The impact of agricultural mechanization on local economy in China：A neglected phenomenon in agricultural mechanization

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Abstract: Agricultural mechanization has brought a series of positive impacts to the agricultural production and social development. However, its impact on local economy, including the non-agricultural sector, has received little attention. Therefore, based on the panel data at the county level in China, this paper used instrumental variable method to analyze the impact of agricultural mechanization on local economy. The results showed that agricultural mechanization significantly reduced the local gross domestic product. Specifically, agricultural mechanization changes the structure of agricultural production and reduces the total agricultural output value. Agricultural mechanization largely replaced labor, so that many young people choose to go out for work. This has led to a decrease in local labor supply and household consumption demand, which is in turn detrimental to the development of local industrial and service sectors. Meanwhile, the outflow of population also caused a series of social problems, such as a large number of left-behind children and elderly people in rural areas. Finally, this paper puts forward some policy suggestions from agricultural production and rural society.

Keywords: Agricultural mechanization; Local gross domestic product; Grain-crops; Instrumental variable; Farmers

1. Introduction

The massive application of machinery in modern agricultural production has brought a series of positive impacts to the agricultural production and social development, mainly including the enhancement of farm productivity, yields and even farmers' incomes, the decrease of per-unit cost of crop production, the expansion of cultivation areas, and labor savings (Chaudhary, et al., 2022, Hamilton, et al., 2021, Pingali, 2007, Van den Berg, et al., 2007). Hence, many developing countries have been committed to promoting the agricultural development by improving the level of farm mechanization like Bangladesh, Nepal, India and China (Daum and Birner, 2020, Qiao, 2017, Rahman, et al., 2021). Being the largest agricultural country(Sun, et al., 2023), China actively increases the agricultural mechanization level by

subsidies for purchasing agricultural machinery in recent years to promote agricultural modernization, raise farmers' incomes and develop rural areas. Currently, there is a significant gap between urban and rural area in China, the rural areas are relatively backward and farmers' income are low. Therefore, the role of agricultural mechanization in rural development is a very important topic to study. This is not only important for China, but also of great interest to other countries with less developed agriculture.

However, most previous studies are limited to the influence of mechanization on agricultural sector only. In fact, agricultural mechanization might affect agricultural production decision and allocation of labor resources, then resulting in change of local economic development. For instance, mechanization will decrease agricultural labor demand, and the surplus labor might be transferred to local industrial sector or move to other areas for employment. Therefore, the influence of mechanization on the whole local economy may be quite different from that on agricultural sector. For less developed countries, we should not ignore its possible negative effects on other economic sectors in rural areas while developing agricultural mechanization. This study tries to shed light on this neglected phenomenon through empirically analyzing the influence of mechanization on local economy and discussing the mechanism taking China as a case.

In the research field of agricultural mechanization, the most studied topic is to examine the linkage between mechanization and agricultural production. Specifically, the utilization of mechanization significantly lowers the per-unit labor cost of crop production (Rahman, et al., 2021, Sarkar, 2020) and decreases the need for labor with capital to substitute labor(Hamilton, et al., 2021), thus enhancing worker productivity, guaranteeing the food security(Paudel, et al., 2019). In addition, some scholars further suggest that the mass application of agricultural machinery could promote the rural land transfer

expanding the scale of agriculture (Qian, et al., 2022), contributing to the increase of agricultural production and further the farmers' incomes (Van den Berg, et al., 2007, Yang, et al., 2013). Other advantages of mechanization include increasing timeliness of operations and ability to cope weather-related risks, and reducing grain harvesting loss (Belton, et al., 2021).

A major critic of mechanization is that it may lead to rural unemployment and labor displacement problems (Adu-Baffour, et al., 2019, Zhang, 2019), but whether these pictures occur or not depends on the scenario. If the cultivation area and crop output can be expanded and enhanced, more labor is needed(Daum and Birner, 2020, Pingali, 2007). These problems may become seriously only when machines are promoted where they are not required, such as low intensity farming systems, or where wage rates and the opportunity cost of labor are low(Pingali, 2007).

Regarding to effects on rural society, mechanization leads to a change in the sex ratio of rural farms(Afridi et al., 2022), and a migration of rural labors from rural areas to cities(Huang, et al., 2022), resulting in the shortage and aging of the agricultural labor force(Liao, et al., 2019). Mechanization may also cause social tensions and conflicts, such as land issues(Daum, et al., 2020).

This research contributes to literature in the following ways. (1)Different from previous studies concentrating on agricultural production and rural society, we paid our attention to the whole local economy change due to agricultural mechanization. The topic is meaningful for countries who want to promote the development of rural areas by mechanization. Although the positive impact of mechanization on agricultural sector has been confirmed by many previous empirical studies, its influence on other sectors and the whole local economy is still open to question. To systematically answer the question, this study firstly estimate the impact of agricultural mechanization on local gross

domestic product (GDP). Second, the economy was divided into agricultural sector, industry sector and service sector, the influence of agricultural mechanization on each sector was analyzed separately. Then we discuss the changes in production within agricultural sector and farmers' choice with the development of mechanization. Based on these macro and micro analysis, this work tries to give a comprehensive overview on the role of agricultural mechanization in the whole economy.

(2) In terms of methods, in order to reduce the endogenous problems that may occur in the estimation, we constructed a unique instrumental variable for the mechanization level of each county, that is, the interaction term between local slope and agricultural machinery subsidies in the province. This time-varying instrumental variable can simultaneously capture the influence of both policy and geographical conditions on agricultural mechanization level. Compared with the previous studies in this field, which usually uses slope or other single indicators as instrumental variables, the instrumental variable constructed in this study has more advantages.

(3) It has become widely acknowledged that promoting mechanization in agriculture is necessary in many developing countries. The results of this paper are helpful to understand the effects and mechanisms of mechanization on different economic sectors and can provide a basis for agricultural policies in less developed countries.

The rest of this paper is organized as follows, second section is the background of agricultural mechanization in China, section 3 describes methodology and data, section 4 presents the results and discussion, section 5 concludes with policy implications.

2. Background on agricultural mechanization in China

With the advance of the global agricultural modernization, many countries attempt to promote the development of agricultural mechanization. However, the agricultural mechanized level varies between economies, being high in the developed countries and relatively low in the developing countries. For example, the mechanized level of the advanced countries, such as America, the western European countries, Japan and Korea, has generally reached over 90 percent, especially America whose level of agricultural mechanization has approached 100 percent (Pingali, 2007, Qin, et al., 2022). These developing countries like China, India and African countries still have a relative low mechanization rate. According to the data reported by China Agricultural Mechanization Information Network, in 2021, the level of the Chinese agricultural mechanization has reached about 72 percent. Although the Chinese mechanized level lags behind the developed countries, the development trend of farm mechanization has been for the better. Especially since 2004, agricultural mechanization has developed rapidly in rural China. The reason is that the Chinese government has launched a series of encouraging policies on the subsidy for agricultural machinery purchases since 2004, contributing to the great improvement of the level of agricultural mechanization in China. More specifically, according to the data released by the National Bureau of Statistics of China (NBSC), in 2021, the total power of agricultural machinery nationwide reached 1077.68 million kilowatts, which was near 1.68 times of 640.28 million kilowatts in 2004. In the past near two decades, China has successfully achieved a “mechanical revolution” in agriculture (Qian, et al., 2022).

China has been a smallholder country with more population and less land, where agricultural production largely depends on small-scale, family-based and labor-intensive operations(Wang, et al., 2016). However, with the development of industrialization and urbanization in China, combined with

the gradual relaxation of Hukou registration(Shi, et al., 2021, Wang and Fu, 2019), the rural labor force continues to migrate to urban and nonagricultural industries(Huang, et al., 2022, Qian, et al., 2022), thereby making the structure of the agricultural labor force gradually feminized and aged(Liao, et al., 2019, Liu, et al., 2019). Furthermore, the massive loss of agricultural labor has not only caused the decrease of agricultural productivity(Shi, et al., 2021), which has limited the agricultural development in China(Tongwei, et al., 2020), but also made labor costs rise in the Chinese rural sector(Qian, et al., 2022). Therefore, agricultural mechanization may be a necessary choice to speed up the modernization of agriculture and rural areas and promote rural vitalization on all fronts in China (Jiang, 2019, Luo, et al., 2016)

3. Data and Methodology

3.1 Empirical Strategy

This main aim of this study is to investigate the effects of agricultural mechanization on local economy. The empirical analysis will be conducted on county level, because county-level administrative regions are the smallest units in China with detailed socio-economic statistical data.

Considering the purpose of the research, municipal districts were not included in the analysis. We employ a panel data fixed-effects regression model in this case. The main independent variable is the local economy which is measured by GDP, and the key explanatory variable is the mechanization level in each county.

Although general fixed-effects modeling approach can eliminate the influence of time-invariant variables at the individual level, there are still omitted variables problems caused by time-variant factors

at the individual level, finally inducing endogeneity problems. Meanwhile, endogeneity problems may also arise from bidirectional causality that the economic development is also likely to affect the level of agricultural mechanization reversely. Therefore, instrumental variable estimation method will be applied in this study. Generally, slope gradient is used as the instrumental variable of the level of mechanization because terrain undulation degree will directly affect the use of agricultural machinery. However, as slope gradient is a time-invariant variable, slope may be not regarded as an appropriate instrumental variable in the panel data model. To this end, we apply the interaction term between the level of the province-level agricultural machinery subsidy in each year and the local slope gradient as the time-variant instrumental variable, contributing to accurately estimating the parameters in the model. It is obviously that agricultural machinery subsidy can encourage farmers to purchase more agricultural machinery. Specifically, two-stage least squares estimation (2SLS) method will be used in this panel instrumental variable model.

The first-stage estimation equation is specified as follows:

$$Mechanization_{ijt} = \alpha + \beta_1 subsidy_{jt} * slope_i + X'_{ijt}\gamma + \theta_i + \mu_t + \varepsilon_{it} \quad (1)$$

Where $Mechanization_{ijt}$ is the endogenous variable, the level of mechanization of county i of province j in year t. $subsidy_{jt}$ is the level of agricultural machinery subsidy of province j in year t; $slope_i$ is the average slope of the land surfaces in county i; X'_{ijt} denotes control variables by county-level used in the model, including a host of other county level social and economic characteristics;θ_i and μ_t indicate county fixed effect (FEs) and time fixed effect (FEs), respectively.

The second-stage estimation equation is as follows:

$$y_{ijt} = \alpha + \beta_1 \widehat{Mechanization}_{ijt} + X'_{ijt}\gamma + \theta_i + \mu_t + \varepsilon_{it} \quad (2)$$

Where $\widehat{Mechanization}_{ijt}$ is the fitted value of the level of mechanization in the first step estimation equation; y_{ijt} is the explained variable, denoting the economic development of a county; Other variables are set as equation (1).

3.2 Data

We use a panel county-level data covering 2082 counties in China from the year 2010 to 2020. Data used for this study is collected from several sources. Data for the level of agricultural mechanization and other economic indicators are collected from the China County Economic Statistical Yearbook and the China Regional Economic Statistical Yearbook ranged from 2009 to 2021.

Data for the average slope of the land surfaces is obtained from the ASTER Global Digital Elevation Model V003 according to the data of the county-level administrative divisions in 2019 of China.

Data for the total agricultural machinery purchase subsidy is collected from the website named as information disclosure of agricultural machinery purchase subsidy of the Ministry of Agriculture and Rural Affairs of China (http://www.amic.agri.cn/subsidy/index).

Local economy development

Since we are mainly interested in the impact of the level of mechanization on local economic development, we focused on several major indicators of local economy development, including gross domestic product(GDP), output of agricultural sector, output of industry sector (including manufacturing industry and construction industry), output of service sector for each sample county. In this way, the influence of agricultural machinery can be analyzed from the whole economy and

individual sector perspective.

Agricultural mechanization

Mechanization is the key explanatory variable. The level of agricultural mechanization of a county is measured by the total power of agricultural machinery. It is a common way to measure the level of mechanization by the aggregation of power of all types of machineries (Daum and Birner, 2020)

Other county characteristics

Our analysis compile data for a host of other county level social and economic characteristics that may affect both agricultural mechanization and the economy development of a county. First, we consider the economic structure, since the structure of industries influences the change in financial institutions and capital markets(Allen, et al., 2018). This paper takes the proportion of agricultural sector output in local GDP, the proportion of industry sector (manufacturing industry and construction industry) output in local GDP of a sample county into account. Note that the public expenditure plays an important role in economic growth and productivity (Afonso and Jalles, 2013), we consider the effect of the size of government expenditures which accessed by the proportion of public expenditure to GDP of a county follow the study of Ferreiro, et al. (2014). Second, to control the influence of loans market on county's economic development, this study set a variable as the ratio of loans of financial institutions to GDP at the end of the year of a county. The loans from financial institutions can not only help to the local economy, but also offer the funds that companies and households need to finance their projects. Otherwise, to measure the situation of education, communication facilities and medical conditions, our model controls the following variables, including ratio of number of middle school students in school

to total population, number of fixed telephone subscribers, and hospital beds per 10,000 population. Finally, the territory area and total population at the end of the year of a county is also considering in the analysis.

Table 1 shows the definition and summary statistics of variables in the model. As can be seen, the average gross domestic product of counties is about 17.1 billion yuan over the period 2010-2020. The mean of the agricultural sector output of sample counties is about 1.5 billion yuan, which is far less than the mean of the second sector output of sample counties (8.5 billion yuan), and the mean of service sector output (6.3 billion yuan). The average total power of agricultural machinery per county amounts to about 0.43 million kilowatts. Table 1 also shows that the mean of ratio of agricultural sector output of to GDP is 0.214, while 0.43 for the output of second sector. The mean of the ratio of public expenditure to GDP is 0.306, which is used to estimate the governmental investment in the county. The average ratio of loans of financial institutions to GDP by county is 0.668, reflecting the level of financial inputs in the county during the period 2010-2020. Table 1 shows that about 4.8% of the total population in the county has a middle school certificate. The average number of fixed telephone subscribers per county is about 55176 persons, indicating the infrastructure level in the county. On average, per 10,000 population has about 38 hospital beds. The average territory area by county covers about 3884.8 hectares.

Otherwise, Table 1 also shows the detailed definitions of the two instrumental variables used in the empirical model. The average total agricultural machinery purchase subsidy by county is about 7.1 billion yuan. And the average slope of the land surfaces of a county is about 12.39.

Table 1. Definition and summary statistics of variables, China 2010-2020

Variable	Description	N	Mean	S. Dev
gdp	Gross domestic product of a county (10 thousand CNY yuan)	17,363	1712158	2409545
agriculture	output of the agricultural sector of a county (10 thousand CNY yuan)	17,297	146090.6	124094
industry	output of the industry sector (manufacturing industry and construction industry) of a county (10 thousand CNY yuan)	17,772	850272	1348848
service	output of the service sector of a county (10 thousand CNY yuan)	17,297	633741	1045003
machinery	Total power of agricultural machinery of a county (10,000 Kw)	17,773	43.16967	40.862
ratio_agriculture	ratio of agricultural sector output to GDP of a county	17,363	0.214	0.157
ratio_industry	ratio of industry sector output to GDP of a county	17,363	0.430	0.173
investment	ratio of public expenditure to GDP of a county	17,295	0.306	0.345
loans_market	ratio of loans of financial institutions to GDP at the end of the year of a county	17,158	0.668	0.436
education	ratio of number of middle school students in school to total population of a county	17,933	0.048	0.016
infrastructure	number of fixed telephone subscribers of a county (person)	17,580	55176.59	79619.05
healthcare	hospital beds (per 10,000 population)	17,867	38.63491	20.145
area	territory area of a county (square kilometer)	17,644	388480	57800000
instrumental variables				
subsidy	total agricultural machinery purchase subsidy of a county(billion CNY yuan)	17,706	7.105633	4.526327
slope	average slope of the land surfaces of a county	17,642	12.39199	7.050059

Sources: Data is mainly collected from the China Rural Statistical Yearbook (2009-2021) and China Statistical Yearbook (2009-2021).

4. Results

4.1 Impact of agricultural mechanization on economic development

Based on the panel instrumental variable model, the impact of agricultural mechanization on local economic development was estimated. Table 2 reports the results of the baseline model. We report first

stage F-Stat for the excluded instrument, which is far greater than 10 in model (1) to model(4). It indicates that the instrumental variable is not weak.

The first-stage estimation results in all models show that the instrumental variable (interaction term between the level of the province-level agricultural machinery subsidy and the local slope) has a significant and positive impact on the level of mechanization. This result is consistent with the reality that more subsidies increase agricultural mechanization when controlling for slope of the land surfaces of a county. It also proves that the instrumental variable satisfies the correlation assumption.

Next, we turn our attention to the second-stage estimation results in table 2. In model 1, only the key explanatory variable, the level of agricultural mechanization, was included in the model. Meanwhile, time fixed effects and county fixed effects were controlled in all models. Model 2 added the industrial structure variables, the proportion of agricultural sector output in local GDP and proportion of industry sector output in local GDP. More social-economic variables were introduced in model 3, such as public expenditure, finance development, the situation of education, communication facilities and medical conditions. Model 4 is the full model which additionally includes territory area and total population of the county. From the estimation results in model 1 to model 4, it is clearly that the estimate coefficients of mechanization variable are significantly negative at 1% level in all specifications. This indicates that the agricultural mechanization development decreases local economic growth and the result changes little as more controlled variables were included. However, the value of the estimation coefficient is changed from -1.408 in model 1 to -0.557 in model 4, which shows that the presence of omitted variables problems may result in overestimating the effect of mechanization. Based on the results in model 4, we can conclude that every 1% increase in the level of mechanization of a county can lead to an averagely

0.557% decline in the GDP of that county.

Turning to estimation results of the control variables, it is interesting to see that the increase in proportion of agricultural sector output can reduce the GDP of a county, while the raise in proportion of industry sector output plays an opposite role in the growth of GDP. This difference suggests that the industry sector has a greater ability to drive regional economic growth than the agricultural sector. This is in line with the law of economic development. The striking finding was that public expenditure and financial market development had a negative impact on local economy. The reason may be that government intervention is bad for economic growth in rural areas and financial market development has benefited farmers little. On the other hand, the situation of education, communication facilities and medical conditions make significant and positive contributions to the GDP growth, which is consistent with the literature on economic development. The estimation coefficients of these variables are basically the same in different models, which further increase confidence in the credibility of the results

Table2 the estimated effects of agricultural mechanization on GDP

VARIABLES	M1	M2	M3	M4
Second stage within regressions				
machinery (ln)	-1.408***	-0.973***	-0.599***	-0.577***
	(-4.52)	(-4.44)	(-5.23)	(-5.28)
ratio_agriculture		-1.337***	-1.243***	-1.270***
		(-11.81)	(-16.55)	(-17.50)
ratio_industry		1.514***	1.165***	1.145***
		(16.75)	(20.80)	(21.28)
investment			-0.296***	-0.302***
			(-10.79)	(-11.50)
loans_market			-0.139***	-0.137***
			(-14.54)	(-14.59)
infrastructure (ln)			0.029***	0.027***
			(4.29)	(4.25)
healthcare			0.002***	0.002***
			(9.59)	(8.00)
education				1.319***
				(5.23)
area (ln)				0.348***

				(9.08)
Constant	18.163***	16.297***	14.944***	12.191***
	(17.33)	(23.78)	(49.87)	(43.63)
Observations	13,910	13,910	13,195	13,195
county FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
R-squared (overall)	0.3318	0.1217	0.0099	0.0381
F test for instrumental variable	33.97	42.16	36.62	43.79
First-stage within regression	**(dependent variable:machinery)**			
subsity_grade	0.00047***	0.00047***	0.00064***	0.00065 ***
	(5.17)	(5.20)	(7.00)	(7.14)

Notes: *** p<0.01, ** p<0.05, * p<0.1,z-statistics in parentheses for the second stage results. t-statistics in parentheses for the first stage results.

The baseline model results shows that agricultural mechanization had a negative impacts on local economy. To further understand the channels through which this influence is exerted, we separately considered three sectors at county level. The estimation results of the effects of agricultural mechanization on three sectors are presented in Table 3. The explained variables in these models are agricultural sector output, industry sector output and service sector output, respectively. The instrumental variable method were also used in this analysis. Similarly as the baseline model, the first-stage results in all three models in table 3 report that there is a significant and positive relationship between instrumental variable and the level of the mechanization, suggesting that the correlation assumption of instrumental variable is accepted. The first stage F-Stat for the excluded instrument is greater than 10, which indicates that the instrumental variable is not weak across Columns (1)–(3).

The main results of interest in this section were the estimation coefficients of mechanization from model 1 to model 3. It clearly shows that the mechanization variable is statistically significance at 1% level in all three models and the estimated coefficients are all negative. This indicates that the agricultural mechanization hindered the development of agricultural sector, industry sector and service sector, simultaneously. From the economic point of view, the coefficients of mechanization are

respectively -0.734, -0.766, -0.490 Columns (1)–(3), indicating that every 1% increase in the level of mechanization of a county lead to a 0.734% decline in the output of the agricultural sector, while a 0.766% decline in output of the industry sector, and a 0.490% decline in output of the service sector of that county.

As for estimation results of control variables, the proportion of agricultural output in GDP has a significant and negative influence on the industry sector output. Similarly, phenomenon was also observed between agricultural sector and service sector. While the proportion of the industry sector output plays a significant and opposite role in the growth of agricultural sector. This indicates the correlation between these sectors in regional economic development. Notice that public expenditure and financial development were found having a negative impact on local GDP. In table 3, we also found that the estimated coefficients of these two variables are all statistically negative. These further confirmed the public expenditure and financial market development in rural China are detrimental to the development of all sectors. On the contrary, the coefficients of education medical and information infrastructure variables are all significantly positive in all models in Table 3. This is consistent with the results in Table 2. These findings fully illustrate the importance of infrastructure construction in China's rural areas and its significant role in promoting economic development.

Table 3 The estimated effects of agricultural mechanization on three industries

VARIABLES	(1) agriculture	(2) industry	(3) service
Second stage within regressions			
machinery (ln)	-0.734***	-0.766***	-0.490***
	(-5.32)	(-4.52)	(-4.61)
ratio_agriculture		-4.193***	-1.678***
		(-50.73)	(-32.40)
ratio_industry	0.111**		
	(2.07)		

investment	-0.027	-0.462***	-0.174***
	(-0.78)	(-11.85)	(-7.13)
loans_market	-0.101***	-0.281***	-0.039***
	(-8.33)	(-20.33)	(-4.50)
infrastructure (ln)	0.039***	0.047***	0.016**
	(4.77)	(4.63)	(2.55)
healthcare	0.001***	0.002***	0.001***
	(4.73)	(6.59)	(5.78)
education	1.094***	1.102***	1.118***
	(3.46)	(2.86)	(4.64)
area (ln)	0.535***	0.554***	0.332***
	(10.71)	(9.08)	(8.69)
Constant	9.572***	11.438***	11.522***
	(26.57)	(25.99)	(41.77)
Observations	13,195	13,195	13,193
county FE	YES	YES	YES
Year FE	YES	YES	YES
R-squared (overall)	0.3132	0.0036	0.0388
F test for instrumental variable	27.88	22.35	51.27
First-stage within regression	**(dependent variable: machinery)**		
subsity_grade	0.00066***	0.00065***	0.00065***
	(7.27)	(7.13)	(7.12)

Notes: *** p<0.01, ** p<0.05, * p<0.1,z-statistics in parentheses for the second stage results. t-statistics in parentheses for the first stage results.

4.2 mechanism analysis

Although the above empirical finding illustrate that agricultural mechanization decreases local economic growth through a decline in output all three sectors, the mechanism behind them is still not fully understand. In this section, we will go further into details to give a better understanding of this research question.

First focusing on the influence on agricultural sector, it is necessary to find out the change of agricultural production structure because of agricultural mechanization development. Compared with grain crops, it is more difficult to replace labor force with mechanization in the production of non-grain crops, such as vegetables(Huong, et al., 2013).

Previous studies also found that the development of mechanization has a positive impact on land

area devoted to grain crops(Qiao, 2017), but a negative impact on non-grain crops(Qiao, 2022). Therefore theoretically, the level of mechanization can increase the proportion of grain crops grown in an area while reducing the proportion of non-grain crops grown. To test this hypothesis, we explore the effect of mechanization on the output of grain crops. The results was given in column 1 in Table 4, which show that mechanization significantly increases grain crops output. The coefficient reveals that every 1% increase in the power of agricultural machinery of a county can improve a 0.234% increase in gross output of grain of that county. Generally, the value per unit of acreage of non-grain crops is much higher than that of grain crops. This fact together with mechanization decreasing total agricultural output prove that the hypothesis proposed before was correct.

Second, based on our findings that agricultural mechanization decreases non-grain crops production and labor need in grain crops production, it is not difficult to conclude that this will lead to a large number of rural labor surplus. Similarly, the study of Afridi et al. (2022) also pointed out agricultural mechanization leads to a greater reduction in labor use in agriculture. These surplus labor forces will generally go into off-farm work. If these people move from the agricultural sector to the local non-agricultural sector, then the impact on the local economy is uncertain. However, if they move to work outside the county, the displacement of surplus labor is generally bad for the local economy. Notice that these people are mainly young, and their outside work is usually temporary, leaving parents and children behind in the countryside. To explore whether this logic is correct, we use an additional survey data to assess the impact of improvement of agricultural mechanization on the mobility of labor in rural areas.

The data was collected from China Labor-force Dynamics Survey (CLDS)[1]in 2016 and 2018. CLDS is a nationally representative and follow-up survey data, which targeted the workforce aged 15 to 64 years. Through a multistage cluster, PPS (Probability Proportionate to Size) sampling method, the survey obtains the sample covers 29 provinces in China, excluding Hong Kong, Macao, Tibet, and Hainan. We constructed imbalanced panel data using the data of rural residents from 2016 and 2018 waves of CLDS.

The definition and descriptive statistics of all variables used in the model are reported in Table A1 in the Appendix. Considering the decision of agricultural machinery use and the decision to work outside the county variables are potentially endogenous (Ma, et al., 2018), we followed the two-stage estimation procedure (2SLS) used in the instrumental variable probit model. Similar to the previous studies, village topography is used as the instrumental variable of the mechanization level of agricultural production.

The first-stage results in Table 5 show that instrumental variable (topography) has a significant and negative impact on mechanization level of agricultural production, which suggests that compared with rural residents lived in plain area, the mechanization level of agricultural production in mountain area is lower. The results in second-stage shows that the mechanization positively and significantly influences the probability of working outside the county. It reveals that agricultural mechanization did promote rural residents working outside their county. As many rural young people work outside the county, local industry and service industries will face labor shortages and declining household demand for consumption. Therefore, this is not conducive to the development of other local non-agricultural

[1] Data source: Center for Social Survey, http://css.cssn.cn/css_sy/fzshxsjzy/201712/t20171212_3778450.html.

sectors.

Third, it is well known that non-grain crops are more profitable than grain crops. Moreover, households that selected to grow cash crops had higher incomes than those that did not grow cash crops(Masanjala, 2006). So for most farmers, when the mechanization level is improved and they have more working time, why they choose to increase the planting of grain crops which are convenient for mechanized production and then go out for work instead of increasing the production of non-grains crops? A reasonable explanation is that the farmer as a rational economic man will generally choose an option with higher income. Then we should get the conclusion that the level of mechanization will increase farmers' disposable income. The empirical results were presented in column 2 in table 4. The coefficient of mechanization is 0.114 and is statistically significant, indicating that every 1% increase in the power of agricultural machinery of a county can drive a 0.114% increase in annual disposable income of rural residents of that county. This empirical evidence further supports the findings from the first two parts of mechanism analysis.

Table 4 The estimated effects of agricultural mechanization on the per capita income of rural residents and the yield of grain

VARIABLES	(1) Grain output (ln)	(2) rural_income (ln)
Second stage within regressions		
machinery (ln)	0.233***	0.114*
	(2.70)	(1.66)
GDP (ln)	0.020	0.171***
	(1.25)	(13.22)
ratio_industry	0.024	-0.100***
	(0.57)	(-4.92)
investment	-0.013	0.100***
	(-0.42)	(5.39)
loans_market	-0.042***	0.060***
	(-4.32)	(8.85)
infrastructure (ln)	-0.012*	0.002

	(-1.95)	(0.47)
healthcare	-0.001***	0.001***
	(-2.87)	(2.67)
education	-0.081	0.525***
	(-0.36)	(3.87)
area (ln)	0.219***	-0.058***
	(5.95)	(-2.97)
Constant	9.438***	6.272***
	(30.53)	(40.59)
Observations	12,630	10,725
county FE	YES	YES
Year FE	YES	YES
R-squared (overall)	0.3408	0.5845
F test for instrumental variable	105.41	61.60
First-stage within regression **(dependent variable:** machinery**)**		
subsity_grade	0.00088***	0.00054***
	(9.61)	(4.68)

Notes: *** p<0.01, ** p<0.05, * p<0.1,z-statistics in parentheses for the second stage results. t-statistics in parentheses for the first stage results. Observations are much lower due to the large absence of data on per capita disposable income of rural residents in 2020.

Table 5 The estimated effects of mechanization level of agricultural production on decision of working outside the county of rural residents (IV probit)

	(1)	(2)
	first stage	second stage
Variable	dependent variable: machine	dependent variable: workplace
machine		0.779***
		(0.191)
topography	-0.232***	
	(0.012)	
gender	-0.017	-0.467***
	(0.017)	(0.086)
age	-0.001**	-0.027***
	(0.001)	(0.003)
education	0.004	0.010
	(0.012)	(0.053)
health	0.004	0.032
	(0.008)	(0.039)
income	0.000**	0.001**
	(0.000)	(0.000)
expenditure	0.001**	-0.003*
	(0.000)	(0.002)
farmland	0.001*	-0.002
	(0.000)	(0.002)
subsidy	-0.135***	0.186**
	(0.020)	(0.082)
village economy	-0.001	-0.002
	(0.000)	(0.002)
village business	-0.001	-0.005
	(0.001)	(0.007)

distance	0.000	0.002
	(0.000)	(0.002)
road	-0.017	-0.208
	(0.042)	(0.200)
Province fixed effect	YES	YES
athrho2_1	-0.452***	-0.452***
	(0.142)	(0.142)
lnsigma2	-0.508***	-0.508***
	(0.009)	(0.009)
Constant	3.046***	-2.250***
	(0.122)	(0.778)
Observations	5,251	5,251

Notes: *** p<0.01, ** p<0.05, * p<0. Robust standard errors in parentheses.

In order to have a more a clear and intuitive understanding of the mechanism of agricultural mechanization affecting the local economy, we integrate the above analysis results into a picture, which is shown in Figure 1.

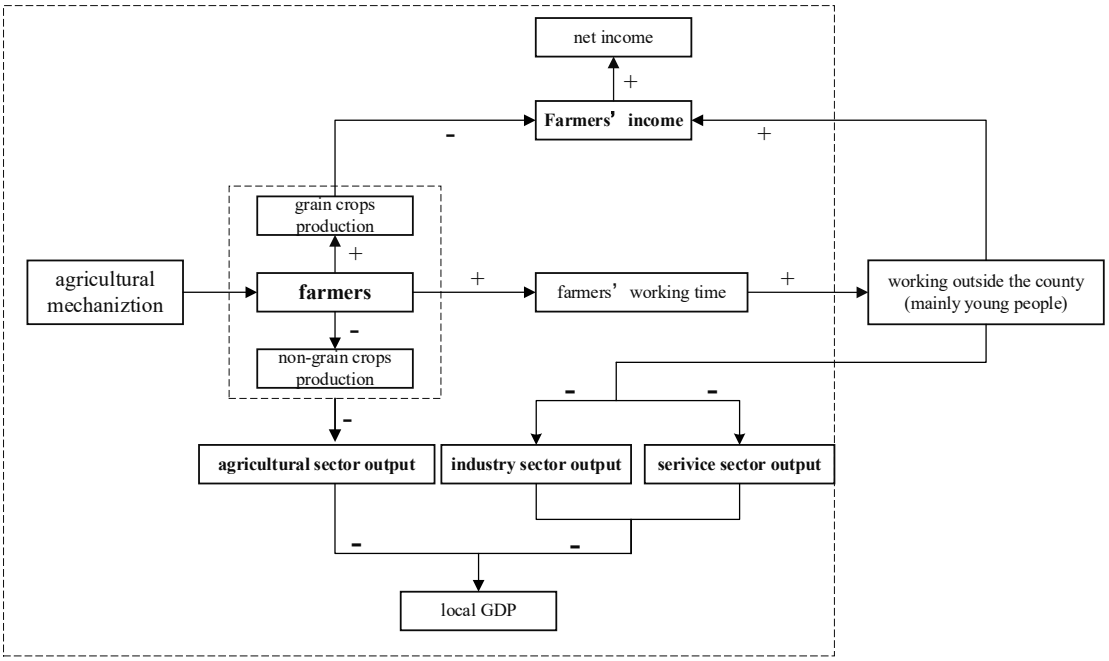

Figure 1 The channels of agricultural mechanization on local economy

5. Conclusion

Agricultural mechanization has brought about the increase of agricultural output, the decrease of labor demand, and the increase of farmers' income. However, the existing literatures on agricultural

mechanization mainly focus on the impact on agricultural production and farmers' behavior, and the research on other economic sectors is relatively scarcely. As mechanization is the main direction of agricultural development in many countries, understanding its impact on the whole local economy is very important for local industrial development planning in the future. Therefore, this paper focuses on the overall impact of agricultural mechanization on the local economy, including on other non-agricultural sectors. Specifically, based on the panel data of China's rural areas at the county level, we use instrumental variable method to analyze the impact of agricultural mechanization on regional economic development, and further discuss its influence mechanism.

The results of this paper show that the increase of agricultural mechanization level reduces the local GDP. Further analysis shows that agricultural mechanization has significant negative impact on local agricultural sector output, industrial sector output and service sector output. Machinery can easily substitute labor in grain crops production than in non-grain crops production. Thus, as the level of mechanization increased, farmers planted more grain crops and less non-grain crops. This phenomenon has led to a decline in agricultural output value because the economic returns per unit area of non-grain crops are greater than grains crops. Both the substitution of machinery by farmers and the reduction in the cultivation of non-grain crops have led to an increase in the supply of labor to farmers. Most of these farmers have chosen to leave home and work in other areas. The reason is that working outside can bring them more income. These rural migrant workers are usually young people, which also leads to the reduction of local labor supply and household consumption demand, and thus reduces the output value of local industrial and service sectors.

Our findings provide policy guidance for agricultural development in China and other countries.

First, increased mechanization has led to a decline in local non-grain cultivation, which is generally of high economic value. This is detrimental to the development of local agricultural industries. It has also resulted in the slow economic development of rural areas and the increasing gap between urban and rural areas. Therefore, in the process of agricultural mechanization, special attention should be paid to the support of some non-grain crops, because they are not easy to be replaced by machinery in the production process, and thus lose market competitiveness. Second, the improvement of agricultural mechanization has reduced the demand for labor force in the process of agricultural production, and a large number of farmers choose to work in other places. As these farmers generally lack professional skills, it is difficult for them to survive in the city for a long time. Most of them work only temporarily and cannot become city residents. These people are usually young, and when they go to work in other places, there are a large number of left-behind children and elderly people in the countryside. The physical and mental health of these vulnerable groups is a social issue of concern.

The conclusion of this paper also provides some ideas for future research. Increased mechanization has reduced the acreage of non-grain crops. Whether this affects all non-grain crops uniformly or only the less economically profitable ones. As for the aging problem caused by the outflow of rural labor force, whether mechanization can solve the aging problem in agricultural production and whether it will further affect the planting structure of agriculture.

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Table A1. Definition and summary statistics of variables, CLDS

Variable	Description	N	Mean	S. Dev
workplace	whether there are family members working outside the county: 1= yes; 0= no	5,451	0.031	0.173
machine	The mechanization level of agricultural production: 3= all mechanization, 2= partial mechanization,1=No machinery used	5,451	1.885	0.742
gender	gender of household head: 1=male, 0=female	5,451	1.507	0.500
age	age of household head (year)	5,449	49.796	14.576
education	education of household head: 6= college or above, 5= junior college, 4= high school, 3= junior high school, 2= primary school, 1= never attended school	5,451	1.671	0.780
health	Health status of household head: 5= Very unhealthy, 4= less healthy, 3= general, 2= health, 1= very healthy	5,439	2.525	1.058
income	The ratio of total household income to the number of workers in a household (thousand yuan)	5,451	39.294	66.984
expenditure	Total family gift and cash disbursement (thousand yuan)	5,429	9.075	24.199
farmland	Area of cultivated land (mu)	5,445	9.938	26.388
subsidy	whether household received agricultural subsidies: 1= yes; 0= no	5,451	1.333	0.471
village economy	per capita annual income of villagers (thousand yuan)	5,397	16.789	26.108
village business	Number of enterprises in the village	5,396	2.004	7.306
distance	The distance from the village to the nearest county government (kilometer)	5,450	27.156	27.457
road	Whether the road surface of the village is hardened (cement)	5,377	1.062	0.241
topography	Village topography: 3= mountain, 2= hills, 1= plain	5,451	1.775	0.849

Sources: Data is collected from the China Labor-force Dynamics Survey (CLDS) in 2016 and 2018, http://css.cssn.cn/css_sy/fzshxsjzy/201712/t20171212_3778450.html. 1 mu = 1/15 hectare.