Capital-Labor Substitution or Complementarity? -Time-Varying Elasticity Estimation from the Perspective of Appropriate Technology Selection in China

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Abstract: From the perspective of China's appropriate technology selection to understand the essence of substitution between factors, this paper estimates the time-varying elasticity series of capital-labor substitution by employing the stochastic frontier translog production function model, and then captures its evolution trajectory. Results show that in the sample period, the time-varying elasticity of capital-labor substitution in China tends to mutual substitution yet fluctuates sharply, even jumps from absolute complementarity to strong substitution directly, which means there exists drastic adjustment of factor combination or technical structure. This paper will play an important role in promoting the estimation of time-varying substitution elasticity, expanding the research of biased technological progress, deepening the analysis of income distribution and skill premium, and evaluating macroeconomic policies.

1. Literature Review

As the pivotal technical parameter of production function, capital-labor substitution elasticity (hereafter σ_{KL}) is very important to the study of economic growth, factor income distribution and policy evaluation. Undoubtedly, it is the key step and the first task to accurately estimate the value of σ_{KL}. With China's rapid rise as the world's second largest economy, much attention has been attracted to its growth mechanism and sustainability, especially to the engine effect from the elasticity of factors' substitution. Therefore, it has become a hot topic to estimate the elasticity of substitution and identify its evolutionary trajectory in recent years.

At present, there are two main directions in the literature of using production function to estimate the elasticity of china factors' substitution: one is to estimate the fixed elasticity of capital-labor substitution based on CES function family; the other is to estimate the variable elasticity series of capital-labor substitution based on different types of production function. With respect to the fixed elasticity of substitution, most studies apply the normalized CES supply-side system approach to estimate σ_{KL} and find big differences among these estimated values. Mallick computes that the substitution elasticity of China from 1950 to 2000 is 0.548 [1], Hao Feng evaluates it as 0.233from 1978 to 2005 [2], and Lei Qinli estimates it as 0.382from 1990 to 2011 [3]. However, similarly based on CES function family, Manu et al. calculates that the same index value between 1978 and 2012 is 1.204, while that between 1992 and 2012 is 1.099 [4], and the provincial substitution elasticity from 1978 to 2008 estimated by Chen and Lian is between 0.126-2.280 [5]. Obviously, even in the estimation of fixed elasticity of substitution, there is still a big dispute about whether capital and labor are substitutes or complements in China. Some scholars have also explored the estimation of time-varying substitution elasticity: Hao and Sheng employ CES production function with variable coefficient to estimate the σ_{KL} series in 1978-2011, then find that the estimates range from 0.23 to 0.55 and significantly less than unity [6]; Zheng and Yang use VES production function to obtain the time-varying σ_{KL} of the Eastern, Central and Western region from 1985 to 2012with averaged value of 1.59, 1.63 and 1.94, respectively [7]. Similarly, there are great differences in the estimated results of time-varying σ_{KL}, and so far there is no effective measurement standard to judge the reasonable range of its value.

In addition to the lack of time-varying substitution elasticity estimation and reasonable interval judgment criteria, there is also a widespread neglect of the specific situation of China's economy. It

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is mainly reflected in the fact that the existing researches generally ignore the essence of the elasticity of substitution under the appropriate technology selection determined by the stage of China's economic development, and the aggregate growth model used to estimate the elasticity of substitution implies the assumption of complete technical efficiency. According to the theory of appropriate technology selection, developing countries are hard to choose advanced technologies because of the huge factor endowment differences between themselves and developed countries. They tend to take advantage of their own resources advantages and pursue the minimum cost or maximum profit by optimizing the factor allocation combination in the production possibility set through a certain degree of substitutability among factors. In China's dual economic transformation period, facing the abundant transfer of agricultural surplus labor, it is not uncommon for enterprises to choose the traditional labor-intensive technology to pursue the production scale with the over investment of low-cost unskilled labor. Under this kind of appropriate technology selection, the factor investment portfolio inevitably has the loss of technical efficiency. However, up to now, in the study of estimating the China' σ_{KL} with different types of production functions, it has not been found that the influence of technological inefficiency and random disturbance in the production process has been taken into account. Without exception, it is assumed that the production uses frontier technology to produce at full technological efficiency.

2. Methodology

As the key technical parameter of production function, the elasticity of capital labor substitution highly depends on the formal setting of production function. For this reason, this paper chooses the translog production function (hereafter TLPF) which has the characteristics of general production function as the aggregate growth model. In order to further highlight the technical characteristics of σ_{KL}, this paper draws on the stochastic frontier production function econometric model from Battese and Coelli, so as to introduce more decisive factors affecting the selection of appropriate technology into the technical inefficiency equation [8].

Specifically, the stochastic frontier production function for panel data is exerted in this paper as follow:

$$\ln Y_{it}=\alpha_0+\alpha_K \ln K_{it}+\alpha_L \ln L_{it}+\alpha_\tau \tau+\frac{1}{2}\alpha_{\tau\tau}\tau_{it}^2+\frac{1}{2}\alpha_{KK}(\ln K_{it})^2+\frac{1}{2}\alpha_{LL}(\ln L_{it})^2+\alpha_{\tau K}\tau\ln K_{it}+\alpha_{\tau L}\tau\ln L_{it}+\alpha_{KL}\ln K_{it}\ln L_{it}+v_{it}-U_{it} \quad (1)$$

$$v_{it}\propto N(0,\varepsilon_v^2);\ U_{it}\propto N(m_{it},\varepsilon_U^2)$$

$$m_{it}=\delta_0+\delta_1 FDI_{it}+\delta_2 TRD_{it}+\delta_3 PMH_{it}+\delta_4 P_{it}+\delta_5 M_{it}+\delta_6 H_{it}+\delta_7 PMH_{it}\times TRD_{it}+\delta_8 PMH_{it}\times FDI_{it}+\delta_9 P_{it}\times TRD_{it}+\delta_{10} M_{it}\times TRD_{it}+\delta_{11} H_{it}\times TRD_{it}+\delta_{12} P_{it}\times FDI_{it}+\delta_{13} M_{it}\times FDI_{it}+\delta_{14} H_{it}\times FDI_{it}+\delta_{15} P_{it}\times M_{it}+\delta_{16} M_{it}\times H_{it}+\delta_{17} P_{it}\times H_{it}+\delta_{18}\tau_{it} \quad (2)$$

Where the subscripts *i* and *t* refer to the *i*-th Chinese province and the t-th observed period, all the α and δ letters depict unknown parameters to be estimated. Here ln represents the natural logarithm (i. e, logarithm to the base e); Y donates output (local gross domestic product); K and L indicate capital stock and total labor input respectively; the time variable τ is introduced to capture any technological change in the production function. FDI shows the degree of dependence on foreign investment and TRD means the degree of opening to the outside world; PMH is the total level of human capital, while P, M and H are the primary, intermediate and senior human capital separately. The cross items, PMH*TRD and PMH*FDI, exhibit the absorptive capacity of different types of human capital to FDI and TRD technology spillover, respectively. P*M, M*H and P*H express the technology spillover effect between different human capital.

The "one-step method" is adopted in stochastic frontier analysis, which can estimate all parameters of the two parts of the production function and technical inefficiency equation at one time, avoid the error superposition under multiple estimates, and ensure the accuracy and reliability of the σ_{KL} series from the measurement means. Using the regression parameters of the production function of the transcendental logarithm, the output elasticity with respect to input is calculated first:

$$\eta_{Lit}=\frac{\partial \ln Y_{it}}{\partial \ln L_{it}}=\beta_L+\beta_{LL}\ln L_{it}+\beta_{KL}\ln K_{it}+\beta_{LS}\ln S_{it}+\beta_{\tau L}t \quad (3)$$

$$\eta_{Kit}=\frac{\partial \ln Y_{it}}{\partial \ln K_{it}}=\beta_K+\beta_{KK}\ln K_{it}+\beta_{KL}\ln L_{it}+\beta_{KS}\ln S_{it}+\beta_{\tau K}t \quad (4)$$

Then the elasticity of substitution between capital and labor is obtained as the follow:

$$\sigma_{KL}=[1+(2\beta_{KL}-\frac{\eta_L}{\eta_K}\beta_{KK}-\frac{\eta_K}{\eta_L}\beta_{LL})(\eta_L+\eta_K)^{-1}]^{-1} \quad (5)$$

If σ_{KL} <0, it means that capital and labor are absolutely complementary, which not only indicates that capital and labor input change in the same direction, but even the price of capital is higher than that of labor, producers will increase the investment of capital in labor; when $0<\sigma_{KL}<1$, it means that capital and labor are relatively complementary, in this case, the two factors change in the same direction only in terms of input quantity, and with σ_{KL} tending to 1, the complementary gradually weakens, while the substitutability gradually increases. If σ_{KL} >1, it means that there is a strong substitution between capital and labor, when the price of capital increases relative to labor, producers will reduce capital and increase labor input.

The elasticity of substitution determines the proportion of factor input in the production process, and the change of factor combination structure caused by it will affect the factor use preference of technological progress. In order to further clarify the types of biased technological progress under China's appropriate technology selection, this paper chooses the biased index of technological progress (Khanna, 2001) to express the relative factor-augmenting technology change [9]:

$$BiaKL=\frac{\alpha\tau K}{\eta K}-\frac{\alpha\tau L}{\eta L} \quad (6)$$

If *BiaKL*>0, it means that technological progress is more inclined to improve marginal productivity of capital; otherwise, it is more inclined to increase marginal productivity of labor; If *BiaKL*=0, it indicates that the technological progress in the production process is Hicks neutral technology.

3. Estimates Result and Discussion

In this paper, the panel data of Chinese provinces are used for analysis. Due to limitations in the availability of relevant data over time, Hainan Province was abandoned; Chongqing City was classified into Sichuan Province. Our principal data sources are the China's National Bureau of Statistics (NBS), China Statistical Yearbook Database (CSYD), and Annual Statistical Bulletin on National Economic and Social Development from each province. In terms of index selection and data processing, refer to and follow Zhang and Lin [10]. The regression result of the TLPF is obtained by running the FRONT4.1 software.

3.1 Estimation Result of TLPF

Of particular note is the form of TLPF exerted to calculate the time-varying elasticity of substitution has been strictly tested with China's provincial panel data, which ensures the accuracy and reliability of the estimated results.

The inspection procedure for the final form of TLPF is as follows: Firstly, it is the validity test of frontier production function model. If the null hypothesis H0 :Y=0 holds, that means production has full technical efficiency and no SFA is needed at all. Otherwise, technical inefficiency cannot be neglected in economic growth and then SFA is the most appropriate of estimate tool. Secondly, once the prerequisite of SFA is satisfied, the likelihood ratio statistic is used to check the feature of frontier production function. Finally, the examination of whether the parameters of frontier production function and of inefficiency equation should be preserved. Specific testing items and their comparison standards have been listed in Table 1.

Table 1 Hypotheses Test of Appropriate Form of TLPF

Test item	Null Hypothesis	Degree of Freedom	Statistics Test	Critical value at 5%
Cobb-Douglas	$\beta_{\tau\tau}=\beta_{KK}=\cdots=\beta_{\tau S}=0$	10	184.96	18.307

Function				
Technical Progress	$\beta_{\tau}=\beta_{\tau\tau}=\beta_{\tau K}=\beta_{\tau L}=\beta_{\tau S}=0$	5	137.18	11.071
Biased Technical Progress	$\beta_{\tau K}=\beta_{\tau L}=\beta_{\tau S}=0$	3	234.48	7.815
Coefficient of Frontier	$\beta_i=0$	Determined by the form of relevant frontier function		
Coefficient of Inefficiency	$\delta_i=0$	Determined by the final form of the frontier function		

The test results display that the technical inefficiency in production is statistically significant at p<0.01, which can explain 28.10% of the fluctuation of output, as shown in table 2, where the inefficiency parameter ϒ equals to 0.281. Hence, the conclusion can be confidently drawn that the stochastic frontier function, rather than the traditional production function, is more suitable for the analysis of China's economic growth. After completing the test in turn as table 1 on the nature form of the frontier production function, the paper reaches the final form of TLPF at China's country-wide level. See the reported result in Table 2.

Table 2 Maximum Likelihood Estimate on TLPF (mean efficiency=0.618)

Variable	Coefficient	Standard Error	t-Ratio
Frontier Production Function			
beta 0 (intercept)	3.1084***	0.6482	4.7951
beta 1 (lnL)	1.3348***	0.1438	9.2821
beta 2 (τ)	0.1965***	0.0346	5.6827
beta 3 (lnK)2	0.0972***	0.0102	9.5719
beta 4 (τ2)	0.0048***	0.0008	6.0763
beta 5 (lnK*lnL)	-0.1209***	0.0179	-6.7382
beta 6 (τ*lnK)	-0.0292***	0.0048	-6.0713
Technological inefficient			
Delta 0 (intercept)	2.3822***	0.5317	4.4807
delta 1 (FDI)	2.5860*	1.4369	1.7998
delta 2 (TRD)	-6.6397***	1.7517	-3.7904
delta 3 (P)	-0.0034*	0.0020	-1.7087
delta 4 (M)	-0.0041***	0.0008	-4.8293
delta 5 (PMH*TRD)	0.0027**	0.0012	2.1293
delta 6 (P*TRD)	-0.0003	0.0036	-0.0865
delta 7 (M*TRD)	0.0044***	0.0007	6.3058
delta 8 (M*FDI)	0.0072**	0.0036	1.9657
delta 9 (H*FDI)	-0.0355***	0.0049	-7.1510
delta 10 (P*M)	0.1E-04***	0.3E-05	3.3243
delta 11 (t)	0.0254***	0.0077	3.2689
Sigma-squared	0.1468***	0.0134	10.9240
gamma	0.2810***	0.0663	4.2373

Notes: ***p<0.01;**p<0.05; and *p<0.1.

3.2 Estimates of Relevant Indicators

With the regression parameters of the translog production function, the time-varying series of the elasticity of capital-labor substitution, the output elasticity and the relative index of biased technological progress are calculated. See Table 3.

Table 3 Estimated values of relevant indicators in 1996-2016

Year	σKL	ηK	ηL	MPK	MPL	BiaKL
1996	-0.146	0.350	0.545	19.046	17.807	-0.084
1997	-1.784	0.343	0.530	18.184	18.863	-0.088
1998	0.548	0.341	0.515	17.609	21.185	-0.091

Year	σKL	ηK	ηL	MPK	MPL	BiaKL
1999	1.303	0.335	0.501	16.702	22.413	-0.095
2000	3.193	0.328	0.487	15.845	23.980	-0.099
2001	0.710	0.320	0.473	15.026	25.407	-0.102
2002	1.359	0.313	0.458	14.519	27.054	-0.106
2003	1.843	0.308	0.442	13.658	27.759	-0.108
2004	3.084	0.303	0.425	13.169	29.376	-0.110
2005	-1.523	0.301	0.406	12.696	30.851	-0.112
2006	1.937	0.298	0.388	12.243	31.975	-0.116
2007	-0.523	0.298	0.369	11.977	34.297	-0.115
2008	-0.229	0.295	0.350	11.300	35.034	-0.117
2009	-0.238	0.295	0.330	10.648	35.564	-0.118
2010	27.883	0.296	0.309	10.425	36.851	-0.117
2011	-0.885	0.291	0.291	9.952	35.503	-0.118
2012	1.882	0.485	0.273	18.454	165.031	-0.073
2013	1.972	0.468	0.255	16.184	147.083	-0.076
2014	1.993	0.463	0.240	15.336	148.752	-0.075
2015	2.034	0.457	0.226	15.349	156.469	-0.076
2016	2.062	0.453	0.213	14.789	165.842	-0.077
Average	2.213	0.350	0.382	14.434	58.909	-0.099

In table 1, the average value of σKL is 0.93 (if the abnormal points in 2010 are not excluded, the average value is 2.21), which is consistent with that of 0.74 estimated by Dai and Xu for 1978-2005[11] and 0.83 for 1978-2008 by Chen and Lian [5]. In particular, it is equal to the average value of 0.93 in 1978-2013 estimated by Zhang et al. [12]! Because they all use CES production function to get fixed estimate of σKL, which means that the translog production function exerted in this paper is more general, which can not only contain the technical characteristics of CES production function, but also obtain consistent time-varying estimates of σKL.

From the perspective of the trend of σKL change , on the one hand, the fluctuation frequency and amplitude of σKL are relatively intense, as shown in Table 1, including absolute complementarity (σKL <0), relative complementarity (0<σKL <1), and strong substitution (σKL >1), especially between 2004-2007 and 2010-2011, there is a big leap from strong substitution to absolute complementarity, which means that during this period, the combination of production factors or production technology has a more drastic adjustment. Until 2012, the change of σKL has entered a stable period of strong substitution. From the perspective of the essence of substitution, on the other hand, there are 9 years of complementary between capital and labor, and 12 years of substitutability between them. Therefore, it seems that this paper can draw a conclusion that the nexus between capital and labor in China are more inclined to substitute, especially after 2011, this trend is more obvious.

3.3 Discussion

What is puzzling, however, is that, with 2011 as the dividing point, whether ηK, ηL, MPK, MPL, or BiaKL, the changes of these indicators in 1996-2011 are relatively stable, while why σKL alone fluctuates violently and frequently? In particular, technological progress has always been more inclined to improve labor productivity, and the substitution of labor for capital has generally increased, then, why does the share of labor contribution continue to decline while the share of capital contribution exceeds that of labor after relatively stable changes? How does China's technology choice adjust to the "appropriate" state?

Obviously, it is the adjustment of matching degree between σKL and BiaKL that quietly changes the relative contribution share of capital and labor to output, while the change of the relative contribution share of factors indicates the change of the relative importance of capital and labor in the production process, which is further reflected in the change of an economy's technological choice. As shown in Table 1, from 1996 to 2011, the labor-augmenting of technology progress bias index is deepening, which leads to the continuous improvement of the marginal production of labor. Under the support of the labor-augmenting technology progress, the gradual improvement of labor quality promotes the differentiation optimization of labor internal structure, thus promoting the dynamic evolution of the labor force from the quantitative comparative advantage to the qualitative comparative advantage. This furthermore provides the possibility for the differential adjustment of the combination between capital and different types of labor. Perhaps, this is the root cause of the drastic adjustment of China's appropriate technology selection in 1996-2011.

4. Conclusion and Enlightenment

Taking into account the essence of substitution between factors and the influence of random disturbance in the period of China's economic transformation, this paper estimates the time-varying elasticity series of capital-labor substitution by using the stochastic frontier translog production function econometric model, and further attempts to explore the evolution path of China's appropriate technology selection by capturing the change trend of substitution elasticity. Results show that an increasing substitution exists in China's capital and labor. During the sample period, there is an obvious boundary between the change tracks of all the estimated indexes. It is worth noting that in the early stage of this boundary, the change trend of output elasticity with respect to input and marginal output of factors are all relatively stable, only the elasticity of capital-labor substitution fluctuates frequently and violently, which may indicate that there is a dynamic comparative advantage of labor force in the process of China's economic growth, which leads to the different substitution degree among capital and different types of labor, so the technology selection can be closer to the appropriate state, but due to the homogeneity of labor hypothesis may exaggerate the elasticity of capital-labor substitution, which makes the process of technology selection turbulent and intense.

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