Human Capital and Technology Change of Chinese Agriculture

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***Abstract*—This paper explores the alternative relationship between agricultural factors and conducts the discussion of technology progress bias. The result shows an alternative trend in the long term between the elements of the physical capital on the timeline. The replacement ability of capital for land has been improved because of human capital of the labour and the elasticity of substitution of human capital for chemical fertilizer has been showed higher(>1) since 1990, which implicates that the role of human capital cannot be ignored. Agricultural technology in China is demonstrated a changed bias after the introduction of human capital: from land-intensive agriculture to material capital (mechanical power and fertilizer) intensive gradually, and machinery technology progress is faster than the fertilizer. Technical progress of China's agricultural sector shows a capital-intensive type. The main reason is the substitution relationship between the agricultural material capital and human capital, rather than a complement one. China's agricultural production is not the function of agriculture human capital investment or skill-bias technological progress, which is a kind of economic technology phenomenon related to the not fully developed growth stage with the labour-abundant situation.**

***Index Terms*—substitution elasticity, human capital, technological progress type, skilled-bias**

I. Introduction

Last 30 years, significant changes occurred in the endowment structure of Chinese agricultural sector. The number of agricultural labour increased from 283 million in 1978 to 391 million in 1991, and began to decrease to 266 million in 2011. Accordingly, the proportion of employment in the primary industry dropped from 70.5% in 1978, to 34.8% in 2011. Meanwhile, agricultural capital investment increased greatly. The total power of agricultural machinery and rural electricity consumption increased respectively from 117,599,000 kilowatts, 25.31 billion kwh in 1978 to 977.347 million kilowatts, and 713.96 billion kWh in 2011, respectively an increase of 8.3 times and 28.2 times. At the same time, the gross output value of farming, forestry rose from RMB139.7 billion, in 1978 to RMB 8.13039 trillion, in 2011, which grew by 58.2 times, calculated at comparable prices.[1] An average annual growth rate of 6.7% from 1990 to 2011 was achieved. After the transfer of agricultural labour, the reason of Chinese agricultural output has shown a steady rise. The questions are: which factors drive the growth of Chinese agricultural output? What is the relationship between various elements of agricultural development? How about the alternative or complementary relationship between elements and biased technological progress? Is there any impact of human capital on complementary (or substitutional) effects?

The earliest study on agricultural input factors elasticity of substitution measures the substitution elasticity between the land, labour, and physical capital, using the overall data of Australian from 1920 to 1969. [1] The results show there is higher substitutability between labour and capital, clear complementarity between capital and land. (Vincent 1977) In recent years, Chinese scholars have conducted the research on the substitution of agricultural production from different perspectives. For example, based on CES production function, some authors (Ma Kai, etc., 2011) have estimated the substitution of farm machinery production for labour input grain production. [2] Chen Qin and Yuan Zhigang (2013), using CHNS data, have empirically analyzed the substitution effect of land for education. The results show that the substitution effect of land to education exists in Chinese various regions, and is larger as land productivity increases or the return to education decreases. The other kind of study is on the change of Chinese agricultural technology. [3] Li Hang (2013) has explained the improvement of the productivity of Chinese agricultural sector arises from the technological advances, especially the replacement of mechanical power technology with the agricultural labour force, and the agricultural investment and government expenditure. [4] Based on CES production function, Liu Yu *et al*. (2009) find that there is the great elasticity of substitution between irrigation water use and water conservancy input of farmland irrigation, and the substitute relation is strong. [5] Wei Kai *et al*. (2013) emphasized the way of Chinese agricultural technology import under the trend of global economic integration. [6]

The literature focused the method of substitution elasticity measurement have connected different production (cost) function or resources. For example, some authors have considered the absolute substitution elasticity and net substitution elasticity of Chinese industrial sectors' energy, using cost function and combining the MES model with technological progress

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[1] All data resource in this paragraph is China Statistical Yearbook 2012. http://data.stats.gov.cn/

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and output effects. [7] (Lu Chengjun and Zhou Ruiming, 2008) Most of the studies are in the estimation of the elasticity of substitution between different fossil fuels and renewable resources. [8], [9] (Kumar Surender, etc., 2015; Zha Donglan and Ding Ning, 2015) As a matter of fact, the more important is the estimation method. A case in point is the research on the estimation of substitution elasticity for a three-level nested constant elasticity of substitution KLEM production structure using up to date nonlinear least squares estimation procedures. [10] (Koesler Simon and Schymura Michael, 2015)

In this paper, we explore and empirically test for the presence or absence of correlations among inputs. Based on trans-log production function model, using ridge regression approach, this paper discusses the relationship between elements of Chinese agricultural development and the role of key elements (especially the human capital) of Chinese agricultural technology change bias. This article is organized as follows: The second part introduces the research methods and data sources. The third part puts forward results of the analysis of time series data across the whole country and interprets China's agricultural technical progress biased interpretations. The fourth part is the conclusion and policy implications of the research.

II. Methods and Data

A. *Elasticity of Substitution Calculation of TLPE*[2]

The substitution between factor inputs (K and L) in trans-log production function (TLPF) is given by

$$\sigma_{KL} = \frac{d(K/L)}{(K/L)} \Big/ \frac{d(MP_L/MP_K)}{(MP_L/MP_K)} \tag{1}$$

where MP is marginal production of K and L, respectively.

with

$$\frac{MP_L}{MP_K} = \frac{\partial Y/\partial L}{\partial Y/\partial K} = \frac{\eta_L}{\eta_K}\frac{K}{L} \tag{2}$$

where K and L are inputs of physical capital and labor, η is output elasticity of K and L respectively, the substitution elasticity of trans-log production function (TLPF) is calculated as

$$\sigma_{KL} = \frac{d(K/L)}{d(MP_L/MP_K)} \Big/ \frac{\eta_L}{\eta_K} = \frac{1}{1 + \dfrac{\dfrac{\eta_K}{\eta_L}\beta_{LL} - \beta_{KL}}{\eta_L - \eta_K}} \tag{3}$$

where

$$\eta_K = d(\ln Y)/d(\ln K) = \beta_K + 2\beta_{KK}\ln K + \beta_{KL}\ln L$$
$$\eta_L = d(\ln Y)/d(\ln L) = \beta_L + 2\beta_{LL}\ln L + \beta_{KL}\ln K$$

The physical capital is represented by agricultural mechanical power M, fertilizer application F and agricultural arable land N. There are many variables in the model, which will result in the collinearity in multiple regression, the ordinary least squares (OLS) is inappropriate.

TABLE I. Variables of Agricultural Production Function

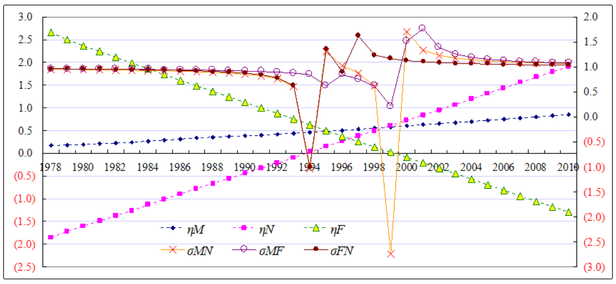
variables	Representation
Y	the output of primary industry
M	agricultural mechanical power
F	fertilizer application F
N	agricultural arable land
H	average education attainment per capita

The problem of multivariate regression is resolved by ridge regression, as there are multiple collinearities among the independent variables.

Time series is from 1978 to 2010 and all annual data is sourced from the Chinese Bureau of Statistics. The statistical software SPSS13.0 is used to carry out a regression analysis.

B. *Econometric Results and Analysis*

Through the analysis of the inflation factor, we found that when the ridge parameter k=0.3, the multicollinearity get better control, so choose k=0.3 for the ridge regression parameter. According to equation (3), we calculate the production elasticity and substitution elasticity of mechanical power M, arable land N and fertilizer application F, respectively, the results are shown in Fig. 1.



Notes: left y-axis is output elasticity; right y-axis is substitution elasticity

Figure 1. Estimated elasticities of output and substitution, 1978-2010

Fig. 1 shows that, since 1978, the output elasticity of fertilizer F and land N shows plummeting and rising trend respectively: the output elasticity of chemical fertilizers F decreases from 2.5 at the beginning of the period to about -2.0 at the end of that period; output elasticity of arable land N increases from -2.0 to about 1.0, 1994 and 1999 are "watershed" of the output elasticity for the two elements. The range has been great, the question we have to ask is if there is more important variable ignored. Therefore, we try to introduce the human capital H (denoted by average education attainment per capita) to TLPF and calculate the elasticity of inputs and substitution elasticity between the various factors.

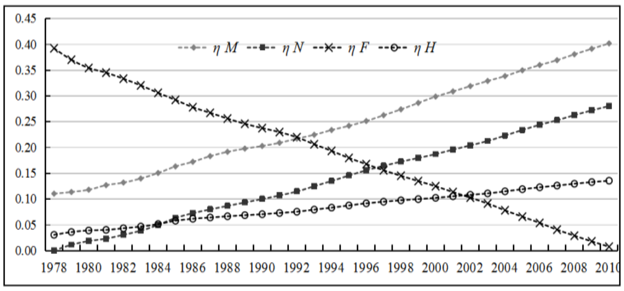


Figure 2. Output elasticity trend after introduction of human capital

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[2] The trans-log production function is $\ln Y = \beta_0 + \beta_K \ln K + \beta_L \ln L + \beta_{KK}(\ln K)^2 + \beta_{LL}(\ln L)^2 + \beta_{KL}(\ln L)(\ln K)$, K and L are inputs of physical capital and labor; β are parameters.

Compared with data in Fig. 1, after the introduction of human capital H, the shape of output elasticity curve for agricultural machinery power M, fertilizer application F and arable land N does not change, though the value is more reasonable. As can be seen from Fig. 2, output elasticity of chemical fertilizer is plummeting, down from 0.392 in 1978 to 0.008 in 2010, indicating that the marginal production of fertilizer gradually emerged from the beginning of the reform of the shortage of state, and then its role in boosting agricultural growth is increasingly weak. Correspondingly, the output elasticity of agricultural machinery power M and arable land N actually is a steady growth, but the output elasticity of agricultural machinery power M is significantly higher than the land N, indicating that China's agricultural machinery is more and more important for agricultural output. Output elasticity of human capital is very small, but it is slowly increasing: from 0.031 in 1978 to 0.136 in 2010.

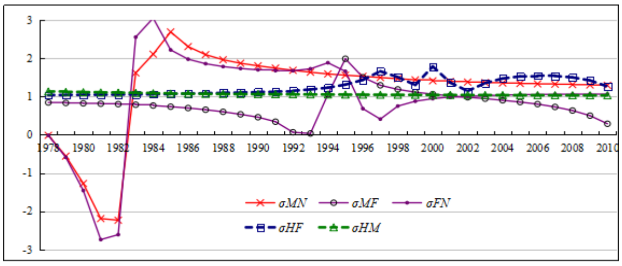

Figure 3. Substitution elasticity between inputs after the introduction of human capital

After the introduction of human capital, significant changes have happened in substitution elasticity between inputs. Before the introduction of human capital, the substitution elasticities between agricultural inputs were hovering nearby 1, except 1992-2003, while in the decade from 1992 to 2003, the substitution elasticities of these three elements appeared large fluctuations. After the introduction of human capital, the substitution elasticity curves between mechanical power M and arable land N, chemical fertilizer F and arable land N showed falling from 0 at the beginning and then rapidly increasing until 1985, and then slowly declining. The substitution elasticity of agricultural machinery power M and arable land N gradually converged at about 1.3. The substitution elasticity of chemical fertilizer F and land N experienced minor fluctuations from 1994 to 2000 then converged nearby 1. The reason is that human capital promoted the conservation of traditional inputs to improve the ability of substitution elasticity of capital to land. The value of substitution elasticity of chemical fertilizers F and agricultural machinery power M was less than 1, except 1995 to 2000. (Fig. 3) It indicates a low level of substitution between these two elements. Indeed, surplus labor is still a prominent feature in Chinese agricultural structure till now. Protecting and improving farmers' basic needs is still the primary function of Chinese agriculture.

Meanwhile, the substitution elasticity curve of human capital H and the chemical fertilizer application F, human capital H and agricultural machinery power M indicate that human capital can not only improve the ability to substitute capital for land, more importantly, the substitution elasticity of human capital for physical capital is greater than 1. Particularly since 1990, the substitution elasticity of human capital for fertilizer F is higher, coupled with increasing output elasticity (Fig. 2), which proves that human capital can not be ignored as one of the important elements of agricultural inputs.

III. TECHNICAL BIAS MEASURE: THE ROLE OF HUMAN CAPITAL

The measurements of technology progress in TLPF is calculated by the change in marginal rate of substitution over time, characterized by BLAS as follows,

$$BIAS_{K,L} = \frac{\beta_{tK}}{\eta_K} - \frac{\beta_{tL}}{\eta_L} \tag{4}$$

where BIASK,L>0, indicating that technology advances is capital(K)-intensive, in other words, the capital saving technology is faster than Labor(L)-saving technological progress.

After the introduction of human capital, China agricultural biased technological progress has been dramatically changed. Before the introduction of human capital, BIASM, N and BIASM, F are positive and then negative, that is, agriculture technological advances exhibit a transformation from mechanical power intensive to fertilizer and land intensive (seen Fig. 4). Instead, agricultural technological progress bias, after the introduction of human capital, shows a transformation from land-intensive to mechanical power and fertilizers intensive (seen Fig. 5). The transition year is 2001. In addition, BIASM, F is always greater than 0, indicating that, technological progress in agricultural machinery power is faster than fertilizer application. Since 2000, the gap began gradually to expand.

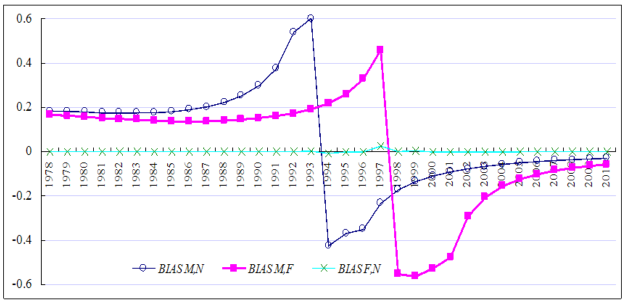

Figure 4. Agricultural technology bias before the introduction of human capital

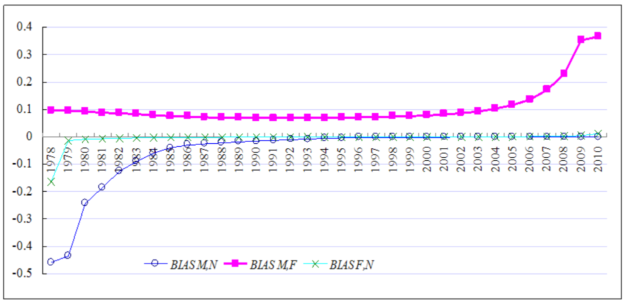

Figure 5. Agricultural technology bias after the introduction of human capital

IV. Explanation of the Bias Technical Progress in Chinese Agriculture: Unskilled-skewed Technical Progress

Why does Chinese agriculture show a capital-intensive skewed technical progress? The relationship between agriculture physical capital and human capital is a substitute, rather than complementary, that is, Chinese agricultural output is not the function of agricultural investment in human capital and skilled-skewed technology. This growth can only be explained by other inputs' increase and widespread use of unskilled-skewed technology.

According to the relationship between technology and the skills of labours, technical progress can be divided into two different types: skilled-skewed and unskilled-skewed. [11] (Acemoglu, D, 2011) If mastering new technologies requires higher ability than the application of existing technical capacity, or bearing the cost of re-learning, that is skilled-skewed technical progress. Instead, if the promotion and application of a type of technology do not demand skilled workers, just rely on existing skills to operate the technology, that is unskilled-skewed technical progress.

The base of unskilled-skewed technical progress is a special endowment structure of labour resources. In such an agricultural economy pattern, whose labour is relatively more abundant than other elements, the feasibility of the technology choices, is to achieve an effective combination of abundant labour resources and other relative scarce resources in order to seek to minimize the costs of a given output. In this context, labour-biased, rather than skilled-biased technological innovation will be the appropriate direction. Only when the labour is transformed into a scarce resource, it will become the direction of technological progress by improving workforce skills, where the limit caused by a shortage of labour is broken. Labour surplus is still a prominent feature of Chinese agricultural structure till now. [12] (Guo Jianxiong and Li Zhijun, 2011) Therefore, unskilled-skewed is more suitable than the skilled-skewed as a technology choice for Chinese agriculture.

The prominent feature of unskilled-skewed technical progress is that there is no significant alternative for capital to labour. Labor resources can be decomposed into quantity and quality (human capital or skills). Technical progress is achieved by increasing physical capital investment. Different types of technological progress will behave as physical capital as the carrier with the introduction of the labour quantity and labour quality. If it is skilled-skewed technical progress, the improvement of labour skill is needed when increasing the investment in physical capital (complementary relationship), reducing the demand for labor quantity (alternative relationship); If it is unskilled-skewed technical progress, investment in physical capital does not obviously reject the input of labor quantity, or require more about labours skill. For Chinese special agricultural endowment, unskilled-skewed technical progress is the only technical form of agricultural development at this stage.

According to the change of Chinese agriculture alternative inputs more than 30 years based on the empirical findings in this paper, lasting shift of rural labor and deepening human capital cause agricultural technical progress biased performance as from land-intensive to agricultural mechanical power and fertilizer intensive, and the technical progress of agricultural machine is faster than chemical fertilizer. The harnessing of the agricultural machine is more inclined to the labour resources than the application chemical fertilizer. With the labour transfer in non-farm sector and elimination of surplus labour, skilled-skewed technical progress will gradually replace unskilled-skewed one, which is the main type of Chinese agricultural technical progress. Labors' skill or human capital accumulation will replace other traditional resources and become a critical element, on which Chinese agricultural development will rely in the future.

V. Conclusion

There is an alternative trend in the long term between the elements of the physical capital on the timeline. The replacement ability of capital for land has been improved because of human capital and the elasticity of substitution of human capital for chemical fertilizer has been shown more than 1, which implicates that the role of human capital cannot be ignored. Agricultural technology in China is demonstrated a changed bias after the introduction of human capital: from land-intensive agriculture to material capital (mechanical power and fertilizer) intensive gradually, and machinery technology progress is faster than the fertilizer.

For Chinese special agricultural endowment, which is a kind of economic technology phenomenon related to the not fully developed growth stage with the labour-abundant situation, unskilled-skewed technical progress is the only technical form of agricultural development at this stage. With the lasting shift of rural labour and deepening human capital, skilled-skewed technical progress will be the main type of Chinese agricultural technology advance, when other physical inputs will be replaced by the human capital or labour skill that will be the key resource for Chinese agricultural development.

Using of industrialization and urbanization as a chance, accelerating the transfer of agricultural labour force and improving the human capital accumulation rate of agricultural labour force, is the basic tasks of China's agricultural modernization and construction in the present and the future.

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