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RURAL SOCIOLOGY

Rural depopulation on agricultural technological choice in China

Xiaoli Hu[1] **Shanlang Lin**[2*]

[1]International college of football, Tongji University, Shanghai, China.
[2]School of Economics and Management, Tongji University, 200092, Shanghai, China. E-mail: 1610007@tongji.edu.cn. *Corresponding author.

ABSTRACT: *Rural depopulation is an inevitable trend due to urbanization and industrial development, and it is a common phenomenon in industrialized countries. The classic theory of induced technological innovation proposed by HAYAMI & RUTTAN (1971) explains the change in agricultural technology during the process of rural depopulation. This paper tests the Hayami-Ruttan induced technological innovation theory from the perspective of agricultural technology choice in the process of rural depopulation. We sort out the influence mechanism of rural depopulation on the choice of agricultural technology from four aspects, namely, factor substitution effect, demand scale effect, conditional bottleneck effect, and agricultural comparative benefit. Using the difference between the rural registered population and the permanent population, we comprehensively compiled the data on the net outflow rate of the rural population from 2005 to 2018 in 313 prefecture-level cities, and reach conclusions through panel regression. The results showed that rural depopulation is not necessarily conducive to labor-saving technological choices, but is conducive to the land-saving technological choice. However, rural depopulation promotes labor-saving technological choices when the population reaches a certain level. The conclusion is not completely consistent with the theory of Hayami-Ruttan, it reflects an idiographic feature of the Chinese environment.*
Key words: *rural depopulation, rural-urban migration, agricultural technological choice.*

Efeito do despovoamento rural na escolha tecnológica agrícola na China

RESUMO: *O despovoamento rural é uma tendência inevitável devido à urbanização e ao desenvolvimento industrial, e é um fenômeno comum em países industrializados. A teoria clássica da inovação tecnológica induzida proposta por Hayami & Ruttan (1971) explica a mudança na tecnologia agrícola durante o processo de despovoamento rural. Este artigo testa a teoria da inovação tecnológica induzida por Hayami-Ruttan sob a perspectiva da escolha da tecnologia agrícola no processo de despovoamento rural. Classificamos o mecanismo de influência do despovoamento rural na escolha da tecnologia agrícola a partir de quatro aspectos, a saber, efeito de substituição de fatores, efeito de escala de demanda, efeito de gargalo condicional e benefício comparativo agrícola. Usando a diferença entre a população rural registrada e a população permanente, compilamos de forma abrangente os dados sobre a taxa líquida de saída da população rural de 2005 a 2018 em 313 cidades em nível de prefeitura e chegamos a conclusões por meio de regressão em painel. Os resultados mostram que o despovoamento rural não é necessariamente propício para a escolha tecnológica de economia de mão de obra, mas é propício para a escolha tecnológica de economia de terra. No entanto, o despovoamento rural promove escolhas tecnológicas que economizam mão-de-obra quando a população atinge um certo nível. A conclusão não é totalmente consistente com a teoria de Hayami-Ruttan, ela reflete uma característica idiográfica do ambiente chinês.*
Palavras-chave: *despovoamento rural, migração rural-urbana, escolha tecnológica agrícola.*

INTRODUCTION

With the continuous advancement of urbanization and industrialization, a large number of young and middle-aged people in rural areas of China have flowed to cities for work. As a result, it has provided abundant labor resources for the development of urban areas and promoted the rapid development of cities. However, due to the serious loss of population and labor resources in rural areas, the economic and social development there has been severely affected, e.g., the lack of development vitality and the occurrence of economic decline. Such phenomenon of rural depopulation has appeared in the process of construction of New Countryside (LE & LI, 2018). Rural depopulation is not unique in China. It has become common in almost all countries in the world in their process of modernization,

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industrialization, and urbanization. From a long-term historical perspective, population migration between urban and rural areas is also the labor transfer from primary production to the growing urban economy, reflecting the transformation from an agricultural society to an industrial society. The release of labor from agriculture industry because of technological progress has facilitated this kind of transformation and is thereby considered as an important part of the modernization process (DE HAAS, 2010; SKELDON, 2012; ZELINSKY, 1971).

With the rapid development of urbanization and the tertiary industry in general, the number of Chinese moving-out agricultural laborers has increased year by year. In 2008, the number of peasants going out for work in China is 220 million while in 2019 it reached 290 million, with an average annual growth rate of 2.35% and a year-on-year increase of 0.84% compared with 2018 (National Migrant Workers Inspection and Survey Report). The scale of labor migrants continues to expand, and the number of agricultural workers is showing a trend of declining. The number of employees in the primary industry in China has dropped from 360 million in 2000 to 190 million in 2019, an average annual decrease of 3.22%. At the same time, the price of agricultural labor input has risen, and the price of hired labor has increased from 18.7 yuan in 2000 to 122.93 yuan in 2018. The daily wage of family labor has increased from 10 yuan in 2000 to 84.89 yuan in 2018. According to Hayami-Ruttan's theory of agricultural induced technological change, farmers decide the amount and structure of labor and capital inputs to carry out agricultural production and management based on the relative prices of factors. As labor prices rise, farmers, as rational economic people, will use machinery instead of labor for agricultural production activities. The investment cost of machinery per mu in China has been increasing year by year, from 22.85 yuan in 2000 to 148.81 yuan in 2018. The total power of agricultural machinery has increased from 525.736 million kilowatts in 2000 to 1027.583 million kilowatts in 2019, indicating that the level of agricultural mechanization in China has been improved (National Bureau of Statistics).

Depopulation in rural areas not only leads to the reconfiguration of the family labor structure, but also induces agricultural machinery to replace labor, alleviating the impact of the loss of rural labor on agricultural production (ZHENG & XU, 2017). Moreover, with the continuous outflow of rural labor, farmers increase the application of chemical fertilizers, pesticides, agricultural films, and other chemicals to improve grain yields (WU, 2011). Moreover, the adoption of mechanized services inevitably influences the input structure of production factors, and thus affects the choice of agricultural production technology.

The paper is organized as follows. Section 2 discusses the related literature and theoretical framework, with a focus on the influence of rural depopulation on agricultural technology choice. Section 3 develops methods for explaining the impact of rural depopulation on agricultural technology choices. Section 4 analyzes the estimation results of the econometric model. Section 5 puts forward the discussion. Conclusions are drawn in Section 6.

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Related literature

In the past few decades, rural depopulation has become a common phenomenon in many emerging and developed countries (SHELUDKOV et al., 2021). The expanding income gap between prosperous metropolitan areas and economically marginalized rural areas has resulted in an increase in the number of migrants from peripheral rural areas (ELIASSON et al., 2015; LANG & GÖRMAR, 2019; RIZZO, 2016). As early as the 1960s, Japan experienced the coexistence and interweaving of rural depopulation and urban overpopulation. Driven by industrialization and urbanization, a large number of farmers have entered cities. On one hand, urban areas are overloaded in their living space, environmental sanitation, and infrastructure. The problem of overpopulation becomes very serious. Conversely, a crisis occurs in the development of agriculture and rural areas due to the declining birthrate, aging population, and feminization of the labor force. As a result, severe rural depopulation problems have emerged. With the urbanization and industrial development in the whole world, rural depopulation has become an indisputable fact today and gradually turned into a global issue (LIU & LI, 2017). Countries like the United States, Canada, Sweden, Australia, China, and Japan have experienced or are experiencing rural depopulation (HEDLUND & LUNDHOLM, 2015; LI et al. al., 2018; LUCK et al., 2010; MARKEY et al., 2008; WOOD, 2008).

Compared with population growth trends in most developing countries, aging and population decline have become two of the most important issues in many developed countries (HORI et al., 2021). "Unprecedented" aging is a pervasive global phenomenon, with an increasing number of countries experiencing population decline due to persistently low fertility or immigration (UNITED NATIONS POPULATION DIVISION, 2019). Chronic population decline, or depopulation, has become a familiar pattern of demographic change in many low-fertility countries in the developed world (MÜNZ, 2006; NIKITINA, 2000). Rural areas have been "hollow" as urbanization continues to rapidly develop across much of Europe and many East Asian countries. The transformation of agricultural production over the past century has clearly initiated a series of long-term demographic processes that have culminated in the reduction of rural populations in much of the developed world (JOHNSON & LICHTER, 2019). For example, 462,000 more people left rural areas than moved into rural areas between 2010 and 2016 in the United States, and most non-urban counties experienced net emigration (CROMARTIE, 2017).

The loss of rural population in China is accompanied by the migration of agricultural labor. There exist distinctive features in the migration process, namely not only does the amount of labor input in agricultural production decrease in both relative, and absolute value, but also the quality of non-migrant labor declines. In general, the labor force migrating from Chinese rural areas possesses some characteristics, including youthfulness, masculinity, and a higher level of education (GUO & LI, 2009). During the process of labor migration, successive replacement forms. After the migration of male labor, women carry out agricultural production. Therefore, the migration of female labor especially young female labor ultimately reduces the labor input in agriculture (GAI et al., 2014). The "aging" and "feminization" of agricultural labor means that, from the physical strength, technology, ability to obtain capital support, and mental state, the left-behind disadvantaged groups are supporting agricultural production and operation and the rural economy. Both the shortage of "quantity" and the weakening of "quality" of agricultural labor have become increasingly prominent.

According to the theory of resource endowment-induced technological change, both labor prices relative to land prices, and agricultural labor wages rise as agricultural labor becomes more and more scarce. The marginal cost for farmers' adopting labor-saving technologies decreases, and the adoption of labor-saving technologies become profitable. Both have a positive impact on farmers' mechanical technology choices (JIANG & BIAN, 2007). The mass migration of the young labor force into non-agricultural industries, and towns changes the age structure of the rural population, accelerating the aging of the rural labor force dramatically. The change in population and structure inevitably leads to change in labor-capital input ratio, and ultimately affects the choice of agricultural technology (DENG, 2014). In addition, due to physical and technical reasons, rural female laborers are more inclined to adopt agricultural technology to overcome their own shortcomings, thereby improving agricultural production efficiency (JI et al. 2016; XIANG et al. 2018). The female labor force is significantly higher than the male labor force in choosing high-yield technology, labor-saving technology, and fertilization technology (ZHANG, 2015).

Theoretical framework

According to the relevant research literature (LIN & HU,2018; MACDONALD et al., 2000; WANG & LUO, 2011), the impact mechanism of rural depopulation on agricultural technology choice includes four main aspects: "factor substitution effect", "demand scale effect", "condition bottleneck effect" and "agricultural comparative advantage" (Figure 1).

Factor substitution effect

Rural depopulation means that the supply of agricultural labor is reduced, and the input of labor factor is relatively lacked in the process of agricultural production. Farmers tend to adopt capital to replace labor, which is manifested in the choice of labor-saving technology. In fact, rural depopulation may not only cause scarcity of agricultural labor, but also reduce the amount of cultivated land. Rural depopulation is usually accompanied with the trend of land abandonment, which is more obvious in remote areas (MACDONALD et al., 2000). According to the CHINA'S RURAL DEVELOPMENT REPORT (2017), due to the large outflow of population and labor, some rural areas have serious phenomenon of cultivated land abandonment, and the abandonment of farmland in the southern part of Henan and western Hunan has even reached a quarter. Resulted from the reduction of cultivated land, the land is relatively scarce, and the farmers tend to replace cultivated land with fertilizers, that is, to choose the land-saving technology. In addition, the induced change theory indicated that the relative share of factors usage is related to the price of factors, and the direction of technological selection tends to save scarce (expensive) factors and adopt rich (cheap) factors. In the depopulation area where agricultural labor migrates in large-scale, the non-agricultural income increases and the labor is relatively scarce.

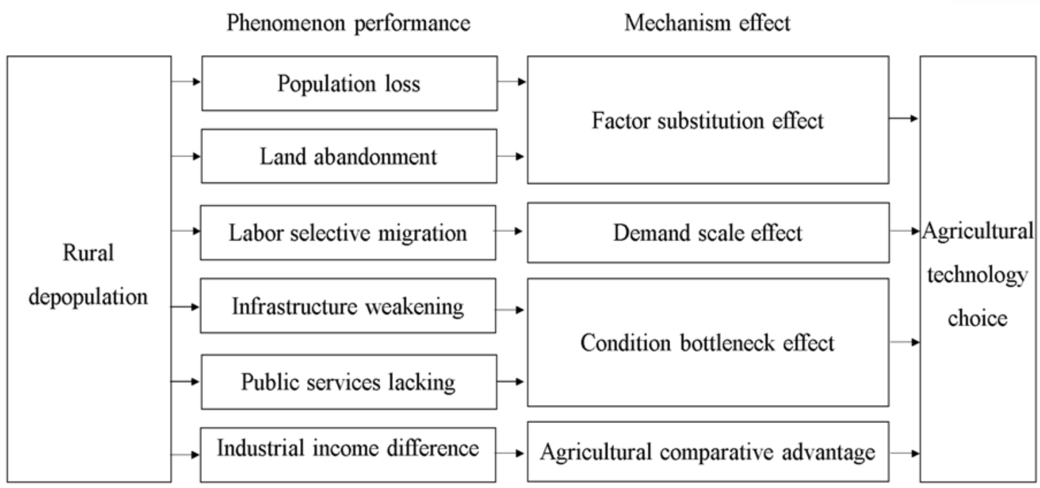

Figure 1 - The mechanism of rural depopulation affecting agricultural technology choice.

The induced technological change thus strengthens the substitution of capital for labor. Meanwhile, due to farmland abandonment and extensive farming, the farmland is relatively scarce compared to the capital. As a result, the effect of induced technological change strengthens the substitution of capital for land.

Demand scale effect

Agriculture production is very distinctive because the first consideration there is the safety demand, and then the profit demand. That is, the family must satisfy firstly its own needs before market demand. Therefore, the loss of population inevitably leads to a decline in the scale of rural land management. In addition, the reduction in rural population also reduces market demand. The over-reduction of the rural population decreases the demand for crops and land, and declines the enthusiasm for agricultural production as well. The result is the extensive cultivation of land or the transfer of self-cultivated land, which promotes the substitution of capital for cultivated land. It reflects the tendency of land-saving technology choices.

Condition bottleneck effect

Depopulation has led to the lack of management institutions and personnel in some rural planning and construction, resulting in a generally low level of rural planning, construction, and management. It has seriously lagged behind the construction of township infrastructure. With the loss of population, the supporting body of infrastructure and public services is less, and the need for investment becomes lower. Similarly, the cost per capita of rural infrastructure construction and maintenance (such as power grids, the internet, water supply, and heating equipment, etc.) rises. Meanwhile, because local government investment usually considers the efficiency of infrastructure and public services, the government's enthusiasm for infrastructure construction and public service investment reduces, and thus the support conditions for agricultural technology innovation decreases. In addition, both the low level of infrastructures such as roads and the lack of public services such as agricultural knowledge promotion inhibit the development of agricultural technology.

Agricultural comparative advantage

Compared with other industries, the comparative advantage in the agriculture sector is low, making the net income per capita of rural residents less than that of urban residents. The expansion of the urban-rural income gap will affect the investment in agricultural technology and limit the development of agricultural technology. Because a large number of rural residents move to non-agricultural industries and towns, extensive arable land management and abandonment occur, which further inhibits agricultural production. In addition, due to the low comparative advantage of agriculture, farmers use the state's subsidies mainly for the purchase of agricultural machinery instead of agricultural technology improvements. Moreover, the subsidies vary greatly from region to region.

METHODS AND DATA

Model specification

We mainly focus on four agricultural production factors, including labor, arable land, fertilizer and agricultural machinery. Generally, fertilizer is the main substitute for cultivated land, and machinery is the main substitute for labor. Therefore, in order to study the difference in agricultural technology choice, we follow the method of HE & XU (2010) and use the two-level fixed CES production function to test the magnitude of the influence. The two-level fixed CES production function forms are as follows:

$$Y = A \cdot [\alpha X_L^{-\rho} + (1-\alpha) X_C^{-\rho}]^{-1/\rho} \quad (1)$$

$$X_L = [\beta L^{-\rho_L} + (1-\beta) M^{-\rho_L}]^{-1/\rho_L} \quad (2)$$

$$X_C = [\gamma C^{-\rho_C} + (1-\gamma) F^{-\rho_C}]^{-1/\rho_C} \quad (3)$$

Among them, A represents the level of agricultural production technology, L stands for labor input, C stands for land input, M stands for agricultural machinery input, F stands for fertilizer input, Y stands for agricultural output. X_L indicates the sum of "laboratory" input, such as number of labor inputs. X_C indicates the sum of "land" input, such as the land input area. α, β, γ are distribution parameters, ρ, ρ_L, ρ_C are substitute parameters. We assumed these functions are linear homogeneous.

We regard agricultural technology choice as a relative indicator of labor-saving technology and land-saving technology, namely $T = t(m, f)$, where m is the input of agricultural machinery, f is the input of agricultural fertilizer, and $\partial T/\partial m > 0$, $\partial T/\partial f < 0$. Then the production function can be written as:

$$Y = A \cdot T \cdot [\alpha X_L^{-\rho} + (1-\alpha) X_C^{-\rho}]^{-1/\rho} \quad (4)$$

After formula conversion we can get:

$$T = Y/A \cdot [\alpha X_L^{-\rho} + (1-\alpha) X_C^{-\rho}]^{1/\rho} \quad (5)$$

We set $L = l(D)$, where D represents the depopulation variable. As the rural depopulation is manifested as the loss of rural population, the process is accompanied by the migration of agricultural labor, thus $\partial L/\partial D < 0$.

Available from formula (4):

$$\frac{\partial T}{\partial L} = \frac{\alpha\beta Y}{A} X_L^{-\rho-1} \cdot L^{-\rho_L-1} \cdot [\alpha X_L^{-\rho} + (1-\alpha) X_C^{-\rho}]^{\frac{1}{\rho}-1} \cdot [\beta L^{-\rho_L} + (1-\beta) M^{-\rho_L}]^{-\frac{1}{\rho_L}-1} > 0 \quad (6)$$

Then $\partial T/\partial D = \partial T/\partial L \cdot \partial L/\partial D < 0$, that is, as the degree of rural depopulation has deepened, the coefficient of agricultural technology choice decreases. It is expected that rural depopulation lead to the adoption of land-saving technologies in agricultural production.

Basing on the above theoretical discussion and the relationship between the variables derived from the model, we set the following model to analyze the impact of rural depopulation on agricultural technological choice:

$$ATC_{it} = \alpha_0 + \alpha_1 D_{it} + \alpha_2 A_{it} + \alpha_3 M_{it} + \alpha_4 C_{it} + \alpha_5 F_{it} + \alpha_6 Y_{it} + \varepsilon_{it} \quad (7)$$

where, i and t respectively represent the city i and the year t; ATC_{it} denotes the technological choice coefficient, D_{it} represents the relevant indicators of rural depopulation, A_{it} represents the overall level of agricultural technology development, and M_{it} represents the agricultural machinery input, C_{it} indicates the land input area, F_{it} represents the agricultural fertilizer input, and Y_{it} represents the agricultural output value. α are unknown coefficients. ε_{it} are residuals.

Sample selection

The data in this paper covers 313 prefecture-level cities in China and spends 14 years from 2005 to 2018. These cities are from 25 provinces and autonomous regions (Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia) and 4 municipalities directly under the Central Government. Due to the lack of data, we do not include Tibet, Taiwan, and some prefecture-level cities in several provinces and autonomous prefectures. The data are mainly from the "China Regional Economic Statistical Yearbook", "China City Statistical Yearbook", statistical yearbooks of provinces and cities (municipalities directly under the Central Government), and statistical bulletins of the national economy and development of prefecture-level cities.

Variable construction

Explanatory variable

The rural depopulation means the loss of rural population. We use the net outflow rate of rural population (net_flow_{it}) to indicate the degree of rural depopulation, which is described in Equation (8).

$$net\_flow_{it} = \frac{HRAP_{it} - RRP_{it}}{HRAP_{it}} \quad (8)$$

where, $HRAP_{it}$ indicates household registered agricultural population of city i at year t, RRP_{it} represents rural resident population of city i at year t.

Due to the existence of cross-regional recurrent population, the net outflow rate of rural population is not equal to the rate of change in urbanization rate, while the national net outflow rate is equal to the total change in urbanization rate. In developed regions, the rate of change in urbanization rate is much smaller than the net outflow rate of rural population, while in underdeveloped regions, the rate of change in urbanization rate is far greater than the net outflow rate of rural population.

Explained variable

The new structural economics represented by LIN (2014) believes that the factor endowment structure determines the relative price of each factor, and the relative intensity of the factor endowment can measure the comparative advantage of the factor, that is, the technological choice index. Following the computational method of the factor endowment coefficient, the technological choice index is defined as:

$$ATCI_{it} = \left(\frac{m_{it}}{M_t}\right)/\left(\frac{f_{it}}{F_t}\right) \quad (9)$$

In the above formula, i and t are the city and time, respectively. $ATCI_{it}$ refers to the technological choice index, m_{it} is the agricultural machinery power on the area of cultivated land per unit, M_t is the total agricultural machinery power of cultivated area per unit of the country, f_{it} is the amount of chemical fertilizer applied in cultivated land per unit, F_t is the amount of chemical fertilizer applied in cultivated land per unit of the country. If $ATCI_{it} > 1$, the city tends to select labor-saving technology; if $\mathrm{ATCI}_{it} < 1$, the city tends to select land-saving technology. The computational method of ratio can be used to unify labor-saving technology and land-saving technology in one indicator, which is convenient for incorporating technological choice into the measurement equation.

Control variables

The control variables relate to three aspects: factor input, industrial structure and infrastructure.

Factor input

The relative endowment of factors determines the relative price of the factors, which in turn affects the relative input of the factors and reflects in the selection of agricultural technology. The agricultural production factors mainly include labor, arable land and capital.

For the labor force, the population loss shows the migration of rural labor, expressed by the proportion of the number of employees employed in the primary industry to the number of all employees in the city (pri_ratio_{it}). In addition, the education level of cities is used to measure the quality of labor in the region. We used the number of full-time teachers in ordinary middle schools (num_te_{it}) as a proxy variable.

For cultivated land, the land resource endowment varies greatly among different regions, and is affected by the land transfer mechanism. Therefore, agricultural technology choices are quite different even in areas with the same population migration. Moreover, abandonment and invisible abandonment exist in some regions. In this paper, the average planting area (ave_sow_{it}) is used as a proxy variable to reflect the actual farming situation in rural areas.

In terms of capital, agricultural expenditure has an important influence on the adoption of technology in agricultural production, which helps farmers to purchase agricultural factors such as mechanized equipment, fertilizer, agricultural film, and so on. The indicator is expressed as the proportion of agroforestry and water affairs expenditure in fiscal expenditure ($agri\_pro_{it}$). In addition, the existing technical level in the region also has an impact on the technological choice of agricultural production. We used the agricultural output value per unit of cultivated land (cul_value_{it}) as a proxy variable to measure the current technical level.

Industrial structure

The industrial structure of a region reflects the status of agriculture in industrial production. New agricultural technologies are adopted with the increase in the proportion of agriculture, the proportion of agricultural output value (pri_pro_{it}) is used as a proxy variable.

Infrastructure

The construction of transportation infrastructure can improve the accessibility of the city, which benefits the transportation of agricultural materials and the trading of bulk crops, and then leads to varies in agricultural production. We use road density ($road\_den_{it}$) as a proxy variable.

Data description

This paper used three major data sets. The first is the China City Statistical Yearbook coedited by NBS. It comprehensively reflects the annual social and economic development of 313 Chinese cities. The second is the city-level statistical yearbook coedited by local statistics bureau. The third is the yearly statistical materials and bulletins that have been publicized by governmental agencies at different administrative level. The dataset presented here is a panel data. It spans a period of 14 years from 2005 to 2018 and covers 313 prefecture-level cities. Table 1 presents the descriptive statistics after data processing.

Table 1 - Descriptive statistics of variables included in the model.

Variable	Observations	Mean	Std. Dev.	Min	Max
$ATCI_{it}$	4382	1.411	2.059	0.070	36.074
net_flow_{it}	4382	0.199	0.207	-1.617	0.938
pri_ratio_{it}	4382	39.482	16.309	0.847	92.056
num_te_{it}	4382	1.568	1.128	0.030	11.716
ave_sow_{it}	4382	0.742	0.620	0.009	6.666
$agri\_pro_{it}$	4382	11.599	5.146	0.293	47.560
cul_value_{it}	4382	5.860	5.803	0.125	85.767
pri_pro_{it}	4382	14.740	9.124	0.301	67.034
$road\_den_{it}$	4382	0.900	0.529	0.013	3.900

RESULTS

Basic regression

We use ordinary least squares (OLS) estimation method for empirical test. Regression analyses are performed according to equation (7), control variables including the proportion of employees employed in the primary industry, the number of full-time teachers in ordinary middle schools, the per capita planting area, the proportion of agroforestry and water affairs expenditure, the agricultural output value per unit of cultivated land, the proportion of agricultural output value and the road density.

The results are in table 2. Column (1) of table 2 shows the regression results of all samples of 313 prefecture-level cities. Generally speaking, the rural population flows from rural areas into towns, and the main inflow areas are central cities such as better-developed provincial capitals. In order to describe the impact more explicitly, we exclude the sample of central cities including municipalities, provincial capitals, and cities specifically designated in the state plan (The revenues and expenditures of the cities specifically designated in the state plan are directly linked to the central government. There are currently five cities specifically designated in the state plan in China, namely Shenzhen, Dalian, Qingdao, Ningbo and Xiamen.). Regression result is shown in column (2) of table 2.

The regression results in table 2 reflect that the net outflow rate of rural population has a significant negative impact on agricultural technological choice index, indicating that with the net outflow of population rising, the trend of technological change is chemical technology, that is land-saving technology. This is inconsistent with the classical theory of induced technological innovation, with the result that, in the process of depopulation in rural areas, the loss of young and middle-aged population has led to a large number of left-behind women, children and the elderly in the sparsely-developed areas. Due to the constraints of knowledge and skills, these left-behind populations are more inclined to select land-saving technologies such as fertilizers and pesticides, which are relatively easy to implement, while ignoring the labor-saving technologies such as machinery and equipment which have high requirements on skills and knowledge reserves. In addition, the household contract responsibility system with remuneration linked to output implemented in China only allows farmers to own the management rights of small plots of land. However, the operating model with small-scale peasant economic characteristics separates the land, which inevitably hinders the development of agricultural mechanization. The comparison of results in columns (1) and (2) shows that after removing the central cities in sample, the impact of the loss of rural population on the index of agricultural technology choice is more obvious, that is, the tendency to choose land-saving technology is greater.

The proportion of the primary industry's employment and the agricultural output value per unit of cultivated land are not significant correlated with the technological choice coefficient, indicating that the number of employees in the primary industry and the level of arable land production have no obvious impact on the technological innovation of agricultural production; therefore, no obvious substitution effect exists.

The proportion of the primary industry's employment is significantly positively correlated with the technological choice index, indicating that with the decrease in the number of employees in the primary industry, agricultural technology selection

Table 2 - Impact of net outflow of population on agricultural technology choice.

Variables	ATCI	
	(1)	(2)
net_flow	-0.775***	-1.113***
	(-2.98)	(-5.31)
pri_ratio	-0.002	-0.002
	(-0.74)	(-0.75)
num_te	-0.054***	-0.010
	(-2.90)	(-0.23)
ave_sow	-0.216***	-0.208***
	(-4.53)	(-3.08)
agri_pro	0.044***	0.041***
	(5.33)	(5.79)
cul_value	0.001	0.008
	(0.22)	(1.19)
pri_pro	-0.037***	-0.039***
	(-6.32)	(-7.29)
road_den	-0.542***	-0.569***
	(-6.64)	(-6.69)
_cons	2.412***	2.478***
	(11.45)	(13.13)
Estimation method	OLS	OLS
R-squared	0.045	0.046
N	4382	3906

Note: t statistics in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

tends to land-saving technology. It shows the substitute effect of land for labor, which is consistent with the aforementioned effects of population loss.

The number of teachers in ordinary middle schools is negatively correlated with the index of technological choice, indicating that the greater the tendency to select land-saving technologies such as fertilizers becomes greater with the higher education level in prefecture-level cities. This is contrary to the so-called education-promoting mechanization. The reason might be that, farmers with a higher level of education tend to participate in the production of non-agricultural industries, which makes the labor force of agricultural production relatively lack the motivation for mechanical adoption.

The average planting area per household is negatively correlated with the technological choice index, indicating that with the reduction of the average planting area per household, agricultural production has a greater tendency to choose labor-saving technologies such as machinery. This is consistent with the current agricultural development trend. With the continuous advancement of technology, agricultural production is increasingly inclined to adopt mechanization for production, showing the trend of capital replacing land.

The proportion of agroforestry and water affairs expenditure is positively correlated with the index of technological selection, indicating that the tendency to select mechanized technology becomes greater with more agricultural production expenditures. This is because the increase in agricultural expenditures is conducive to the scale operation of agriculture. Within the allowable scope, farmers increase the input of agricultural machinery and equipment and therefore promotes the development of labor-saving technologies.

The proportion of agricultural output value is negatively correlated with the index of technological choice, indicating that the greater the proportion of regional agriculture, the more they use land-saving technologies such as fertilizers. It is consistent with the fact that the contribution of current agricultural output is more dependent on the application of fertilizers.

There is a significant negative correlation between road density and technological choice index. It means that, the greater the road density is, the smaller the agricultural technology choice index becomes. This indicated that the tendency to choose land-saving technologies becomes greater when transportation convenience improves. This is mainly because the areas with convenient transportation are relatively developed and densely populated areas, where the land is relatively scarce, and agricultural production is more inclined to adopt land-saving technology to satisfy demand.

Endogeneity test

The endogenous problems of this paper come from two aspects: conversely, the agricultural technological choice index and the net outflow rate of rural population may be affected by the same factors; on the other hand, some variables may be missed in the empirical regression process. Since the outflow of population is continuous, the change is a continuous process. Therefore, the net outflow of rural population in the current period is highly correlated with its historical data. This paper applied the method of substituting explanatory variables for endogeneity test. We use firstly the lag of net outflow rate of rural population (*lnet_flow*) to replace the net outflow rate of rural population, then use the GMM estimation method to test the endogenous problem. The empirical results are shown in table 3.

The endogeneity test shows that, the overall sample in Column (1) has a significant negative impact at the 1% level. In addition, the coefficient in Column (2) still shows significantly negative at the 1% level after excluding central cities. Moreover, the magnitude and significance of the coefficients of all control variables consistent of basic regression results. It indicates that the conclusions are reliable.

Robustness check

In the previous test of the relationship between the rural depopulation and agricultural technological choice, we have drawn some important conclusions. In order to ensure the robustness of the conclusions, it is necessary to conduct a robust analysis for the measurement model. The degree of change in the density of rural resident population is used to replace the net outflow rate of rural population. The indicator refers

Table 3 - Endogeneity test.

Variables	ATCI	
	(1)	(2)
lnet_flow	-0.722***	-1.074***
	(-2.72)	(-4.93)
pri_ratio	-0.001	-0.001
	(-0.38)	(-0.34)
num_te	-0.052***	-0.009
	(-2.87)	(-0.21)
ave_sow	-0.188***	-0.175**
	(-4.15)	(-2.57)
agri_pro	0.040***	0.038***
	(4.77)	(4.93)
cul_value	0.004	0.010
	(0.67)	(1.62)
pri_pro	-0.037***	-0.039***
	(-5.79)	(-7.03)
road_den	-0.497***	-0.518***
	(-6.64)	(-5.96)
_cons	2.311***	2.360***
	(12.21)	(11.91)
Estimation method	2SLS	2SLS
R-squared	0.042	0.042
N	4069	3627

Note: t statistics in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

to the rate of decline in the density of rural permanent residents, expressed as $g\_den_{it} = (den\_ru_{i(t-1)} - den\_ru_{it}) / den\_ru_{i(t-1)})^{*}100$. Where den_ru_{it} denotes the density of rural resident population of city *i* at year *t*, $den\_ru_{i(t-1)}$ represents the indicator at year (*t - 1*). The test results are shown in table 4. The regression results are consistent with the previous empirical results, indicating that the empirical test results are robust.

Further analysis

In order to further analyze the impact of rural depopulation on agricultural technology selection, we used the quantile regression method, which regresses the explanatory variables with the conditional quantiles of the explained variables. We obtained the various effects of different population net outflow rate on agricultural technology choice. The results are shown in figure 2.

As the quantile increases, the quantile regression coefficient of the net population outflow rate shows a trend, which firstly declines, and then rises. It means that the negative impact of rural depopulation on agricultural technological innovation is smaller than the middle part. That is, the increase in the degree of the rural population net outflow rate has less negative impact on the high and low technological choice coefficient, while has a greater impact on the medium technology choice coefficient.

DISCUSSION

Population decline is most prominent in rural areas, leading to rapid aging and decline of communities, and high urban migration rates, with young people choosing to go to college—many choose not to return (HARDING, 2019). Depopulation occurs when a region experiences a large amount of population loss over a long period of time, resulting in a significant decline in population (JOHNSON & LICHTER, 2019). INAGAWA (2018) has pointed out that, due to the declining birth rate and aging, remote areas face not only population exodus and demographic changes, but also industrial recession and economic shrinkage. According to the induced development model, restrictions on agricultural production because of population loss induces labor-saving trends in agricultural production

Table 4 - Robustness check.

Variables	ATCI	
	(1)	(2)
net_flow	-0.023***	-0.025***
	(-3.35)	(-3.25)
pri_ratio	-0.003	-0.003
	(-0.99)	(-0.94)
num_te	-0.042**	-0.010
	(-2.48)	(-0.23)
ave_sow	-0.180***	-0.159**
	(-3.74)	(-2.38)
agri_pro	0.041***	0.037***
	(5.25)	(5.23)
cul_value	0.001	0.005
	(0.11)	(0.78)
pri_pro	-0.037***	-0.038***
	(-6.30)	(-7.14)
road_den	-0.561***	-0.617***
	(-6.66)	(-7.31)
_cons	2.328***	2.375***
	(11.34)	(12.64)
Estimation method	OLS	OLS
R-squared	0.042	0.041
N	4382	3906

Note: t statistics in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

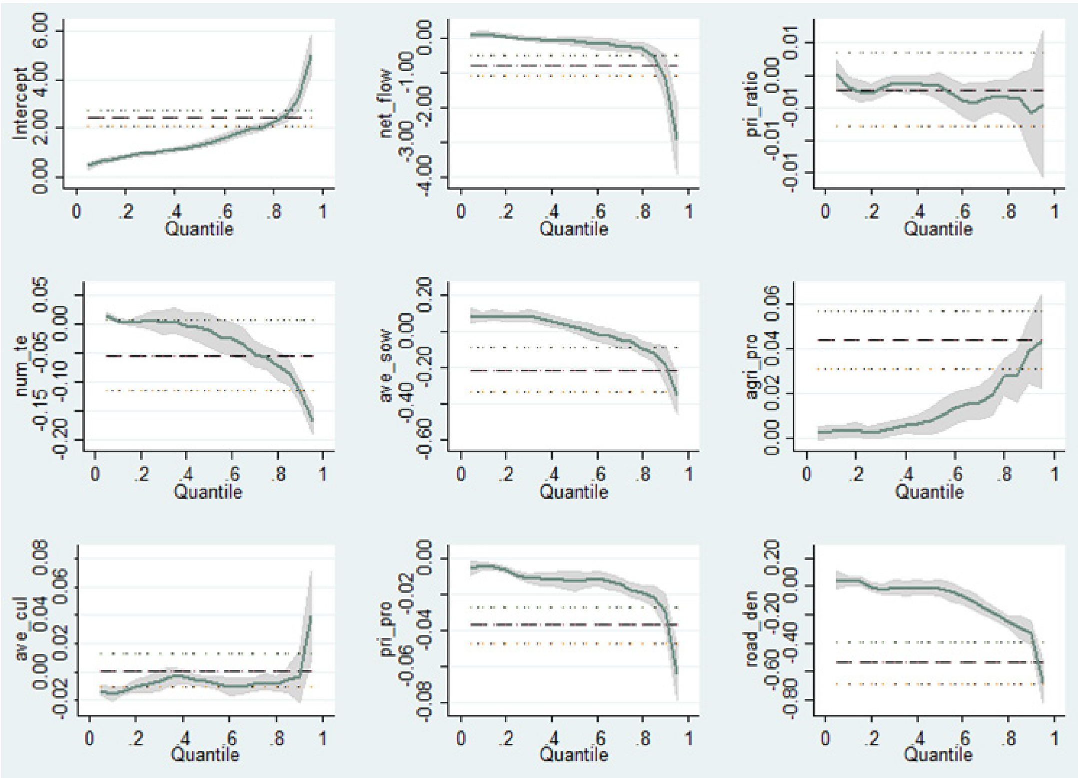

Figure 2 - Change in quantile regression coefficient.

(HAYAMI & RUTTAN, 1971). Obviously, replacing labor with mechanical and biological inputs has become an important development direction for changes in agricultural production technology.

The purpose of technology selection is to reduce costs or to create greater benefits. To respond to the massive loss of rural population, farmers usually adjust the factor input structure with the help of the market mechanism, replace labor force with relatively abundant and cheap mechanical factors, and promote the transformation of production methods to the technical direction of labor saving. However, mechanical replacement is not the only way to alleviate population loss. Improving the standardization of agricultural production through the selection of improved varieties or new fertilizers can also help replace labor directly or indirectly. Since labor and land are complementary factors for production, both improving land productivity and increasing the income per unit area also help alleviate the impact of rising labor costs caused by population loss. Therefore, the rational choice of farmers is to increase the input of biological products. Two different paths of technological selection work together on agricultural production and have become comprehensive means of alleviating rural depopulation (YAN et al., 2021).

Compared with the existing literature, this paper makes following contributions. First, different from the previous method which equate the rate of rural population changes with the rate of urbanization, we summarized the data on rural household registration and permanent population in prefecture-level cities across the country, and constructs an indicator of the rate of rural population net outflow. China’s household registration system classifies household registration into urban and rural household registration, and categorizes household registration attributes into agricultural and non-agricultural household registration according to geographical and family member relationships. The implementation of this system has caused that, residents in the suburbs or “urban villages” who do not engage in agriculture at all still possess agricultural hukou. Similarly, there are many rural residents who work in the city but cannot obtain non-agricultural hukou. Therefore, inconsistency exists between the registered population and the permanent population. Second, empirical results of the panel regression showed that, compared with the adoption of labor-saving technology, the net outflow of the rural population is more conducive to the choice of land-saving technology. Moreover, the effect becomes more obvious to promote labor-saving technological choice after the net outflow rate of the rural population exceeds a certain level. This result complements the induced technology innovation theory of Hayami-Ruttan to some degree.

Although, our research has contributed to exiting literature to certain extent, there are still some topics worth investigating. In fact, the migration of rural population and labor causes changes not only in the relative prices of factors, but also in the size of the rural market and in the supply of rural infrastructure and public services. According to the theory of new spatial economics, changes in transaction costs, market size, infrastructure, and public services also cause changes in technology (WANG & HUO, 2014). In addition, the variety in crops also brings differences in agricultural technology (ZHANG et al., 2018). Therefore, in the process of rural population and labor migration, the changes in agricultural technology are much more complicated than those described in Hayami-Ruttan's classic theory. As a result, the unprecedented migration of rural population and labor force in China provides a good opportunity and evidence to test the classic theory.

CONCLUSION

From the perspective of agricultural technology choice in the process of rural depopulation, we measured the indicators related to agricultural technology choice and rural depopulation, and thus construct an econometric model that reflects the impact of rural depopulation on agricultural technology choice. The panel data in this paper includes 313 cities (municipalities) in 29 provinces (cities) over 14-year period. The paper empirically analyzes the impact of depopulation on agricultural technology choice. The empirical results showed that the net outflow of rural population is not necessarily related to the choice of labor-saving technology. However, it is conducive to the selection of land-saving technology. The net outflow rate of the population promotes labor-saving technological selection only within a certain level. Our results complement to Hayami-Ruttan's theory of induced technical innovation to some degree.

The findings of this paper provided also some practical implication. Firstly, the influence of the rural depopulations on the choice of agricultural technology shows that the loss of population has led to the "lightening of labor" in agricultural production and increasingly induces "deepening of capital". However, the current "capital deepening" in agricultural production mainly exhibits in the increase in chemical inputs such as pesticides and fertilizers. As China's rural resources and environmental problems are prominent and agricultural non-point source pollution is increasing, excessive application of chemical inputs such as fertilizers and pesticides not only threatens the quality and safety of agricultural products, but also restricts the sustainable development of agriculture. It is urgent to promote biotechnology and realize green production for farmers. Secondly, various measures need to be adopted. These measures can be human capital investment, technical training on soil, fertilizer and water management, plant diseases, insect pests and natural disaster prevention in a differentiated manner for growers of different ages, the collaboration among scientific research institutions, local agricultural technology stations, and cooperatives. We should promote the production and management of growers of different ages in a scientific and standardized way. Also, we need to improve the ability to allocate production factors and the management level as well. Thirdly, to absorb young and middle-aged labor, we can learn from Japan's "Agricultural Successor Training Project". It is important to use incentives such as credit and technical support to attract farmers' children, college graduates, and returnees to join agriculture. It is necessary to solve the problem of structural shortage of the agricultural labor force, and to ensure "successors" in agricultural production. Finally, the promotion policy of mechanization should be customization by regions. Regional population outflow, labor transfer status, and the economic attributes of prefecture-level cities all have influence on agricultural production technology and result in differences in agricultural technology innovation. Therefore, it is necessary to adjust the technology promotion policy in consideration of the regional heterogeneity, such as the development and promotion of suitable machinery, and realization of the mechanization of farmers' production.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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AUTHORS' CONTRIBUTIONS

Conceptualization: Shanlang Lin. Data acquisition: Xiaoli Hu. Design of methodology and data analysis: Xiaoli Hu. Xiaoli Hu prepared the draft of the manuscript. All authors critically revised the manuscript and approved of the final version.

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