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## Can rural human capital inputs enhance agricultural total factor productivity? - Based on the dualistic economic structure perspective

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### ABSTRACT

Human factor inputs are key to promoting agricultural modernisation. Traditional economic theory suggests that improving human capital is the key to boosting agricultural productivity, but can this conclusion hold in China's dualistic economic structure? We use Chinese provincial panel data from 2000-2017 to examine the impact of rural human capital inputs on agricultural total factor productivity. We find that, on the whole, rural human capital inputs have a negative effect on agricultural total factor productivity, and that there is a "rural human capital trap". Mechanism analysis reveals that rural human capital inputs, on the one hand, cause labour loss and reduce the quality of agricultural workers, while on the other hand, they may promote the application of mechanization, which has both positive and negative effects on agricultural total factor productivity. Heterogeneity analysis finds that this negative effect is more pronounced in the central region of China because of the serious loss of rural labour. This study provides new policy insights for further improving the structure of rural education inputs and promoting human capital accumulation in agriculture.

### KEYWORDS

Human capital inputs; labour quality; total factor productivity in agriculture; dual economy

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## 1. Introduction

In China, a country with a large population, agriculture has always played an important role. The modernisation and development of agriculture not only affects the well-being of hundreds of millions of farmers, but also has a direct impact on the stability of the national economy and the development of society. In the process of agricultural modernisation, improving agricultural total factor productivity is a crucial part of the process. Total factor productivity in agriculture refers to the relationship between the output of agricultural products per unit of area and per unit of labour input and the cost of various factors, including not only traditional factors such as land, labour and capital, but also modern factors such as scientific and technological innovation, agricultural mechanisation and the comprehensive development and use of agriculture. Increasing total factor productivity in agriculture means producing more agricultural products with fewer resources, which in turn can meet growing demands for food security, nutrition and health, and respond effectively to the challenges of rural depopulation and accelerated urbanization (Colli and Rao, 2005). Studies have explored the factors influencing the development of agricultural modernisation and the improvement of agricultural total factor productivity from the perspectives of land property rights improvement (Liu et al., 2023), climate change (Song et al., 2022), financial resources accessibility (Hu et al., 2021), and transport infrastructure (Gebresilasse, 2023), respectively.

Schultz (1964) argued that human capital factors such as the level of knowledge of the labour force are important factors contributing to the efficiency of agricultural production. With the comprehensive promotion of China's compulsory education in rural areas, the level of rural human capital investment has increased significantly, and some studies have confirmed that the rate of return on rural human capital investment has been rising, boosting farmers' incomes, but mainly in the form of increased non-farm incomes (Reardon, 2001; Jolliffe, 2004; Sumaryanto, 2011). Schultz's theory of human capital is based on the experiments of traditional agricultural countries and the assessment of the development experience of modern agricultural countries. Unlike these two, the development of agriculture in China, as a developing country, is accompanied by the transition from a dualistic to a monistic economic structure.

Lewis (1954) argues that under the dual economic structure, the labour productivity gap between industry and agriculture and the income gap between urban and rural areas lead to rural labour migration, and the decline and disappearance of the countryside is a result of the market economy. Krugman's (1991) centre-periphery theory suggests that when factors such as raw materials, capital, people and technology flow completely freely in the context of a market economy, an unequal economic development relationship is created in which the industrial sector and the city dominate the peripheral agricultural sector and the countryside, and the countryside is in a state of accelerated decline.

At the same time, some studies have found that the urban-rural income gap not only triggers the transfer of ordinary labour, but also attracts the transfer of highly skilled rural labour to the cities. Ruan and Zheng (2009) put forward the "education pump" hypothesis, in which the function of the current education system is to a large extent to pump high-quality rural workers from the countryside to the cities, turning the potential human capital that might have benefited rural economic development into human capital that only benefits urban economic development. Zhu and Ma (2009), based on the perspective of broadly defined rural human capital spillovers, found that more than 40% of China's urban-rural income gap in 2007 was due to human capital spillovers resulting from the transfer of rural labour to the cities. Liu (2014), based on panel data from 13 major grain-producing provinces and regions, found that the transfer of rural labour to non-agricultural industries has led to varying degrees of loss of rural human capital in various regions, as well as lowering the stock of agricultural human capital and reducing the output elasticity of human capital with respect to regional agricultural growth. Liu et al. (2023) found that, in an urban-rural dual structure, the establishment of land property rights in rural areas can promote the loss of highly skilled labour and loss of agricultural total factor productivity.

The typical facts about the labour factor in China's rural areas at present are: a massive transfer of the new generation of workers to secondary and tertiary industries, a particularly serious problem of rural ageing, and the emergence of women and the elderly as the mainstay of agricultural production. So, under the dual economic structure, will rural talent be attracted to the cities and not be employed in modern agriculture, but instead become an obstacle to the improvement of total factor productivity in agriculture?

Using Chinese provincial panel data from 2000 to 2017, we examine the impact of rural human capital inputs on the development of agricultural modernisation, using agricultural total factor productivity as an indicator of the development of agricultural modernisation. We find that, on the one hand, rural human capital improvement promotes rural labour migration, reduces the quality of agricultural labour, and is not conducive to agricultural total factor productivity; on the other hand, rural human capital improvement promotes the application of mechanisation, which has a positive effect on agricultural total factor productivity. Overall, the level of rural human capital input in Upper China is not conducive to the improvement of agricultural total factor productivity, and there is a "rural human capital trap" problem, and this effect is more pronounced in Central China.

The possible contributions of this paper are as follows: first, most of the existing research on rural human capital focuses on the micro level, and there is less research on the macro level, i.e. the rural human capital input to agricultural development itself. This paper analyses the relationship between rural human capital investment and agricultural development qualitatively and quantitatively at the macro level, providing evidence for the "rural human capital trap"; second, in terms of research perspective, this paper studies the specific mechanism of rural human capital investment on agricultural development from the perspective of the transformation of the dualistic economic structure, abandoning the original static assumptions of a closed agricultural economy and a monistic urban-rural relationship. Second, in terms of research perspective, this paper studies the specific mechanism of rural human capital investment on agricultural development from the perspective of the transformation of the dualistic economic structure, abandoning the original static assumption of a closed agricultural economy and a one-dimensional urban-rural relationship, and studying the intrinsic connection between variables from the dynamic perspective; Thirdly, most of the researches pay attention to the problem of "education premium" caused by rural human capital, but they neglect the research of the impact object and study the effectiveness of rural human capital input on agricultural development. In the context of the real dilemma of the urgent need of rural development, the study of the effectiveness of rural human capital investment on agricultural development suggests that the central task of rural human capital work should be shifted to the introduction and compensation strategy, which has important policy implications.

The remainder of the article is structured as follows: the second part is a literature review and hypothesis formulation; the third part introduces the data sources, model setting and variable meanings; the fourth part is an empirical test; and the fifth part is the research conclusions and policy recommendations.

## **2. Background and hypotheses development**

### *2.1. Background*

#### **2.1.1. Traditional Chinese agricultural production patterns**

Since ancient times, China's agricultural civilisation has been highly developed, resulting in the formation of a traditional smallholder economy that is self-sufficient. In recent times, however, it has become clear that its inefficiency and low productivity cannot be adapted to the external environment of large-scale industrial production, and that it has not been able to make a good transition to retaining the characteristics of traditional agriculture. Smallholder farming is an important feature of China's traditional agricultural model, and China's basic

national agricultural situation is one of large numbers of people and small amounts of land, with "one acre and three-thirds of land per capita, and no more than ten acres of fields per household". Data from the third agricultural census show that there are about 203 million small farmers nationwide, accounting for 98.1 per cent of the total number of agricultural households of all types, and that the area of arable land operated accounts for about 70 per cent of the total area of arable land, with households with an average arable land area of less than 10 acres accounting for 85.2 per cent of the total number of farming households. China's average household area of cultivated land is equivalent to only 1/3 of that of Korea, 1/40 of that of the European Union and 1/400 of that of the United States. In contrast, the average farm size in the United States was 177.3 hectares in 2014, making full use of economies of scale and the transformation of scientific and technological achievements; in Japan, agricultural reforms have been carried out since the 1960s, and by 2010 the average land area of Japanese farmers had reached 1.56 hectares, providing an opportunity to modernise and transform Japanese agriculture.

2.1.2. Dual economic structure of urban and rural areas

China's urban and rural development is uneven, creating a unique dual economic structure. Figure 1 shows that while the incomes of both urban and rural residents in China have risen in recent years, the urban-rural income gap has also remained at a high level. In modern times, agricultural production was severely damaged by the impact of external forces, the development of domestic industrialisation and political unrest. In the early years of the founding of the People's Republic of China, with social stability, agricultural production gradually recovered, but with a very weak industrial base, the state, in order to give priority to the development of industrial cities, used the "price scissors" method to exploit agriculture and achieve primitive capital accumulation. Since China's reform and opening up, the rapid process of industrialisation and urbanisation has been accompanied by a steady exodus of rural workers, the transformation of land resources into industrial parks, and the widespread phenomena of "aging" and "hollowing out", with the per capita disposable income of urban residents being 2.71 times higher than that of rural residents. For a long time, the problem of unbalanced development between urban and rural areas has been very serious in China, and China's remarkable economic achievements have to some extent been made at the expense of agriculture and the countryside.

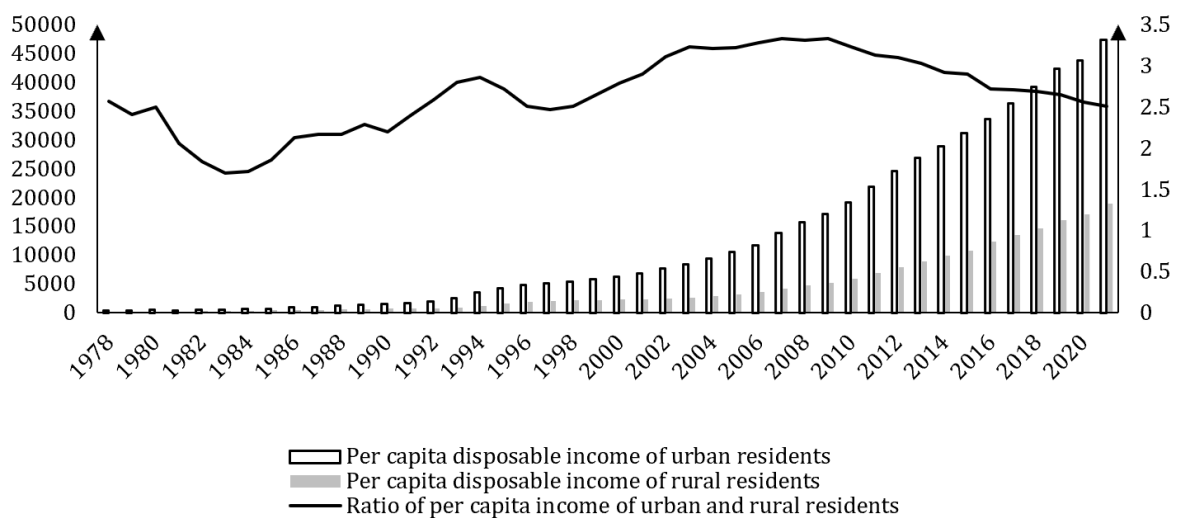


Figure 1. Trends in China's urban-rural income gap, 1978-2021.

In 2021, the per capita disposable income of China's urban residents will reach 47,412 yuan, while the per capita net income of rural residents will be only 18,931 yuan. The distribution of income is prioritised, and people will satisfy their living needs before considering other issues such as education, and the low level of farmers' income

is the root cause of their underinvestment in human capital. In 2021, the per capita expenditure on culture, education and recreation for urban residents will be 3,322 yuan, while the per capita expenditure on culture, education and recreation for rural residents will be only 1,645 yuan. The level of human capital in agriculture under the current economic conditions is inevitably lower than that in rural areas, so the lack of human capital investment in rural households will inevitably bring about the problem of insufficient human capital in agriculture.

Due to China's long-term dual economic structure, the rural economy lags far behind that of the cities, and the education level and health level of farmers are far lower than that of the urban population, so that the agricultural labour force is not competitive in the process of transferring to the non-agricultural industry, and therefore, only the rural labour force with a higher education level and better physical and health conditions can find jobs in the urban sector. As a result, China's rural labour force is moving younger, more male and more educated. According to the 2021 Migrant Labour Monitoring Survey Report released by the National Bureau of Statistics, the total number of rural migrant workers in China in 2021 will be 292.51 million, an increase of 6.91 million in the last 2020. Of the total number of rural migrant workers, 64.1 per cent are male and 35.9 per cent are female. Checking the 2013-2021 Migrant Worker Monitoring Survey Report also found that the proportion of male migrant workers are more than 64%, the proportion of female migrant workers is less than 36%, and the proportion of male migrant workers who go abroad is even higher. Migrant workers in China are characterised by a predominance of males, while the tasks of agricultural production are more often undertaken by females. At the same time, rural migrant workers are predominantly young adults, with the average age of rural migrant workers being 41.7 years old. In terms of age structure, the proportion of rural migrant workers under the age of 40 is 48.2 per cent.

## *2.2. The impact of rural human capital inputs on regional total factor productivity in agriculture*

With the advancement of agricultural science and technology, agricultural production is no longer simple physical labour, but a highly technological and information-based mode of production that requires the application of advanced technology and the mastery of complex knowledge. Highly skilled labourers have better professional knowledge and skills and can make more effective use of modern agricultural technology and equipment to improve the efficiency of agricultural production. At the same time, highly skilled labour can also monitor and control the quality of agricultural products, thus improving the quality and added value of agricultural products and meeting consumer demand for high-quality agricultural products. However, the contribution of human capital to economic development depends not only on the size and quality of human capital stock, but also on the efficiency of human capital utilisation.

Under the urban-rural dual structure, the input of rural human capital will lead to the loss of rural labour, thus causing a shortage of labour factors in agricultural production, which is not conducive to the improvement of total factor productivity in agriculture. From the perspective of micro-individual decision making, farmers' input decisions in choosing education mainly depend on three considerations: costs, benefits and risks (Becker and Gary, 1968). The input costs of rural education are mainly derived from the capital accumulation of agricultural production, which, due to the large investment in education, accounts for a large share of reinvestment in the rural household sector as a whole. Therefore, with rational expectations, farmers generally choose not to invest or to invest in low-risk, high-return investments: non-agricultural employment allows for higher yields, more stable returns and the release of the education premium, while agricultural production is characterised by high risk and low returns due to the constraints imposed by natural factors. In contrast, groups with high human capital investment will flow autonomously into non-agricultural industries (Liu et al., 2023). The transfer of skilled labour to cities and industries further accelerates the widening of the rural-urban income gap, creating a vicious cycle. The new generation of workers has moved to the non-agricultural sector, and the mainstays of agricultural production are the elderly and women; these two groups, on the one hand, have lower levels of education and cultural skills

due to historical factors and cultural attitudes; On the other hand, they are not as physically productive as young men, and women in rural areas have to take care of children and carry out work within the family, so they do not have enough time to work, which overall leads to a decline in the quality of the inputs they put into their work and hinders the development of agriculture (Julien et al., 2023; Liu et al., 2023).

Rural human capital inputs facilitate the transfer of labour and provide impetus to the industrial economy. In the interdependence between industry and agriculture, the development of the industrial and urban economy increases the demand for agriculture, especially for high-value agricultural products, and induces progress in agriculture as a whole. On the one hand, from the perspective of complementary aggregate demand, the increase in demand for agricultural production has raised the price of agricultural products, increased the rate of return to agricultural production, helped narrow the gap between agriculture and industry, and led to the inflow of more factors; On the other hand, from the perspective of the allocation of factors of production, the increase in demand for agricultural products has pushed up the price of products and pushed up the changes in the price of factors through indirect demand, and at the same time the transfer of labour has pushed up the cost of labour, which has led the main body of agricultural production to choose the substitution of technology and capital for labour, and increased the degree of mechanization in agricultural production (Li et al., 2021; Mohammed et al., 2023). Agricultural mechanisation can promote total factor productivity in agriculture through "learning by doing" (Paudel et al., 2019). At the same time, the use of agricultural mechanisation can increase the level of farmers' income, further promote the family sector's investment in education, and improve the level of rural human capital, forming a cumulative cycle of causal effects. Ultimately, this will lead to a synergy between the continuous improvement of agricultural technology, the improvement of rural human capital and the long-term development of agricultural production.

Based on the above analyses, we propose two competing hypotheses:

**Hypothesis 1a:** Rural human capital inputs cause a decline in the quality of the agricultural labour force and have a negative inhibitory effect on agricultural total factor productivity improvement;

**Hypothesis 1b:** Rural human capital inputs promote mechanisation levels and have a positive contribution to agricultural total factor productivity improvement.

### 3. Research design

#### 3.1. Methodology

We test the role of rural human capital in agricultural development based on the macro-additive Mincer equation (Mincer, 1962) and construct the following econometric model:

$$tfp_{c,t} = \beta_0 + \beta_1 agirih_{c,t} + \beta_2 t + \beta_3 t^2 + \varphi X_{c,t} + \mu_c + \gamma_t + \varepsilon_{c,t} \quad (1)$$

Letters  $c$  and  $t$  represent the province and year, respectively.  $tfp_{ct}$  denotes the total factor productivity in agriculture of province  $c$  in year  $t$ ,  $agirih_{ct}$  denotes the level of rural human capital.  $t$  denotes the level of accumulated experience in agricultural production.  $X_{ct}$  denotes a set of control variables,  $\mu_c$  is a fixed regional effect used to reflect the characteristics of different cities that do not change over time,  $\varepsilon_{ct}$  is the random error term, and  $\gamma_t$  denotes a time-fixed effect.

#### 3.2. Description of variables

**Total factor productivity in agriculture (tfp):** We refer to the Gandhi et al. (2020) approach to measure total factor productivity in agriculture across provinces using the DEA-Malmquist index method. The method does not

require a production function form and is able to factorise total factor productivity growth using input-output data of different magnitudes. With constant returns to scale, the Malmquist index measures the change in economic efficiency from technical conditions in period  $t$  to  $t+1$ , expressed by the formula:

$$M_{0,t=1}(x^t, y^t, x^{t+1}, y^{t+1}) = \left\{ \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \right\} \times \left\{ \left( \frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} \right) \left( \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)} \right) \right\}^{\frac{1}{2}} \quad (2)$$

$M_{0,t=1}(x^t, y^t, x^{t+1}, y^{t+1})$  represents the Malmquist index of total factor productivity, which can be decomposed into the index of technical efficiency and technical progress in the case of constant returns to scale. In terms of indicator selection, according to the DEA-Malmquist index method to measure the total factor productivity of agriculture in each province, it is necessary to specify the agricultural output-input indicators. In this paper, one of the outputs chosen in the calculation of total factor productivity in agriculture is the gross value of agriculture, forestry, animal husbandry, fishery and fishery, and the inputs are labour, land, mechanization, fertilizer and irrigation inputs. Specific input-output and total factor productivity indicators are selected in the data selection section, and statistical descriptions are shown in Table 1.

**Table 1.** Statistical description.

Variable	Obs	Mean	Std.Dev.	Min	Max
tfp	553	1.080	0.449	0.479	7.379
agrih	557	7.427	0.836	3.740	9.768
agfe	558	85.71	73.40	1.091	311.6
plastic	558	66,089	63,103	128	343,524
power	558	2,670	2,659	95.30	13,353
elec	558	194.4	316.8	0.300	1,888
pesti	558	51,465	43,165	583	173,461
pop	544	2,165	1,549	160.8	7,287
health	496	20,137	16,631	1,187	66,389
hydr	529	141	239	0	1198
ferti	558	168.7	138.3	2.500	716.1
culti	558	5,134	3,622	120.9	14,903

**Level of rural human capital (agrih):** Drawing on Klenow and Rodriguez-Clare (1997) and Hall and Jones (1999), we use a measure of the average number of years of schooling of the rural population per year in each province.  $agrih = \text{Proportion of illiterate persons} \times 0.5 + \text{Proportion of primary school population} \times 6 + \text{Proportion of lower secondary school population} \times 9 + \text{Proportion of upper secondary schools} \times 12 + \text{Proportion of university population} \times 16$

**The level of experience,  $t$  (years),** is used as a proxy variable at the macro level by deflating the base period year by the year in the panel data, in accordance with the previous technical treatment of the micro Mincer equation.

**Control variables:** Considering issues such as omitted variables in the model setup, we chose the government's financial expenditure on agriculture (*agfe*), the use of plastic film in agriculture (*plastic*), the use of electricity in rural areas (*elec*), the use of pesticides (*pesti*), the number of people in villages (*pop*), the number of village health rooms (*health*), the power of mechanisation in agriculture (*power*), the use of chemical fertilisers (*ferti*), the area under cultivation (*culti*), and the capacity of rural hydroelectricity (*hydr*).

### 3.3. Data sources and descriptive statistics

The time period for all our variables is selected as 2000-2017. The selected geographical areas are the 31 provinces in China excluding Hong Kong, Macao and Taiwan. The relevant data sources are China Statistical

Yearbook, China Rural Statistical Yearbook, China Population and Employment Statistical Yearbook of past years, and the database of CEIC. In order to exclude the influence of price factors, this paper takes 2000 as the base period and uses the consumer price index to deflate the relevant variables.

## 4. Result analysis

### 4.1. Benchmark regression results

There are many factors affecting agricultural development, the omission of variables is inevitable, at the same time, due to the level of rural economic development and rural human capital enhancement also has a potential causal relationship, there is a certain endogeneity of the problem, resulting in the regression results have bias and inconsistency, we will select the lagged term of the independent variable of the level of rural human capital for the basis of the regression, the use of mixed least squares estimation, fixed-effects model, random effects model of the three methods of regression test, respectively, the regression results are shown in Table 2.

**Table 2.** Benchmark regression results.

	OLS	FE	RE
<i>agrih</i>	-0.127* (-1.89)	-0.127* (-1.89)	-0.127* (-1.89)
<i>t</i>	-0.181*** (-4.52)	-0.181*** (-4.52)	-0.181*** (-4.52)
<i>t</i> <sup>2</sup>	0.010*** (6.69)	0.010*** (6.69)	0.010*** (6.69)
<i>agfe</i>	0.121* (1.74)	0.121* (1.74)	0.121* (1.74)
<i>ferti</i>	-0.044 (-0.15)	-0.044 (-0.15)	-0.044 (-0.15)
<i>pesti</i>	-0.064 (-0.45)	-0.064 (-0.45)	-0.064 (-0.45)
<i>pop</i>	0.114 (0.66)	0.114 (0.66)	0.114 (0.66)
<i>plastic</i>	-0.143 (-1.40)	-0.143 (-1.40)	-0.143 (-1.40)
<i>elec</i>	0.169 (1.36)	0.169 (1.36)	0.169 (1.36)
<i>health</i>	-0.112 (-0.70)	-0.112 (-0.70)	-0.112 (-0.70)
<i>power</i>	0.071 (0.44)	0.071 (0.44)	0.071 (0.44)
<i>culti</i>	-0.867*** (-2.70)	-0.867*** (-2.70)	-0.867*** (-2.70)
<i>cons</i>	8.351*** (3.70)	8.351*** (3.70)	8.351*** (3.70)
province fixed	yes	yes	yes
year fixed	yes	yes	yes
R <sup>2</sup>	0.6459	0.6373	0.6459
N	483	483	483

Notes: The *t*-statistics are in parentheses and the superscripts "\*\*\*\*", "\*\*\*" and "\*" denote the 1 per cent, 5 per cent and 10 per cent confidence levels, respectively.

The P-value of Hausman test is 0, which indicates that the fixed effect model is better than the random effect model. According to the results in Table 2, the coefficients of the core explanatory variables are all significantly



negative, indicating that rural human capital inputs are not conducive to agricultural TFP, which verifies the competitiveness hypothesis 1a, and indicates that there is still the problem of "rural human capital trap" in China. The results of the control variables show that the quadratic term of the time experience variable is significantly positive and the primary term is significantly negative, indicating that work experience becomes more important for agricultural total factor productivity improvement over time. Government expenditure on agriculture, rural population and mechanization inputs all have a positive effect on agricultural total factor productivity, indicating that traditional factors of production, such as labour and capital, are still the basic components of agricultural modernization and should not be ignored.

## 4.2. Robustness tests

### 4.2.1. Endogeneity Problem Test

Rural human capital inputs and total factor productivity improvements in agriculture are causal. An increase in human capital inputs can improve farmers' technological level and innovation capacity, thus promoting the development of agricultural productivity and total factor productivity. At the same time, an increase in total factor productivity in agriculture will also increase farmers' income and economic efficiency, providing them with more incentives to invest in human capital.

In order to better overcome the endogeneity disturbance and make the test results more robust, we perform two-stage least squares regression (2SLS) with generalised moment estimation (GMM) model estimation and compare it with the previous results. Instrumental variables are selected to be highly correlated with endogenous variables on the one hand, and uncorrelated with the disturbance term on the other hand, which is exogenous. "Carp leaping over the Dragon Gate" is an important way for rural children to achieve social class transition, and the important consideration for farmers to invest in education is to achieve class transition through the college entrance examination, so the number of students enrolled in universities in each region will have an "anticipation effect" on the investment in rural human capital, and at the same time, due to the integration of urban and rural enrollment, the investment in rural human capital will have an "anticipation effect". At the same time, due to the integration of urban and rural enrolment, the level of urban human capital will also have an impact on rural people's access to university education and thus affect their human capital investment, but the number of university enrolment is regulated by the government's indicators every year, and the level of urban human capital is not very correlated with the level of agricultural development in the local area, and thus is also exogenous. Therefore, this paper intends to select the number of university enrolment and urban human capital level in each region as instrumental variables for empirical analysis, and the selection of instrumental variables has passed the test of over-identification and the test of weak instrumental variables.

According to Table 3 regression results show that rural human capital has a significant negative effect on agricultural total factor productivity and the significant coefficients are even more pronounced, indicating that after endogeneity treatment, the increase in the level of rural human capital is an impediment to the development of agriculture, and the results of the benchmarks are still robust.

### 4.2.2. Quantile regression

Unlike traditional OLS regression, quantile regression can provide more comprehensive information and is particularly suitable for exploring heterogeneous effects at different quantile positions in the data. In addition traditional OLS regression is more affected by extreme values, whereas quantile regression, by estimating coefficients at multiple quantile positions, is better able to capture potential heterogeneity between different parts of the data distribution and reduces the impact of outliers on the results.

**Table 3.** Robustness tests: IV.

	<i>2SLS</i>	<i>GMM</i>
<i>agrih</i>	-0.0072** (-2.48)	-0.0062** (-2.48)
<i>t</i>	-0.0475 (-0.71)	-0.0672 (-0.82)
<i>t</i> <sup>2</sup>	0.0073*** (3.76)	0.0076*** (2.99)
<i>agfe</i>	0.2888** (2.36)	0.2692** (2.10)
<i>ferti</i>	0.2263 (0.56)	0.1309 (0.27)
<i>pesti</i>	-0.2055 (-1.05)	-0.1565 (-0.54)
<i>pop</i>	-0.3076 (-1.04)	-0.2033 (-0.72)
<i>plastic</i>	-0.4282** (-2.41)	-0.4338** (-2.51)
<i>elec</i>	0.2271 (1.37)	0.3147 (0.81)
<i>health</i>	-0.2359 (-1.10)	-0.2404 (-1.01)
<i>power</i>	0.1588 (0.74)	0.1529 (0.67)
<i>culti</i>	-0.8497** (-2.00)	-0.9561 (-1.49)
<i>cons</i>	15.1197*** (3.53)	15.1197*** (3.53)
providence fixed	yes	yes
year fixed	yes	yes
Over-identification tests	<i>P</i> =0.2842	<i>P</i> =0.2788
weak instrumental variables test	<i>F</i> =5.0852	<i>F</i> =5.8052
<i>N</i>	483	483

Notes: The *t*-statistics are in parentheses and the superscripts "\*\*\*\*", "\*\*\*" and "\*\*" denote the 1 per cent, 5 per cent and 10 per cent confidence levels, respectively.

By comparing regression coefficients at different quantile positions, we can test the sensitivity of the model to extreme observations and thus obtain more robust estimates. We use quantile regression to test the degree of usefulness at different quantiles of agricultural development. The regression results are shown in Table 4. We can see that overall, the level of agricultural human capital and agricultural development are negatively correlated, and in terms of stage, and to satisfy the problem reflected in our subregional tests, the coefficient is getting larger and larger as agricultural development deepens, suggesting that the mismatch between the level of rural human capital and agricultural development, is getting larger and larger. At the same time, we can also see that the first and last of the quantile regressions are not significant, and the significance is concentrated in about 50 per cent of the quartiles, indicating that the results are robust by excluding the effect of heteroscedastic values.

### 4.3. Influence mechanism test analysis

According to the previous hypothesis, rural human capital accumulation will have an impact on agricultural total factor productivity through two channels: the loss of rural labour and the increase of mechanization level. Based on this, we construct a mediation effect model to test it. In testing the mediation effect, in addition to the need

**Table 4.** Robustness tests: quantile regression.

	(1)	(2)	(3)	(4)	(5)	(6)
	10%	35%	45%	50%	60%	90%
<i>agrih</i>	-0.0212 (-0.49)	-0.0312* (-1.58)	-0.0527*** (-2.97)	-0.0528*** (-3.30)	-0.0623** (-2.13)	-0.1199 (-0.68)
cons	2.2163 (1.52)	0.9408 (1.41)	1.2789** (2.14)	1.8226*** (3.38)	2.2303** (2.26)	10.4509* (1.75)
controls	yes	yes	yes	yes	yes	yes
province fixed	yes	yes	yes	yes	yes	yes
year fixed	yes	yes	yes	yes	yes	yes
R2	0.1716	0.0441	0.0389	0.0382	0.0370	0.4523

Notes: The *t*-statistics are in parentheses and the superscripts "\*\*\*\*", "\*\*\*" and "\*" denote the 1 per cent, 5 per cent and 10 per cent confidence levels, respectively.

to construct equation (1), the following two econometric models should be constructed sequentially:

$$M_{c,t} = \alpha + \alpha_1 agrih_{c,t} + controls + \mu_c + \gamma_t + \varepsilon_{c,t} \tag{3}$$

$$tfp_{c,t} = \alpha_0 + \alpha_2 agrih_{c,t} + \alpha_3 M_{c,t} + controls + \mu_c + \gamma_t + \varepsilon_{c,t} \tag{4}$$

$M_{c,t}$  denotes the mediating variable of the impact of rural human capital on agricultural development, and in this paper we mainly take labour outflow and mechanisation level as the test of the mediating variable. The specific steps are as follows: firstly, test whether the  $\beta_1$  coefficient is significant by regressing equation (1), and if it is significant, then regress equation (2) and equation (3) sequentially; Test whether the coefficients  $\alpha_1$  and  $\alpha_3$  are significant, if they are both significant, then the variable  $agrih_{c,t}$  will have a significant mediating effect through mediation on  $M_{c,t}$ , which will have an effect on  $tfp_{c,t}$ . If  $\alpha_2$  is also significant there is also a direct effect, and vice versa, there is only a mediating effect, i.e., the variable  $agrih_{c,t}$  has no significant effect on  $tfp_{c,t}$ , and there is only an effect of  $M_{c,t}$  on  $tfp_{c,t}$ .

According to the results of column (2) of the regression in Table 5, we can see that the level of rural human capital has a significant negative correlation with the rural labour force, and according to the results of column (3) of the regression, the *labor* coefficient is also significantly positive, and we can corroborate that the rural human capital has a negative effect on the agricultural development through the intermediary mechanism of the flow of the rural labour force, and verifies the competing hypothesis 1a, that the inputs of rural human capital will Reduce rural labour input and thus is not conducive to agricultural total factor productivity. Meanwhile, the *agrih* coefficient in column (3) of the regression is also significantly negative, indicating that there is only a partial mediation effect.

According to the regression results in column (2) of Table 6, the level of rural human capital and the level of mechanisation are significantly positive, and according to the regression results in column (3), the *power* coefficient is also significantly positive, and we can confirm that the level of rural human capital can have a positive effect through the mediating effect of the level of agricultural mechanisation, which verifies the competing hypothesis 1b, and indicates that the inputs of rural human capital will promote the development of agriculture through the enhancement of the level of agricultural mechanisation. the substitution effect and thus promote agricultural development. At the same time, the *agrih* coefficient in column (3) of the regression results is significantly positive, indicating the existence of partial mediation effect and direct effect. When column (4) is added to both labour and power variables, it is found that the coefficient of *labor* is significantly positive, and the coefficient of power is not significant, indicating that when the two are interactively included in the estimation model, the positive mediating effect disappears, and there is only a negative mediating effect, which indirectly proves that the rural human capital input has a negative effect on agricultural development, and the positive effect does not appear, which is in line with

**Table 5.** Influence mechanism test: labor.

	(1)	(2)	(3)
	tfp	labor	tfp
agrih	-0.127*	-0.0494**	-0.121*
	(-1.89)	(-2.14)	(-1.90)
labor			0.9048***
			(6.94)
cons	8.351***	-1.2571***	6.6144***
	(3.70)	(-2.69)	(3.06)
controls	yes	yes	yes
providence fixed	yes	yes	yes
year fixed	yes	yes	yes
R2	0.2442	0.9828	0.3190
N	486	486	483

Notes: The *t*-statistics are in parentheses and the superscripts "\*\*\*\*", "\*\*\*" and "\*" denote the 1 per cent, 5 per cent and 10 per cent confidence levels, respectively.

the previous basic estimation results, but the intrinsic cause of the mechanism is still to be further researched.

**Table 6.** Influence mechanism test: power.

	(1)	(2)	(3)	(4)
	tfp	power	tfp	power
agrih	-0.127*	0.0449**	0.1401**	-0.1364**
	(-1.89)	(2.46)	(2.51)	(-2.44)
labor				0.8528***
				(7.71)
power			0.3343**	0.0175
			(2.61)	(0.14)
cons	8.351***	1.6902***	1.2462	5.1032***
	(3.70)	(4.06)	(0.76)	(2.68)
controls	yes	yes	yes	yes
providence fixed	yes	yes	yes	yes
year fixed	yes	yes	yes	yes
R2	0.2442	0.7683	0.0722	0.3188
N	486	510	507	507

Notes: The *t*-statistics are in parentheses and the superscripts "\*\*\*\*", "\*\*\*" and "\*" denote the 1 per cent, 5 per cent and 10 per cent confidence levels, respectively.

#### 4.4. Heterogeneity analysis

There are large differences in the level of economic development between regions in China. We divided the sample into three sample groups in the eastern, central and western regions, combined with the basic estimation results of the situation, to take the fixed effects and random effects model for estimation, the regression results are shown in Table 7, from which we can see that: in most of the regions, rural human capital is still negatively correlated with the development of agriculture, and through the test of significance, once again verified our assumptions, but from the more detailed aspects, we also see that the coefficient in the central region is significantly negative and the largest, indicating that the mismatch between rural human capital input and agricultural development is the largest in the central region, which is behind the fact that the central region is the main area of rural labour transfer in China, which also indirectly verifies our theoretical mechanism.

**Table 7.** Heterogeneity test.

	Eastern part		Central Region		Western Region	
	(1)	(2)	(3)	(4)	(5)	(6)
<i>agrih</i>	-0.2442** (-2.15)	-0.1624** (-2.09)	-0.5109*** (-5.36)	-0.3768*** (-4.43)	-0.0274 (-0.54)	0.0212 (0.50)
<i>t</i>	-0.3034** (-2.42)	-0.1948*** (-2.54)	-0.1945*** (-3.86)	-0.2097*** (-3.27)	-0.0230 (-0.40)	-0.1061*** (-3.45)
<i>t</i> <sup>2</sup>	0.0139*** (3.40)	0.0121*** (3.01)	0.0106*** (4.48)	0.0107*** (3.67)	0.0063*** (2.75)	0.0079*** (4.80)
<i>cons</i>	18.3827** (2.28)	3.1765** (4.40)	15.0964*** (3.06)	5.5782** (4.11)	8.0932** (2.17)	1.8733** (2.40)
controls	yes	yes	yes	yes	yes	yes
province fixed	yes	yes	yes	yes	yes	yes
year fixed	yes	yes	yes	yes	yes	yes
R2	0.2740	0.4990	0.3023	0.6200	0.3510	0.2868
N	159	159	153	153	171	171

Notes: The *t*-statistics are in parentheses and the superscripts "\*\*\*\*", "\*\*\*" and "\*\*" denote the 1 per cent, 5 per cent and 10 per cent confidence levels, respectively.

## 5. Conclusions and policy recommendations

The revitalisation of the countryside is key to the upliftment of human capital. Human capital enhancement is an important factor in promoting agricultural productivity. However, under the dual economic structure, it is still debatable whether rural human capital input can promote the development of agriculture itself. Based on the typical facts of China's dual economic structure, this paper describes the specific mechanism of rural human capital investment on agricultural development from the three dimensions of factor quantity, factor allocation, and factor demand, and empirically tests its causal effect and mechanism of action based on the panel data of 31 provinces in China from 2000 to 2017. We find that: (1) from the overall benchmark regression results, rural human capital investment is not conducive to the improvement of agricultural total factor productivity, and this core conclusion is still very robust after considering endogeneity problems caused by measurement error, omitted variables and two-way causality, as well as other statistical biases, such as sampling error, standard error clustering bias, and modeling bias; (2) from the point of view of mechanism of action, rural human capital enhancement mainly leads to the loss of labour and thus is not conducive to the enhancement of agricultural total factor productivity, but it also promotes the level of agricultural mechanization and other ways to promote agricultural development, but in the overall regression model, the positive promotional effect is not significant, and the negative impediment effect is significant; (3) the impact of rural human capital input on agricultural total factor productivity has heterogeneous characteristics, from the perspective of the spatial dimension, the central region, due to excessive labour mobility, leads to its excessive labour mobility, resulting in a more serious mismatch between its rural human capital level and agricultural development. we make corresponding policy recommendations centred on the above conclusions:

First, implement differentiated rural human capital training programmes. In response to the reduced quality of the labour force noted in the study, the Government can develop a differentiated rural human capital training programme. The programme should provide training courses tailored to the characteristics of different regions and industries to help rural workers upgrade their skills, thereby improving their efficiency and quality in agricultural production.

Secondly, rural mechanisation should be promoted. Given that studies have shown that rural human capital enhancement promotes mechanisation applications, the Government should increase its support for rural mechanisation. This includes providing subsidies for mechanised equipment, promoting training and guidance in

the use of agricultural machinery, and improving the agricultural mechanisation service system. By promoting rural mechanisation, the efficiency and productivity of agricultural production can be effectively improved.

Thirdly, support for agricultural development in the central region should be strengthened. Considering that the effects are more pronounced in central China, the Government should increase its support for agricultural development in the central region. This could include measures such as increasing agricultural inputs, improving infrastructure, and providing more technical support and training, in order to promote total factor productivity in agriculture in the central region and mitigate the effects of the "rural human capital trap".

In response to the return of talent, the Government can attract the return of highly skilled rural labour by promoting the restructuring of rural industries, fostering new industries and services, and providing more high-paying, stable employment opportunities; increasing investment in rural transport, energy, communications and other infrastructure construction, improving rural production and living conditions, and providing a better platform for the development of talent; and perfecting the rural social security system, providing a full range of guarantees, including old-age pension, medical care, housing and so on, to increase the sense of security and stability of the return of rural talent.

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## Conflict of interest

The author claims that the manuscript is completely original. The author also declares no conflict of interest.

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