areas [9]. [10]Yang Mengmeng believes that the improvement of agricultural mechanization has a significant role in promoting the transfer of agricultural labor. [11]Zhu Yangyang. argue that large-scale agricultural operations will promote the transfer of rural labor to cities. In addition, through the introduction of advanced management concepts and technical means, large-scale agricultural operations can bring about income growth and effectively narrow the income gap between urban and rural areas [12]. [13]Zhou Yangyang found that the scale of agricultural labor transfer has a widening effect on the income gap between urban and rural areas. This is mainly due to the restrictions of the huji system and the mismatch between the demand for jobs and their own skills. Although non-farm employment usually means higher incomes, due to the influence of traditional concepts such as valuing agriculture over business and fatalism, some rural labor force has a deep affection for the land and

is reluctant to leave their hometowns to switch to non-agricultural work, and they are worried about losing their livelihood security after leaving the land [14]. In addition, the effective transfer of labor will be hindered by factors such as the restrictions of the huji system and the poor continuity of social security transfer, as well as the mismatch between employment opportunities and skills, family burdens (such as taking care of the elderly and children), and local sentiments [15].

In summary, the existing studies mainly analyze the direct impact of agricultural mechanization on agricultural production efficiency and income structure from the perspective of labor transfer. In the context of agricultural modernization, the direct impact of agricultural mechanization and large-scale operation on agricultural production efficiency and income structure deserves attention [16]. Moreover, existing studies mainly use data at the individual level or individual provinces to reveal how agricultural mechanization affects farmers' income by improving production efficiency and promoting labor transfer, but the research in different regional contexts needs to be deepened. Agricultural mechanization is not only a key link to improve agricultural production efficiency, but also an important link between traditional agriculture and modern agriculture. In the past, the direct impact of agricultural mechanization on farmers' non-farm income and urban-rural income gap has been studied with micro data, but few follow with interest the impact of agricultural mechanization on the urban-rural income gap and its path from the macro level. Therefore, this paper analyzes the impact of agricultural mechanization development on the urban-rural income gap using provincial panel data and the mediating effect model, and explores the bridging role of agricultural mechanization and the increase of operating income brought about by the development of agricultural mechanization on agricultural mechanization and urban-rural income gap. The marginal contributions of this paper are as follows: First, from the perspective of scale effect and operating income, this paper analyzes the impact of agricultural mechanization development on the income gap between urban and rural areas, so as to provide a new perspective for promoting agricultural modernization, realizing rural revitalization and urban-rural integration development. Second, by exploring the influence mechanism of agricultural mechanization and agricultural scale operation on the urban-rural income gap, the research literature on agricultural mechanization and urban-rural income gap is enriched, which is of practical significance for improving the level of agricultural mechanization, building modern agriculture and narrowing the urban-rural income gap.

2. Theoretical Analysis and Research Hypothesis

2.1 The Direct Impact Mechanism of the Level of Agricultural Mechanization on the Income Gap Between Urban and Rural Areas

The nature of agricultural mechanization lies in replacing traditional human labor by introducing external factors of production. This process is mainly manifested in the application of advanced agricultural machinery and equipment, which can not only greatly reduce the demand for manpower, but also greatly improve the operation efficiency. With the increase of output per unit area, the cost per unit of product can be effectively reduced. Such improvements are not only conducive to improving the quality and yield of agricultural products, but also provide a solid foundation for farmers to generate income. In addition, due to the increased pace of agricultural operations and the shortening of the cultivation cycle, it is possible to rotate crops in multiple seasons under suitable climatic conditions, thereby further increasing total yields and crop yields. Agricultural mechanization has also enhanced the ability of the agricultural system to resist natural disasters to a certain extent, and provided a guarantee for the stability of farmers' incomes. Through the application of precision agriculture technology, land resources can be used more efficiently, and the planting structure can be optimized, so as to improve the output efficiency of land. Agricultural mechanization has promoted the standardization and refinement of agricultural production, improved the quality of crops, and enhanced its market competitiveness. Based on the above analysis, hypothesis 1 is proposed.

H1: The improvement of agricultural mechanization can significantly reduce the income gap between urban and rural areas

2.2 The Indirect Mechanism of the Impact of the Level of Agricultural Mechanization on the Income Gap Between Urban and Rural Residents

2.2.1 Agricultural Mechanization Promotes the Effect of Agricultural Scale Operation

Large-scale households usually invest a lot in agricultural mechanization for large-scale operation, rotation planting, and diversified planting, mainly operating income[17], regional planting , agricultural production is more specialized, and the application of agricultural machinery can change the farming mode of decentralized and small-scale operation, promote the transformation of agricultural production to large-scale, and promote the realization of economies of scale in agriculture. When the comparative advantage of non-agricultural employment is higher than that of agricultural employment, farmers with comparative advantages will give up land management and

choose non-agricultural employment [18], and large-scale households can lease or help to cultivate more land, making it possible to expand the scale of land management. At the same time, for large-scale households, large-scale agricultural production can benefit more from reducing production costs, improving production efficiency, and agricultural technological progress, and organizing scattered land and small farmers into agricultural production units with a certain scale through land integration and cooperative management. This method can not only effectively solve the problems of low resource utilization and insufficient market competitiveness in the production of small farmers, but also help to introduce advanced agricultural technology and management experience to improve the overall efficiency of agricultural production. At the same time, large-scale operation can promote the development of related industrial chains, such as agricultural product processing and logistics distribution, and provide more employment opportunities. The progress of agricultural technology is fundamentally a labor saving, and the promotion of the application of modern agricultural machinery technology has released a large amount of labor so that it can be invested in other high value-added activities. Based on the above analysis, a research hypothesis 2 is proposed.

H2: Agricultural mechanization can indirectly reduce the income gap between urban and rural areas through the scale effect of agriculture

2.2.2 Agricultural Mechanization Improves the Effect of Farmers' Operating Income

"Own and use" agricultural machinery is mainly designed to meet the production needs of farmers, while large-scale, high-efficiency and specialized agricultural machinery and equipment are specially oriented to the rental market. The scale of farmland management is the key prerequisite for realizing agricultural mechanization. However, the small-scale operation of agriculture not only increases the cost of agricultural machinery application, but also reduces the efficiency of equipment use. Due to the long growth cycle of crops, frequent manual participation is required during the period, which leads to a high dependence of agricultural production on labor factors, which is not conducive to the promotion and adoption of agricultural machinery services [18]. Expanding the scale of farmland management can motivate farmers to increase investment in agricultural machinery and equipment, and promote the transformation of traditional smallholder farming models to mechanized production with high labor productivity [19]. For the young and elderly in rural areas, they lack comparative advantages in terms of physical strength and economic benefits, so they are more inclined to choose agricultural machinery leasing and comprehensive agricultural production services, such as agricultural machinery maintenance, complete machine leasing (including dry rental and wet leasing), and even transform into agricultural machinery service providers. By providing a series of services such as agricultural machinery leasing, agricultural machinery parts sales, substitution farming, crop harvesting, etc., we can expand agricultural services and increase operating income for surrounding farmers. In addition, this transformation will not only help optimize the allocation of resources and improve agricultural production efficiency, but also alleviate the problem of an aging rural labor force by reducing labor-intensive operations. At the same time, the rise of specialized services has also created more employment opportunities in rural areas, promoted the development of rural service industries, and further promoted the process of agricultural modernization. Based on the above analysis, a research hypothesis 3 is proposed.

H3: Agricultural mechanization can indirectly narrow the income gap between urban and rural residents by increasing the effect of farmers' operating income.

3. Research Design

3.1 Model Setting

In order to study the impact of agricultural mechanization on the income gap between urban and rural areas, this paper constructs a two-way fixed-effect model:

$$Theil\ Indexl_{it} = \alpha_0 + \beta_0 Mac_{it} + \beta_1 X_{it} + \mu_i + \delta_t + \varepsilon_{it} \tag{1}$$

In this model, t and i represent the year and province, respectively; The Theil index is used to measure the income gap between urban and rural areas; Mac indicates the degree of mechanization of agriculture; X contains a series of control variables that may affect the urban-rural income gap; β_0 is the estimation coefficient of the core explanatory variable (i.e., the level of agricultural mechanization); β_1 is the coefficient of the control variable; μ_i represents individual fixed effects; δ_t Indicates a fixed effect of time; Rather, ε_{it} it is the residual term.

3.2 Variable Selection

3.2.1 Explanatory Variables

Urban-rural income gap: At present, the urban-rural income gap is mainly measured by the Gini coefficient, the ratio of disposable income between urban and rural areas, and the Theil index. The Theil index is mainly used to assess the degree of income inequality between individuals or regions, taking into account the influence of demographic factors. In this study, the Theil index is used to quantify the income gap between urban and rural areas. The formula is as follows:

$$T_t = \sum_{i=1}^{2} \left(\frac{I_{it}}{I_t}\right) ln \frac{I_{it}/P_{it}}{I_t/P_t} = \left(\frac{I_{1t}}{I_t}\right) ln \frac{I_{1t}/P_{1t}}{I_t/P_t} + \left(\frac{I_{2t}}{I_t}\right) ln \frac{I_{2t}/P_{2t}}{I_t/P_t}$$

T_t represents the income gap between urban and rural areas, and the larger the value, the more unequal the income distribution, I_{2t} represents the income of urban residents and rural residents in period T, I_t is the total income in period T. P_{2t} represent the urban and rural population in the T period, respectively, and P_t is the total population in the T period.

3.2.2 Explanatory Variables

Agricultural Mechanization level (Mac). The total power of agricultural machinery is selected to measure the level of agricultural mechanization.

3.2.3 Control Variables

Based on the principles of data availability and rationality, and referring to previous studies, the advanced industrial structure (Is), regional economic development level (Pgdp), urbanization rate (Urb), financial support for agriculture (Support), and openness to the outside world (Open) were selected as the control variables, and the specific definitions and descriptive statistics of the relevant variables are shown in Table 1.

3.2.3 Mechanism Variables

Agricultural Income: Operating income is used as a proxy variable. The scale factor in total factor production is used to represent the scale of agriculture.

3.3 Data Sources

The data comes from 31 provinces (autonomous regions and municipalities) in Chinese mainland from 2010 to 2020 for empirical verification. The data used in this article are from: the "National Bureau of Statistics", the "China Rural Statistical Yearbook", the "China Statistical Yearbook" (calendar years), and the descriptive statistical analysis of each major variable is detailed in Table 1.

Table 1. Descriptive statistics

	Variable name	Variable definitions	Mean	Standard deviation
Explanatory variables	Urban-rural income disparity	Thiel Index	.091	.04
Core explanatory variables	Mechanization level	Mechanized total power	7.674	1.111
	Regional economic development level	Regional per capita disposable income	5.182	2.701
	Urbanization level	Urban Population/Total Population	.584	.125
Control variables	Industrial structure	Tertiary Sector Value/Secondary Sector Value	1.258	.706
	Financial support for agriculture	Expenditure on agriculture, forestry and water affairs/GDP	526.368	277.49
	Degree of openness to the outside world	Total Exports / GDP	.004	.004
Mechanism variables	Agricultural-scale operations	Cultivated land area/primary sector employees	1.021	1.241
	Agricultural income	The logarithm of farmers' operating income was taken as its proxy variable	8.296	.432

4. The Analysis of Regression Results

4.1 Benchmark Regression Results

Based on the panel data of 31 provinces (autonomous regions and municipalities) in China from 2010 to 2020, a two-way fixed-effect model was used for regression. The benchmark regression results of the impact of agricultural mechanization on the urban-rural income gap are shown in Table 2, in order to exclude the interference of individual non-temporal factors and annual unobservable factors, column 1 of Table 2 controls the year and individual effects, and only the core explanatory variables are included, and the results show that the correlation coefficient is negative, and it passes the significance test at the 1% statistical level. After adding the control variables and fixing provinces and years, the results are still significant (column 2 of Table 2), indicating that the increase in the level of agricultural mechanization can significantly narrow the urban-rural income gap. Efficient production methods simplify heavy manual labor, and farmers can devote more time and energy to other high-value-added agricultural activities, such as special planting, breeding and agricultural processing. This regression confirms the hypothesis H1 proposed in this paper, that is, the input of agricultural machinery can significantly converge the urban-rural income gap.

Table 2. Benchmark Regression Results

	（1）Urban-rural income disparity	（2）Urban-rural income disparity
Mechanization level	-0.0103***	-0.0042***
	(0.0000)	(0.0000)
Control variables	NO	YES
Year fixed effects	YES	YES
County fixed effects	YES	YES
Constant terms	0.1089***	0.2247***
	(0.0000)	(0.0000)
Observed quantity value	330	330
adj.R2	0.9759	0.9912

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, P values in parentheses in the table

4.2 Robustness Test

4.2.1 Replace the Core Explanatory Variables

Thiel Index is a more general measure of inequality and is suitable for income inequality analysis between individuals or regions, while Gap is specifically used to measure the income difference between urban and rural residents, after replacing the explanatory variables, the regression results show that the improvement of the level of agricultural mechanization significantly converges the income gap between urban and rural areas, Consistent with the regression results in Table 2, the positive impact of the improvement of agricultural mechanization on the convergence of urban-rural income gap is more significant.

4.2.2 Replace Core Explanatory Variables

Most of the previous studies used the level of comprehensive agricultural mechanization and the total power of agricultural machinery [20] to reflect the development level of agricultural mechanization. In order to further reduce the possible bias of index selection on the research results and more comprehensively reflect the level of agricultural mechanization, the level of agricultural mechanization is measured by the ratio of the total power of agricultural machinery to the cultivated land area (column 2 of Table 3) with reference to the existing literature [21], and the results are consistent with the basic results of benchmark regression.

4.2.3 Add Control Variables

Some scholars have found that rural human capital plays a positive moderating role in the relationship between agricultural mechanization and urban-rural income gap, and its mechanism is that the level of human capital directly affects the acceptance ability and application efficiency of agricultural technology by rural residents. A high level of human capital means that the rural labor force has a stronger ability to accept technology, is more likely to understand and accept new agricultural machinery and technology, and can quickly master and apply these technologies, improve the efficiency and quality of agricultural production, and thus more fully enjoy the dividends brought by technology [22]. The rational use of chemical fertilizers can significantly increase crop yields,

promote healthy crop growth by supplementing the nutrients lacking in the soil, and thus increase the yield per unit area. At the same time, the right amount of chemical fertilizer can also improve the quality of crops. In this paper, the robustness of the results is further tested by adding control variables. As can be seen from the third column of Table 3, the coefficient of the core explanatory variable agricultural mechanization level changes little and is still significant after the increase of the control variables, which further indicates that the estimation results are robust enough.

4.2.4 Change the Sample Size

Due to the advantages of municipalities directly under the central government in terms of transportation and policies, it may have an impact on the convergence effect of the urban-rural income gap. Considering that the scale of agricultural output in municipalities such as Beijing, Tianjin, Shanghai, and Chongqing is relatively small and significantly different from other provinces, they are excluded from the regression analysis to ensure the accuracy of the results (column 4 of Table 3). It can be found that compared with the second column of Table 2, the coefficients of the key explanatory variables did not change after the regression of the replacement samples, and the significance decreased, but it was still significant at the level of 5%.

Table 3. Robustness test

	（1）	(2)	(3)	(4)
	Gap	Urban-rural income gap	Urban-rural income gap	Urban-rural income gap
Agricultural mechanization level	-0.0504**		-0.0046***	-0.0043**
	(0.0103)		(0.0037)	(0.0205)
Mechanization rate		-0.0558***		
		(0.0082)		
Human capital level			-0.0031*	
			(0.0597)	
Fertilizer usage			-0.0001***	
			(0.0019)	
Control variables	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES
County fixed effects	YES	YES	YES	YES
Constant terms	3.0517***	2.6872***	0.2545***	0.2453***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Observed quantity value	330	330	330	286
adj.R2	0.9852	0.9853	0.9912	0.9889

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, P values in parentheses in the table

5. Mechanism Analysis

In order to test hypothesis 2, this paper uses the stepwise regression method proposed by Baron and Kenny (1986) to test the mediating effect, and refers to the mediating effect test model proposed in the existing literature [23], and constructs the following mediating effect test:

$$Theil\ Index_{it} = \alpha_0 + \beta_0 Mec_{it} + \beta_1 X_{it} + \mu_i + \delta_t + \varepsilon_{it} \tag{2}$$

$$M_{it} = \alpha_0 + \beta_0 Mec_{it} + \beta_1 X_{it} + \mu_i + \delta_t + \varepsilon_{it} \tag{3}$$

$$Theil\ Index_{it} = \alpha_0 + \beta_0 Mec_{it} + \beta_1 M_{it} + \beta_2 X_{it} + \mu_i + \delta_t + \varepsilon_{it} \tag{4}$$

The M of equations (3) and (4) indicate large-scale agricultural operations, and the meanings of the other variables are consistent with those in equation (1).

The results of the mechanism of the improvement of agricultural mechanization level affecting the urban-rural income gap through agricultural scale operation are shown in Table 4. The results of columns 1 and 3 of Table 4 show that the correlation coefficient is positive and passes the significance level test of 1%, and the second and fourth columns of Table 4 show that agricultural scale operation has a positive impact on the convergence of urban-rural income gap. This shows that in addition to having a direct impact on the income gap between urban and rural areas, agricultural mechanization also indirectly narrows the income gap between urban and rural residents through large-scale agricultural operation and increasing the operating income of rural residents. Scale operation can enjoy the cost advantage brought by economies of scale, although agricultural machinery has a substitution effect on

rural labor, but the input of mechanical elements and the release of labor force is subject to the shortcomings of their own skills, the scope of transfer does not jump out of the agricultural sector, but relying on agricultural mechanization derived from a series of agricultural machinery leasing, collection, farming and other services, to obtain operating income and then converge the income gap between urban and rural areas, so far, the indirect mechanism of the impact of agricultural mechanization level on the income gap between urban and rural residents is assumed to be true.

Table 4. Mechanism test

	(1) Agricultural-scale operations	(2) Urban-rural income disparity	(3) Operating income	(4) Urban-rural income disparity
Agricultural mechanization level	3.0907***	-0.0027*	0.1237***	-0.0025
	(0.0000)	(0.0894)	(0.0001)	(0.1091)
Agricultural-scale operations		-0.0005***		
		(0.0008)		
Operating income				-0.0141***
				(0.0000)
Control variables	YES	YES	YES	YES
Year and county fixed effects	YES	YES	YES	YES
Constant terms	1.6233	0.2255***	5.8189***	0.3068***
	(0.8882)	(0.0000)	(0.0000)	(0.0000)
Observed quantity value	330	330	330	330
adj. R2	0.9374	0.9915	0.9697	0.9918

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, P values in parentheses in the table

6. Heterogeneity Analysis

6.1 Analysis of Regional Heterogeneity

Due to the combined effect of geographical, social and economic environment, the progress of agricultural mechanization and the difference between urban and rural income in different regions show significant heterogeneous characteristics. In order to test the robustness of the model results and analyze such regional differences, according to the standards of the National Bureau of Statistics, 31 provinces in China were divided into three major regions, heterogeneity analysis was performed separately (see Table 5). The study found that in both the eastern and western regions, the promotion of agricultural mechanization had a positive impact on narrowing the income gap between urban and rural areas. However, the eastern region has advantages in terms of location and infrastructure, and the efficiency of agricultural factor use and policy implementation are also better, so the income increase effect of agricultural mechanization may be more significant. Due to the special geographical environment in the western region, the effect of agricultural mechanization in narrowing the income gap between urban and rural areas is not obvious. For the central region, agricultural mechanization has had a negative effect on narrowing the income gap between urban and rural areas, that is, the improvement of the level of agricultural mechanization has mainly played a substitution role for some farmers, which may lead to the expansion of the income gap between urban and rural areas. This conclusion is different from the results of the study [24], they believe that the economic development in the eastern region is rapid, the development of agricultural mechanization has been widespread, with the development of industrialization and urbanization, the value of agricultural output is small, and farmers' income is mainly increased through non-agricultural income, and the improvement of agricultural mechanization level will reduce farmers' income. The overall level of economy and mechanization in the eastern cities is higher, resulting in marginal effects. The improvement of the level of agricultural mechanization will increase the cost input of farmers, and then exacerbate the income gap between urban and rural areas.

6.2 Heterogeneity Analysis of Major Grain Producing Areas

In 2004, China identified 13 provinces as the main grain producing areas   The state has issued a series of policies to promote the development of non-major grain producing areas, which cover many aspects such as agricultural

structural adjustment, scientific and technological support, infrastructure construction, and market system construction. In order to analyze this effect more accurately, this study conducted a regression analysis in the main grain producing areas and non-grain producing areas, and the results in columns 4 and 5 of Table 5 show that the input of agricultural mechanization has a more significant impact on narrowing the income gap between urban and rural areas in the non-main grain producing areas. This may be because the main grain-producing areas tend to focus on the cultivation of grain crops, and the industrial structure is relatively simple. In contrast, non-major producing areas may have a more diversified economic structure. The introduction of agricultural mechanization can significantly improve the production efficiency of these crops, and by using machinery and equipment suitable for special crops, labor intensity can be reduced, production efficiency can be improved, output per unit area can be increased, total value can be increased, and farmers' income can be increased. At the same time, with the increase of mechanization input, the expected income of farmers' land cultivation in non-major grain producing areas will increase, which can motivate ordinary small farmers to carry out large-scale management of farmland, including large-scale management of grain crops and large-scale management of cash crops, and obtain both benefits.

Table 5. Heterogeneity analysis

	(1) Eastern	(2) Central	(3) Westward	(4) Main grain producing areas	(5) Non-major grain producing areas
Agricultural mechanization level	-0.0171*** (0.0000)	0.0063** (0.0391)	-0.0028 (0.3373)	-0.0033 (0.1056)	-0.0043** (0.0481)
Control variables	YES	YES	YES	YES	YES
Year and county fixed effects	YES	YES	YES	YES	YES
Constant terms	0.2513*** (0.0000)	0.2309*** (0.0000)	0.2052*** (0.0000)	0.1808*** (0.0000)	0.3033*** (0.0000)
Observed quantity value	132	110	88	143	187
adj.R2	0.9905	0.9889	0.9774	0.9831	0.9942

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, P values in parentheses in the table

7. Main Conclusions and Policy Recommendations

7.1 Research Conclusions

Based on the macro data from 2010 to 2020, this paper theoretically analyzes the mechanism of agricultural machinery investment on improving farmers' operating income, and empirically studies the convergence effect of agricultural mechanization on the urban-rural income gap. The results show that from the perspective of national overall regression analysis, the core explanatory variable, agricultural mechanization level, has a significant positive impact on the operating income of rural households, and has a negative effect on the income gap between urban and rural areas. After a series of robustness tests, this conclusion still holds. From the perspective of the impact path, the impact of the level of agricultural mechanization on the operating income of farmers and the gap between urban and rural income is mainly realized through two mechanisms: one is the direct mechanism, that is, the input of agricultural machinery can reduce the cost of agricultural production, agricultural production from low efficiency to high efficiency, and the growth of farmers' income. The second is the indirect mechanism, that is, agricultural mechanization promotes the scale operation of agriculture, so that farmers can obtain higher returns through scale effect, and obtain additional operating income by providing socialized services for agricultural machinery. Therefore, the improvement of the level of agricultural mechanization is conducive to increasing farmers' income, and can also effectively close the income gap between urban and rural areas.

According to the heterogeneity regression results, agricultural mechanization has a more significant effect on the urban-rural income gap in the eastern region, while it has a negative impact on the urban-rural income gap in the central region. It may be due to the differences in capital, technology and talent in the central region that the process of promoting agricultural mechanization in the central region is slow, and it is difficult for ordinary farmers to keep up with the pace of technological progress, which further aggravates the income differentiation. For the western region, the natural conditions and geographical environment are complex due to the influence of special

geographical environment and topography. The complex natural conditions and geographical environment make it difficult to mechanize agriculture in some areas, especially in the snow-capped mountains and plateau areas, which will only increase the unit input cost of machinery and equipment for farmers, which makes it difficult for farmers to improve production efficiency through mechanization, and the income growth is slow, and the convergence effect is not significant.

7.2 Policy Recommendations

Develop mechanized agriculture in accordance with local conditions. According to natural conditions and economic conditions, focus on supporting the research and development and promotion of small light agricultural machinery in mountainous and hilly areas, and increase the amount of subsidies. Precise training, establish a combination of online and offline training system, and improve farmers' operational skills. Encourage the research and development of agricultural machinery with local characteristics, expand the scope of subsidies, and strengthen the supervision of funds to prevent false claims and fraudulent claims.

Promote the socialized service of agricultural machinery. Increase financial investment, optimize agricultural machinery purchase and operation subsidies, and attract social capital to participate. Talent train, Through multi-level training and Internet platform, improve the professional level of employees. Optimize infrastructure, improve rural transportation and storage conditions, and improve operational efficiency. Promote land circulation, improve the rules for the circulation of use rights, protect the rights and interests of farmers, and promote moderately large-scale operations. Improve agricultural finance and insurance, broaden financing channels, increase loss ratios, and enhance anti-risk capabilities.

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